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Nuclear Waste Policy Act
(Section 112)

Environmental Assessment

Reference Repository Location, Hanford Site, Washington

Volume I

May 1986

U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Washington, DC 20585

FOREWORD

The Nuclear Waste Policy Act of 1982 (the Act) established a process for the selection of sites for the disposal of spent nuclear fuel and high-level radioactive waste in geologic repositories. The first steps in this process were the identification of potentially acceptable sites and the development of general guidelines for siting repositories. In February 1983, the DOE identified nine sites in six States as potentially acceptable for the first repository. The Hanford site in Benton County, Washington, was identified as one of those sites. The general guidelines were issued in November 1984 as Title 10 of the Code of Federal Regulations, Part 960. The DOE is now proceeding with the next step in the site-selection process for the first repository: the nomination of at least five of the nine potentially acceptable sites as suitable for site characterization, which is a program of detailed studies.

The Act requires that site nomination be accompanied by an environmental assessment (EA). The DOE has prepared EAs for the nominated sites through a process that provided opportunity for public input. Public hearings were held during March, April, and May 1983 to obtain recommendations on the issues to be addressed in an EA. All such recommendations were considered in preparing the EAs. The DOE issued draft EAs for public review and comment in December 1984 and conducted a series of public hearings in February and March 1985. The issues raised in the comment letters and hearings were considered in preparing the final EAs. These issues are addressed in a comment-response document appended to the final EAs (Appendix C).

The information presented in the EAs is derived from hundreds of technical reports containing more-detailed data and analyses. All of these reference documents are available to the public in various libraries and reading rooms; a listing of their locations is given in Appendix B.

After the nomination, the Secretary is required by the Act to recommend to the President not fewer than three of the nominated sites for characterization as candidate sites for the first repository. This recommendation will be submitted and documented in a separate report that is being issued separately from this environmental assessment. After submittal, the Act provides the President 60 days to approve or disapprove the candidate sites. The President may delay his decision for up to six months if he determines that the information supplied with the recommendation of the Secretary is insufficient to permit a decision within the 60-day period. If the President does not approve, disapprove, or delay the decision, the candidate sites shall be considered approved. After the President approves the candidate sites, the DOE will start site characterization.

ABSTRACT

In February 1983, the U.S. Department of Energy (DOE) identified a reference repository location at the Hanford Site in Washington as one of the nine potentially acceptable sites for a mined geologic repository for spent nuclear fuel and high-level radioactive waste. The site is in the Columbia Plateau, which is one of five distinct geohydrologic settings considered for the first repository. To determine their suitability, the Hanford site and the eight other potentially acceptable sites have been evaluated in accordance with the DOE's General Guidelines for the Recommendation of Sites for the Nuclear Waste Repositories. These evaluations were reported in draft environmental assessments (EAs), which were issued for public review and comment. After considering the comments received on the draft EAs, the DOE prepared the final EAs.

On the basis of the evaluations reported in this EA, the DOE has found that the Hanford site is not disqualified under the guidelines. The DOE has also found that it is suitable for site characterization because the evidence does not support a conclusion that the site will not be able to meet each of the qualifying conditions specified in the guidelines. On the basis of these findings, the DOE is nominating the Hanford site as one of five sites suitable for characterization.

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EXECUTIVE SUMMARY

1. INTRODUCTION

By the end of this century, the United States plans to begin operating the first geologic repository for the permanent disposal of commercial spent nuclear fuel and high-level radioactive waste. Public Law 97-425, the Nuclear Waste Policy Act of 1982 (the Act), specifies the process for selecting a repository site, and constructing, operating, closing, and decommissioning the repository. Congress approved geologic disposal by declaring that one of the key purposes of the Act is "to establish a schedule for the siting, construction, and operation of repositories that will provide reasonable assurance that the public and the environment will be adequately protected from the hazards posed by high-level radioactive waste and such spent nuclear fuel as may be disposed of in a repository" [Section 111(b)(1)].

A geologic repository can be viewed as a large underground mine with a complex of tunnels occupying roughly 2,000 acres at a depth between 1,000 and 4,000 feet. To handle the waste received for disposal, surface facilities will be developed which will occupy about 400 acres. The repository will be operational for about 25 to 30 years. After the repository is closed and sealed, waste isolation will be achieved by a system of multiple barriers, both natural and engineered, that will act together to contain and isolate the waste as required by regulations. The natural barriers include the geologic, hydrologic, and geochemical environment of the site. The engineered barriers consist of the waste package and the underground facility. The waste package includes the waste form, the waste disposal container, and materials placed over and around the containers. The underground facility consists of underground openings and backfill materials, not associated with the waste package, that are used to further limit ground-water circulation around the waste packages and to impede the subsequent transport of radionuclides into the environment.

In February 1983, the DOE carried out the first requirement of the Act by formally identifying nine sites in the following locations as potentially acceptable sites for the first repository (the host rock of each site is noted in parentheses):

1. Vacherie dome, Louisiana (domal salt)
2. Cypress Creek dome, Mississippi (domal salt)
3. Richton dome, Mississippi (domal salt)
4. Yucca Mountain, Nevada (welded tuff)
5. Deaf Smith County, Texas (bedded salt)
6. Swisher County, Texas (bedded salt)
7. Davis Canyon, Utah (bedded salt)
8. Lavender Canyon, Utah (bedded salt)
9. Reference repository location, Hanford Site, Washington (basalt flows).

The locations of these sites are shown in Figure 1.

Figure 1. Potentially acceptable sites for the first repository.

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After identifying these potentially acceptable sites, the DOE published draft General Guidelines for the Recommendation of Sites for Nuclear Waste Repositories (the guidelines) in accordance with the Act. The draft guidelines were revised in response to extensive comments and received the concurrence of the Nuclear Regulatory Commission (NRC) in June 1984. Final guidelines were published in December 1984 as 10 CFR Part 960.

The Act requires the DOE to nominate at least five sites as suitable for site characterization--a formal information-gathering process that will include the sinking of one or more shafts at the site and a series of experiments and studies underground. The DOE must then recommend not fewer than three of those sites for characterization as candidate sites for the first repository. After site characterization is completed, one of the characterized sites will be recommended for development as a repository.

The Act also requires the DOE to prepare environmental assessments (EAs) to serve as the basis for site-nomination decisions. These EAs contain the following information and evaluations consistent with the requirements of Section 112 of the Act:

- A description of the decision process by which the site is being considered for nomination (EA chapters 1 and 2).
- A description of the site and its surroundings (EA Chapter 3).
- An evaluation of the effects of site characterization activities on public health and safety and the environment and a discussion of alternative activities that may be taken to avoid such effects (EA Chapter 4).
- An assessment of the regional and local effects of locating the proposed repository at the site (EA Chapter 5).
- An evaluation as to whether the site is suitable for site characterization (EA Chapter 6).
- An evaluation as to whether the site is suitable for development as a repository (EA Chapter 6).
- A reasonable comparative evaluation of the site with other sites that have been considered (EA Chapter 7).

This executive summary highlights the important information and evaluations found in the accompanying EA. Section 2 of this executive summary presents a summary of the decision process and findings leading to the nomination of the Hanford site. Sections 3 through 7 summarize the results of evaluations contained in corresponding chapters in the EA.

2. DECISION PROCESS AND PRELIMINARY CONCLUSIONS

2.1 DECISION PROCESS

The guidelines require the DOE to implement the following seven-part evaluation and decision process for nominating and recommending sites for characterization:

1. Evaluate the potentially acceptable sites against the disqualifying conditions specified in the guidelines.

2. Group all potentially acceptable sites according to their geohydrologic settings.

3. For those geohydrologic settings that contain more than one potentially acceptable site, select the preferred site on the basis of a comparative evaluation of all potentially acceptable sites in that setting.

4. Evaluate each preferred site within a geohydrologic setting and decide whether such site is suitable for the development of a repository under the qualifying condition of each applicable guideline.

5. Evaluate each preferred site within a geohydrologic setting and decide whether such site is suitable for site characterization under the qualifying condition of each applicable guideline.

6. Perform a reasonable comparative evaluation under each guideline of the sites proposed for nomination.

7. Consider an order of preference of the nominated sites as recommended sites and, on the basis of this order of preference, recommend not fewer than three sites for characterization to the President.

The DOE prepared a draft EA for each of the nine potentially acceptable sites to give all interested parties an opportunity to review the full evaluation of all sites considered. In preparing the final EAs, the DOE considered all comments that were received, as documented in Appendix C.

With the issuance of the final EAs, the DOE will formally nominate at least five sites as suitable for characterization. The Secretary of Energy will then recommend not fewer than three of these sites to the President as candidate sites for characterization. After the President approves the Secretary's recommendation, characterization activities will begin at those sites. After characterization is completed, the DOE will again evaluate each site against the guidelines and, after completing an environmental impact statement, will recommend one site to the President for the first repository. The President may then recommend the site to Congress. At this point, the host State, and (or) an Indian Tribe on whose reservation the proposed repository would be located, may issue a notice of disapproval that can be overridden only by a joint resolution of both Houses of the U.S. Congress. If the notice of disapproval is not overridden, the President must submit another

repository site recommendation within 12 months. If no notice of disapproval is submitted, or if Congress overrides the notice of disapproval, then the site designation is effective, and the DOE will file an application with the NRC to obtain a construction authorization for a repository at that site.

2.2 PRELIMINARY FINDINGS AND DETERMINATIONS

Summarized below are the DOE's preliminary findings and determinations that apply to the reference repository location at the Hanford Site.

2.2.1 EVALUATION AGAINST THE DISQUALIFYING CONDITIONS

The evidence does not support the disqualification of the reference repository location at the Hanford Site under the guidelines; nor is any of the other eight potentially acceptable sites found to be disqualified.

2.2.2 GROUPING OF SITES BY GEOHYDROLOGIC SETTING

The nine potentially acceptable sites are contained within five distinct geohydrologic settings as defined by the U.S. Geological Survey. The sites are grouped by the DOE's geohydrologic designations as follows:

Geohydrologic setting	Site
Columbia Plateau	Reference repository location, Hanford Site, Washington
Great Basin	Yucca Mountain, Nevada
Permian Basin	Deaf Smith and Swisher, Texas
Paradox Basin	Lavender Canyon and Davis Canyon, Utah
Gulf Interior Region of the Gulf Coastal Plain	Vacherie Dome, Louisiana; Cypress Creek Dome and Richton Dome, Mississippi

The reference repository location is distinct in terms of the host rock and the geohydrologic setting. The region in which the site is located is characterized by a thick and laterally extensive sequence of basalt flows. The hydrologic system is a complex sequence of horizontal aquifers separated by the dense interiors of basalt flows. Ground-water movement in the region

is predominantly through zones at and near the top of basalt flows and, to a lesser extent, through cooling joints and other fractures within the basalt flows.

2.2.3 SELECTION OF THE PREFERRED SITE IN THE COLUMBIA PLATEAU

The reference repository location at the Hanford Site is the only potentially acceptable site identified in the Columbia Plateau. The process by which it was identified as the preferred site in that setting is described in Chapter 2 of this EA.

2.2.4 SUITABILITY OF THE REFERENCE REPOSITORY LOCATION AT HANFORD FOR DEVELOPMENT AS A REPOSITORY

Section 112(b) of the Act requires the DOE to evaluate the suitability of a site for development as a repository under each such guideline that does not require site characterization as a prerequisite for the application of such guideline. The intent is to preclude the investment of money and effort in sites that could be disqualified under those guidelines for which substantial information is available for site evaluations. The guidelines that do not require characterization primarily relate to those characteristics of a site that are related to the effects of a repository on public health and safety, quality of the environment, and socioeconomic conditions before the repository is closed and sealed.

For a site to be suitable for repository development under each of those guidelines that do not require site characterization, no disqualifying conditions can be present, and each of the qualifying conditions must be met. A final determination of suitability for repository development cannot be made until site characterization is complete. However, at this stage, the evidence does not support a finding that the reference repository location is disqualified. Furthermore, the evidence does not support a finding that the reference repository location is not likely to meet all the qualifying conditions under those guidelines that do not require site characterization.

2.2.5 SUITABILITY FOR SITE CHARACTERIZATION

To determine whether a site is suitable for characterization, the DOE must evaluate the site against all the guidelines, including those that require site characterization. To judge that a site is suitable, the DOE must conclude that the evidence does not support a finding that the site is not likely to meet all of the guidelines. The evaluations against the guidelines have led to a preliminary conclusion that the reference repository location at the Hanford Site is suitable for characterization.

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2.2.6 DECISION ON NOMINATION

Having made the above findings, the DOE has decided to nominate the reference repository location at Hanford as suitable for characterization. The other potentially acceptable sites selected for nomination are Davis Canyon, Utah; Deaf Smith, Texas; the Richton Dome, Mississippi; and Yucca Mountain, Nevada.

3. THE SITE

The reference repository location is in the west-central part of the DOE-controlled Hanford Site in south-central Washington (Fig. 2). The reference repository location lies within the Pasco Basin, a 4,850-square-kilometer (1,900-square-mile) topographic depression in the Columbia Plateau and, more specifically, in the central part of the Cold Creek syncline. This location was chosen partly because the basalt flows there are nearly flat lying and should be structurally less disturbed than other areas at the Hanford Site (Fig. 3). The terrain at the site is relatively flat--its features were formed by glacially related floods and more-recently developed sand dunes. The terrain to the north and to the west is dominated by prominent linear ridges formed by arch-like folds (anticlines) of basalt lavas.

The Columbia Plateau is underlain by a thick sequence of strata deposited many millions of years ago in Miocene time. The lower strata consist entirely of basalt-lava flows and the upper strata include increasing amounts of interbedded sedimentary deposits. Semiconsolidated sediments overlie the basalt sequence and attain thicknesses of as much as 525 meters (1,200 feet). Approximately 50 basalt flows, with a total thickness of perhaps 5,000 meters (16,000 feet), have been identified within the Pasco Basin. One of these basalt flows, the Cohassett flow, has been identified as the candidate horizon for the repository. Structures at the Hanford Site consist of long, narrow anticlines and broad synclines (trough-like folds) that roughly trend east-west. Faults associated with anticlinal fold axes probably developed concurrently with folding.

Ground water occurs at the reference repository location in an unconfined aquifer and in numerous confined aquifers. The unconfined aquifer is in the sediments that lie above the sequence of basalt flows. Confined aquifers occur at greater depths, within the sequence of basalt flows. There are three potential pathways for ground-water movement in the basalt sequence: (1) The more permeable contact zones between basalt flows and in the sedimentary interbeds, (2) the structural discontinuities (e.g., faults or fracture zones) that may cross-cut the basalt flows, and (3) the stratigraphic discontinuities within the basalt flows. The shallow basalts are thought to recharge locally in outcrop areas, where the rocks are exposed at the surface, and to discharge to the overlying unconfined aquifer and the Columbia River. The deeper basalts appear to be recharged from interbasin ground-water movement and vertical leakage from the upper to the lower basalts. The location of ground-water discharge is not known; it has been suggested to be south of the Hanford Site.

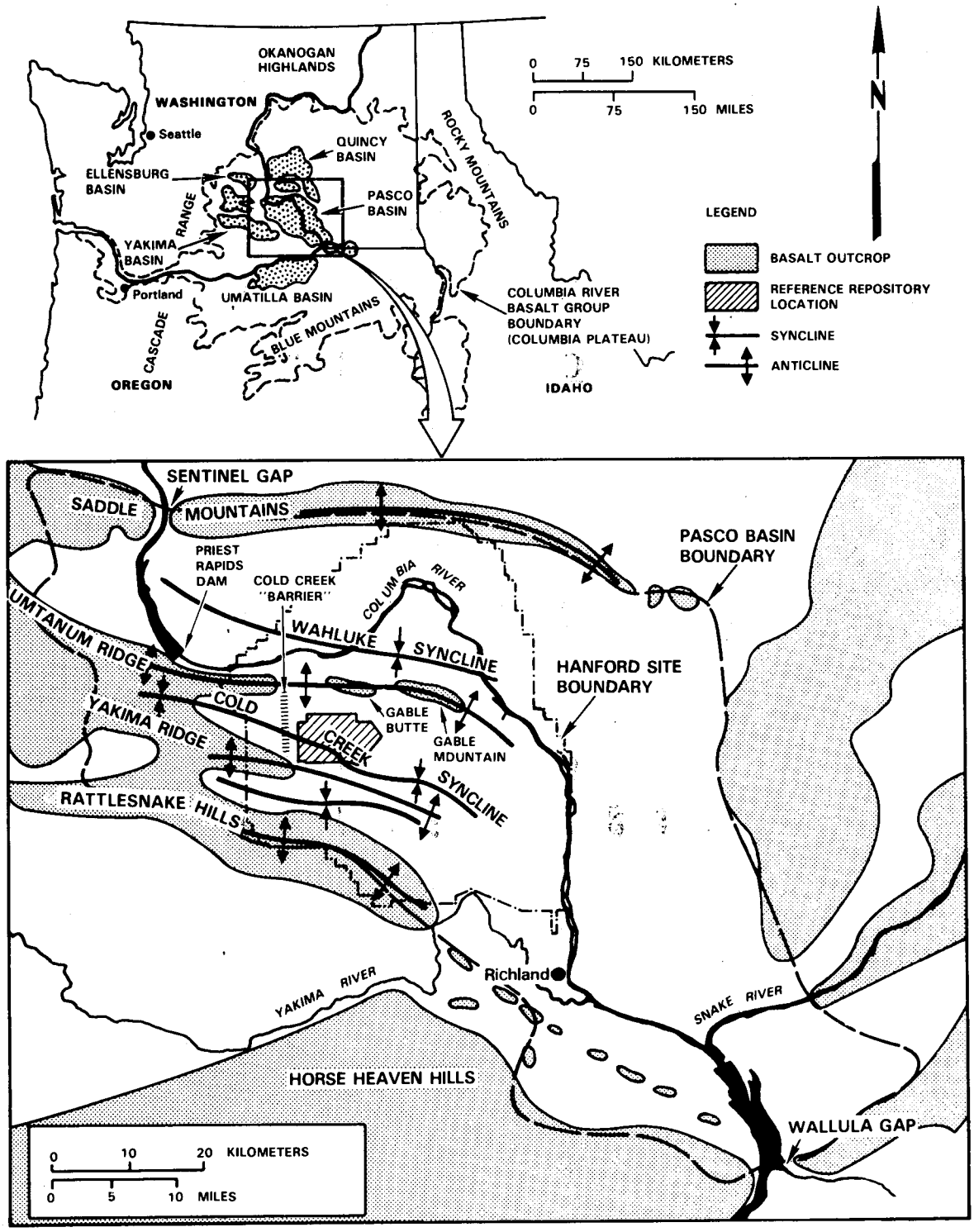

Figure 2. Reference repository location on the Hanford site, Washington.

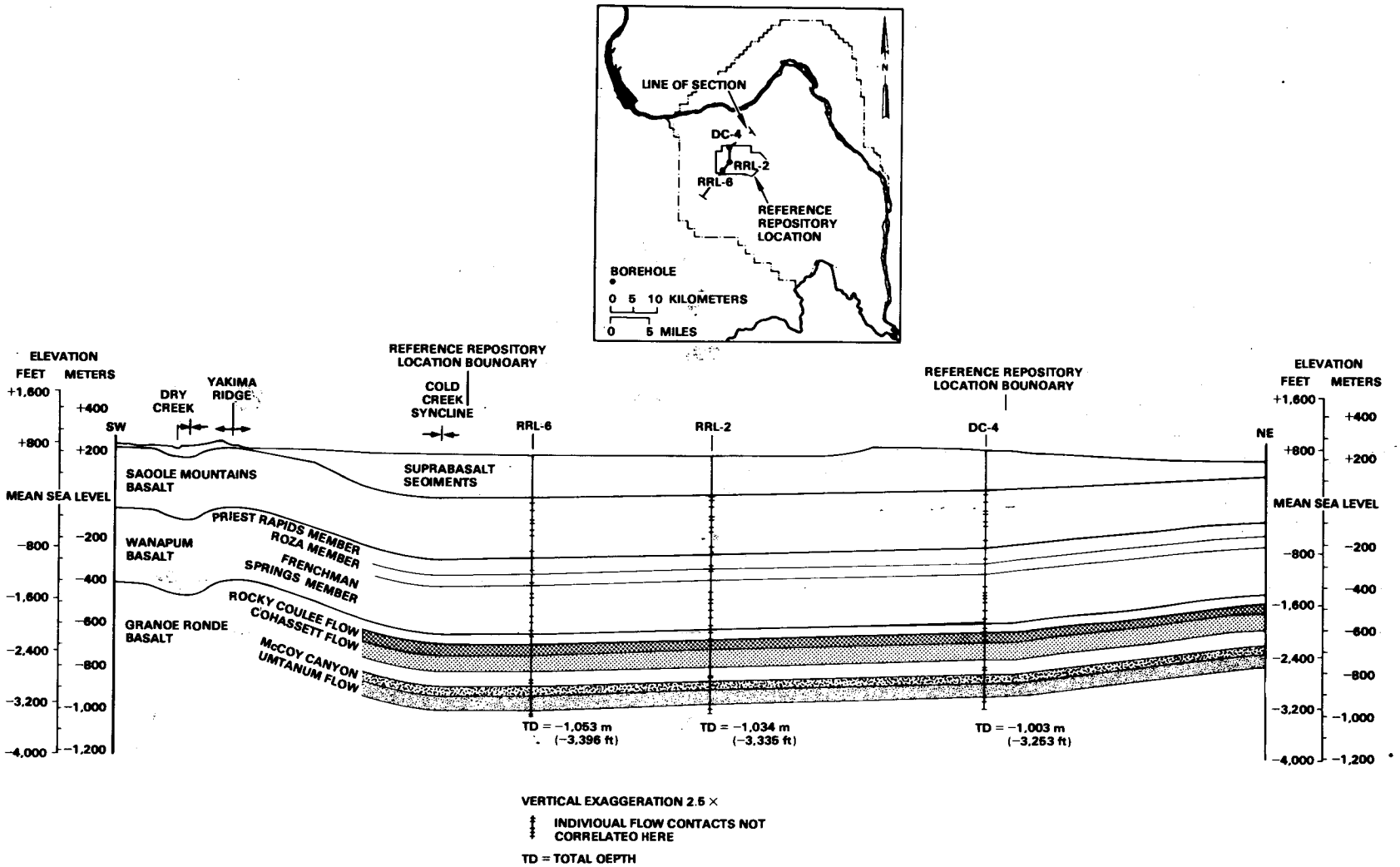

Figure 3. Geologic cross section of the reference repository location on the Hanford site.

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No mining or exploration activities have occurred at the site since 1943, when the Federal Government assumed control of the area now known as the Hanford Site. Although exploration for natural gas is currently being conducted near the Hanford Site, the geologic conditions at the site are not expected to be favorable for the commercial production of natural gas, petroleum, or other mineral resources.

Atmospheric dispersion over the site is generally good, although periods of shallow mixing depths, low-level inversions, and light winds do occur. Air quality in the vicinity of the site is generally good and in compliance with applicable air-quality standards. Occasional dust storms produce high short-term concentrations of total suspended particulates.

The Columbia River system, several natural springs, and a number of ponds (natural and manmade) and ditches comprise the aquatic environment of the Hanford Site. No naturally occurring surface waters, however, are on the reference repository location. Manmade catchments on the Hanford Site support a variety of aquatic plants and animals that would not normally occur in this arid region.

No threatened or endangered animals or plants are known to reside or grow and no critical habitats are known to exist at the reference repository location. However, the bald eagle (an endangered species) and the peregrine falcon (a threatened species) reside on other parts of the Hanford Site.

The area surrounding the Columbia River was a densely inhabited region of aboriginal North America. At present, nine archaeological sites at the Hanford Site are listed in the National Register of Historic Places. The closest known archaeological site is 2.5 kilometers (1.6 miles) to the west of the reference repository location. Field surveys have not revealed any archaeological sites of national significance at the reference repository location. The natural aesthetic features in the area include the Columbia River, Yakima and Snake Rivers, and nearby mountains and bluffs.

The areas most likely to experience socioeconomic effects from site characterization or repository development are Benton and Franklin Counties. These counties include the cities of Richland, Kennewick, and Pasco (the Tri-Cities), West Richland, and Benton City, Washington, and several unincorporated towns. The 1984 population of these two counties was 138,840. While the socioeconomic study area was one of the fastest growing metropolitan areas in the country during the 1970's, its economic and population bases currently are declining, largely because construction activities at the nuclear powerplants of the Washington Public Power Supply System have ceased. As a result, this area has excess housing and public-service capacity. The U.S. Department of Energy controls the rail spur to the Hanford Site; this rail spur ties in with the Union Pacific tracks southeast of Richland, Washington. Road access to the reference repository location is provided by Route 240 and DOE roadways. Barge access to the Hanford Site is provided through the Port of Benton in north Richland, Washington.

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Unlike much of the land in southeastern Washington, the Hanford Site is not developed for agricultural use. The Hanford Site is institutionally controlled and has been restricted to projects directly associated with nuclear activities since 1943. The major nuclear facilities and activities occupy only about 6 percent of the total restricted land area at the Hanford Site.

4. EFFECTS OF SITE CHARACTERIZATION

To obtain the information necessary for evaluating the suitability of the reference repository location at Hanford for a repository, the DOE will conduct a site-characterization program of underground testing. To carry out this program, the DOE will construct two shafts, excavate drifts at the proposed repository depth, and construct support facilities on the surface. In addition to the tests performed underground and in the exploratory shaft, geologic field studies will be conducted to characterize underground conditions. This site-characterization program requires the clearing of 18 hectares (46 acres) of land of which 8 hectares (20 acres) have already been cleared and stabilized.

At the same time, the DOE will study the environment of the reference repository location and its vicinity, including weather conditions, air quality, noise, plant and animal communities, and archaeological and cultural resources. Socioeconomic conditions will also be further investigated in the area expected to be affected by the repository.

The site-characterization program will last several years. At the end of this period, if the reference repository location is found unsuitable for a repository, the shafts will be filled and sealed, and the surface facilities will be removed.

The land at the reference repository location has been dedicated to the DOE or related nuclear activities, and, consequently, land-use conflicts are not expected. Since there are no natural aquatic habitats at the selected site, no direct effects on natural aquatic ecosystems are expected. However, some small-diameter borehole drilling may be carried out near the Columbia River, and care will be taken to avoid affecting threatened species (the peregrine falcon) and endangered species (the bald eagle). While the impacts of noise on the local wildlife may be adverse, the effects on the local human population will be minor because of the remoteness of any human habitations.

Adverse and beneficial effects may result from characterization activities at the Hanford Site. The Hanford Site tends to experience naturally generated fugitive dust, which leads to elevated levels of total suspended particulates. Site-characterization activities would aggravate this condition, since site-preparation and earth-moving activities could significantly increase the potential for dust generation from cleared areas. The actual level of total suspended particulates will depend on a number of factors, including the amount of activity at the site, size of the exposed surface area, soil characteristics, weather conditions, and dust-suppression techniques employed. Although dust-suppression techniques will be used, the

environmental conditions are such that higher than normal dust levels could still occur. However, it is expected that fugitive dust can be mitigated to acceptable levels, as has been demonstrated in the past by large-scale construction projects at the Hanford Site.

Some tall structures (e.g., the drill rig for the exploratory shafts) and the night lighting used for site-characterization activities will be visible from Route 240. However, the structures will not be within the line of sight of any scenic view or overlook, and the light is not expected to have a significant effect.

The Hanford Site and surrounding area have an excellent transportation network that should be more than adequate for the requirements of site characterization.

Archaeological field surveys have not identified any potential archaeological resources at the reference repository location, nor is any known to exist. Site-characterization activities at other parts of the Hanford Site will avoid any known archaeological sites.

Examples of the types of mitigating measures that will be taken include locating and conducting site-characterization activities in a way that tends to minimize adverse environmental impacts, employing equipment and engineering measures to reduce the adverse conditions created by site-characterization activities, and using appropriate control measures to minimize the adverse environmental impacts of those activities.

The clearing of areas for exploration and testing has the potential for adverse impacts on the terrestrial ecosystem through the loss of vegetation and wildlife habitat and through direct kills. Approximately half the area needed for site characterization has already been cleared and stabilized. The effects of clearing additional land can be mitigated, to some degree, by avoiding sensitive areas; the loss of habitat during site characterization is expected to be insignificant. After site restoration, if the reference repository location is not selected for development, the cleared areas can be allowed to revegetate.

The local economy is expected to benefit from projected expenditures during site characterization. Given the extent to which the local economy has developed for other large construction projects, it is likely that local firms will be able to provide many of the necessary materials and services and will benefit accordingly.

5. REGIONAL AND LOCAL EFFECTS OF REPOSITORY DEVELOPMENT

To determine the effects of developing a repository at the site, three phases of repository development were examined: Construction, operation, and closure and decommissioning. During the construction phase, which will last approximately 7 years, the DOE would construct surface support facilities, construct access shafts, excavate and prepare underground drifts and waste-disposal rooms, and improve access roads and utility services. During

the first few years of the operation phase, the repository would receive small amounts of waste while the surface and underground facilities are completed. After construction is completed, the rate of waste receipt would increase to a maximum of 3,000 metric tons (3,300 tons) of uranium per year. During the operation phase, underground development would continue concurrently with waste emplacement until the required area is excavated. This full-operation phase is estimated to last some 25 to 30 years; it would be followed by a caretaker period, because the U.S. Nuclear Regulatory Commission requires the DOE to preserve the option of retrieving the waste for 50 years after the initial emplacement. During closure and decommissioning, the underground repository would be backfilled, shafts and boreholes would be closed and sealed, land-use controls would be instituted, surface facilities would be decontaminated and decommissioned, and permanent markers or monuments would be erected at the site to warn future generations of the underground repository.

Adverse and beneficial effects may result from the development of a repository at the reference repository location. As in the case of site characterization, the most significant effects will be on air quality and the terrestrial ecosystem.

It is expected that a repository would exert little, if any, effect on land use. Surface facilities would occupy a small area, and less than 5 kilometers (3 miles) of new roads would be needed. In addition, there would be no interference with security measures at the Hanford Site.

Repository development, especially site preparation and underground development and to some extent the decommissioning of surface facilities and closure of the repository, could increase the potential for dust generation and, consequently, increase the concentrations of total suspended particulates. Wind erosion of cleared areas and mechanical activity would be responsible for fugitive dust. Just as in site characterization, dust-suppression techniques would be used, and it is expected that dust emissions can be controlled to acceptable levels. The expected levels of dust emissions and specific methods for their suppression will be evaluated during site characterization.

While surface facilities would be visible from Route 240, the structures would be comparable with those of other facilities already present at the Hanford Site. No significant visual effects are, therefore, expected.

Repository development also has the potential for affecting the terrestrial ecosystem at the site. The most significant effect would be the loss of vegetation and wildlife habitat from the 80 hectares (200 acres) cleared for facility development. Several plant and animal species are present and may be adversely affected. However, special measures can be taken to minimize impacts, where appropriate. These include careful route selection for utility lines, timing of construction activities, and use of as many existing facilities as possible. It is not expected that the presence of a repository would have any effect on the local manmade aquatic ecosystems. Moreover, the evidence does not demonstrate that a repository would have an adverse effect on the fisheries in the Columbia River. Noise levels during

the construction and, to a lesser extent, the operation of a repository at the site would be elevated locally. However, because of the remoteness of the site from human habitations, the noise would not affect any members of the public. Several field surveys have produced no indications that the reference repository location contains cultural resources that could be impacted by a repository.

The communities surrounding the Hanford Site should be able to absorb population changes without significant impacts. Unexpected cutbacks in the job market and work stoppage in 1981 at two of the three nuclear powerplants of the Washington Public Power Supply System resulted in excess capacities in community services and housing. If current conditions continue, this situation is expected to last into the 1990's. Repository construction and operation would generate approximately 1,100 and 900 jobs, respectively, and thus strengthen the local economy. Much of the required work force would be available from the highly skilled labor force in the Tri-Cities area. Although some miners would have to be hired from outside the area, the likely employment opportunities in the short term and for the long-term economic potential of the project should exert a beneficial economic effect on the area.

Increases in local tax bases, especially for sales, use, and business and occupation taxes, as well as grants-equal-to-taxes and financial assistance from the DOE to provide for additional community services, are also expected to be beneficial to local public fiscal conditions.

Two types of transportation effects would result from increased commuter traffic and the hauling of supplies and radioactive waste. They are radiological risks, which would result from the direct external radiation emitted by the radioactive waste as a shipment passes by and which could result from possible radioactive material releases due to transportation accidents, and nonradiological risks. The latter are the nonradiological consequences of traffic accidents and the health effects that result from the pollutants emitted by combustion engines; they would occur regardless of the cargo carried by the railcar or truck. In general, both types of risk will vary with the distance traveled and with the mode of transportation (road or rail). Since the reference repository location at the Hanford Site is farther from the sources of waste than the other potentially acceptable sites, its nonradiological risks are likely to be higher than the other sites. While the nonradiological risks would vary with the transportation mode, they are expected to be lower for rail transport than for shipment by truck.

The radiological risks for the site are expected to be much lower than the nonradiological risks. The actual radiological risks would vary with the number of shipments in each transportation mode; they are expected to be lower for shipments by rail.

On the local level, because major municipalities near the Hanford Site are geographically arranged in a linear pattern along existing transportation routes, traffic bottlenecks would have been expected. However, recent highway construction has alleviated this problem. Transportation to the repository facilities from existing roadways would be relatively simple. The access routes that would be constructed from the surface facilities of the repository to the local rail line or highway would be less than 5 kilometers (3 miles)

long and would be economical to construct. Possible access routes are free of terrain-related hazards. Minimal upgrading would be required for the existing local system in connection with the regional transportation network.

There are no legal impediments in the State of Washington or in adjoining states that would prevent or impede waste transportation. There is also little likelihood that weather conditions will cause transportation to be disrupted on a seasonal basis.

6. EVALUATIONS OF SITE SUITABILITY

The DOE has evaluated the reference repository location to determine its suitability as a candidate for site characterization. This evaluation was based mainly on the siting guidelines, but it was also based in part on the expected effects of site characterization and of repository development, as summarized in the preceding sections.

6.1 THE STRUCTURE OF THE GUIDELINES

The guidelines are divided into two sets: Postclosure (the period after the repository is permanently closed) and preclosure (the period of repository siting, construction, operation, and closure and decommissioning). The postclosure and the preclosure guidelines contain technical and system guidelines. The technical guidelines address the specific characteristics of the site that are considered to have a bearing on the preclosure and the postclosure performance of the repository. The system guidelines address the expected performance of the total system, including its engineered components; their objective is to protect public health and safety and to preserve the quality of the environment.

The postclosure technical guidelines address the characteristics that could affect the long-term ability of the site to isolate the waste from the accessible environment. In particular, they cover geohydrologic conditions, geochemical conditions, rock characteristics, climatic changes, erosion, dissolution, tectonics, and human interference. The postclosure system guideline requires the site to contain and isolate the waste from the accessible environment in accordance with the standards and the regulations specifically promulgated for repositories by the Environmental Protection Agency (EPA) and the NRC.

The set of preclosure guidelines is divided into three groups: (1) Preclosure radiological safety; (2) environment, socioeconomics, and transportation; and (3) ease and cost of siting, construction, operation, and closure. A preclosure system guideline is specified for each of these groups. The associated technical guidelines address site suitability in terms of population density and distribution, site ownership and control, meteorology, offsite installations and operations, environmental quality, socioeconomics, transportation, surface characteristics, rock characteristics, hydrology, and tectonics.

6.2 SUMMARY OF SITE EVALUATIONS AGAINST THE POSTCLOSURE GUIDELINES

The features of the reference repository location at the Hanford Site that contribute to its ability to isolate waste from the accessible environment include the time of ground-water travel to the accessible environment and a favorable geochemical environment.

Estimates of ground-water travel times from the flow top above the Cohassett flow interior to the accessible environment yield a median value of slightly greater than 70,000 years. Although there are many uncertainties in the travel-time calculations, there is no reason to believe, on the basis of current information, that the ground-water travel time is not well in excess of 10,000 years. If credit were taken for ground-water travel through the Cohassett flow interior, then travel times to the accessible environment would be significantly longer than the times calculated solely for travel in the basalt flow tops. There are also strong indications that the reference repository location has chemically reducing conditions that will promote precipitation and will maintain radionuclides in their least mobile state. Moreover, clay minerals and zeolites in the rock itself and lining joints and fractures have a high sorptive capacity and will further retard the movement of radionuclides.

Other favorable attributes of the reference repository location include ownership of the land by the Federal Government and its control by the DOE, as well as the remoteness of the reference repository location from highly populated areas. Moreover, socioeconomic benefits to the area would be expected from the development of a repository at the site.

Conditions that could adversely affect the ability of the geologic setting to isolate the waste are the fractured and jointed nature of basalt flows as well as the resulting complex geohydrologic system. Ground-water systems in multilayered, fractured basalt are difficult to characterize and to model; the potential for vertical flow through them is currently unknown. In addition, the fractures in the basalt flows and the high in situ stress beneath the reference repository location could result in the instability of excavated openings that would require ground support.

Because methane gas may be commercially present, the potential for human interference may influence the ability of the site's natural barriers to isolate waste. Methane gas has been found off the Hanford Site in the sediments underlying the basalt flows, but these deposits are thought to be associated with traps in anticlinal structures. Because the site is located in a syncline, it is not thought to be a likely target of future exploration for methane. Thus, the potential for human interference appears to be low, but the issue will be studied further during site characterization.

To meet EPA standards for long-term waste isolation, the NRC requires that the engineered barriers at the site meet two performance objectives: (1) The waste package must provide substantially complete containment of the waste for a minimum of 300 years and (2) the radionuclide-release rate beyond the period of containment must not exceed one part in 100,000 per year of the repository inventory at 1,000 years after closure. The lifetime of waste packages at the reference repository location is estimated to be between 4,500 and 8,500 years. Moreover, the expected favorable geochemical

conditions would further control releases from the engineered barrier system. Preliminary assessments of engineered barrier performance under realistic but conservative assumptions indicate that the EPA limit for release rates to the accessible environment could be met at the reference repository location.

6.3 SUMMARY OF SITE EVALUATIONS AGAINST THE PRECLOSURE GUIDELINES

The evaluations of the reference repository location against the three groups of preclosure guidelines are summarized below.

6.3.1 RADIOLOGICAL SAFETY

Preliminary assessments of preclosure performance for the reference repository location at the Hanford Site do not indicate releases that would exceed any applicable radiation standards during repository operation and closure regardless of the mix of spent fuel, commercial high-level waste, or defense high-level waste. In addition, the site was evaluated against the following technical guidelines that are concerned with the radiological effects of repository operation on public health and safety: Population density and distribution, site ownership and control, meteorological conditions of the site, and effects of operations and accidents at nearby installations.

The reference repository location is 24 kilometers (15 miles) from Sunnyside, Washington, the closest highly populated area. The closest Indian reservation, governed by the Yakima Indian Nation, is 50 kilometers (30 miles) away. The population density for the Hanford Site is 0.34 person per square kilometer (0.13 person per square mile). The meteorological conditions at the site are such that the atmospheric releases of radioactive material, should such releases occur, are not expected to exceed exposure limits to the general public. There are occurrences of high winds, dust storms, and severe temperatures, but these conditions can be accommodated through repository design. Finally, there are nearby nuclear facilities and potentially hazardous installations within 8 kilometers (5 miles) of the area proposed for the surface facilities at the repository. However, these installations are not expected to present any conflict with repository operations or result in radioactive releases exceeding allowable limits.

6.3.2 ENVIRONMENT, SOCIOECONOMICS, AND TRANSPORTATION

Three technical guidelines address the environmental, socioeconomic, and transportation effects of a repository before closure. These effects, which could be beneficial and adverse, are summarized in Sections 4 and 5 above. Preliminary analyses indicate that the expected adverse effects can be mitigated.

With respect to the system guideline on the environment, socioeconomics, and transportation, the evidence does not support a finding that the reference

repository location is not likely to meet the qualifying conditions of protecting the public and the environment from the potential hazards associated with waste disposal.

6.3.3 EASE AND COST OF SITING, CONSTRUCTION, OPERATION, AND CLOSURE

The major conditions that affect the ease and cost of repository siting, construction, operation, and closure are the site's surface characteristics, rock characteristics, tectonic stability, and hydrologic conditions. Because the site is on level terrain, the construction of surface facilities would be relatively easy. The major potential difficulty lies in the rock characteristics; there is evidence of stratigraphic and structural discontinuities in the basalts (e.g., faults and breccia zones). The possible existence of these features at the reference repository location, coupled with the high in situ stress and the potential for inflows of ground water, could make construction difficult and expensive. Also, there is some risk of microearthquakes in the vicinity of the site. It is expected that the configuration of the access tunnels can be designed to accommodate the expected stress conditions, but some support will be required for underground openings. Because there is no natural surface water at the reference repository location and because the drainage channels for the 100-year flood do not intersect this area, flooding of the surface facilities during repository operations is not expected. Repository facilities would be designed to minimize any impacts that might result from the probable maximum flood. Also, more than sufficient water is available for construction. Each of these issues will be investigated further during site characterization.

These evaluations suggest that the repository can be constructed with reasonably available technology and that the cost would be comparable to the cost of constructing a repository at the other potentially acceptable sites.

7. COMPARATIVE EVALUATION OF NOMINATED SITES

7.1 PURPOSE AND REQUIREMENTS

Chapter 7 presents a comparative evaluation of the five sites nominated as suitable for site characterization: Davis Canyon, Deaf Smith County, Hanford, Richton Dome, and Yucca Mountain. Each site is a preferred site within a geohydrologic setting: Davis Canyon is in the bedded salt of the Paradox Basin in Utah; Deaf Smith County is in the bedded salt of the Permian Basin in Texas; Hanford is in basalt in the Columbia Plateau in Washington; Richton is a salt dome in Mississippi; and Yucca Mountain is in tuff in the Southern Great Basin in Nevada.

The purpose of this chapter is to present a comparative evaluation of the nominated sites in order to satisfy the following:

1. Section 112(b)(1)(E)(iv) of the Nuclear Waste Policy Act of 1982, which requires that a "reasonable comparative evaluation" be included in the environmental assessments that accompany site nomination, and

2. Section 960.3-2-2-3 of the DOE's siting guidelines (10 CFR Part 960), which requires that a reasonable comparative evaluation be made and that a summary of evaluations with respect to the qualifying condition for each guideline be provided to "allow comparisons to be made among sites on the basis of each guideline."

This comparative evaluation is intended to allow the reader to compare the more detailed suitability evaluations of the individual sites that are presented in Chapter 6 of each environmental assessment. The comparison should assist the reader in understanding the basis for the nomination of five sites as suitable for characterization [112(b)(1)(A)]; it is not intended to directly support the subsequent recommendation of three sites for characterization as candidate sites.

7.2 APPROACH AND ORGANIZATION

This comparative evaluation of the five nominated sites is based on the postclosure and preclosure guidelines (10 CFR Part 960, Subparts B and C, respectively). The evaluation presented in this chapter includes the system guidelines and the technical guidelines. The approach used to compare the sites with respect to each system and technical guideline in summarized below.

7.2.1 TECHNICAL GUIDELINES

Major considerations that could be used to compare the sites on the basis of the qualifying condition of each technical guideline were derived by identifying the favorable, potentially adverse, and disqualifying conditions that deal with the same general topic. Contributing factors that represent the characteristics of the site that are potentially important in evaluating the sites with respect to each major consideration were also identified. The relative importance of the major considerations was determined primarily by the degree to which they contribute to the qualifying condition; that is, the stronger the tie between the consideration and the qualifying condition, the greater the importance of the consideration.

The purpose of identifying major considerations for each guidelines is to combine closely related site conditions so that the balance of the favorable and potentially adverse conditions can be considered directly. Most guidelines that contain a disqualifying condition have one or more potentially adverse conditions that relate to the disqualifying condition. Since these potentially adverse conditions are considered in the formulation of a major consideration, the important aspects of the disqualifying conditions indirectly enter the comparative evaluation. Where a major consideration that

is needed to evaluate the qualifying condition does not have a related favorable or potentially adverse condition, the consideration is derived directly from the qualifying or disqualifying condition.

The comparative evaluation of the sites with respect to each guideline, using the approach described above, is summarized in Sections 7.2 and 7.3 for the postclosure and preclosure guidelines, respectively.* These sections are organized in the following manner:

1. For each guideline, the major consideration(s) and associated contributing factors are identified.

2. The evaluation of each site on the basis of each major consideration is then summarized. The evaluation of each site with respect to each major consideration is presented in alphabetical order, by site.

3. The sites are then compared on the basis of the qualifying condition. This comparative evaluation describes the sites with the most favorable combination of characteristics first and those with a less favorable combination of characteristics last in order to allow easier comparison of the suitability evaluation of the site presented in Chapter 6 with sites having other combinations of characteristics.

7.2.2 SYSTEM GUIDELINES

The comparison of sites on the basis of the individual technical guidelines uses the major considerations to incorporate the favorable and potentially adverse conditions in an evaluation of a site's standing on the qualifying conditions for each technical guideline. It is not appropriate, however, to use this approach for a comparative evaluation of sites on the basis of the system guidelines. The qualifying conditions for the system guidelines do not lend themselves to the identification of major considerations in the way that the qualifying conditions for the technical guidelines do. The system guidelines for postclosure repository performance and preclosure radiological safety are stated in terms of regulatory requirements of the NRC and EPA. The evaluations of these two system guidelines are based on preliminary performance assessments that consider the associated technical guidelines as the elements of the system. These evaluations are summarized directly from Sections 6.3.2 and 6.2.2.1 of each environmental assessment.

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*Since the comparative evaluations in Section 7.2 and 7.3 are already a summary of information in Chapter 6, this executive summary does not attempt to further abstract the substance of the comparative evaluation. The DOE believes that a further synopsis of Section 7.2 and 7.3 for the purpose of this executive summary would distort the information and possibly mislead the reader.

The system guidelines for environment, socioeconomics, and transportation, and for ease and cost of repository construction, operation, and closure are not stated as regulatory standards, and they cannot be evaluated by a performance assessment as are the other two system guidelines. Instead, they are evaluated by considering the individual guidelines that make up these two system guidelines collectively to determine whether each site meets the qualifying condition of the relevant system guidelines. The evaluation of these system guidelines is summarized from Section 6.2.2.2 and 6.3.4, in each environmental assessment.

Chapter 1

PROCESS FOR SELECTING SITES FOR GEOLOGIC REPOSITORIES

1.1 INTRODUCTION

By the end of this century, the United States plans to begin the operation of a geologic repository for the permanent disposal of commercial spent nuclear fuel and high-level radioactive waste.* Public Law 97-425, the Nuclear Waste Policy Act of 1982 (the Act), specifies the process for selecting a repository site and assigns to the U.S. Department of Energy (DOE) the responsibility for siting, constructing, operating, closing, and decommissioning the repository.

A number of alternative methods for disposing of spent nuclear fuel and high-level radioactive waste have been studied during the past 10 years (DOE, 1980a; EPA, 1979; Interagency Review Group, 1979; Schneider and Platt, 1974). After an extensive evaluation of these alternatives, as documented in the final environmental impact statement on the management of commercially generated radioactive waste (DOE, 1980a), the DOE chose disposal in mined geologic repositories as the preferred method and documented this decision in a notice published in the Federal Register (Vol. 46, p. 2667, May 14, 1981). Congress endorsed this preference by declaring that one of the key purposes of the Act is "to establish a schedule for the siting, construction, and operation of repositories that will provide reasonable assurance that the public and the environment will be adequately protected from the hazards posed by high-level radioactive waste and such spent nuclear fuel as may be disposed of in a repository" (Section 111(b)(1)).

1.1.1 THE GEOLOGIC REPOSITORY CONCEPT

A geologic repository will be developed much like a large mine. Shafts will be constructed to allow for the removal of excavated material and to permit the construction of tunnels and disposal rooms at depths between 1,000 and 4,000 feet underground. Other shafts will be constructed to allow for the transfer of waste. Surface facilities will be provided for receiving and

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*High-level radioactive waste means (1) the highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations, and (2) other highly radioactive material that the U.S. Nuclear Regulatory Commission (NRC), consistent with existing law, determines by rule requires permanent isolation. The terms "radioactive waste" and "waste" are used for both spent fuel and high-level radioactive waste.

preparing the waste for emplacement underground. The surface and underground facilities will occupy about 400 and 2,000 acres of land, respectively. When the repository has been filled to capacity and its performance has been shown to be satisfactory, the surface facilities will be decommissioned and all shafts and boreholes will be backfilled and permanently sealed. A more detailed description of a conceptual design for a repository is presented in Section 5.1.

A repository can be viewed as a system of multiple barriers, both natural and engineered, that act together to contain and safely isolate the waste. The engineered barriers will include the waste package, the underground facility, and shaft and tunnel backfill materials. The waste package will consist of the waste form, either spent nuclear fuel or solidified high-level waste, a metal container, and specially designed backfill material to separate the waste container from the host rock. The waste package will contribute to long-term isolation by delaying eventual contact between the waste and the geologic environment. The underground facility will consist of underground openings and backfill materials not associated with the waste package. These barriers will further limit any ground-water circulation around the waste packages and impede the subsequent transport of radionuclides into the environment.

The geologic, hydrologic, and geochemical features of the site constitute natural barriers to the long-term movement of radionuclides to the accessible environment. These natural barriers will provide waste isolation by impeding radionuclide transport through the ground-water system to the accessible environment and will possess characteristics that will reduce the potential for human interference in the future.

Although the DOE plans to use engineered barriers--as required by both the Nuclear Regulatory Commission (NRC) in 10 CFR Part 60 and the Environmental Protection Agency (EPA) in 40 CFR Part 191--the DOE places primary reliance on the natural barriers for waste isolation. Therefore, in evaluating the suitability of sites, the use of an engineered-barrier system will be considered to the extent necessary to meet the performance requirements specified by the NRC and the EPA but will not be relied on to compensate for deficiencies in the natural barriers.

1.1.2 THE NUCLEAR WASTE POLICY ACT OF 1982

The search for suitable repository sites has been under way for about 10 years, although preliminary screening began in the mid-1950s. With the passage of the Act, a specific process for siting and licensing repositories was established. Through provisions for consultation and cooperation as well as financial assistance, the Act also established a prominent role in the siting process for potential host States, affected Indian Tribes, and the public. To pay the costs of geologic disposal, the Act provides for a Nuclear Waste Fund through which commercial electric utility companies are charged a fee that is based on the amount of electricity they produce in nuclear power plants. The DOE's strategy for implementing the Act is discussed in detail in the Mission Plan for the Civilian Radioactive Waste Management Program (DOE, 1985).

In February 1983, the DOE carried out the first requirement of the Act by formally identifying potentially acceptable sites in the following locations (the host rock of each site is shown in parentheses):

1. Vacherie Dome, Louisiana (salt dome)
2. Cypress Creek Dome, Mississippi (salt dome)
3. Richton Dome, Mississippi (salt dome)
4. Yucca Mountain, Nevada (welded tuff)
5. Deaf Smith County, Texas (bedded salt)
6. Swisher County, Texas (bedded salt)
7. Davis Canyon, Utah (bedded salt)
8. Lavender Canyon, Utah (bedded salt)
9. Reference repository location, Hanford Site, Washington (basalt flows)

The location of these sites in their host States is shown in Figure 1-1.*

The Act further requires the DOE to issue general guidelines to be used in determining the suitability of sites. In February 1983, the DOE published draft General Guidelines for the Recommendation of Sites for Nuclear Waste Repositories (DOE, 1983). The DOE revised the guidelines after receiving extensive comments from the NRC, the States, Indian Tribes, other Federal agencies, and the public. The NRC concurred with the revised guidelines in June 1984, and the final guidelines were promulgated in December 1984 (DOE, 1984a).

The Act requires that, after the guidelines are issued, the DOE nominate at least five sites as suitable for site characterization. The DOE must then recommend not fewer than three of those sites for characterization as candidate sites for the first repository. During site characterization, the DOE will construct exploratory shafts for underground testing to determine whether geologic conditions will allow the construction of a repository that will safely isolate radioactive waste. The Act requires the DOE to prepare site-characterization plans for review by the NRC, States, Indian Tribes, and the public. After site characterization and an environmental impact statement are completed, the DOE will recommend one of the characterized sites for development as the first repository.

1.1.3 THE ENVIRONMENTAL ASSESSMENT

The Act requires the DOE to prepare environmental assessments to serve as the basis for site nominations. Although not required by the Act, draft environmental assessments were prepared for each of the nine potentially acceptable sites and issued for comment by the NRC and other Federal agencies, the States, affected Indian Tribes, and the public. The DOE has considered the comments received on these drafts before making final decisions about

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*In Texas, the DOE first identified two locations that were up to 300 square miles in area. These were subsequently narrowed to 9 square miles. The other potentially acceptable sites identified in February 1983 were on the order of tens of square miles.

Figure 1-1. Potentially acceptable sites for the first repository.

7 0 1 6 8 0 5 1 7

nomination and recommendation. The issues raised by the comments and the DOE's responses are presented in Appendix C.

The final environmental assessments contain the following kinds of information and evaluations to meet the requirements of Section 112 of the Act:

- A description of the decision process by which the site being considered for nomination was selected (Chapter 2).
- A description of the site and its surroundings (Chapter 3).
- An evaluation of the effects of site characterization on the health and safety of the public and the environment as well as a discussion of alternative activities that may be taken to avoid such impacts (Chapter 4).
- An assessment of the regional and local impacts of locating the proposed repository at the site (Chapter 5).
- An evaluation as to whether the site is suitable for site characterization (Chapter 6).
- An evaluation as to whether the site is suitable for development as a repository (Chapter 6).
- A reasonable comparative evaluation of the five nominated sites (Chapter 7).

1.2 SUMMARY OF THE OVERALL DECISION PROCESS

In seeking sites for geologic repositories, the DOE divides the siting process into the following phases: (1) screening, (2) site nomination, (3) recommendation for characterization, (4) site characterization, and (5) site selection (recommendation for development as a repository). This section describes the site-screening process that led to the identification of the nine potentially acceptable sites listed in Section 1.1 and reviews how the process of site nomination is implemented under the guidelines.

1.2.1 SITE SCREENING

During the screening phase, the DOE identified potentially acceptable sites for characterization. This phase provided the information needed for judging which of these sites appear to justify the investment in characterizing them. Screening consisted of as many as four stages, each of which progressively narrowed the study area to a smaller land unit. These stages were as follows:

1. A survey of the nation or <u>geologic provinces</u>, narrowing to <u>regions</u>. Regions are generally smaller than provinces but may extend across several States and occupy tens of thousands of square miles.

2. A survey of the regions, narrowing to areas, which encompass hundreds to thousands of square miles. For the salt sites, the regional screening phase was completed with the publication of regional characterization reports and area-recommendation reports.

3. A survey of the areas, narrowing to locations, which usually occupy an area smaller than 100 square miles. This phase was completed with the publication of location-recommendation reports for bedded salt and site-recommendation reports for salt domes.

4. A survey of the locations, narrowing to sites, which are generally smaller than 10 square miles. Although a location may be large enough to contain several sites, only one or two potential sites were usually identified in a particular location.

During each screening phase for the first repository, the DOE identified as many potentially suitable land units as were judged to be necessary for an adequate sample to be studied in the next stage. Only the regions and areas believed most likely to contain suitable sites received further study; the evaluation of all others was deferred.

Data for comparing regions, areas, and locations became increasingly detailed as progressively smaller land units were considered and as exploration and testing were concentrated on them. National, province, and regional surveys were based on the distribution of potential host rocks, published geologic maps, maps of earthquake epicenters, land use, available geohydrologic information, and other information available in the open literature. Area and location surveys required more-thorough investigations that included field exploration and testing and drilling of boreholes to investigate subsurface hydrologic, stratigraphic, and geochemical conditions. The field studies were supported by laboratory studies that focused on the waste-isolation and the engineering characteristics of potential host rocks.

The bedded-salt sites under consideration in Texas and Utah were identified by the general siting process described above, beginning with national surveys and progressively narrowing to areas, locations, and sites. The salt domes were selected by a screening that began with more than 200 domes and ended with the one site being nominated.

The screening of sites in basalt and tuff was initiated when the DOE began to search for suitable repository sites on some Federal lands where radioactive materials were already present. This approach was recommended by the Comptroller General of the United States (1979). Although land use was the beginning basis for this screening of Federal lands, the subsequent progression to smaller land units was based primarily on evaluations of geologic and hydrologic suitability. These studies began at roughly the area stage.

The technical factors used to guide site-screening decisions have evolved throughout the screening phase and are specified in a number of published documents (Brunton and McClain, 1977; DOE, 1981; DOE, 1982a; International Atomic Energy Agency, 1977; NAS-NRC, 1978).

The sections that follow summarize how the DOE applied the screening process outlined above to determine that the nine sites listed in Section 1.1.2 are potentially acceptable. Section 2.2 of each environmental assessment discusses in detail how the DOE conducted site screening in specific geohydrologic settings.

1.2.2 SALT SITES

Salt was first recommended as a potentially suitable host rock for waste disposal in 1955, after the National Academy of Sciences-National Research Council evaluated many options (NAS-NRC, 1957). This recommendation was reaffirmed in subsequent reports (e.g., American Physical Society, 1978; NAS-NRC, 1970). Rock salt, which occurs both as bedded salt and in salt domes, has several characteristics that are favorable for isolating radioactive waste, including the following:

- Salt deposits that are sufficiently deep, thick, and laterally extensive to accommodate a repository are widespread in the United States and generally occur in areas of low seismic and tectonic activity.
- Many salt bodies have remained undisturbed and water-free in comparison with other rock types for tens of millions to several hundred million years.
- Because of its high thermal conductivity, rock salt can dissipate the heat that will be generated by the waste.
- Since salt is relatively plastic under high confining pressure, the fractures that might develop at repository depth would tend to close and seal themselves.
- Rock salt undergoes only minor, highly local change as a result of exposure to radiation.
- Rock salt has excellent radiation-shielding properties.

Screening of the entire United States in the 1960s and 1970s resulted in the identification of four large regions that are underlain by rock salt of sufficient depth and thickness to accommodate a repository and represent diverse geohydrologic conditions (Johnson and Gonzales, 1978; Pierce and Rich, 1962). The four regions are as follows:

- Bedded salt in the Michigan and the Appalachian Basins of southern Michigan, northeastern Ohio, western Pennsylvania, and western New York (also called the "Salina Basin").
- Salt domes within a large part of the Gulf Coastal Plain in Texas, Louisiana, and Mississippi.
- Bedded salt in the Permian Basin of southwestern Kansas, western Oklahoma, northwestern Texas, and eastern New Mexico.

- Bedded salt in the Paradox Basin of southeastern Utah, southwestern Colorado, and northernmost Arizona and New Mexico.

This screening at the national level served as the basis for all subsequent screening in salt. After proceeding to the area phase, further screening of the salt deposits in the Salina Basin was deferred. The studies of the Salina region were not specific enough to judge that any part of the region was suitable or unsuitable for a repository. They did reveal a number of unfavorable characteristics, including a high population density associated with the concentration of urban areas in Ohio, Michigan, and New York, and an abundance of natural resources, especially oil and gas. In view of these unfavorable conditions, the DOE decided to concentrate its siting efforts on more-promising areas in the remaining three regions.

1.2.2.1 Salt domes in the Gulf Coast salt-dome basin of Mississippi and Louisiana

There are more than 500 salt domes in the Gulf Coast salt-dome basin of Texas, Louisiana, Mississippi, and areas offshore from these States. An initial screening by the U.S. Geological Survey (USGS) eliminated all offshore domes because siting a repository under water would probably not be feasible. The application of this criterion eliminated about half the domes. The USGS also evaluated the remaining 263 onshore domes (i.e., Gulf interior domes) and identified 36 as being potentially acceptable for a repository and another 89 that were worthy of further study (Anderson et al., 1973). The USGS screening factors were the depth to the top of the dome and present use for gas storage or hydrocarbon production.

The DOE and its predecessor agencies conducted regional studies of the 125 salt domes identified in the above-mentioned USGS screening. All but 11 of the domes were eliminated on the basis of three screening factors: the depth to the salt, the lateral extent of the dome, and the history of use for hydrocarbon production or storage (NUS, 1978; BNI and LETCO, 1980). Three of the 11 domes were removed from consideration on the basis of environmental factors, and a fourth was eliminated because solution mining at the site contributed to a collapse of strata above the dome.

Area-characterization studies were completed for the seven remaining dome areas: Rayburn's and Vacherie Domes in Louisiana; Cypress Creek, Lampton, and Richton Domes in Mississippi; and Keechi and Oakwood Domes in Texas. The geologic field work conducted during this phase included the drilling of deep holes to collect rock cores from the aquifers and other strata for laboratory tests of their properties and geophysical surveys to determine the underlying rock structures. The area environmental studies included descriptions of the plant and animal communities, surface- and ground-water systems, weather conditions, land use, and socioeconomic characteristics. An evaluation of the seven domes on the basis of the DOE's criteria is summarized in a location-recommendation report (ONWI, 1982a).

In the area-characterization studies, the DOE chose a repository-size criterion that was more restrictive than the one used in earlier screening studies. The application of this stricter criterion resulted in the

elimination of Keechi, Rayburn's, and Lampton Domes (ONWI, 1982a). Thus, at the conclusion of area characterization, the Vacherie, Richton, Oakwood, and Cypress Creek Domes were recommended for further screening. After further review of the area-characterization studies, the Oakwood Dome was deferred from further consideration because of uncertainties raised by large-scale petroleum exploration.

In accordance with the Act, the DOE identified the Cypress Creek, Richton, and Vacherie Domes as potentially acceptable sites in February 1983.

1.2.2.2 Bedded salt in Davis Canyon and Lavender Canyon, Utah

Screening criteria were developed for the bedded salt of the Paradox Basin, which the USGS had identified as worthy of further investigation (Pierce and Rich, 1962). The following factors were applied to identify areas for further investigation (Brunton and McClain, 1977; DOE, 1981): the depth to, and the thickness of, the salt; mapped faults; surface igneous features; hydrocarbon and mineral resources, and potential for flooding. The results of this screening were integrated with the results of screening for environmental and socioeconomic factors, such as proximity to urban areas and the presence of certain dedicated lands. On the basis of this regional screening, four areas were recommended for further study: Gibson Dome, Elk Ridge, Lisbon Valley, and Salt Valley (ONWI, 1982b).

The primary screening factors used to identify potentially favorable locations within the four areas were the depth to the salt, the thickness of the salt, proximity to faults and boreholes, and proximity to the boundaries of dedicated lands (ONWI, 1982c). These screening factors were judged to have the strongest potential for differentiating possible locations within the areas.

Salt Valley and Lisbon Valley were both deferred from further consideration because all areas with an adequate depth to the salt were too close to zones of mapped surface faults and, for Lisbon Valley, existing boreholes (ONWI, 1982c).

Application of the screening factors to the Gibson Dome showed a location of 57 square miles near the center of the area that contained appropriately deep and thick salt deposits and was sufficiently far from faults or exploration boreholes that would make a site unsuitable. It was also outside the boundaries of the Canyonlands National Park. This location is referred to as the Gibson Dome location (ONWI, 1982c). The Elk Ridge area contained one location of about 6 square miles and several smaller ones, each less than 3 square miles, that met the screening criteria (ONWI, 1982c). The smaller locations were not large enough for a repository and were therefore excluded from further consideration. The larger location was designated the Elk Ridge location.

Further comparisons of the Gibson Dome and the Elk Ridge locations were made on the basis of more-refined criteria that discriminated between them. The thickness of the salt, the thickness of the shale above and below the depth of a repository, and the minimum distance to salt-dissolution features

were considered the most critical geologic discriminators. Archaeological sensitivity and site accessibility were considered the most important environmental factors. The Gibson Dome location was judged to be superior to the Elk Ridge location in terms of the number and relative importance of favorable factors and was selected as the preferred location (ONWI, 1982c).

During 1982 and 1983 three sites were identified for further evaluation: Davis Canyon, Lavender Canyon, and Harts Draw. Since much of the intrinsic value of southeastern Utah stems from its scenic and aesthetic character, a study of visual aesthetics was performed to evaluate the three sites (Bechtel Group Inc., 1984). Harts Draw was found to be less desirable than the sites at Davis Canyon and Lavender Canyon because it affords a greater total area of visibility, and it was eliminated from further consideration. In February 1983, Davis Canyon and Lavender Canyon were identified as potentially acceptable sites.

1.2.2.3 Bedded salt in Deaf Smith and Swisher Counties, Texas

In 1976, the Permian bedded-salt deposits in the Texas Panhandle and western Oklahoma that had been identified in the USGS study (Pierce and Rich, 1962) were evaluated to determine whether they contained any areas that might be suitable for waste disposal (Johnson, 1976). This screening focused on five subbasins: the Anadarko, Palo Duro, Dalhart, Midland, and Delaware Basins. The primary screening factors were the depth to, and the thickness of, the salt; faults; seismic activity; salt dissolution; boreholes; underground mines; proximity to aquifers; mineral resources; and conflicting land uses, such as historical sites and State or national parks. All the subbasins contain salt beds of adequate thickness and depth. The Palo Duro and the Dalhart Basins had far less potential for oil and gas production and have not been penetrated as extensively by drilling as have the Anadarko, the Delaware, and the Midland Basins. Therefore, the Palo Duro and the Dalhart Basins were judged to be preferable to the other three and were recommended for further studies at the area stage (ONWI, 1983a). These two basins rated higher on six major screening factors: the depth to, and the thickness of, the salt; seismicity; known oil and gas deposits; the presence of exploratory boreholes; and evidence of salt dissolution.

More-detailed geologic and environmental studies of the Palo Duro and the Dalhart Basins began in 1977, and screening criteria were developed to define locations with favorable characteristics. The screening criteria that were most useful in the area-to-location screening were the following: salt depth and thickness, salt purity, existing and abandoned oil and gas fields, flooding, urban areas, and conflicting land use. Six locations in parts of Deaf Smith, Swisher, Oldham, Briscoe, Armstrong, Randall, and Potter Counties, Texas, met the screening criteria. A second set of criteria was then applied to further differentiate among the six locations: distance from the margins of the Southern High Plains, distance from known oil and gas fields, more than one potential repository horizon, depth of salt, number of boreholes that penetrate the repository horizon, a large geographic area, low population densities, and potential land-use conflicts. After applying these criteria, the DOE decided to focus on the two locations that had the greatest likelihood of containing a suitable site, one in northeastern Deaf Smith and southeastern

Oldham Counties and one in northcentral Swisher County. All other locations in the Palo Duro Basin were deferred from further consideration (ONWI, 1983b). In February 1983, the DOE identified parts of Deaf Smith County and Swisher County as potentially acceptable sites and subsequently narrowed the size of the two sites to be considered at each location to 9 square miles each (DOE, 1984b).

1.2.3 SITES IN BASALT AND TUFF

In 1977, the waste-disposal program was expanded to consider previous land use as an alternative basis for site screening. This approach considered the advantages of locating a repository on land already withdrawn from public use and committed to long-term institutional control. Because both the Hanford Site and the Nevada Test Site are dedicated to nuclear operations, will remain under Federal control, have a large geographic area, and are underlain by potentially suitable rocks, screening was initiated in these two areas.

1.2.3.1 Basalt lava in the Pasco Basin, Washington

The DOE and its predecessor agencies have investigated the geologic and hydrologic characteristics of the Pasco Basin since 1977 as a continuation of studies conducted for the defense-waste management program between 1968 and 1972 (Gephart et al., 1979; Myers et al., 1979). These investigations showed that the thick formations of basalt lava in the Pasco Basin are suitable for further investigation as a geologic repository for the following reasons:

- Several basalt flows more than 2,100 feet below ground apparently are thick enough to accommodate a geologic repository.
- The slow rate of deformation of the basalt ensures the long-term integrity of a repository at the Hanford Site. Also, there are synclines where structural deformation appears to be limited.
- The potential for renewed volcanism at the Hanford Site is very low.
- The likely geochemical reactions between the basalt rock, ground water, and the materials that would be emplaced in the repository are favorable for long-term isolation.

The Pasco Basin was selected for screening to provide a broader scope from which to study processes that might affect the Hanford Site and to determine whether there are any obviously superior sites in the natural region outside, but contiguous with, the Hanford Site (Woodward-Clyde Consultants, 1980, 1981).

The first step in screening was to define the candidate area. The screening factors used at this step were fault rupture, ground motion, aircraft traffic, ground transportation, operational radiation releases from nuclear facilities at the Hanford Site, protected ecological areas, culturally

important areas, and site-preparation costs. The DOE identified a candidate area that included the central part of the Hanford Site and adjacent land east of the Hanford Site.

The second step in the screening was to define subareas (locations). The siting factors used in this step were fault rupture, flooding, ground failure, erosion, the presence of hazardous facilities, induced seismicity, and site-preparation costs. This step eliminated approximately half the candidate area.

Locations were identified through an evaluation of the subareas inside and adjacent to the Hanford Site. On the basis of land use, hydrologic conditions, and bedrock dip, subareas outside the Hanford Site were eliminated because they were not obviously superior to those found within the Hanford Site. After these subareas were eliminated, five locations were identified within the boundaries of the Hanford Site.

The identification of sites from among the five locations was based on an evaluation of 23 parameters (Rockwell, 1980). Nine sites were identified, seven of which lay in the Cold Creek Syncline, a major structural feature of the Pasco Basin. This syncline was selected partly because it is not as extensively deformed as nearby anticlines and is underlain by relatively horizontal strata. Since the other two sites were not technically superior to those in the Cold Creek Syncline and were closer to the Columbia River, they were removed from further study. To avoid some geophysical anomalies of uncertain source, the DOE identified three other sites that were largely superimposed on parts of the original seven sites in the Cold Creek Syncline (Myers and Price, 1981).

Since preliminary evaluations of the resulting 10 partly overlapping sites indicated that the sites were too closely matched to be differentiated by routine ranking, a formal decision analysis was used to identify the best site (Rockwell, 1980). Decision criteria were derived from the following siting factors: bedrock fractures and faults, lineaments, potential earthquake sources, ground-water travel times, contaminated soil, surface facilities, the thickness of the proposed repository horizon, the repetitive occurrence of columnar-jointed zones (colonnades) within the host flow, natural vegetative communities, unique microhabitats, and special species. The analysis showed that two approximately coincident sites rated higher than the other sites. These two sites were combined and designated the reference repository location. In February 1983, the DOE identified the reference repository location as a potentially acceptable site.

1.2.3.2 Tuff in the southern Great Basin, Nevada

At the same time that the DOE was considering the Nevada Test Site (NTS) on the basis of land use, the USGS proposed that the NTS be considered for investigation as a potential repository site for a variety of geotechnical reasons, including the following:

- Southern Nevada is characterized by closed hydrologic basins. This means that ground water does not discharge into rivers that flow to major bodies of surface water.

- Long flow paths occur between potential repository locations and ground-water discharge points.

- Many of the rocks occurring at the NTS have geochemical characteristics that are favorable for waste isolation.

- The NTS is located in an arid region (6 to 8 inches per year of rainfall). With the very low rate of recharge, the amount of moving ground water is also low, especially in the unsaturated zone.

In 1977, the geologic medium of prime interest at the NTS was argillite (a clay-rich rock), which occurs under the Syncline Ridge, near the center of the NTS. Geologic investigations and exploratory drilling there revealed a complex geologic structure in the center of the area being considered (Hoover and Morrison, 1980; Ponce and Hanna, 1982). It was decided in July 1978 that the geologic complexity of the area would make characterization prohibitively difficult, and further evaluation was deferred.

A question then arose concerning the compatibility of a repository with the testing of nuclear weapons--the primary purpose of the NTS. A task group formed to evaluate this issue determined in 1978 that a repository located in other than the southwest portion of the NTS might be incompatible with weapons testing. At that time the program refocused on the area in and around the southwestern corner of the NTS, which subsequently was named the Nevada Research and Development Area (NRDA). The entire area then being evaluated included land controlled by the Bureau of Land Management west and south of the NRDA and a portion of the Nellis Air Force Range west of the NRDA.

In August 1978, a preliminary list of potential sites in and near the southwestern part of the NTS was compiled. The areas initially considered were Calico Hills, Skull Mountain, Wahmonie, Yucca Mountain, and Jackass Flats. Of these five areas, Calico Hills, Wahmonie, and Yucca Mountain were considered the most attractive locations for preliminary borings and geophysical testing.

The Calico Hills location was known to contain argillite. It was of particular interest because a geophysical survey showed that granite might occur approximately 1,600 feet below the surface. The first exploratory hole for waste-disposal studies at the NRDA was drilled in 1978 in an attempt to confirm the existence of granite beneath the Calico Hills. Drilling was discontinued at a depth of 3,000 feet without reaching granite (Maldonado et al., 1979). Additional geophysical surveys indicated that the argillite at Calico Hills is probably very complex structurally, comparable with that at Syncline Ridge (Hoover et al., 1982). Because the granite was considered too deep and the argillite appeared too complex, further consideration of the Calico Hills was suspended in the spring of 1979.

Concurrent with drilling at Calico Hills, geophysical studies and surface mapping conducted at Wahmonie indicated that the granite there may not be large enough for a repository, that any granite within reasonable depths may contain deposits of precious metals, and that faults in the rock may allow vertical movement of ground water (Hoover et al., 1982; Smith et al., 1981). For these reasons, Wahmonie was eliminated from consideration in the spring of 1979.

Surface mapping of Yucca Mountain indicated the existence of a generally undisturbed structural block large enough for a repository. In 1978, the first exploratory hole drilled at Yucca Mountain confirmed the presence of thick, highly sorptive units of tuff (Spengler et al., 1979). Because tuff previously had not been considered as a potential host rock for a repository, a presentation was made to the National Academy of Sciences (NAS) Committee for Radioactive Waste Management in September 1978 to solicit its views on the potential advantages and disadvantages of tuff as a repository host rock. The NAS committee supported the concept of investigating tuff as a potential host rock, and the USGS subsequently pointed out the considerable advantages of locating a repository in the unsaturated zone. After comparing the results of preliminary exploration at Calico Hills, Wahmonie, and Yucca Mountain, the USGS recommended that attention be focused on Yucca Mountain. A technical peer-review group supported the DOE's decision to concentrate exploration efforts on the tuffs of Yucca Mountain (DOE, 1980b).

Because the foregoing process of selecting Yucca Mountain for early exploration was not highly structured, a more thorough, formal analysis was begun in 1980 to evaluate whether Yucca Mountain was indeed appropriate for further exploration. This analysis was conducted in a manner compatible with the area-to-location phase of site screening described in the national siting plan (DOE, 1982b), which was used by the DOE before the passage of the Act and the formulation of the guidelines. Details of the formal analysis are presented by Sinnock and Fernandez (1984). In brief, this formal decision analysis evaluated 15 potential locations and concluded that Yucca Mountain was indeed the preferred location. Several potentially suitable horizons were identified in the saturated and unsaturated zones. Therefore, the DOE identified Yucca Mountain as a potentially acceptable site in February 1983.

1.2.4 NOMINATION OF SITES FOR CHARACTERIZATION

The guidelines, in 10 CFR Part 960.3, require the DOE to implement the following six-part decision process in selecting sites for nomination from among the potentially acceptable sites:

1. Evaluate the potentially acceptable sites in terms of the disqualifying conditions specified in the guidelines.

2. Group all potentially acceptable sites according to their geohydrologic settings.

3. For those geohydrologic settings that contain more than one potentially acceptable site, select the preferred site on the basis of a comparative evaluation of all potentially acceptable sites in that setting.

4. Evaluate each preferred site within a geohydrologic setting and decide whether such site is suitable for the development of a repository under the qualifying condition of each applicable guideline.

5. Evaluate each preferred site within a geohydrologic setting and decide whether such site is suitable for site characterization under the qualifying condition of each applicable guideline.

6. Perform a reasonable comparative evaluation under each guideline of the sites proposed for nomination.

Section 1.3 presents the results of evaluating the nine potentially acceptable sites against the disqualifying conditions of the guidelines (step 1) and explains how the DOE has grouped the potentially acceptable sites by geohydrologic setting (step 2). Chapter 2 begins with a detailed description of the geohydrologic setting in which the Hanford site is located and provides the basis for the identification of a preferred site in that geohydrologic setting (step 3). Chapter 6 evaluates the site against the guidelines and presents the findings required in steps 4 and 5. Chapter 7 provides a comparative evaluation of the sites proposed for nomination (step 6).

Having issued the final EAs, the DOE will formally nominate five sites as suitable for characterization. The Secretary of Energy will then recommend three of these sites to the President as candidate sites for characterization. The Secretary's recommendation is presented and documented in a separate report that is being issued simultaneously with this environmental assessment.

1.2.5 FINAL STEPS IN THE SITE-SELECTION PROCESS

After the President approves the sites recommended by the Secretary, characterization activities will begin at those sites. If site characterization reveals new information that shows that a site is unsuitable for development as a repository under the guidelines, the DOE will eliminate that site from further consideration and take steps to reclaim the site and to mitigate any significant adverse impacts caused by site characterization. In the event that a site is eliminated from further consideration during characterization, the DOE does not expect to substitute another site for characterization.

After characterization is completed, the DOE will again evaluate each site against the guidelines, prepare an environmental impact statement, and recommend one site to the President for the first repository. The President may then recommend the site to the Congress. At this point, the Governor or the legislature of the host State may submit to the Congress a notice of disapproval that can be overridden only by a joint resolution of both Houses of the Congress. If the notice of disapproval is not overridden, the President must submit another repository-site recommendation within 12 months. If no notice of disapproval is submitted, or if the notice of disapproval is overridden, then, as prescribed by the Act, the site designation is effective, and the DOE will proceed to file an application with the NRC to obtain a construction authorization for a repository at that site.

1.3 EVALUATION OF POTENTIALLY ACCEPTABLE SITES AGAINST THE DISQUALIFYING CONDITIONS OF THE GUIDELINES AND GROUPING INTO GEOHYDROLOGIC SETTINGS

1.3.1 EVALUATION AGAINST THE DISQUALIFYING CONDITIONS

Having evaluated the nine potentially acceptable sites against the disqualifying conditions in the guidelines, the DOE has found no evidence to support a finding that any site is disqualified. Details of this analysis are contained in Chapter 6, and a summary of findings for each disqualifying condition is presented in Section 2.3.

1.3.2 DIVERSITY OF GEOHYDROLOGIC SETTINGS AND TYPES OF HOST ROCK

Sections 960.3-1-1 and 960.3-1-2 specify that, to the extent practicable, sites recommended as candidate sites for characterization shall be located in different geohydrologic settings and shall have different types of host rock. This guideline-mandated diversity of geohydrologic settings and host rocks is consistent with similar requirements in the NRC's rule governing the disposal of high-level radioactive waste, 10 CFR Part 60. This requirement will protect against the possibility that future investigations might reveal a generic deficiency in a given rock type or within a given regional geohydrologic environment. Such deficiencies might lead to the disqualification of sites in that setting or rock type. If one rock type or geohydrologic environment were viewed initially as the most favorable for a repository, site nomination and recommendation might be dominated by sites in that type of host rock or geohydrologic environment. If later analyses revealed an unacceptable weakness in either the host rock or in the characteristics of the geohydrologic environment, all candidate sites might have to be eliminated. This could leave the program with no viable alternatives available without lengthy additional site exploration.

The guidelines (Part 960.2) define "geohydrologic setting" as a system of geohydrologic units located within a geologic setting. They further define "geohydrologic unit" as an aquifer, a confining unit, or a combination of aquifers and confining units comprising a framework for a reasonably distinct geohydrologic system. A "geologic setting" encompasses thousands to hundreds of thousands of square miles and is characterized by general similarities in physiography, stratigraphy, structural style, and ground-water flow.

For the intents and purposes of the analyses contained in this environmental assessment, the term "geohydrologic setting" refers to a large and relatively distinct major geohydrologic province of the United States commonly identified and accepted in the technical literature. Such a geohydrologic province has recognizable distinct geologic, hydrologic, and geochemical characteristics and boundaries that distinguish it from other geohydrologic settings.

1.3.2.1 Geohydrologic classification system

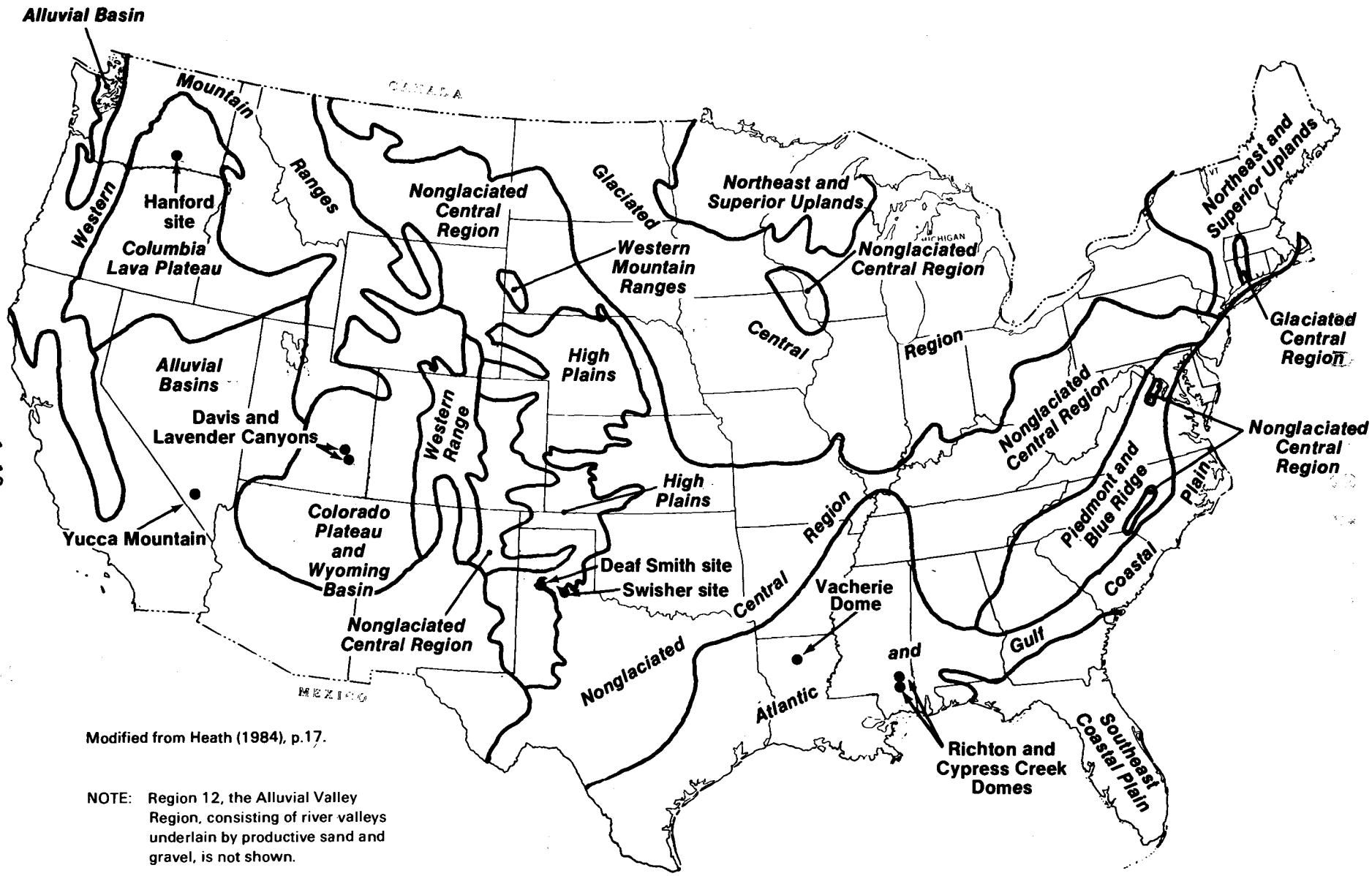
In a report entitled "Ground-Water Regions of the United States" (Heath, 1984), the USGS presents a classification that meets these broad criteria for geohydrologic settings. The USGS applied a logical set of criteria for classifying major geohydrologic regions that considers aquifers and confining units of the system, the nature of water-bearing openings in the rocks, the composition of the rocks, the water-transmitting and water-storage properties of the rocks, and the nature and location of recharge and discharge areas. These characteristics are also those that relate to repository performance (ground-water pathways, rates of radionuclide migration, and other factors important to waste isolation). Therefore, these general criteria appear suitable for application to this guideline requirement.

The USGS classification resulted in the delineation of 12 geohydrologic regions in the contiguous United States (see Figure 1-2). The specific rationale for the delineation and characteristics of each region is described in Heath's report.

It is within the framework of the USGS geohydrologic regions that the nine potentially acceptable sites were examined and classified as to their particular geohydrologic setting. In addition to the general criteria used in the USGS classification, other considerations were used to further subdivide the regions on the basis of tectonic activity, geologic structure, subbasins within the regions, and so on. Accordingly, the DOE has determined that the nine sites fall within the following five distinct geohydrologic settings (the name of the region within which each geohydrologic setting is located is listed in parentheses):

Geohydrologic setting	Site
Columbia Plateau (Columbia Lava Plateau)	Reference repository location as on the Hanford Site, Washington
Great Basin (Alluvial Basins)	Yucca Mountain, Nevada
Permian Basin (High Plains)	Deaf Smith County and Swisher County, Texas
Paradox Basin (Colorado Plateau and Wyoming Basin)	Lavender and Davis Canyons, Utah
Gulf Coastal Plain (Atlantic and Gulf Coastal Plain)	Vacherie Dome, Louisiana; Cypress Creek Dome and Richton Dome, Mississippi

The fundamental distinguishing characteristics associated with these settings as they relate to waste isolation are briefly described below. More-specific details on the characteristics of each of the geohydrologic settings are presented in Section 2.1.



Modified from Heath (1984), p.17.

NOTE: Region 12, the Alluvial Valley Region, consisting of river valleys underlain by productive sand and gravel, is not shown.

Figure 1-2. Geohydrologic regions of the contiguous United States.

7 0 1 6 8 0 5 3 1

1.3.2.2 Distinct differences among the geohydrologic settings and host rocks

The major distinguishing differences among the five geohydrologic settings of the nine potential repository sites are summarized below.

The Hanford and the Yucca Mountain sites are clearly unique in terms of the host rock, the geologic conditions, and the hydrologic conditions that make up the geohydrologic setting. The Hanford site is located within the Pasco Basin, which is a subunit of the Columbia Lava Plateau geohydrologic setting as defined by Heath (1984). It is underlain by a thick, extensive sequence of rocks composed entirely of basalt lava flows in the lower part and of increasing amounts of interbedded, sedimentary deposits in the upper part. Aquifers generally are in the upper parts of the lava flows and in the interbeds. Ground-water drainage is to the Columbia River or its tributaries.

The Yucca Mountain site is located in a region composed of alternating sequences of block-faulted mountains and alluvium-filled valleys of the Alluvial Basins geohydrologic setting as defined by Heath. Yucca Mountain is a typical small fault-block mountain in this region and is composed entirely of volcanic rocks called tuff. The site is in the relatively dry unsaturated welded zone, well above the water table. This is a unique geohydrologic setting in comparison with the other sites, which are all situated well below the water table. The Hanford site will rely principally on the interaction of the low permeability of the dense basalts, the ion-exchange characteristics of the host rock, and a long ground-water flow path for waste isolation. The Yucca Mountain site will rely principally on a very low water flux through unsaturated rocks in a very arid environment, the natural ability of this type of system to exclude flowing or standing water from the repository, and the sorption characteristics of the minerals in the host rock.

The salt-site settings are also clearly distinguishable from one another, but perhaps not as obviously as the nonsalt sites. The first distinction among the salt settings is between salt domes and bedded salt. Although both bedded and dome salt have salt as a host rock, the properties of the two types of salt are quite different, and the hydrologic framework of salt differs greatly from setting to setting. Bedded salt occurs as sedimentary layers of salt and impurities and is typically bounded by aquifers above or below the salt units or both. The domes are anomalous piercements of the thick unconsolidated to semiconsolidated sedimentary clays, silts, and sands that make up the Atlantic and Gulf Coastal Plain, as defined by Heath. The domes are surrounded by aquifers at different depths. Thus, the geohydrologic conditions around the domes are distinctly different from that of bedded salt.

The pathways and mechanisms by which radionuclides might reach the accessible environment are also quite different for bedded and dome salt because of their fundamental structural and stratigraphic differences. Salt domes originated from thick beds of deeply buried salt. When sediments were deposited on these salt beds, the salt was forced upward, forming a dome. Some domes have risen as much as 20,000 feet above their source rock. The salt rock was intensely deformed and "kneaded" during this intrusive rise of the salt dome; as a result, nearly all of the water originally contained in the salt was squeezed out. Consequently, salt domes contain less water than

salt beds. In addition, and largely because of the different mode of formation, the following differences between the two types of salt rock are noteworthy:

- Because of its higher water content, bedded salt has a lower strength than dome salt.
- At equal depths of burial, bedded salt has lower geothermal temperatures than dome salt.
- Bedded salt tends to have a faster rate of creep than dome salt.
- Bedded salt has a more variable chemical composition than dome salt.
- Bedded salt has a simpler structure than salt domes.

Some of the most important of the above factors affecting waste isolation at salt sites are related to the chemical composition and configuration of the host rock. All salt sites would rely primarily on the extremely low permeability of the salt and the isolation of the host rock from surrounding aquifers. One significant potential failure mechanism in salt that can affect ground-water flow is the dissolution of the salt in ground water, whether initiated by inadvertent human intrusion or by unexpected salt deformation. The nature and the relative importance of this failure mechanism differ significantly for bedded and dome salt in their respective geohydrologic environments. For example, at salt domes dissolution would occur along the flanks by ground water from surrounding sedimentary strata. The dissolution of bedded salt could be induced by laterally migrating dissolution fronts, inter-salt-bed sedimentary aquifers, or vertically circulating water in fault zones.

Finally, although the Paradox Basin in Utah and the Permian Basin in Texas are both bedded-salt settings, they also have significant differences that warrant considering them as separate and distinct geohydrologic settings. The bedded-salt sites in Swisher and Deaf Smith counties, Texas, are located in the High Plains setting as defined by the USGS. This setting is underlain by relatively horizontal bedded sedimentary rocks that are capped by the partially unconsolidated sands, gravels, and clays of the Ogallala Formation. The geohydrologic system is dominated by the High Plains aquifer (the Ogallala Formation). Other aquifers, such as the Triassic Dockum Group, occur in deeper strata, but they produce poor-quality water in comparison with the Ogallala.

The bedded-salt sites of Davis Canyon and Lavender Canyon, Utah, on the other hand, are located in the Paradox Basin, which is a subsetting of the Colorado Plateau and the Wyoming Basin and is characterized by a broad uplifted plateau consisting of gently folded sedimentary sandstones, shales, carbonates, and evaporites. The stratigraphic sequence includes a few low-yield aquifers that generally contain poor-quality water. Ground water generally flows toward drainage systems in deeply dissected canyons of the region. Other specific differences include the following:

- Because of overburden and tectonic stresses, the Paradox Basin salt deposits have been structurally deformed into anticlines and synclines

(thickened and thinned zones) much more than the Permian Basin salt deposits have.

- The recharge and discharge patterns of ground water in the two settings are expected to be significantly different.

- The age, stratigraphic sequence, depositional history, and mineral composition of the salts and interbeds in two settings are different.

- The elevation, climate, and physiography of the two settings are significantly different.

- The ground-water system of the Paradox Basin sites is dominated by a deep aquifer well below the repository level, of low yield and poor water quality, whereas the ground-water system at the Permian Basin sites is dominated by a shallow productive aquifer well above the repository level.

On the basis of the criteria and known site characteristics presented above, the DOE has concluded that the nine potentially acceptable sites lie within five distinctly different geohydrologic settings, as indicated, and four distinctly different types of host rock (basalt, welded tuff, bedded salt, and dome salt).

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CHAPTER 2 SUMMARY

Chapter 2 describes the process by which the reference repository location was identified as a potentially acceptable site for a high-level nuclear waste repository and describes the regional geohydrologic setting of the reference repository location—in this case, the Columbia Plateau. Chapter 3 will provide a more detailed discussion of the geohydrology of the Pasco Basin within the Columbia Plateau and of the Hanford Site, which contains the reference repository location. Because much of the above information is related, Table 2-A presents a cross-reference matrix to help the reader locate sections in the rest of this document that relate to topics found in Chapter 2.

Section 2.1 discusses the geohydrology of the Columbia Plateau. Geologically, the Columbia Plateau is a flood-basalt province of eastern Washington, northern Oregon, and western Idaho, which was formed primarily through the eruption of lava between 6 and 17 million years ago. Structurally, the Columbia Plateau is divided into three different areas: The Yakima Fold Belt subprovince, the Palouse subprovince, and the Blue Mountains subprovince. The Yakima Fold Belt subprovince covers the central and western parts of the Columbia Plateau, including the Cold Creek syncline in which the reference repository is located.

Over 50 different basalt flows within the Columbia Plateau have been identified, totaling perhaps as much as 5,000 meters (16,000 feet) in thickness. The flows vary in thickness from a few centimeters (inches) to more than 90 meters (300 feet). Sedimentary deposits overlie and are interbedded with the upper part of the basalt sequence. The Grande Ronde Basalt, the most areally extensive and most voluminous of the Columbia River Basalt Group, includes the flow identified as the candidate horizon, the Cohassett flow. According to current data, the candidate horizon is continuous throughout the Pasco Basin.

The seismicity of the Columbia Plateau that has been instrumentally monitored since 1969 is considered moderate.

Studies of tectonics in the region indicate that over millions of years the Columbia Plateau has been subjected to north-south compressive forces as a result of tectonic plate interactions. These forces have manifested themselves in a series of low-profile ridges or uplifts (anticlines) and broad valleys (synclines); e.g., the Cold Creek syncline.

The Columbia River, which enters the Columbia Plateau from the north, is the major feature of the surface-water hydrology in the plateau. The portion of the Columbia Plateau within the State of Washington can be divided into basins according to the major surface drainage system present; e.g., the Pasco Basin, in which the Hanford Site and reference repository location lie.

Ground water beneath this region lies in the confined aquifers (located in flow tops and sediments interbedded between the basalt flows) and in unconfined aquifers (mainly in those sediments above the basalt flows).

Table 2-A. Sections related to Chapter 2 discussions

	Chapter 2	Chapter 3	Chapter 4	Chapter 5	Chapter 6
Geology Stratigraphy Structure Seismicity	2.1.1 2.1.1.1 2.1.1.2 2.1.1.3	3.2 3.2.2 3.2.3 3.2.4	4.2.1.1 4.1.1.1 4.1.1.1	5.2.1.1	
Tectonics	2.1.2	3.2.3	4.1.1.2		6.3.1.7/6.3.3.4
Surface-water hydrology	2.1.3	3.3.1	4.1.1.7/4.2.1.2.1	5.2.1.2.1	6.3.3.3/6.3.3.1
Ground-water hydrology Columbia Plateau and Pasco Basin Regional ground-water management	2.1.4 2.1.4.2 2.1.4.3	3.3.2	4.1.1.3 4.1.1.4 4.1.1.5 4.1.1.6.3 4.2.1.2.2	5.2.1.2.2	6.3.1.1 6.3.3.3
Geohydrology	2.3.1*	3.3	4.2.1	5.2.1.2	6.3.1.1
Erosion	2.3.2*				6.3.1.5
Dissolution	2.3.3*				6.3.1.6
Tectonics (postclosure)	2.3.4*				6.3.1.7
Natural resources	2.3.5*				6.3.1.8
Population density and distribution	2.3.6*	3.6.1	4.2.2.1		6.2.1.2
Offsite installations and operations	2.3.7*				6.2.1.5
Environmental quality	2.3.8*	3.4	4.1.2.3/4.2.1.3	5.2.1.3	6.2.1.6/6.2.2.2
Socioeconomic impacts	2.3.9*	3.6	4.1.2.2/4.2.2	5.2.3	6.2.1.7/6.2.2.2
Rock characteristics	2.3.10*				6.3.1.3
Hydrology	2.3.11*	3.3	4.1.1/4.2.1.2	5.2.1.2	6.3.3.3
Tectonics (preclosure)	2.3.12*	3.2.3	4.1.1.2		6.3.3.4

*Disqualifier analysis.

7 0 1 6 8 0 5 4 0

Section 2.2 summarizes how the screening criteria were used in the process to identify the reference repository location. Through initial screening, the Cold Creek syncline was selected for further evaluation. A number of boreholes were drilled, and on the basis of the new data, a reference repository location was selected. A principal borehole location was then selected within the reference repository location. Based on information obtained from the principal borehole, a site was chosen for an exploratory shaft facility. Final selection criteria generated by the U.S. Department of Energy eliminated those basalt flows at a shallow depth and those bounded by sedimentary interbeds, as they either were not considered sufficiently isolated for long-term radiological safety or did not provide the thickness required for repository construction. These criteria, along with additional criteria aimed at avoiding features such as potentially adverse geologic features and proximity to aquifers, allowed investigators to narrow the search to the four basalt flows, each of which was considered a suitable candidate horizon. The Cohassett flow was selected as the candidate horizon and is the primary focus of ongoing investigations.

Finally, Section 2.3 provides a summary of the findings at the reference repository location with respect to the disqualifying conditions of the General Siting Guidelines (DOE, 1984) to determine whether this site should be retained for further consideration. Although reaching a final conclusion will require site characterization, based on the existing data the reference repository location is not disqualified by any of the disqualifying conditions.

Chapter 2

DECISION PROCESS BY WHICH THE SITE PROPOSED FOR NOMINATION WAS IDENTIFIED

2.1 GEOHYDROLOGIC SETTING

2.1.1 REGIONAL GEOLOGY

The reference repository location lies within the central portion of the Cold Creek syncline (Fig. 2-1). This syncline is part of the Pasco Basin, one of several structural and topographic basins located within the Columbia Plateau. The Columbia Plateau is defined by the distribution of Miocene flood basalts of the Columbia River Basalt Group and lies primarily within the Columbia Basin and northern part of the Central Highlands subprovinces of the Columbia Intermontane Physiographic Province (Fig. 2-2).

The lavas of the Columbia Plateau comprise a tholeiitic flood-basalt province covering an area of approximately 200,000 square kilometers (78,000 square miles) and having an estimated volume of 375,000 cubic kilometers (90,000 cubic miles) (Reidel et al., 1981, p. 1). The plateau is a structural and topographic depression with its low point in the vicinity of the reference repository location. Here, the accumulation of flows of the Columbia River Basalt Group and interbedded sediments attain their maximum thickness, perhaps as much as 5,000 meters (16,000 feet) (Mitchell and Bergstrom, 1983).

The basalt flows of the Columbia Plateau formed between 17 and 6 million years before present (Watkins and Baksi, 1974; McKee et al., 1977, 1981) when large volumes of lava were erupted from north-northwest-trending linear vent systems now preserved as dikes (Waters, 1961; Taubeneck, 1970; Swanson et al., 1975, 1977; Fruchter and Baldwin, 1975; Price, 1977). The high eruption rates of the volcanic event resulted in lavas that spread considerable distances from their source fissures (Shaw and Swanson, 1970). In doing so, lavas inundated older rocks and structures within the plateau interior, onlapped highlands, and diverted drainages around the plateau margin. Individual basalt flows are voluminous, generally 10 to 30 cubic kilometers (2 to 6 cubic miles), with a maximum known volume of 700 cubic kilometers (145 cubic miles). Flows range in thickness from a few centimeters (inches) to more than 90 meters (300 feet), with most flows ranging in thickness from 27 to 37 meters (90 to 120 feet).

The internal structures that develop during emplacement and subsequent cooling of the molten lava are termed intraflow structures. Three primary types were found: The vesicular or brecciated flow top, the entablature and colonnade of the flow interior, and flow bottom (Long and WCC, 1984) (Fig. 2-3). The flow top typically consists of the upper few

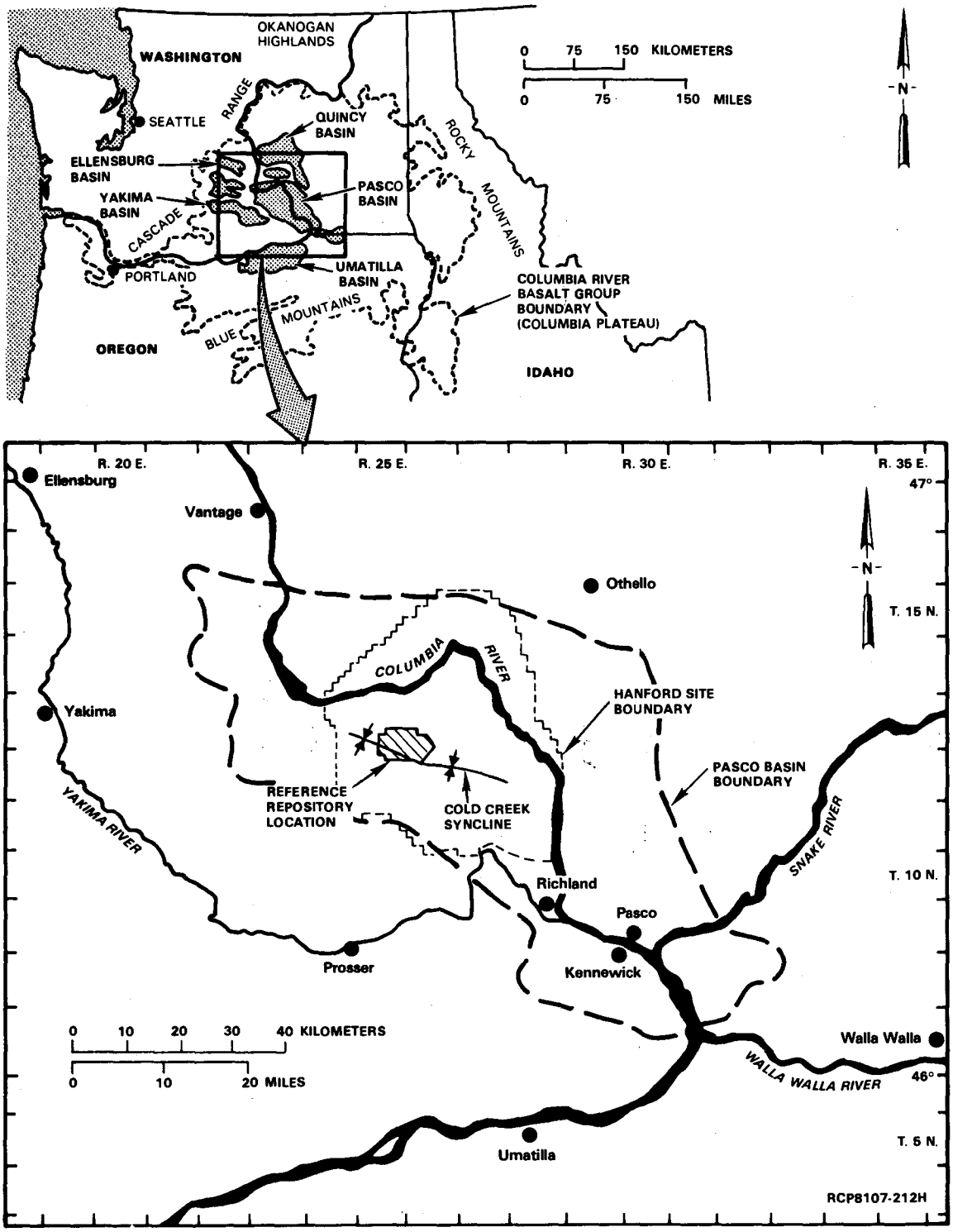

Figure 2-1. Location of the Hanford Site, southeastern Washington State.

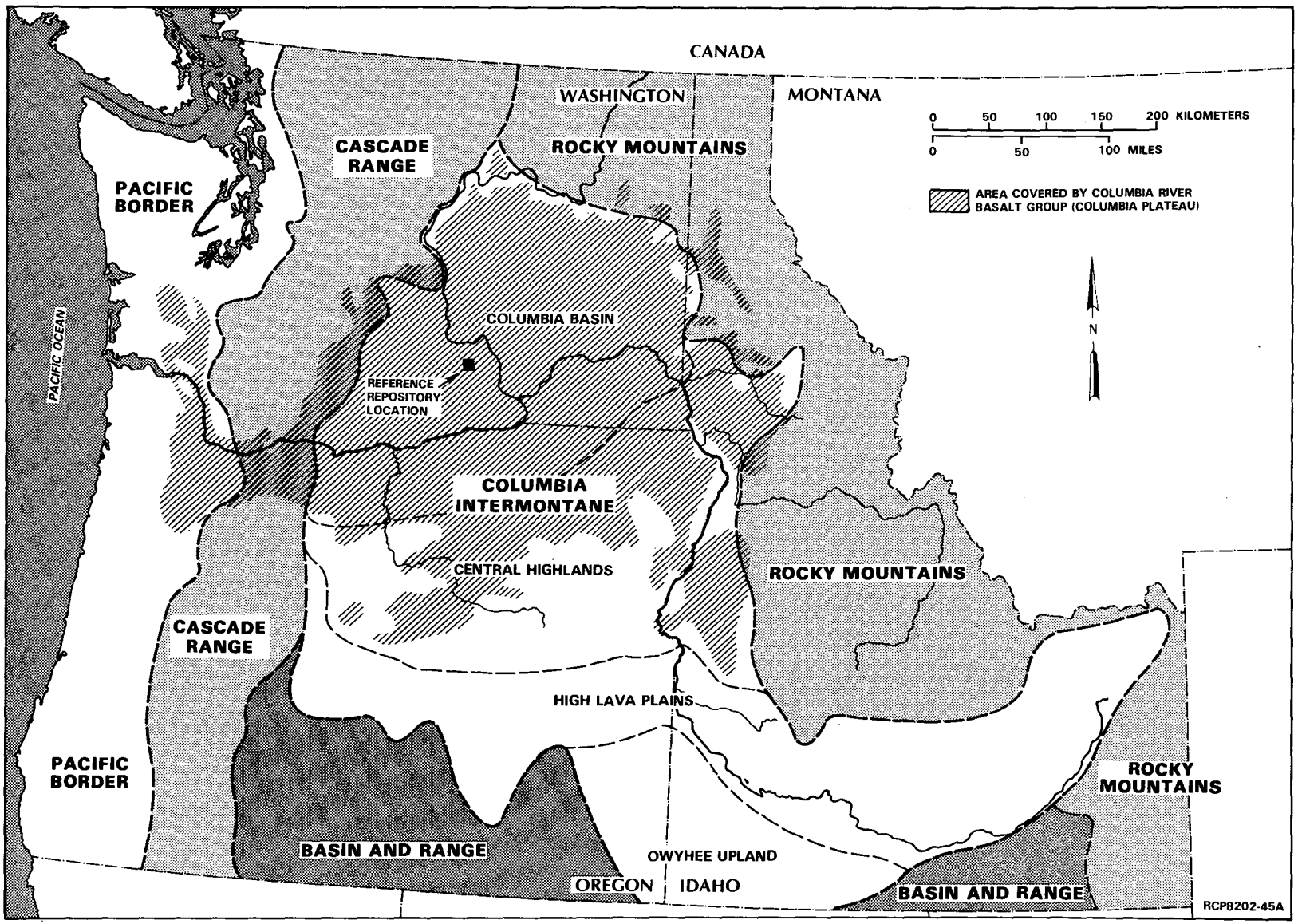

Figure 2-2. Divisions of the Columbia Intermontane Physiographic Province (after Freeman et al., 1945).

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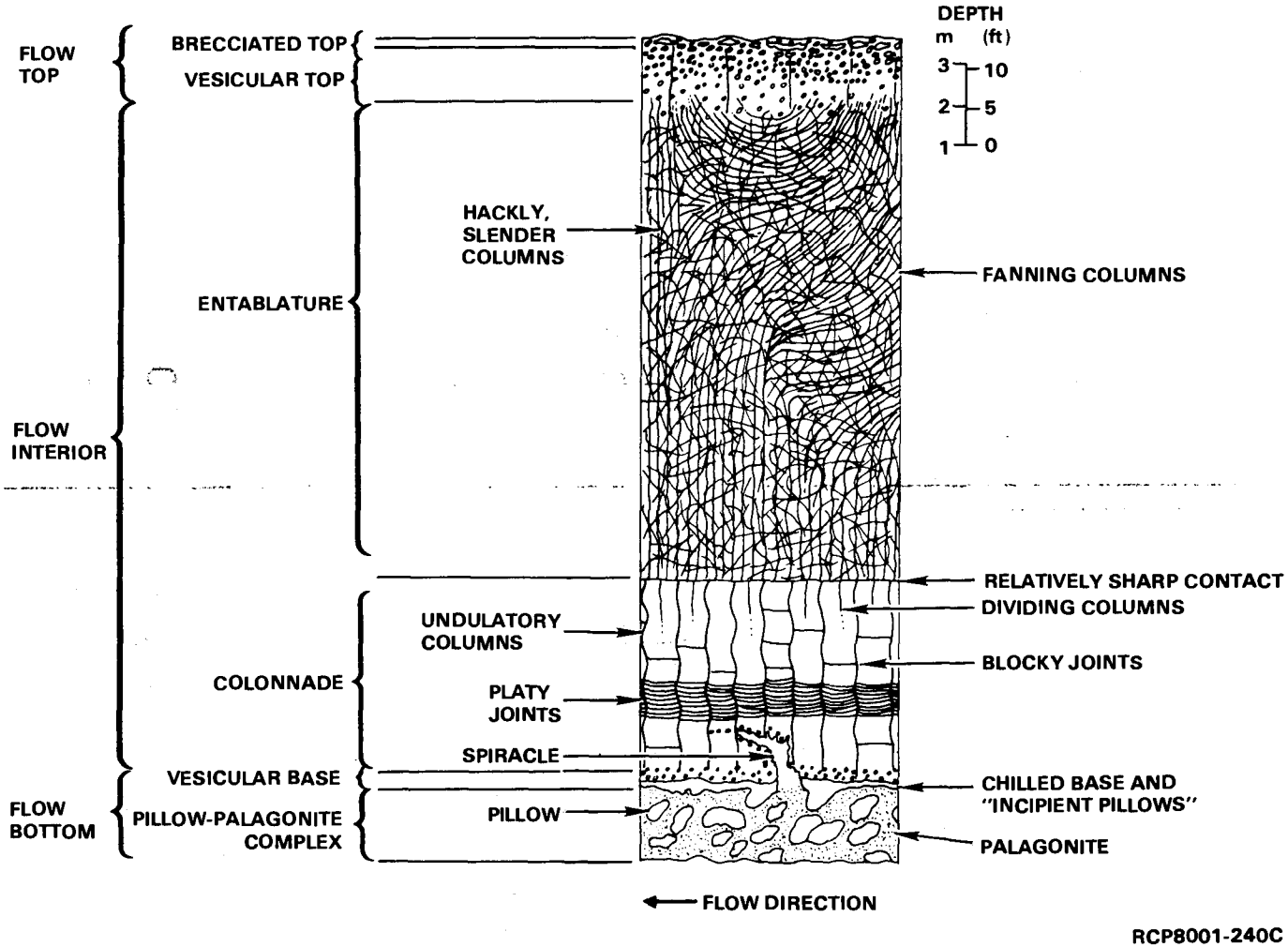


Figure 2-3. Cross section of a typical flow in the Columbia River Basalt Group illustrating, in idealized form, jointing patterns and other structures (modified from Swanson and Wright, 1976).

7 0 F 6 8 8 0 9 4 5

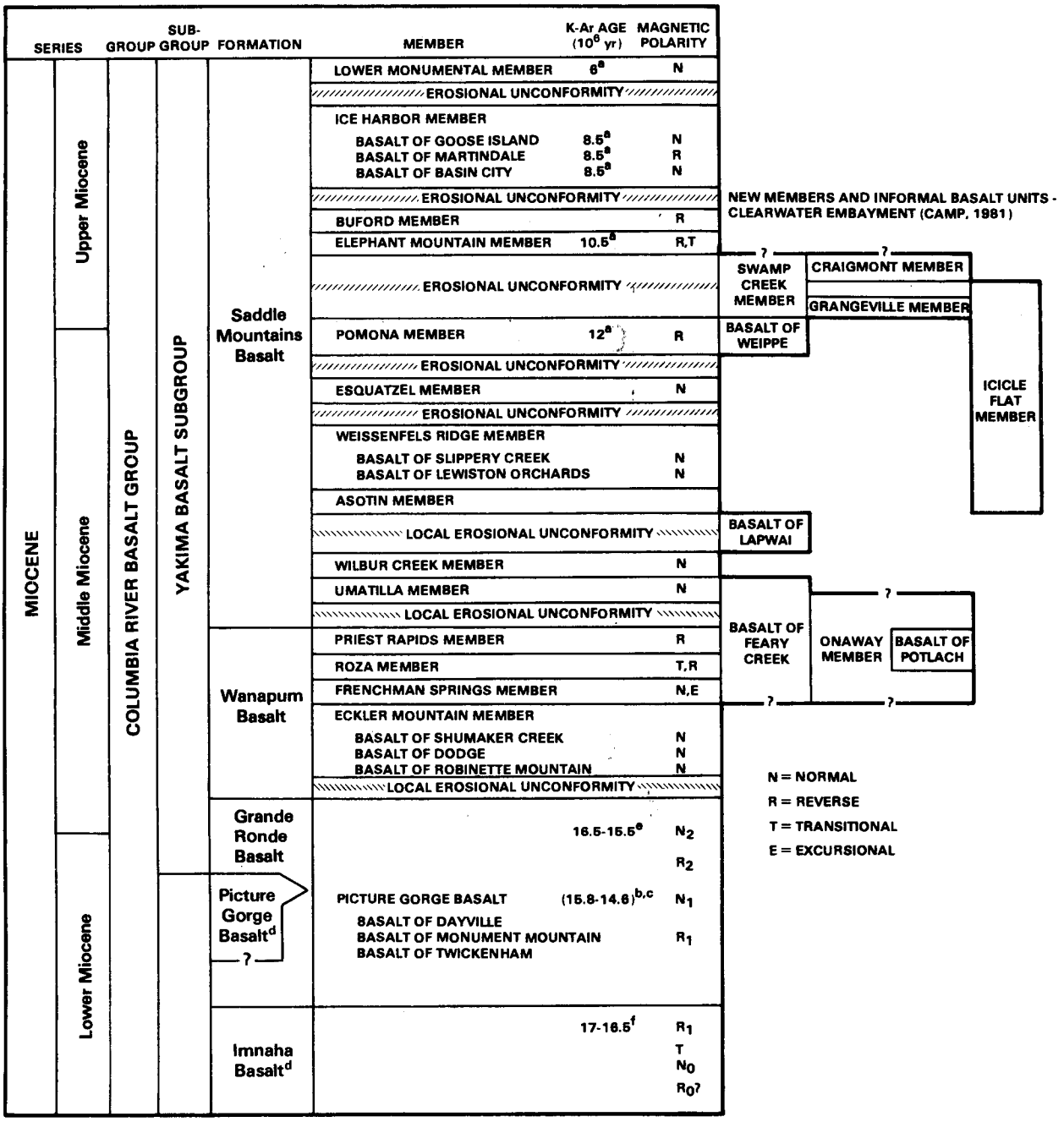
meters (feet) of a flow, although vesicular and brecciated basalt can form up to half the thickness. The flow interior consists of entablature and colonnade. The entablature is composed of jointed rock with relatively small columns (approximately 0.2- to 1.0-meter (1- to 3-foot) diameter). The orientation of columns ranges from vertical to horizontal. The colonnade consists of relatively well-formed columns (approximately 0.5- to 2-meter (1.6- to 6.5-foot) diameter) with fewer fractures than the entablature. Columns are normally upright but radiate locally. In some flows, the entablature overlies a single colonnade; in other flows, colonnade and entablature zones may be repeated in the flow interior (Long and Davidson, 1981). A prominent textural difference between entablature and colonnade exists because of a greater percentage of mesostasis in the entablature than in the colonnade. The basal portion of a basalt flow is usually a thin (approximately 0.5-meter (1.6-foot)) zone of fractured, glassy basalt. Spiracles (zones of fissured glassy rock) may extend a few meters (feet) into the lower portion of a flow.

Fracture logging of basalt flows indicates that fracture abundances in surface exposures range from approximately 1 to 37 fractures per meter (less than 1 to 12 fractures per foot) (Long and WCC, 1984, p. I-69). Fracture frequency in core samples has been found to be similar to that of surface exposures. In core samples, fractures have narrow widths (less than 0.5 millimeter (0.02 inch)) and are filled with multiple generations of secondary minerals. The exact mineral distribution in fractures will differ among basalt flows in response to varying depths of burial, fracture widths, and basalt flow composition. Dominant secondary minerals are clay, zeolites, and silica (Long and Davidson, 1981, pp. 5-38 through 5-40). Pyrite and calcite are less common secondary minerals. The percent of void spaces in fractures in core samples, particularly those from the flow interiors, is typically small. The unfilled fractures range from 2.5 to 5.9 percent of the total fracture volume (Long and Davidson, 1981, p. 5-23).

2.1.1.1 Stratigraphy

Regional geologic maps at a scale of 1:250,000 define the stratigraphy and structure of the Columbia River Basalt Group that is generally coincident with the Columbia Plateau (Swanson et al., 1979a, 1981). A compilation of these maps shows a plateau-wide basalt stratigraphy. Figure 2-4 gives the stratigraphic nomenclature for the Columbia River Basalt Group of the Columbia Plateau. Basalt flows throughout the region can be correlated through a combination of compositional, paleomagnetic, and field criteria.

The Columbia River Basalt Group has been formally divided into 5 formations, 19 members, and 4 informal paleomagnetic subdivisions (Swanson et al., 1979b, pp. 6 and 7; Camp, 1981, pp. 669 through 678). The oldest formation (approximately 17 to 16.5 million years old), the Imnaha Basalt, is known to crop out only within the extreme southeastern portion of the Columbia Plateau where it is conformably overlain by flows



[a] DATA FROM McKEE et al. (1977)
[b] DATA MOSTLY FROM WATKINS AND BAKSI (1974)
[c] INFORMATION IN PARENTHESES REFERS TO PICTURE GORGE BASALT
[d] THE IMNAHA AND PICTURE GORGE BASALTS ARE NOWHERE KNOWN TO BE IN CONTACT
[e] DATA AFROM McKEE et al. (1981) AND LONG AND DUNCAN (1982)
[f] DATA FROM McKEE et al. (1981)

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Figure 2-4. Stratigraphic nomenclature for the Columbia River Basalt Group of the Columbia Plateau (modified from Swanson et al., 1979b; Beeson et al., 1985).

of the Grande Ronde Basalt. The Picture Gorge Basalt that is 15.8 to 14.6 million years old crops out only in the southern portion of the plateau and is considered partly equivalent in age to the Grande Ronde Basalt.

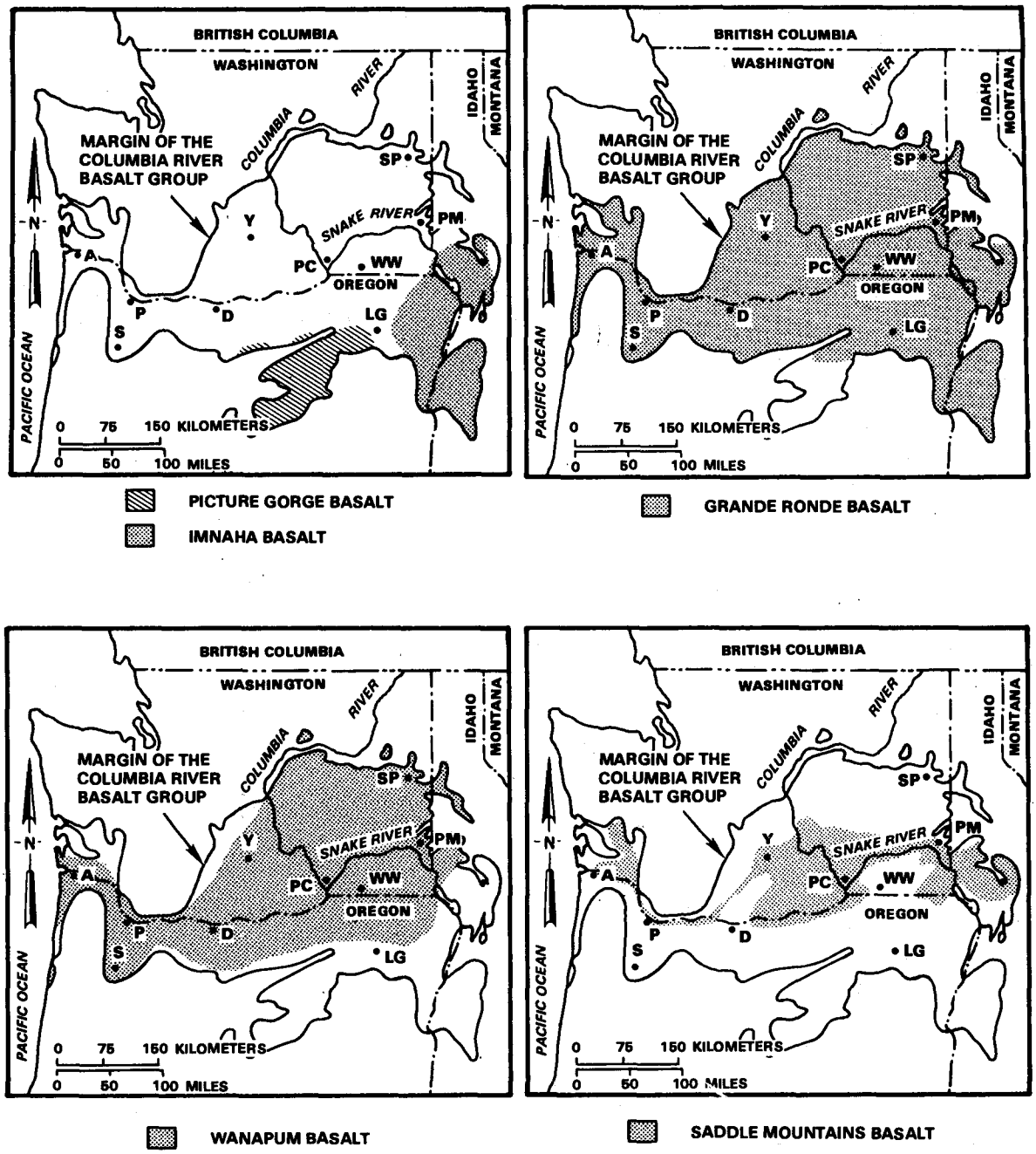
The Grande Ronde Basalt is the most areally extensive and voluminous unit of the Columbia River Basalt Group underlying most of the Columbia Plateau (Fig. 2-5). The basalt comprising this formation was extruded between 16.5 and 15.5 million years ago from vents, now exposed as dikes, in the southeastern portion of the plateau. The known thickness of the Grande Ronde Basalt ranges from tens of meters (feet) along the margins of the plateau to perhaps as much as 4,000 meters (13,000 feet) within the Pasco Basin. The only consistently mappable regional subdivisions of the Grande Ronde Basalt are four magnetostratigraphic units defined on the basis of remanent-magnetic polarity: Reversed-one (R_1), normal-one (N_1), reversed-two (R_2), and normal-two (N_2) (listed in order of decreasing age) (Swanson et al., 1979b, p. G20).

A subdivision of Grande Ronde Basalt (beyond the regional magnetic units) has not been recorded on reconnaissance geologic maps. However, previous work revealed distinctive Grande Ronde Basalt flows in the Pasco Basin, termed through-running flows (Long and Landon, 1981). Identifiable through a combination of compositional, paleomagnetic, and field criteria, they generally have a known areal extent of greater than 250 square kilometers (100 square miles) and a thickness of greater than 30 meters (100 feet). Although such flows are particularly evident in the deep canyon exposures of Grande Ronde Basalt in the southeastern portion of the Columbia Plateau (Reidel, 1983), they are also recognized in the Pasco Basin (Long and Landon, 1981). Included in the through-running flows is the Cohassett flow, which is the candidate horizon for a nuclear waste repository in the reference repository location. Section 3.2 contains a more detailed discussion of the geology of the reference repository location.

Grande Ronde Basalt is overlain by the Wanapum Basalt, the second-most voluminous of the formations. Wanapum Basalt flows erupted between 15.5 and 13.5 million years before present and define much of the Columbia Plateau surface (see Fig. 2-5). These flows can be subdivided into four recognized members (see Fig. 2-4). Source dikes for the four members have been identified in the eastern Columbia Plateau.

Finally, the Saddle Mountains Basalt is the youngest formation of the Columbia River Basalt Group and has been formally divided into 10 members (see Fig. 2-4). Members of the Saddle Mountains Basalt display the greatest petrographic and compositional variability of any formation of the Columbia River Basalt Group (Swanson et al., 1979b; Wright et al., 1973). Because of their distinctive character, these members form mappable horizons throughout the region.

The Saddle Mountains Basalt was erupted between 13.5 and 6 million years ago and represents the waning phase of Columbia River volcanism. Most of the flows were erupted from fissures located in the southeastern



A = ASTORIA
D = THE DALLES
LG = LA GRANDE
P = PORTLAND
PC = PASCO
PM = PULLMAN
S = SALEM
SP = SPOKANE
WW = WALLA WALLA
Y = YAKIMA

PS8510-158

Figure 2-5. Distribution of Columbia River Basalt Group formations. Distribution information from Swanson and Wright (1981).

and south-central portions of the Columbia Plateau. The distribution of several of the Saddle Mountains Basalt members in relation to their source vents indicates that they advanced down ancestral drainages (primarily the ancestral Snake River) to reach the central and western portions of the plateau. The distribution of Saddle Mountains Basalt and intercalated sedimentary units can be used to indicate the timing of the development of structures within the plateau (Subsection 3.2.3.8).

The stratigraphy and structure of late-Cenozoic sediments within the Columbia Plateau have also been defined through the compilation of a regional geologic map at a scale of 1:250,000 (Myers, Price et al., 1979). The stratigraphy of the late-Cenozoic sediments of the Columbia Plateau are illustrated in Figure 2-6. The most widespread late-Cenozoic sedimentary deposits in the State of Washington portion of the plateau include the Ellensburg and Ringold Formations, the Pleistocene catastrophic flood deposits, and Pleistocene to Recent loess deposits.

The Ellensburg Formation includes weakly lithified clastic and volcaniclastic sediments, which occur within the western and central portions of the Columbia Plateau. Units of the formation underlie, interfinger, and overlie flows of the Columbia River Basalt Group (Bentley, 1977; Waitt, 1979). The formation thickens and becomes coarser grained in the far western portion of the plateau and reflects a nearby Cascade Range source area (Subsection 3.2.2.4).

The Miocene-Pliocene Ringold Formation, which is a sequence of fluvial and lacustrine deposits, overlies the Columbia River Basalt Group in the central Columbia Plateau. Sediments of this formation have been subdivided into several fluvial units (Subsection 3.2.2.5).

The central and eastern portions of the Columbia Plateau are dominated by erosional features of the Channeled Scablands and sedimentary deposits of Pleistocene catastrophic flooding. During Pleistocene glaciation, the scablands area was subjected to a number of catastrophic floods that resulted from the breakup of ice dams impounding glacial lakes in Idaho, Montana, and northeastern Washington (Bretz, 1923; Waitt, 1980). The number and sequence of floods are not known, but most surficial flood deposits are thought to be associated with the last major flood dated at approximately 13,000 years before present (Mullineaux et al., 1977, p. 1105).

The eastern portion of the Columbia Plateau is covered by eolian loess that includes four distinct units: Three Pleistocene units and a younger late-Wisconsinan to Recent loess, which have been correlated with glacial events in the region (Myers, Price et al., 1979).

2.1.1.2 Structure

The stratigraphic framework (established by geologic mapping) has been used to interpret the structural character of the Columbia Plateau. In general, the plateau can be divided into three areas of different

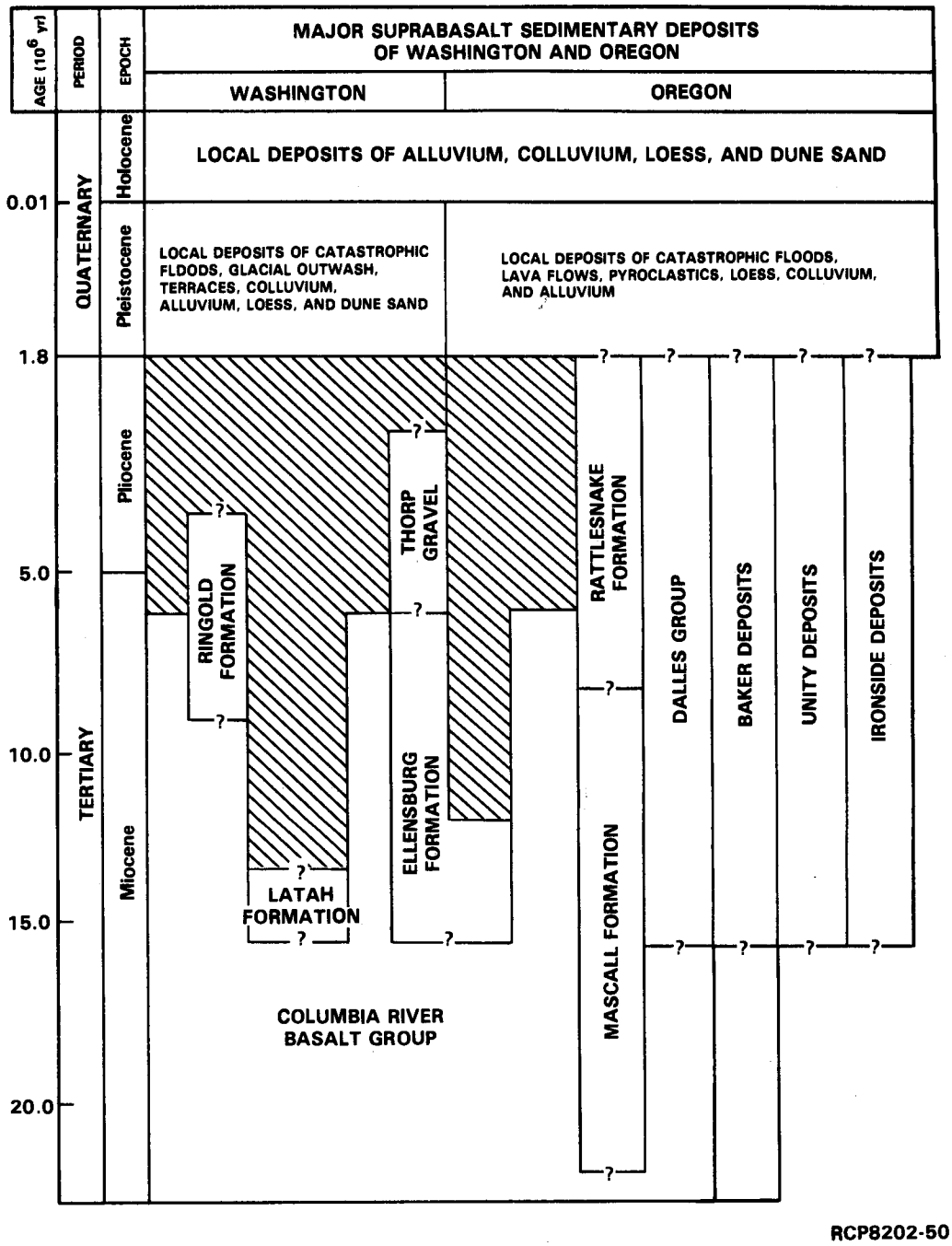


Figure 2-6. General stratigraphic relationship of late-Cenozoic sediments of the Columbia Plateau.

structural character, informally termed the Yakima Fold Belt, Palouse, and Blue Mountains subprovinces (Fig. 2-7). Figure 2-8 is a map illustrating geologic structures of the Columbia Plateau.

2.1.1.2.1 Yakima Fold Belt subprovince

The Yakima Fold Belt subprovince comprises the western and northwestern parts of the Columbia Plateau that are characterized by largely compressional structural features, the Yakima folds (see Fig. 2-8). In the eastern portion of the subprovince, Yakima folds are generally east-trending to southeast-trending anticlinal ridges and synclinal valleys. The folds extend from the Palouse subprovince to the east flank of the Cascade Range, and possibly from the west side through the Cascade Range (Tolan and Beeson, 1984; Beeson et al., 1985). Myers, Price et al. (1979, pp. 11 through 73) and Caggiano (1983, pp. 2-11 through 2-16) provide additional discussion of the structural characteristics of the area.

In general, the anticlines of the Yakima Fold Belt are asymmetrical and overturned to the north; but variations in the geometry of the folds as well as changes in trend along strike give a segmented character to the folds. The geometry varies from almost symmetrical, open folds, to asymmetrical folds with steep northern limbs or southern limbs, to conjugate folds. Second- and third-order folds commonly are developed on the first-order anticlinal folds and impart another order of complexity to the structures.

Thrust to high-angle reverse faults, with fault planes that strike subparallel to the fold axes, are common along the steeper limbs. Estimated amounts of displacement along these faults range from several meters (feet), as in the Horse Heaven Hills at Wallula Gap (Gardner, 1977; Gardner et al., 1981, pp. 1 through 63; PSPL, 1982), to more than 2.5 kilometers (1.6 miles) in the Saddle Mountains at Sentinel Gap (Reidel, 1984, pp. 972 and 973). The inclination of the fault planes beneath the structures varies. Estimates range from steep (45 degrees to nearly vertical) inclinations (Bentley, 1977; Reidel, 1984; Price, 1982, pp. 112 through 118) to shallow (less than 45 degrees) inclinations (Laubsher, 1981).

Northwest- and northeast-trending, steep faults that transect the Yakima folds and that have several meters (feet) to several tens of meters (feet) of dip-slip displacement have been mapped (Bentley et al., 1980, pp. 41 through 58; Gardner et al., 1981, pp. 1 through 6; Swanson et al., 1981). Strike-slip displacements of varying amounts have been postulated for these northwest- and northeast-trending faults along the Columbia Gorge near The Dalles, Oregon (Swanson et al., 1981). The length, straightness, seeming reversal of slip along strike, and the spatial relationship to the axes of folds and other faults suggest that they are wrench faults (Bentley, 1980). However, the amount of strike-slip movement of these faults has not been firmly established because of lack of steep strata or marker horizons.

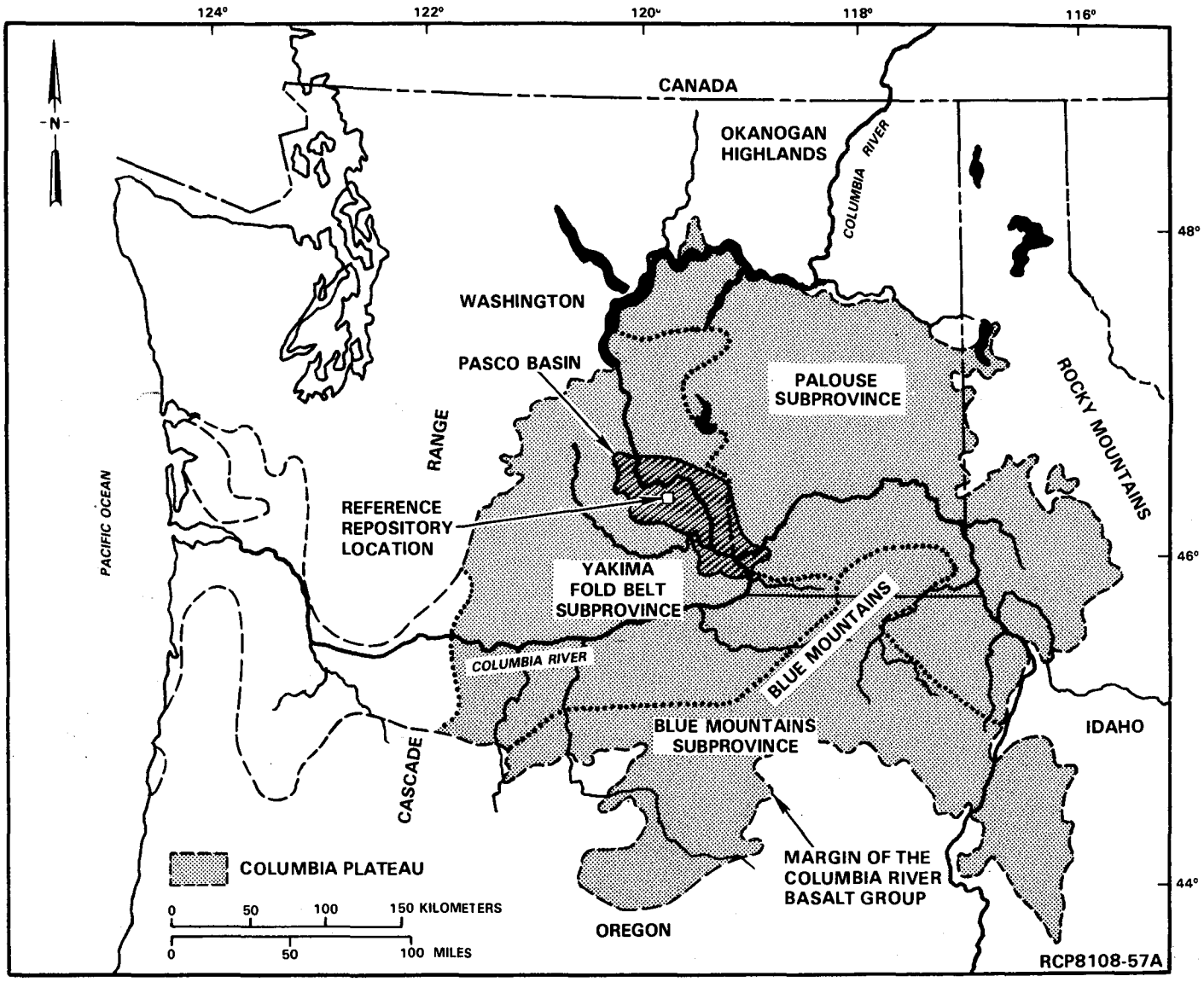


Figure 2-7. Structural subdivisions of the Columbia Plateau.

7 0 1 6 8 0 5 5 3

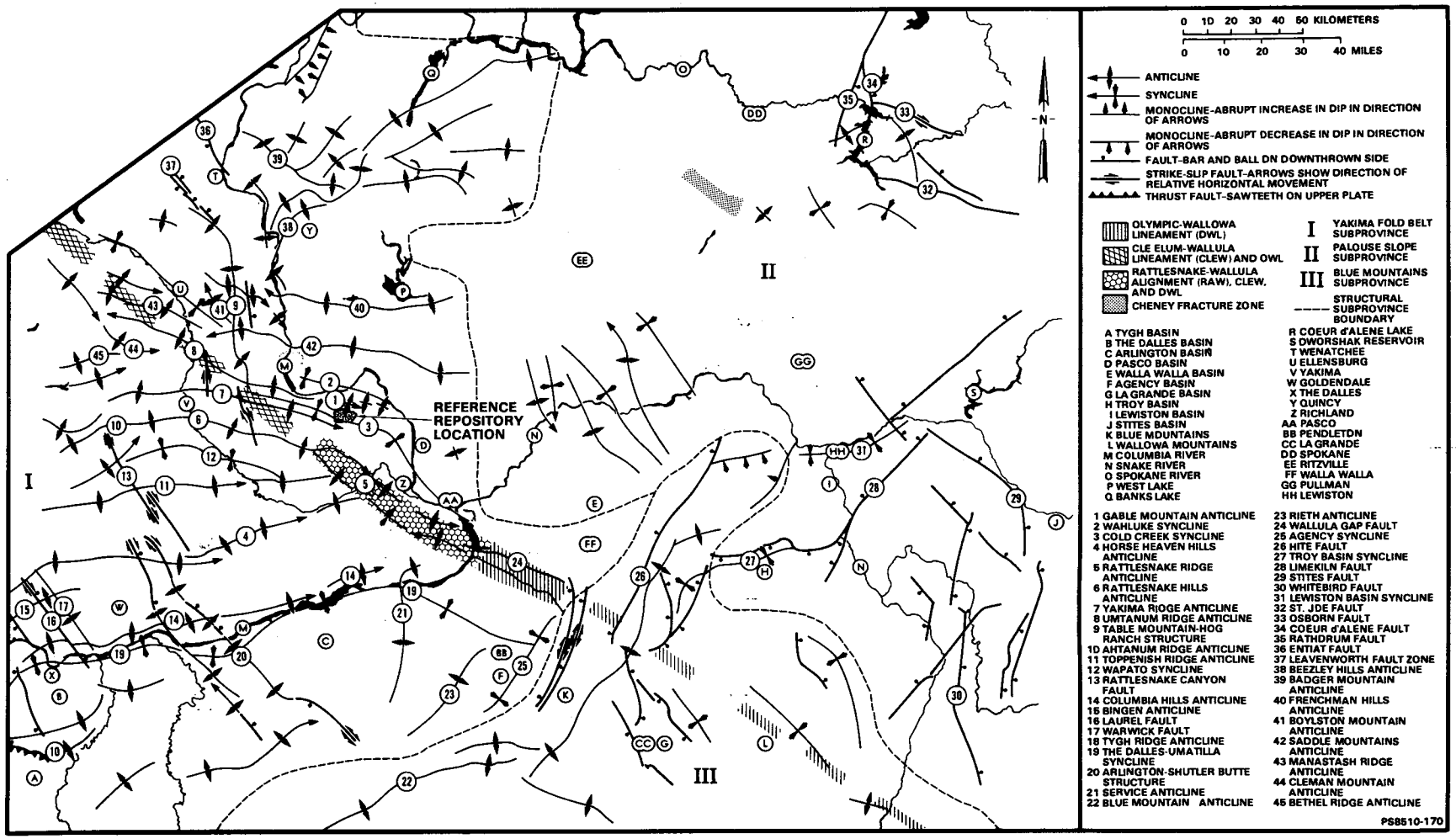


Figure 2-8. Geologic structures and features of the Columbia Plateau.

7 0 1 6 8 0 5 5 4

Evidence for possible Quaternary faulting outside the Pasco Basin and within the Yakima Fold Belt is reported, as discussed as follows, for Toppenish Ridge and Union Gap. Quaternary faulting that occurs within the Pasco Basin is discussed in Chapter 3. Scarps that cut Miocene and Quaternary units occur near the crest and toe of Toppenish Ridge, the topographic expression of the first-order Toppenish anticline that is approximately 40 kilometers (24 miles) long and approximately 75 kilometers (47 miles) west of the Hanford Site (Campbell and Bentley, 1981, pp. 523 through 524; Rigby et al., 1979, pp. 49 through 52; Myers, Price et al., 1979, pp. II-79 through II-82; WCC, 1981b, pp. 1 through 31). Scarps near the crest and midslope on the north side of the ridge are nearly straight, nearly vertical, have relief of up to 2 meters (6.6 feet), are discontinuous, and have individual lengths of as much as 3 kilometers (1.9 miles). The scarp at the toe of the ridge has as much as 2 meters (6.6 feet) of relief, is continuous for several kilometers (miles), cuts Quaternary alluvial fan and landslide units, follows topography, and approximates the trace of the 15-degree south-dipping, largely concealed Mill Creek thrust fault. A tectonic interpretation is favored for these features (Campbell and Bentley, 1981, pp. 522 through 524; WCC, 1981b, pp. 19 through 31), but a nontectonic interpretation (e.g., landslide) has not been ruled out. Since the scarps cut deposits physically similar to those that contain tephra approximately 13,000 years old, they are assumed to be late Quaternary by Campbell and Bentley (1981, pp. 521 through 524). Campbell and Bentley (1981, p. 521) also report radiometric dates of a few hundred years (505 plus or minus 160 years and 620 plus or minus 135 years) on organic matter in sediments deposited in small ponds created by the disruption of drainage.

The long narrow anticlines of the Yakima Fold Belt are separated by broad to narrow synclines whose bedrock exposures are limited because of overlying late-Cenozoic sediments. Consequently, information on synclines in the central portion of the plateau is based primarily on interpretation of borehole and geophysical data.

Two regional structural features, the Olympic-Wallowa lineament and the Hog Ranch-Naneum Ridge anticline, trend into the Columbia Plateau and transect the Yakima Fold Belt. Both features have been interpreted to be controlled by basement structures that have deformed the overlying basalt. The Olympic-Wallowa lineament is a northwest-trending topographic lineament greater than 400 kilometers (250 miles) long that extends from the northwest side of the Olympic Mountains to the Wallowa Mountains of northeast Oregon (Raisz, 1945, pp. 479 through 485). The Cle Elum-Wallula lineament (Kienle et al., 1977) is the central third of Raisz's (1945, pp. 479 through 485) Olympic-Wallowa lineament and is interpreted to be a fundamental structural feature of the Columbia Plateau (Laubscher, 1981; Davis, 1981, pp. 31 through 35; Bentley, 1980). The Cle Elum-Wallula lineament is a narrow zone approximately 200 kilometers (125 miles) long in which folds change trend from west-northwest or east-west to northwest (Kienle and Newcomb, 1973; Kienle et al. 1977, p. 6) and in which faults, especially of northwest trend, are more common. In the Pasco Basin, this trend is topographically and structurally well displayed by the alignment of Rattlesnake Mountain and several southeast-trending, broad, doubly

plunging anticlines (brachyanticlines) also known as "The Rattles." This segment of the Cle Elum-Wallula lineament between Rattlesnake Mountain and Wallula Gap forms part of the Rattlesnake-Wallula alignment. East of Wallula Gap, the west-northwest-trending faults of the Wallula fault system, extending to the Hite fault, form the remaining part of the Rattlesnake-Wallula alignment. The west-northwest-trending faults, approximately parallel to those of the Brothers fault zone, continue along this trend.

Skehan (1965, p. 7) suggested that the Olympic-Wallowa lineament marks the boundary between oceanic and continental crust. Swanson (in Zietz et al., 1971) interpreted magnetic anomalies from a high-latitude aeromagnetic survey as suggestive of a continental-oceanic crustal boundary. However, neither the regional gravity data nor magnetotelluric data (Mitchell and Bergstrom, 1983, pp. 4-1 through 4-18) indicate the juxtaposition of rocks of highly contrasting density or resistivity along the Rattlesnake Mountain segment of the Olympic-Wallowa lineament.

The north-trending Hog Ranch-Naneum Ridge anticline to the west of the Columbia River (Mackin, 1961, p. 3) marks the western boundary of the Pasco Basin. Five Yakima folds from the Frenchman Hills on the north to Yakima Ridge in the south and probably a sixth in the Horse Heaven Hills (Myers, Price et al., 1979, Plate III-1; Hagood, 1985) are transected by the Hog Ranch-Naneum Ridge cross structure. The northwestern-most extension of the anticline can be traced to southwest of Wenatchee, Washington, near Table Mountain (Tabor et al., 1982). It trends southeast to Wenatchee Mountain where it swings south and enters the Columbia Plateau. The southern extension of the anticline is not known, but may extend as far south as the Horse Heaven Hills (Hagood, 1985, p. 45). A gravity gradient (Konicek, 1975, pp. 111 and 112) that parallels the southern extension of the anticline has not been directly associated with the anticline.

2.1.1.2.2 Palouse subprovince and paleoslope

The Palouse subprovince is located in the northeastern portion of the Columbia Plateau and consists of two tectonically diverse regions. The northern part is the Palouse paleoslope, which is a gentle, relatively undeformed, westward-dipping slope that developed no later than the Miocene (see Fig. 2-8). The southern part is characterized by graben and basins of southeast Washington, northeast Oregon, and western Idaho. Deformation in the Palouse subprovince is dominated by extensional features in contrast to the compressional features of the Yakima Fold Belt subprovince. This style of deformation is principally expressed as the north-northwest-trending Columbia River basalt vent-dike system.

According to Swanson and Wright (1976, p. 6), the Palouse slope is a paleoslope of gentle west-southwest dip (1 to 2 degrees) that has been relatively stable for at least the last 12 million years (Reidel et al., 1983, p. 5-5). Superimposed on this slope are north- to northwest-trending folds of low amplitude and long wavelength (Swanson et al.,

1980). In the northeastern part of the Palouse slope, northwest-trending zones of fractures spaced 10 kilometers (6 miles) apart and extending for 40 kilometers (25 miles) or more are found near Cheney, Washington (Griggs, 1973). These fractures, informally called the Cheney fracture zone, have the same trend as folds and faults that lie beyond the edge of the basalt (45 kilometers (30 miles) or more distant) and are presumed to continue beneath the basalt. Minor deformation of the thin basalt overlying basement structures presumably has resulted in development of zones of closely spaced fractures that have been eroded by catastrophic floods. Kiver and Stradling (in Rigby et al., 1979) found no evidence of any late-Quaternary movement along any of these fractures.

The southern Palouse slope stands out in marked contrast to the northern portion of the Palouse slope. In the southern Palouse subprovince, major topographic basins are connected by deep canyons eroded by the Snake, Salmon, and Clearwater Rivers. The Lewiston Basin, the most prominent, is a fault-bounded graben on the northern end of the Blue Mountains uplift. The pattern and distribution of Columbia River basalt flows suggest that the graben began to develop by at least late-Grande Ronde Basalt time (Reidel, 1978, 1983, pp. 530 and 531) and had developed significant relief by the end of deposition of the Wanapum Basalt (Camp and Hooper, 1981, pp. 659 through 668).

The Stites graben and the Troy Basin also were developing during the eruption of the Columbia River basalt. The thick section of Grande Ronde Basalt in the Stites Basin along the margin of the Idaho batholith attests to early development of the basin during or by Grande Ronde Basalt time, perhaps by movement on the north-south-trending Stites fault (Camp and Hooper, 1981, pp. 659 through 668). North-south faults in prebasalt rocks south of the Stites Basin continue beneath the basalt (Hamilton, 1962, pp. 511 through 516) and suggest reactivation as a possible cause for development of the basin. Ross (1978, pp. 130 through 151) documented evidence for the initial development of the Troy Basin during the late-Grande Ronde Basalt time and its continued growth through the Wanapum and Saddle Mountains Basalt time.

The deep canyons of the Clearwater embayment and adjacent area expose the dikes of the Chief Joseph dike swarm, the principal vent system for the Columbia River basalt. These linear vent systems appear to be more prevalent in a zone extending from the eastern margin of the Pasco Basin to the eastern edge of the Columbia Plateau. This zone is as much as a few hundred kilometers (miles) long (Swanson et al., 1975, pp. 877 through 905; Taubeneck, 1970, pp. 73 through 96). Individual dikes range from a few centimeters (inches) to a few meters (feet) wide and trend north-northwest. Holden and Hooper (1976) and Ross (1978) have found fault gouge with subhorizontal striae along the margins of some dikes, suggesting deformation along these trends in post-dike emplacement.

2.1.1.2.3 Blue Mountains subprovince

The Blue Mountains subprovince is located in the southern portion of the Columbia Plateau and is characterized by the Blue Mountains anticlinorium and several structural basins including the Tygh, John Day, The Dalles, La Grande (Grande Ronde), Baker, and Unity Basins (see Fig. 2-8).

The Blue Mountains are a broad anticlinal uplift that extends east-northeast from the foothills of the Cascade Range in Oregon to west of Lewiston, Idaho. The Blue Mountains anticlinorium (Newcomb, 1970) is broad compared with anticlines in the Yakima Fold Belt; flanks dip as much as 8 degrees on the north limb and as much as 3 degrees on the south limb (Kendall, 1981, pp. 1 through 103). Strata in the broad axial region dip gently and appear almost undeformed. The geometry of the Blue Mountains anticlinorium suggests it resulted from uplift of a structural block of Mesozoic and older rocks in the basement beneath the capping basalt. The Blue Mountains apparently began to uplift in late-Grande Ronde Basalt time, and subsequently influenced the distribution of Columbia River basalt flows (Camp and Hooper, 1981, pp. 659 through 668; Ross, 1978, pp. 134 through 136, 153 and 154) and served as a source for Neogene sediments in basins to the north and south (Farooqui et al., 1981, pp. 10 through 39). Thus, evidence indicates that deformation of Columbia River basalt and uplift of the Blue Mountains were under way by at least middle-Miocene time, and that folding and faulting were coincident (Pigg, 1961; Ross, 1978, pp. 134 through 136; Shubat, 1979).

The broad, east-west-trending Blue Mountains uplift has been affected by northwest-trending folds and faults of dip-slip displacement that are especially prominent near La Grande, Oregon, the location of the Grande Ronde graben (Walker, 1977; Kienle et al., 1979, pp. 1 through 58; Barrash et al., 1980). Northeast-trending folds and faults are also present. Gehrels et al. (1980, p. 107) interpret the La Grande Basin as a rhomb-shaped, pull apart graben formed by right-lateral slip on a fault system that trends north 30 degrees west. North-northeast-trending, steep faults along the northwest edge of the Blue Mountains between Prineville, Oregon, and the Snake River in Washington belong to the Hite fault system (Newcomb, 1970; Kienle et al., 1979, pp. 1 through 58; Kienle, 1980, pp. 1 through 76). Other subparallel faults that trend essentially north-south have a similar geologic history and are included as part of the Hite fault system (Kienle, 1980, pp. 1 through 58). Two major episodes of movement have occurred on the Hite fault: (1) Primarily down-to-the-west dip-slip motion in pre-Frenchman Springs Member time and (2) primarily strike-slip motion in post-Frenchman Springs Member (Wanapum Basalt) time (Kienle et al., 1979, pp. 1 through 58; Kendall, 1981, pp. 1 through 103). The Hite fault is expressed as a gouge zone as much as 150 meters (492 feet) wide or as a stratigraphic separation where up to 120 meters (394 feet) of dip-slip movement (Kendall, 1981, pp. 1 through 103) have occurred since Frenchman Springs Member time (15 million years before present). Kienle et al. (1979, pp. 1 through 58) believe that right-lateral movement has occurred on the Hite fault in post-Frenchman Springs Member time, but Kendall (1981, pp. 1 through 103)

considers motion on the fault in post-Frenchman Springs Member time to be left lateral and the Hite fault to be one member of a conjugate fault system, the La Grande fault system being the right-lateral member.

Different thicknesses of Grande Ronde Basalt on opposite sides of the Hite fault suggest the fault was active during Grande Ronde Basalt time (Kendall, 1981, pp. 1 through 103). Kienle et al. (1979, pp. 1 through 58) consider the Hite fault to be older than the west-northwest-trending Wallula fault, which they suggest was capable (with respect to nuclear reactor licensing) based on offset of late-Pleistocene units. Trenching at Warm Springs, Oregon, at a locality known as Bingham's linear (Bingham et al., 1970) along the Wallula fault suggests that the most recent movement predates the deposition of late-Wisconsinan slackwater flood deposits (known as the Touchet Beds Member of the Hanford formation), which are at least 13,000 years old. The Hite fault may be the south-eastern terminus of the topographic feature described by Raisz (1945, pp. 479 through 485) as the Olympic-Wallowa lineament. Davis (1981, pp. 20 through 23) suggested that this topographic feature and the Wallula fault system may be terminated at the Hite fault.

The basins of the Blue Mountains subprovince are generally of two types (Farooqui et al., 1981, p. 53): (1) Fault-bounded basins; e.g., the La Grande, Baker, and Unity Basins; and (2) fold-bounded basins, including The Dalles, Tygh, and John Day Basins. The anticlinal ridges that bound this last group of basins are similar to many of the anticlinal ridges of the Yakima Fold Belt. They generally trend east-west, are asymmetrical to the north, and have a high-angle reverse or thrust fault along the northern flank.

2.1.1.3 Seismicity

Although records of earthquakes in the Pacific Northwest go back to approximately 1850, early records are very qualitative and yield only general information about seismicity in the Columbia Plateau. Before a network of seismographs was installed on the Columbia Plateau in 1969, earthquakes were documented mainly from reports of tremors that were felt (Myers, Price et al., 1979, pp. IV-1 through IV-11; Weston, 1977, pp. 2RJ-1 through 2RJ-21; WPPSS, 1981, pp. 2.5J-6 through 2.5J-10). Figure 2-9 shows the distribution and intensity of historical earthquakes and indicates that the plateau is in an area of moderate seismicity (Berg and Baker, 1963, pp. 95 through 108; Rasmussen, 1967, pp. 463 through 476). Figure 2-10 indicates instrumental seismicity of earthquakes occurring within the plateau between 1969 and 1983 that were greater than magnitude 3.0. Since the 1936 Milton-Freewater earthquake was a magnitude 5.75, the seismicity of the Columbia Plateau is moderate (Lee and Stewart, 1981). Although seismic activity above magnitude 3.0 has occurred in the central Columbia Plateau region, activity above magnitude 3.5 is most commonly found around the northern and western portions of the plateau, and a few events occur along the border between Washington and Oregon.

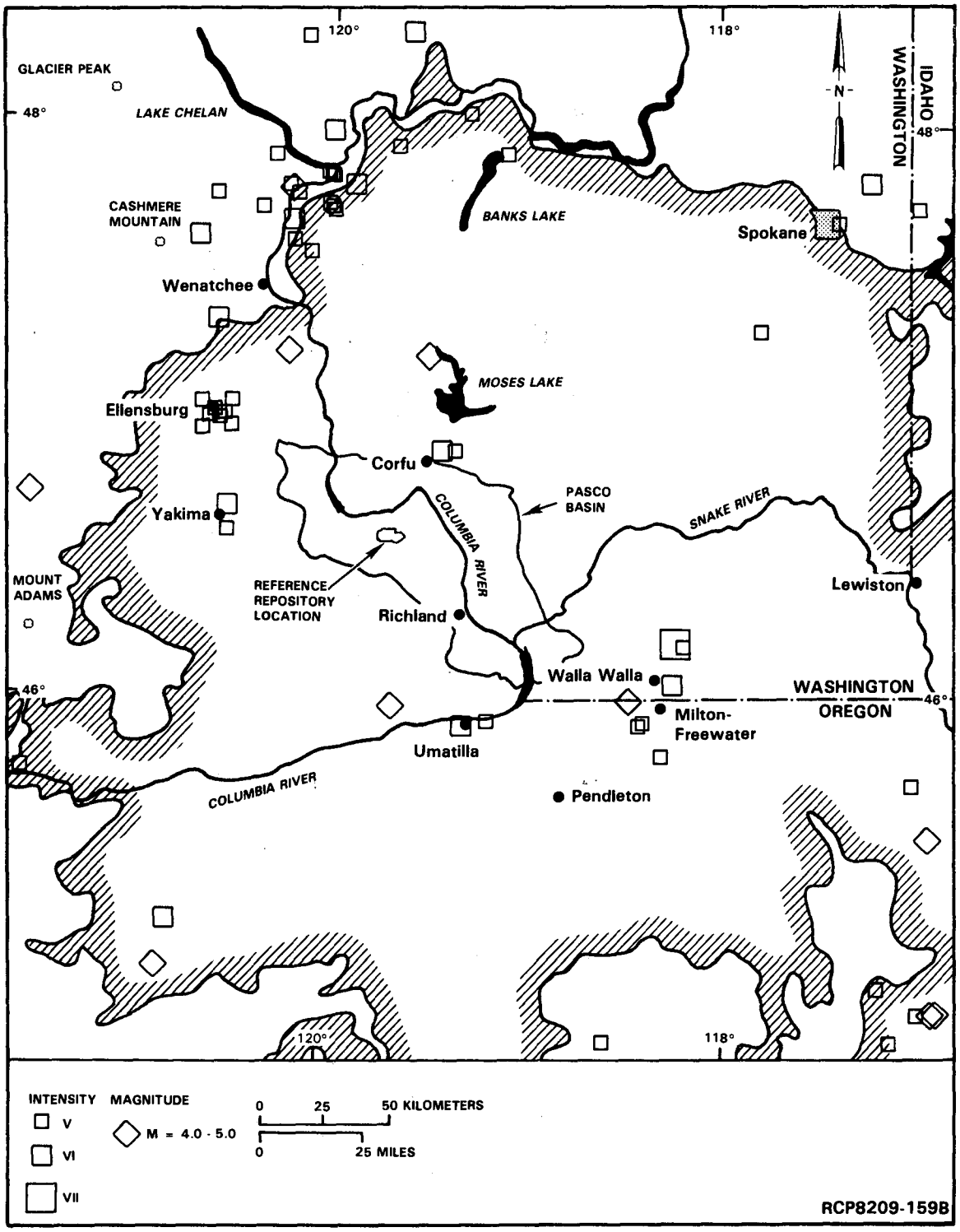


Figure 2-9. Historical seismicity of the Columbia Plateau. All earthquakes between 1850 and 1969 with modified Mercalli intensity equal to or greater than V are shown.

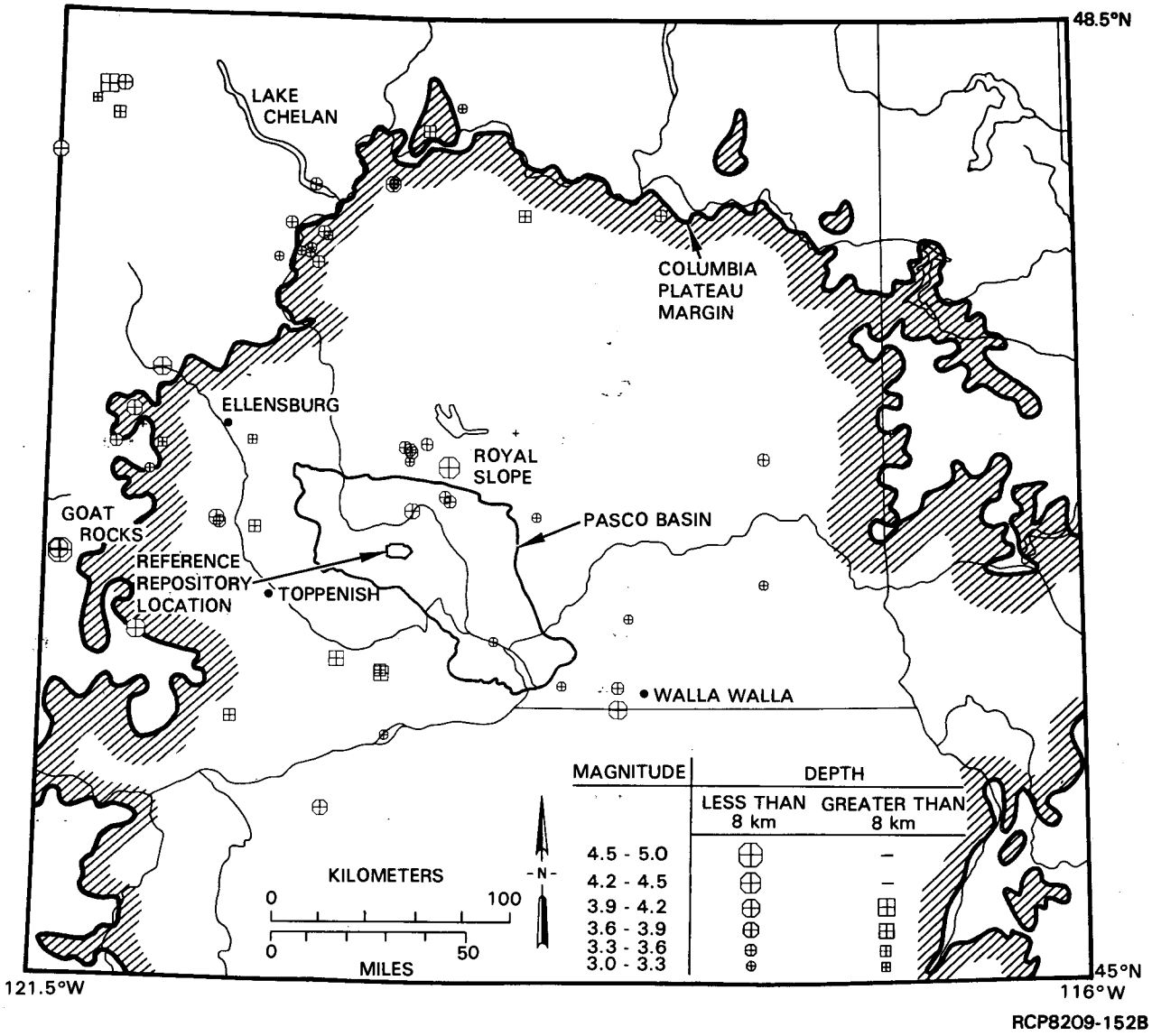


Figure 2-10. Instrumental seismicity (1969 through 1983) of earthquakes greater than magnitude 3.0 occurring in the Columbia Plateau.

7 0 1 6 8 0 5 6 1

Earthquake swarms are the predominant seismic events of the Columbia Plateau (Rohay and Davis, 1983, pp. 6-1 to 6-11). Earthquake swarms (as detected and located by the regional seismic network) may contain from 4 to greater than 100 locatable earthquakes of magnitude 1.0 to 3.5, but most are less than magnitude 2.0. These earthquake swarms typically last a few days to several months and occur in a volume of rock with typical dimensions of 2 by 5 kilometers (1 by 3 miles) areally and 3 to 5 kilometers (2 to 3 miles) vertically. Earthquake swarms characteristically do not have a large event followed by generally decreasing levels of seismicity, as is typical of a mainshock-aftershock sequence. Earthquakes within a swarm tend to increase gradually and decay in frequency, but not in magnitude.

Shallow earthquake swarm activity is concentrated in the central Columbia Plateau region, principally north and east of the Hanford Site (Fig. 2-11 and 2-12). In this region earthquakes greater than magnitude 3.0 also occur, including possibly the largest magnitude swarm-related earthquake. This was instrumentally recorded on December 20, 1973, as a magnitude 4.4 earthquake (see Fig. 2-11) and was located in the Royal Slope area.

Earthquakes occur to a depth of 28 kilometers (18 miles) in the central Columbia Plateau, but at a much lower frequency than the shallower swarm earthquakes (University of Washington, 1979, pp. 1 through 35). This 28-kilometer (18-mile) depth is the approximate thickness of the crust as determined from seismic refraction studies (Caggiano, 1983, pp. 2-1 through 2-7). Generally, no large concentration of deep seismicity is apparent in the areas of intense shallow swarm activity deeper than approximately 4 kilometers (2 miles). Deep seismicity generally takes place in a seemingly random pattern, associated neither with known geologic structures nor areas of shallow seismicity.

Focal mechanisms or fault plane solutions of earthquakes and the direction of slip can be determined from analysis of the first sense of motion of P-waves in a seismogram. Solutions give the orientation of principal axis of compression and tension. For earthquakes of eastern Washington, the axis of principal compression is nearly horizontal and oriented approximately north-south. In the central Columbia Plateau region, the tension (or minimum compression) is nearly vertical, reflecting thrust or reverse faulting on east-west-striking planes (Rohay and Davis, 1983). Focal mechanism solutions are shown in Figure 2-13. Solutions for a northern hemisphere are projected as stereo plots with compression axes (small circles) concentrated at the north and south poles and the tension axes (triangles) positioned near the center of the plots. These principal stress directions are in good agreement with mapped east-west orientations of fold axes and associated thrust or reverse faults. Recent in situ stress measurements using the hydrofracturing method also indicate that the maximum horizontal stress at a 1-kilometer (0.6-mile) depth is oriented approximately north-south and the minimum principal stress is the vertical stress (Kim and Haimson, 1982, p. 4.6 through 4.10).

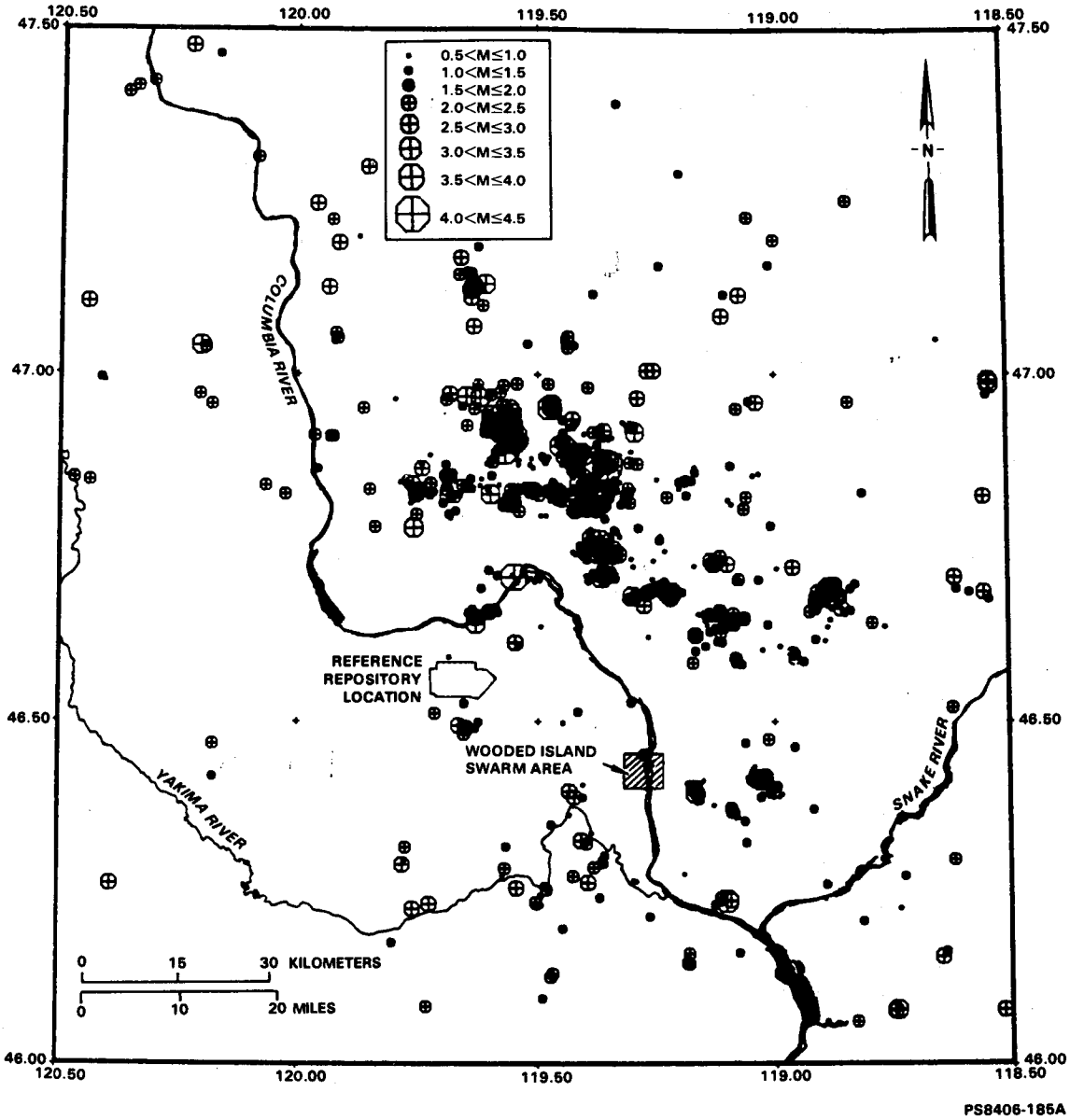


Figure 2-11. Earthquakes located by the University of Washington through March 1983. All earthquakes larger than M coda = 0.5 with focal depths less than 4 kilometers (2 miles) are shown.

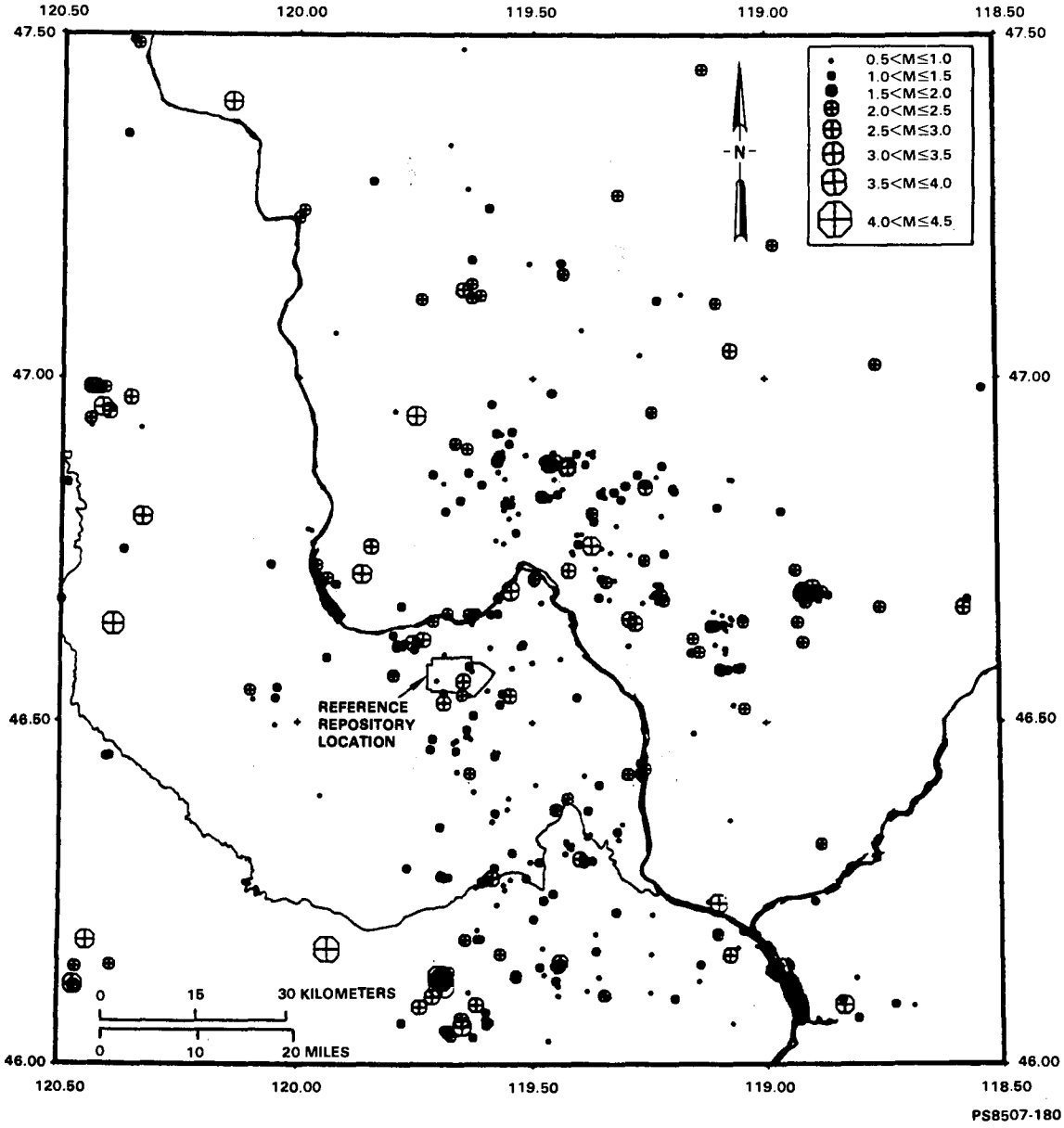


Figure 2-12. Earthquakes located by the University of Washington through March 1983. All earthquakes larger than M coda = 0.5 with focal depths greater than 4 kilometers (2 miles) are shown.

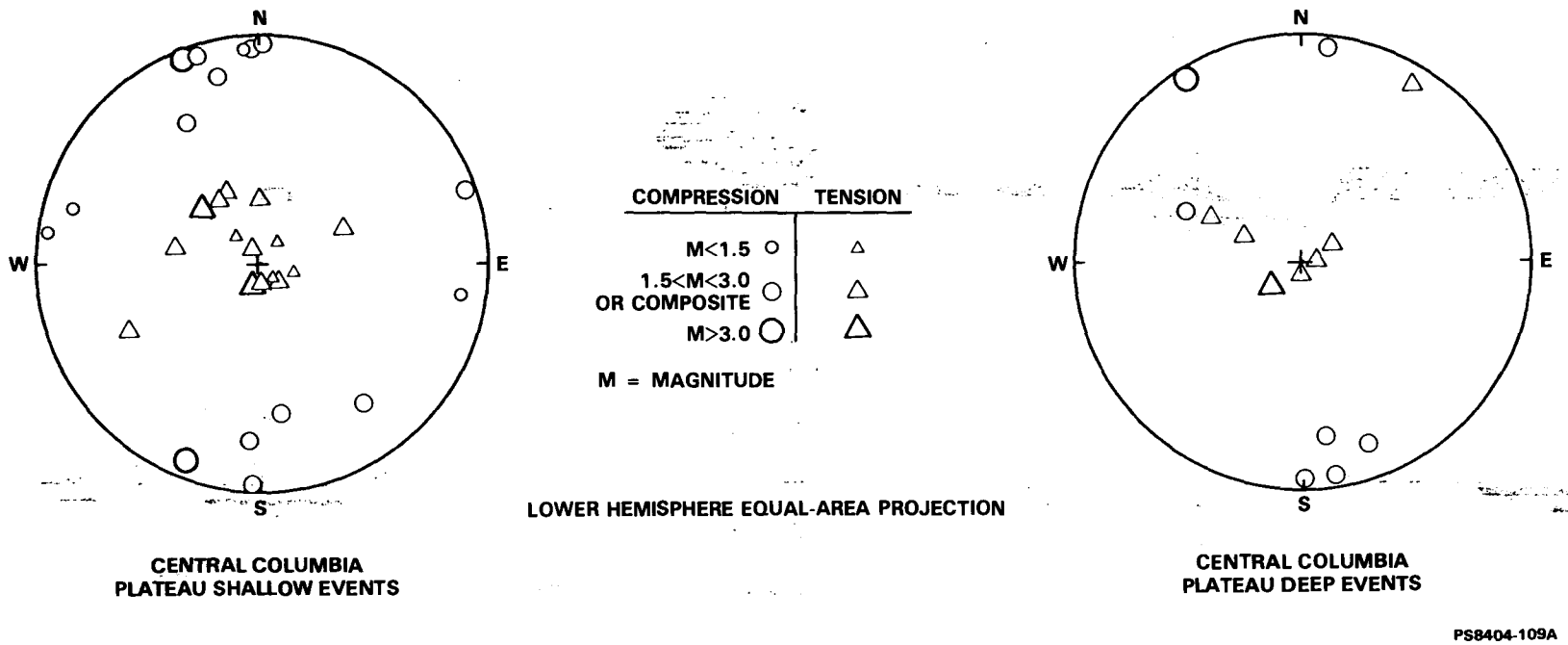


Figure 2-13. Stereo plots of compression and tension axes derived from focal mechanism solutions.

7 0 1 6 8 0 5 6 5

2.1.2 TECTONICS

Geologic data suggest that the Columbia Plateau, including the Pasco Basin, was deforming at an average low rate of strain in the middle to late Miocene; geodetic data indicate that this rate has continued into the late Cenozoic. The basis for these statements is listed below.

- Average uplift rates (vertical strain rates) for the Pasco Basin were approximately 40 to 80 meters (130 to 260 feet) per million years on anticlinal folds from 14.5 to 10.5 million years ago (Reidel and Fecht, 1982). Once initiated, deformation appears to have continued along the same structures formed in the Miocene.

- Quaternary sediments overlying faults associated with Yakima Fold Belt anticlines generally do not appear offset. Sediments of the suprabasalt Ellensburg and Ringold Formations were involved in the folding process, but younger sediments are generally undeformed. However, areas of possible Quaternary faulting have been observed along Toppenish Ridge, located 80 kilometers (50 miles) to the southwest of the reference repository location (Campbell and Bentley, 1981), near Wallula Gap, located 70 kilometers (45 miles) to the southeast (WPPSS, 1981), and at Gable Mountain, located 8 kilometers (5 miles) to the northeast (PSPL, 1982). An average displacement of less than 0.01 millimeter (0.0004 inch) per year (horizontal displacement rate) was calculated for the Gable Mountain faulting (PSPL, 1982).

- Historically, few earthquakes have been felt in the Pasco Basin, and most of these occurred beyond the margins of the basin (Rasmussen, 1967; WPPSS, 1981).

- Eight trilateration surveys across the Pasco Basin indicate that nonuniform compression at a rate of less than 0.1 millimeter per kilometer (0.0006 inch per mile) per year (near the limit of detection) is occurring along northeast and northwest axes (Savage et al., 1981; Prescott and Savage, 1984).

- Instrumental earthquake data for eastern Washington indicate minor stress release as microearthquakes (University of Washington, 1979). The frequency, areal distribution, and mechanisms suggest that stress is not relieved as earthquakes along mapped or inferred faults. The east-west to northwest trend of folds and faults and the north-south trend of dikes in the basalt suggest north-south compression; such compression agrees with the stress field determined from focal mechanism solutions (Rohay and Davis, 1983) and the hydraulic fracturing method (Kim and Haimson, 1982; Kim et al., 1984).

2.1.3 REGIONAL SURFACE HYDROLOGY

This section outlines the regional surface hydrologic setting of the Columbia Plateau, focusing on the State of Washington. The surface hydrology and flooding potential within the Pasco Basin, Hanford Site, and reference repository location are addressed in Section 3.3.1.

The Columbia River, along its 1,954-kilometer (1,214-mile) course, drains portions of seven states and Canada (Fig. 2-14), an area of approximately 670,000 square kilometers (260,000 square miles). The river enters the Columbia Plateau from the north where it joins with the Spokane River and begins a westerly and then southerly course (Fig. 2-15). Along this southerly course, the river cuts through several anticlinal ridge structures, including the Saddle Mountains (at Sentinel Gap), before turning eastward at Umtanum Ridge near the location where it enters the Hanford Site. On clearing the eastern-most surface expression of the Umtanum Ridge-Gable Mountain structure, the Columbia River resumes its southerly course, joining with the Yakima River from the west and the Snake River, its principal tributary, from the east below the Hanford Site in the vicinity of the Tri-Cities (Richland, Kennewick, and Pasco, Washington). Beyond this point, it is joined by the Walla Walla River before cutting across the Horse Heaven Hills anticline at Wallula Gap. The Columbia River then begins a 480-kilometer (300-mile) westerly course to its mouth at the Pacific Ocean. The average annual discharge of the Columbia River out of the Pasco Basin is on the order of 1.7×10^{11} cubic meters (1.4×10^{8} acre-feet) (Gephart et al., 1979).

The portion of the Columbia Plateau within the State of Washington can be divided into basins according to the major surface drainage systems present. Figure 2-15 shows such a division (Leonhart, 1979). The Pasco Basin, in which the Hanford Site is located, is one of these basins.

An extensive network of multipurpose water-resource projects is located along the course of the Columbia River (Fig. 2-16). Most notably, the Grand Coulee Dam backs up to a capacity of 1.2×10^{10} cubic meters (9.4×10^{6} acre-feet) of water. Combined with the 1.9×10^{10} cubic meters (1.5×10^{7} acre-feet) of storage upstream in Canadian reservoirs, a total of 3.1×10^{10} cubic meters (2.5×10^{7} acre-feet) of usable storage are available above Grand Coulee Dam to regulate the flow of the Columbia River for power and flood control. Additionally, the system has been designed to deliver a full supply of water to 443,100 hectares (1,095,000 acres) of irrigable land within the Columbia Basin Irrigation Project, located north and east of the Hanford Site (see Fig. 2-14). The Yakima Irrigation Project, located along the Yakima River, maintains a storage capacity of approximately 1.2×10^{9} cubic meters (9.5×10^{5} acre-feet) and is designed to deliver irrigation water to 186,800 hectares (461,500 acres). Although no comparably significant irrigation development is set up along the Snake River, several dams and reservoir projects have been constructed for other multipurpose uses. The current hydraulic regime along the Columbia and Snake Rivers as they pass through the Columbia Plateau is discussed by the U.S. Army Corps of Engineers (COE, 1976) and U.S. Department of Energy (DOE, 1982).

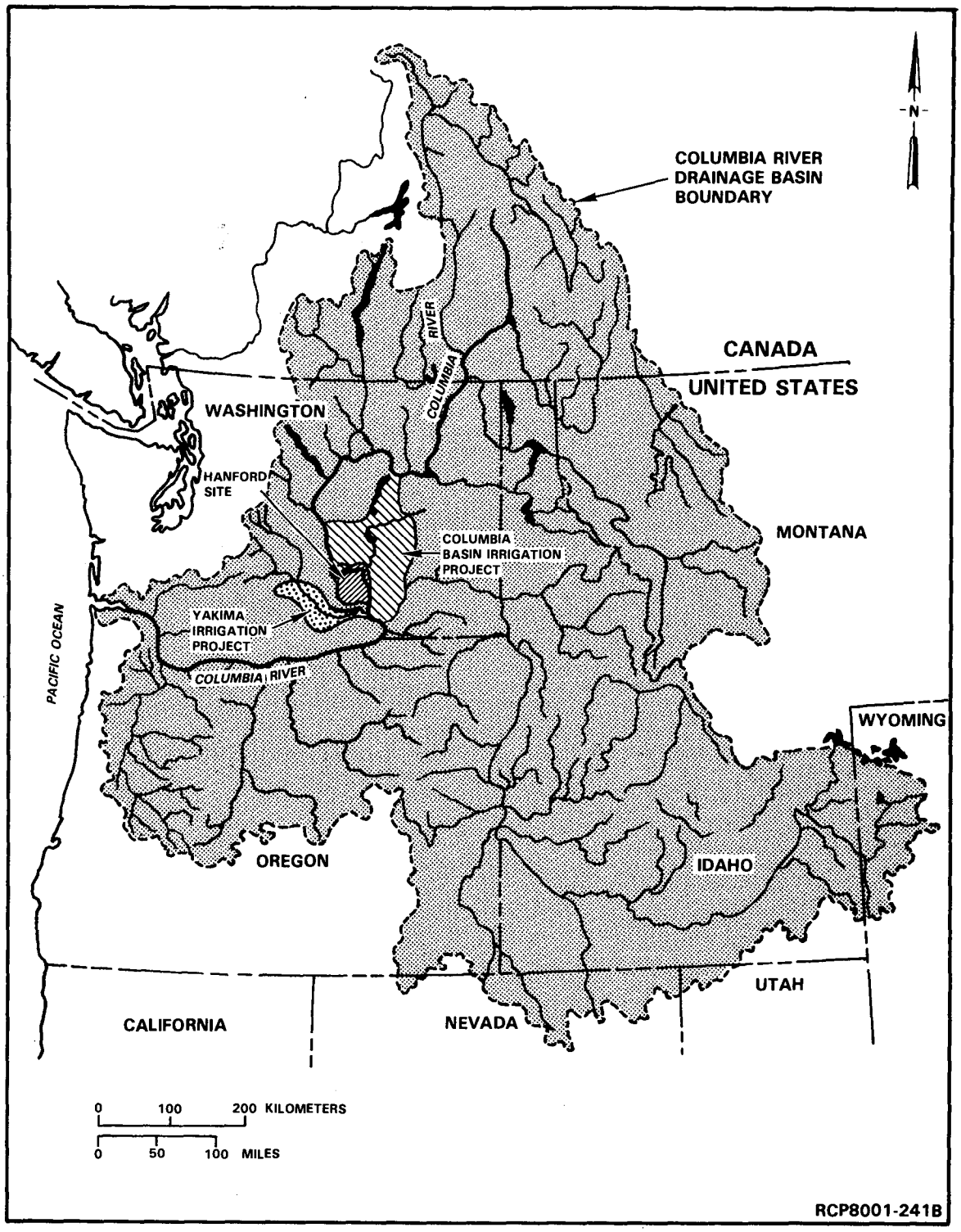


Figure 2-14. Columbia River drainage basin.

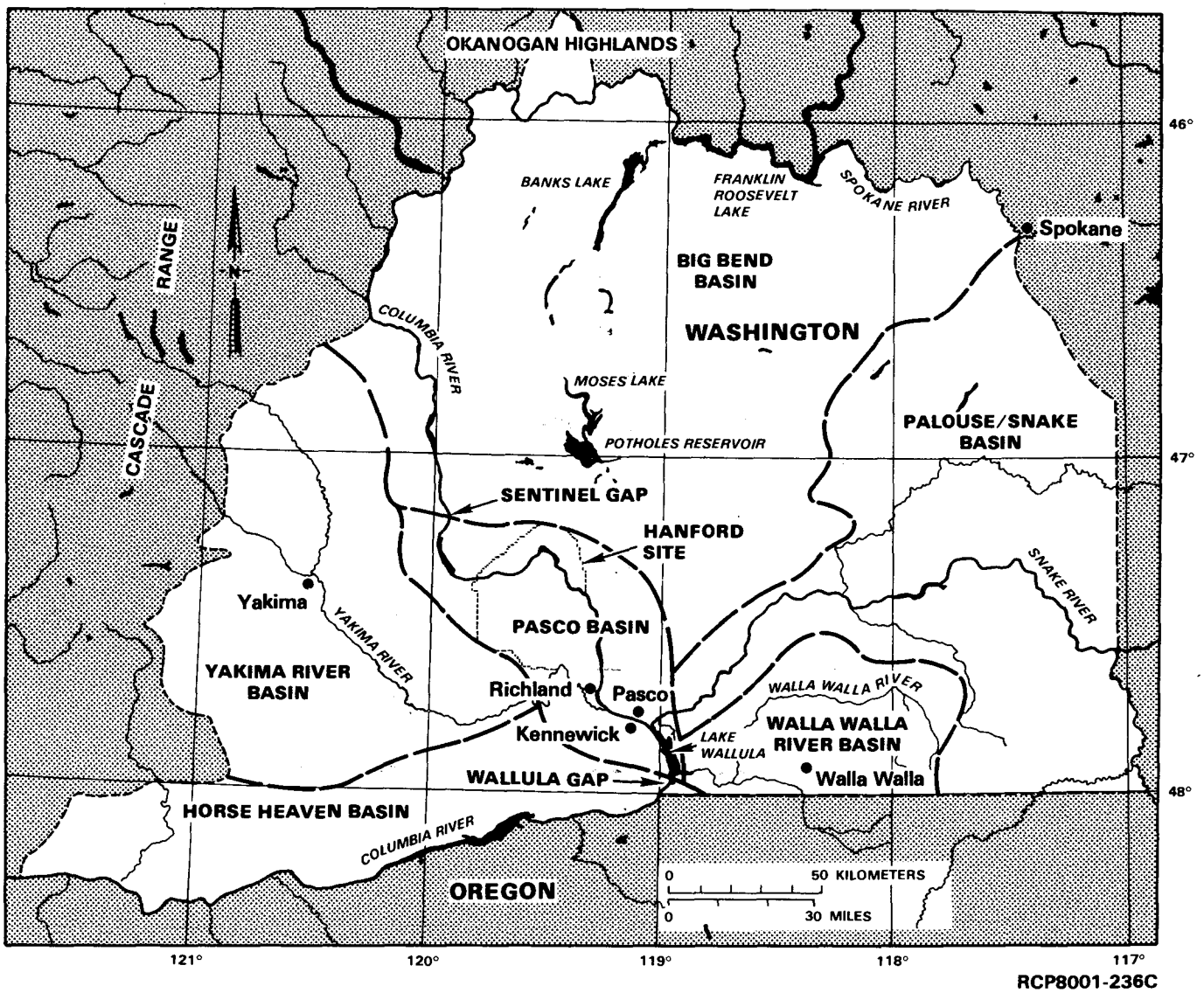


Figure 2-15. Hydrologic basins designated for the Columbia Plateau (after Leonhart, 1979).

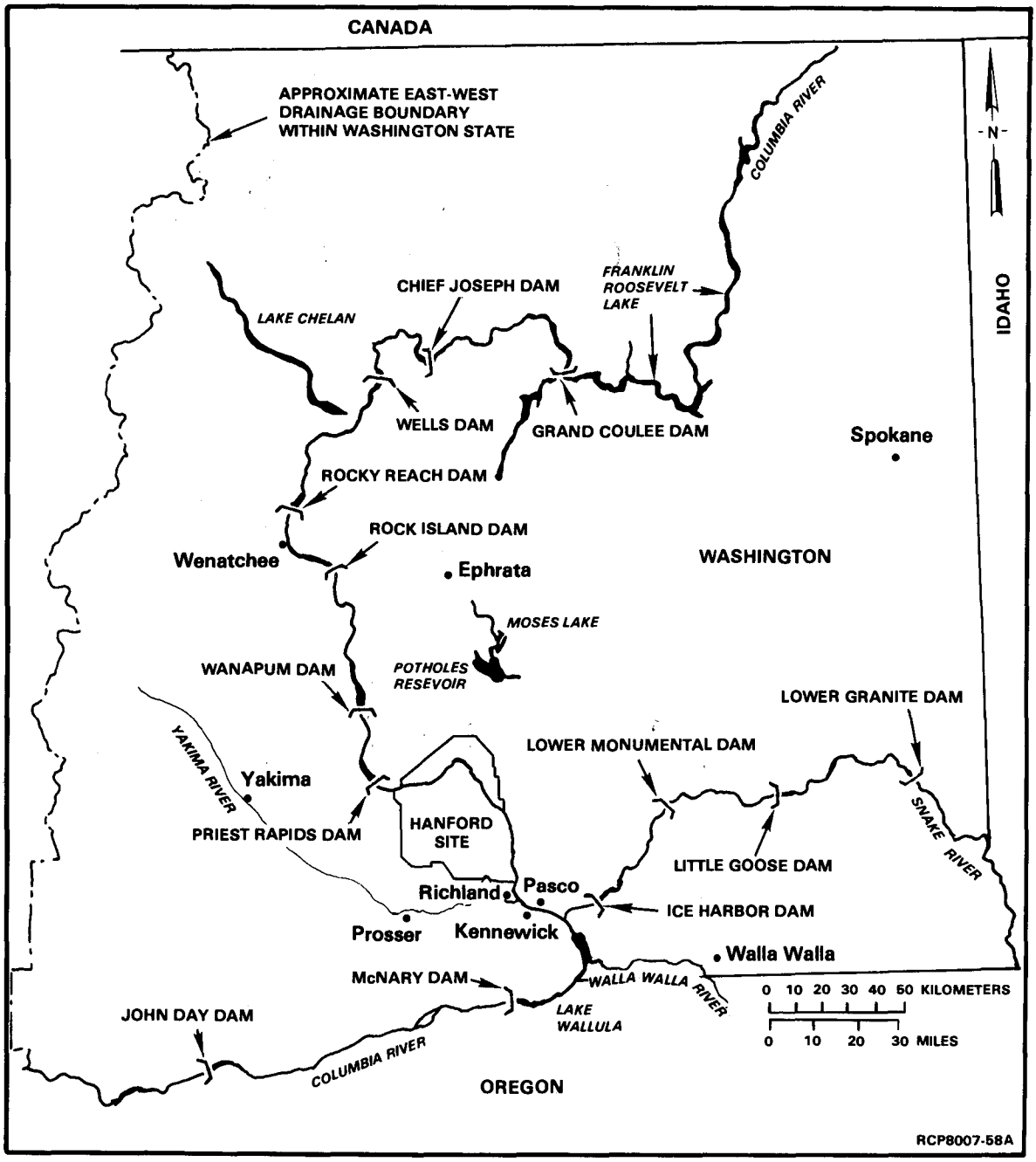


Figure 2-16. Locations of principal dams within the Columbia Plateau study area (after Leonhart, 1980).

2.1.4 REGIONAL GROUND-WATER HYDROLOGY

This section presents a broad discussion of regional ground-water hydrology within the Columbia River Basalt Group of the State of Washington. Topics addressed include ground-water occurrence in basalt formations, piezometric surfaces, hydrochemistry, ground-water use, and regional ground-water management. The ground-water hydrology of the Hanford Site and vicinity is addressed in Section 3.3.2.

As part of the research into understanding regional ground-water movement in basalt, an interagency hydrology working group was formed in 1983. This group consists of representatives from the U.S. Geological Survey, Pacific Northwest Laboratory, and Basalt Waste Isolation Project who share data and conduct computer model studies to examine hydrologic properties and ground-water flow dynamics within portions of the Columbia Plateau, particularly those areas surrounding the Pasco Basin. In addition, a regional ground-water monitoring program has been established for measuring hydraulic head changes with time and for collecting ground-water samples. This monitoring utilizes data collected in part by the U.S. Geological Survey national ground-water survey program Regional Aquifer System Assessment. Portions of the regional ground-water hydrology discussed herein are taken from a report prepared for the U.S. Department of Energy (DOE, 1982). The information presented is considered preliminary in nature.

Presently, preliminary estimates are available for precipitation, evapotranspiration, surface-water runoff, water inflow and outflow, water use, and net ground-water recharge and discharge quantities for the six major basins in the Columbia Plateau (Leonhart, 1979). These include the Horse Heaven Plateau, Yakima River, Pasco, Walla Walla River, Palouse-Snake, and Big Bend Basins. Detailed studies are planned to better define regional ground-water exchanges between surface and subsurface flow systems as well as between basins in the Columbia Plateau (Subsection 4.1.1.7).

The areal distribution of the principal basalt formations within the Columbia Plateau—the Saddle Mountains, Wanapum, and Grande Ronde Basalts (see Fig. 2-5)—is important in understanding regional ground-water movement across the plateau and within the Pasco Basin (Gephart et al., 1979; DOE, 1982). In this regard, the following observations are offered.

- Ground water in shallow basalts in each structural basin of the Columbia Plateau is probably recharged and discharged locally. This corresponds with Toth's (1963) local ground-water system. Thus, depending on location within the plateau, the Saddle Mountains Basalt would form the local system in one basin, while the Wanapum or Grande Ronde Basalts could form the local flow system in another basin. Deeper intermediate or regional flow systems underlying larger sections of the plateau would form interbasin ground-water systems. The topographic effects of the major anticlines trending east-west across portions of the plateau (see Section 2.1.1) could contribute to the development of local flow systems and perhaps complicate (impede, redirect, or vertically mix) interbasin regional movement of ground water.

- Most of the Saddle Mountains Basalt in the Columbia Plateau lies within and adjacent to the Pasco Basin. As discussed in Section 3.3.2, data suggest that ground water in this formation is locally recharged and discharged.

- For most regional geohydrologic purposes, the Wanapum and Grande Ronde Basalts can be considered present and continuous; whereas, as noted above, the Saddle Mountains Basalt is discontinuous. The regional lateral continuity of these deeper basalts, particularly in the eastern half of the Columbia Plateau, would favor development of areally extensive, regional ground-water flow patterns. These patterns most likely converge toward the lowest topographic area of the plateau (i.e., the Pasco Basin).

- Grande Ronde Basalt comprises 85 percent of the total rock volume of the Columbia River Basalt Group (Reidel et al., 1981). Outcrops of Grande Ronde Basalt are principally restricted to the northwest and southeast portions of the plateau, plus isolated localities where surface erosion has exposed the formation (see Fig. 2-5). Throughout most of the plateau the Grande Ronde Basalt was covered by the younger Wanapum and Saddle Mountains Basalts. Regionally, ground-water recharge of the Grande Ronde Basalt is believed to occur along margins of the plateau where the formation is at or close to ground surface (DOE, 1982). Here, the Grande Ronde Basalt crops out in areas of high elevation and, thus, in regions of greater-than-average precipitation for the plateau. In addition, large portions of the Columbia and Snake Rivers flow atop Grande Ronde Basalt bedrock along which ground-water recharge and (or) discharge can take place. Ground water can also move in and out of the Grande Ronde Basalt as a result of leakage from adjoining basalt formations.

- Basalt flows older than the Grande Ronde Basalt (i.e., Imnaha Basalt and Picture Gorge Basalt) are probably of minor importance to the regional hydrologic dynamics because of their limited volumes and areal extent (see Fig. 2-5).

Section 3.3.2 contains a general discussion of ground-water occurrence within, and basic hydrologic properties of, a basalt sequence.

Regionally, discrete and composite potentiometric surfaces (hydraulic head trends) within the Columbia River Basalt Group were mapped by Tanaka et al. (1979). The general accuracy and limitations of data used were discussed in Tanaka et al. (1979) and further detailed in Gephart et al. (1979). Figures 2-17 and 2-18 reproduce some of these data as three-dimensional perspective views. A comparison between these figures and regional bedrock maps for corresponding rock units reveals similarities in surface trends and attitudes. This suggests that regional ground-water movement generally follows the regional bedrock dip as noted by Newcomb (1982). Figures 2-17 and 2-18 also suggest that the Pasco Basin, in relation to the surrounding Columbia Plateau, is an area of regional ground-water flow convergence. This is expected since the basin occupies the lowest topographic area in the plateau.

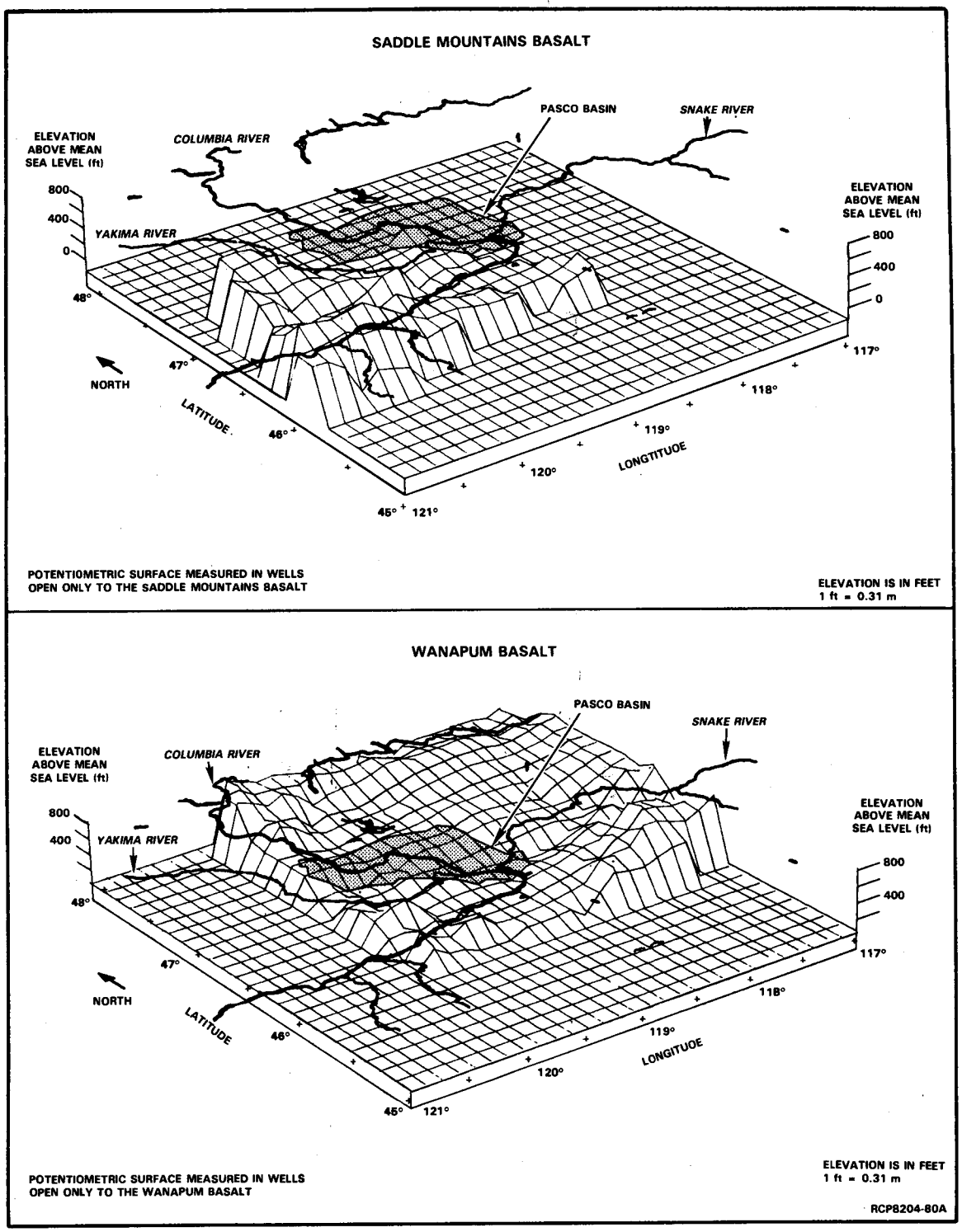


Figure 2-17. Three-dimensional perspective views showing the regional potentiometric surface (hydraulic head) configuration of Saddle Mountains and Wanapum Basalts.

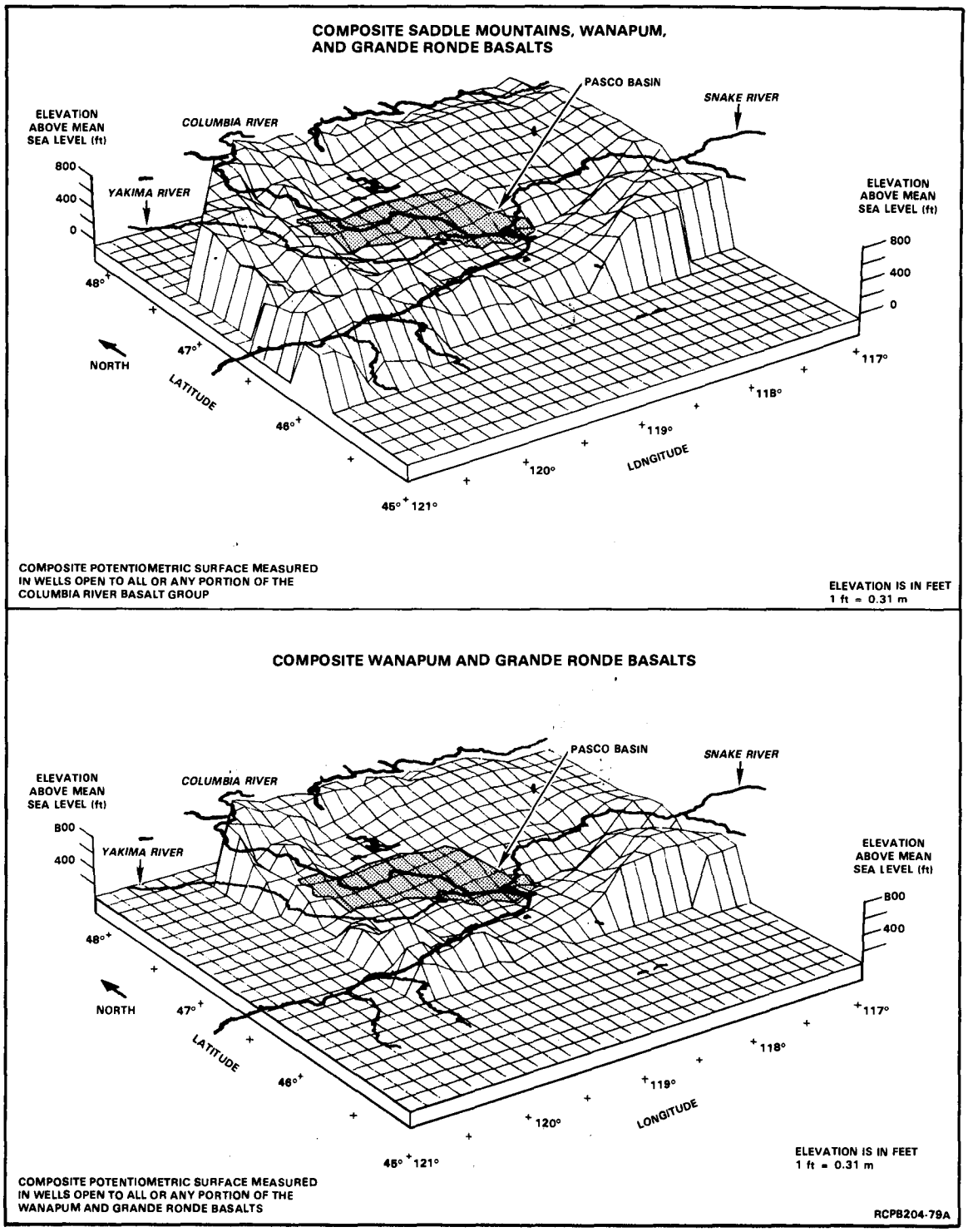


Figure 2-18. Three-dimensional perspective views showing the regional potentiometric surfaces for various strata within the Columbia River Basalt Group.

In addition to these potentiometric maps, the piezometric network established by the State of Washington Department of Ecology also examines vertical hydraulic head relationships in the Columbia Plateau. The locations of wells comprising this network are shown in Figure 2-19. Principally, these regional ground-water monitoring wells were located in areas of heavy irrigation; e.g., the Columbia Basin and Yakima Irrigation Projects. A schematic representation of the vertical head distribution at these sites is also provided (see Fig. 2-19). Note that these schematics are intended to represent only general relationships and vertical head distributions for a fixed period of time. A summary of construction statistics with respect to these monitoring wells is given in a report by the U.S. Department of Energy (DOE, 1982), which also discusses the head relationships and time-variant characteristics observed. From these vertical head data, the following generalizations are noted:

- The data show a general trend of decreasing hydraulic heads with increasing depth from ground surface in many wells, which means that ground-water recharge is taking place at those respective locations.

- At certain locations, head similarities are observed over tens to hundreds of meters (feet) of the vertical section. This could be attributed to any one (or combination of) the following natural or artificial factors:

  - High vertical leakage

  - Relative vertical positioning of the open intervals of the piezometers

  - Failure of piezometer seals

  - Nearby ground-water use patterns

  - Well location; i.e., in areas of lateral ground-water movement.

- At certain locations, a significant head drop across a threshold depth may be interpreted. While this may be a real phenomenon, several factors (including those factors just noted) prevent its confirmation, based on the available data. These include the following:

  - Irregular intervals represented by piezometer placement over the vertical section

  - Ground-water use

  - Local hydrogeologic factors.

- The distribution of wells across the Columbia Plateau tends to provide data that allow researchers to evaluate in a preliminary manner vertical head distributions of the Wanapum and Grande

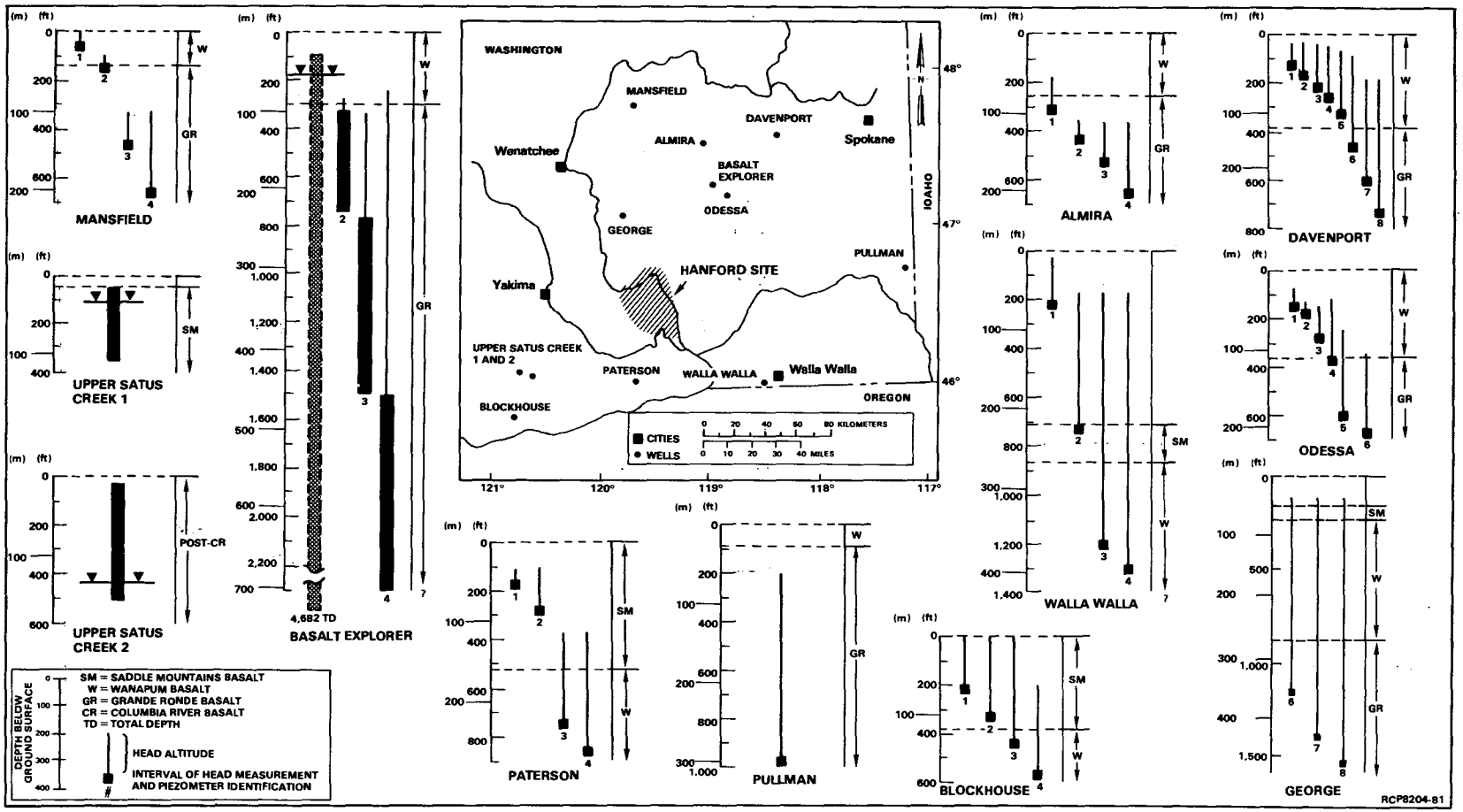


Figure 2-19. Locations and vertical head distributions of the State of Washington Department of Ecology test observation wells.

7 0 1 6 8 0 5 7 6

Ronde Basalts at locations where these units are nearest the surface and closer to their probable recharge source. The wells south of the Hanford Site are designed to monitor conditions within the Saddle Mountains and Wanapum Basalts. Therefore, vertical head distributions of the Grande Ronde Basalt at locations south of the Hanford Site are presently unknown (DOE, 1982).

Because the piezometers shown in Figure 2-19 have been monitored by the U.S. Geological Survey on a periodic basis since installation, the time-variant behavior of the potentiometric surfaces at these monitoring points within the Columbia Plateau can also be evaluated. A brief description of the dynamic behavior observed at each of the State of Washington Department of Ecology test-observation wells is given in a report by the U.S. Department of Energy (DOE, 1982).

The three-dimensional hydraulic head distributions across the Columbia Plateau are in a very preliminary state of understanding.

2.1.4.1 Regional ground-water chemistry

Ground-water chemical analyses available for the Columbia Plateau are usually composite and represent water samples obtained from a number of hydrogeologic units penetrated at the sampled well site. Hydrochemical data for specific basalt flows within the plateau are primarily limited to data obtained at the Hanford Site.

Hydrochemical data for ground water within the Columbia River Basalt Group are reported on a regional basis by Walters and Grolier (1960), Van Denburgh and Santos (1965), and Newcomb (1972). Chemical data for separate areas within the Columbia Plateau are available from several sources, including Eakin (1946), Sceva et al. (1949), Foxworthy (1962), Foxworthy and Washburn (1963), and Newcomb (1965). Results from several of these studies are summarized in Gephart et al. (1979) and U.S. Department of Energy (DOE, 1982).

Hydrochemical data are based on analyses obtained from the ground-water quality data files of the U.S. Geological Survey for the State of Washington portion of the Columbia Plateau, exclusive of the Pasco Basin (DOE, 1982). Specific information for the Pasco Basin is addressed in a report by the U.S. Department of Energy (DOE, 1982). Figure 2-20 shows locations of regional sampling sites for which there appear to be reliable hydrochemical data from the basalts. For most locations, available hydrochemical data consist of major inorganic constituents and selected trace elements.

Table 2-1 presents the range and mean composition of chemical constituents within the ground water of the Columbia River Basalt Group. These data are principally from wells penetrating the Saddle Mountains or upper Wanapum Basalts. These data indicate that, regionally, ground

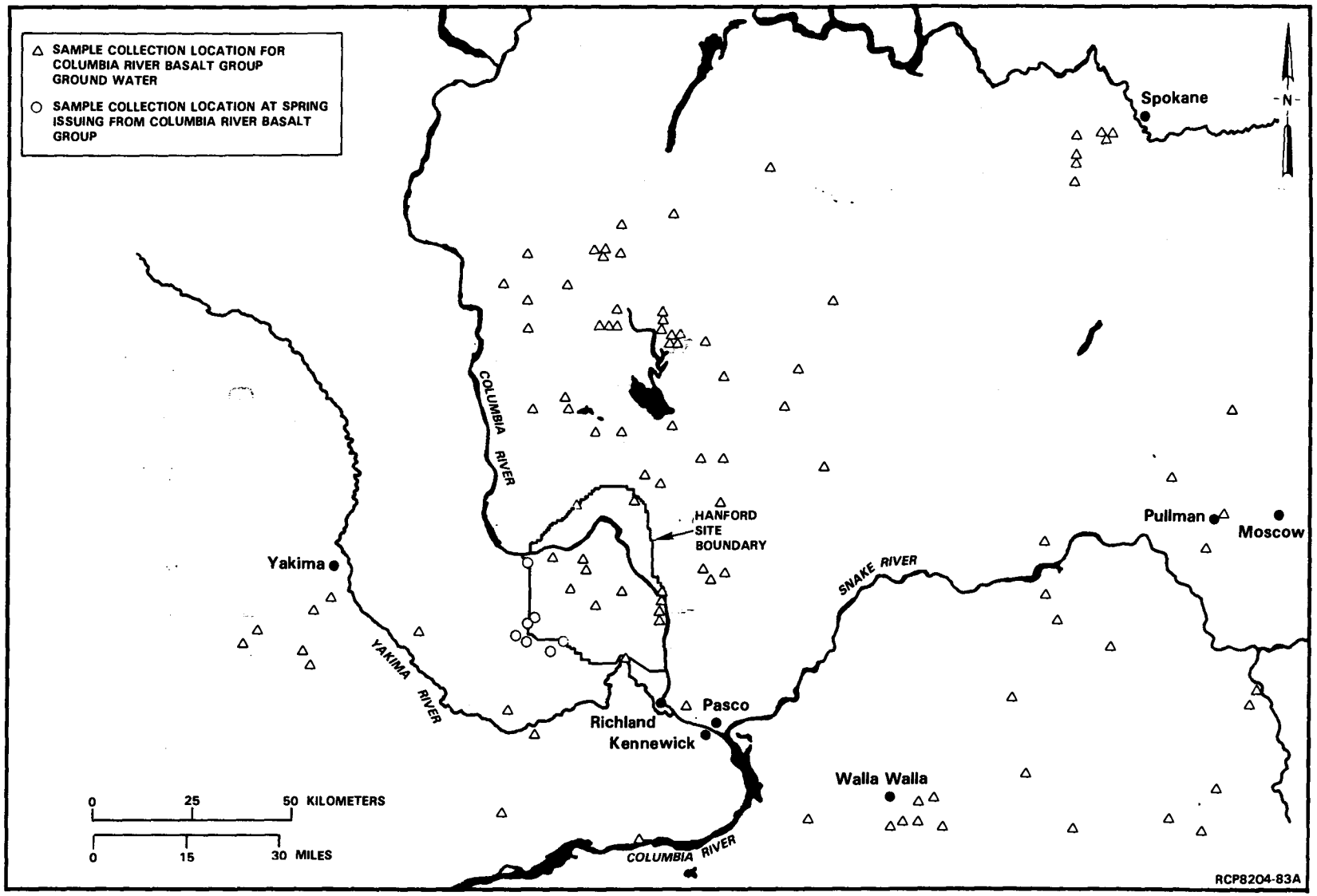


Figure 2-20. Sampling sites for ground water collected from Columbia River basalt zones (after DOE, 1982).

7 0 1 6 8 0 5 7 8

Table 2-1. Range in concentration and mean composition of major chemical constituents within ground water of the Columbia River Basalt Group

Constituent	Range (mg/L)	Mean (mg/L)
Anions		
Alkalinity, as HCO_3^-	72 to 297	160
Cl^-	0.5 to 56	12
SO_4^{-2}	0.2 to 95	21
NO_3^-	0.01 to 18	2.3
F^-	0.1 to 3.9	0.76
Cations		
Na^+	7.8 to 80	34
K^+	0.1 to 38	6.5
Ca^{+2}	2.1 to 64	21
Mg^{+2}	0.2 to 24	10
SiO_2	30 to 83	55
Total dissolved solids	154 to 510	325

NOTE: U.S. Department of Energy (DOE, 1982, p. 5.1-85). Based on 83 hydrochemical analyses.

waters generally possess a low total dissolved solids content (e.g., less than approximately 350 milligrams per liter). Principal chemical constituents are present in the following dominance relationship (by weight): Bicarbonate, which is greater than silica, which is greater than sodium, which is greater than calcium and sulfate, which is greater than magnesium. Chemical classifications for these ground waters range from calcium-magnesium bicarbonate to sodium bicarbonate-sulfate types. Regional dissimilarities in ground-water composition are ascribed to differences in aquifer samples, ground-water mixing due to multiple aquifer completions, sources of recharge, and rock and ground-water reactions.

Concentrations for trace elements reported in basalt ground waters across the Columbia Plateau are low and are commonly below detection levels of the analytical equipment used. The principal trace elements present are aluminum, boron, iron, manganese, strontium, and zinc (DOE, 1982). The higher concentration values for iron and manganese suggest that some analyses may exhibit the effects of poor sampling procedures and (or) the corrosion of well casings.

Isotopic data for the Columbia River Basalt Group are primarily available from sampling locations concentrated within the Pasco Basin (DOE, 1982). Isotopic data for most of the remaining portion of the Columbia Plateau are limited to carbon-14 analyses as, for example, reported by Crosby and Chatters (1965), Silar (1969), and Robinson (1971). These data are not distributed uniformly, but are confined primarily to two small areas within the southeastern portion of the plateau. Absolute ground-water ages cannot be reliably calculated from these regional data because of ground-water mixing across different basalt horizons in the sampled boreholes, and the lack of carbon-13 (dead carbon) corrections in the carbon-14 analyses. Because of the lack of carbon corrections, age dates (from modern to greater than 32,000 years before present) cited by the above authors are considered relative and can only be compared qualitatively.

Overall, regional hydrochemistry is only understood in a preliminary manner. This results from the scarcity of three-dimensionally distributed hydrochemical data. Most of the hydrochemical data have been collected from shallow wells drilled less than a few hundred meters (feet). Many of these wells sample only the dilute, local ground-water chemical types. There are few deep (i.e., 500 to 1,500 meters (approximately 1,600 to 5,000 feet)) ground-water sampling wells outside of the Hanford Site in the Pasco Basin. Many of the shallow regional wells sampled are used for water supply, which is the topic of the next subsection.

2.1.4.2 Ground-water use in the Columbia Plateau and Pasco Basin

Detailed information on ground-water use within the Pasco Basin and the surrounding region can be found in several sources. Of principal interest are reports by Bell and Leonhart (1980), Brown (1979), Dion and Lum (1977), Foxworthy (1979), Geosciences Group/George Leaming Associates (GG/GLA, 1981), Pacific Northwest River Basins Commission (1981), Stephan et al. (1979), Wukelic et al. (1981), and U.S. Department of Energy (DOE, 1982). Additionally, numerous records are maintained in open file by State and Federal agencies. In particular, the U.S. Geological Survey maintains a computerized file known as the Groundwater Site Inventory Data Base, which is a systematic digital collection of available data for permitted water wells. The U.S. Department of Energy has acquired digital tapes of these records corresponding to 15 counties in southeastern Washington and 4 counties in northeastern Oregon. This assemblage represents data for nearly 15,000 wells.

The Groundwater Site Inventory Data Base can be used to tally the number of wells within the region according to use designation. Although such statistics do not provide an evaluation of the quantities of water withdrawn, they can be useful in describing the dominant types of ground-water use within an area and in generalizing well construction characteristics. Table 2-2 provides such a data reduction for the Columbia Plateau and the Pasco Basin. Another reduction of the data in terms of generic groupings is given in Table 2-3. In reviewing these tables, note that approximately 50 percent of the total number of wells within the Columbia Plateau and the Pasco Basin are used for households (domestic); again, however, these numbers do not speak to the water volumes withdrawn, and it can be generalized that most of the wells are of relatively shallow depth (less than about 150 meters (500 feet)). Agricultural use represents one-third of the total number of wells. Industrial users represent a comparatively small segment of the total number. The overall well-use distribution for the Pasco Basin is comparable to that of the Columbia Plateau.

The distribution of well uses in the Pasco Basin according to selected depth intervals is shown in Figure 2-21. This histogram shows that approximately 65 percent of the wells reported in the Groundwater Site Inventory Data Base derive water from less than 60 meters (195 feet) below ground surface. For most locations, this depth interval may be considered to approximate the range of depth for the unconsolidated aquifers. The histogram also shows that approximately 50 percent of the wells in the Pasco Basin are used for domestic water supply.

A compilation of total ground-water quantities used in the Pasco Basin by agricultural (irrigation), municipal, industrial, and domestic ground-water users is given in Table 2-4. Figures given for agricultural and domestic ground-water users are based on 1980 data, and statistics cited for industrial and municipal ground-water users are based on 1975 data (DOE, 1982).

Table 2-2. Distribution of wells according to major-use categories within the Columbia Plateau and Pasco Basin

Wells	Human contact or consumption[a]	Industrial[b]	Agriculture or irrigation[c]	Total[d]
		Columbia Plateau		
Total number	7,379	312	3,158	10,849
Percentage in a given category	68.0	2.9	29.1	100
		Pasco Basin		
Total number	574	33	190	797
Percentage in a given category	72.0	4.1	23.8	100

NOTE: Modified after U.S. Department of Energy (DOE, 1982, p. 5.1-191).

[a]Includes wells designated as being used for bottling, domestic, medicinal, commercial, public supply, recreation, and institutional.

[b]Includes wells designated as being used for air conditioning, dewatering, fire fighting, and other industrial activities.

[c]Includes wells designated as being used for irrigation and stock watering.

[d]Includes only wells within the U.S. Geological Survey Groundwater Site Inventory Data Base having use designations. Wells designated as "other use" or "unused" were excluded.

Table 2-3. Distribution of wells within the Columbia Plateau and Pasco Basin according to use

Use	Columbia Plateau wells		Pasco Basin wells	
	Total	%	Total	%
Air conditioning	2	0.0	0	0
Bottling	1	0.0	0	0
Commercial	19	0.2	2	0.2
Dewatering	19	0.2	0	0
Fire	24	0.2	0	0
Domestic	6,664	53.3	493	49.4
Irrigation	2,804	22.4	167	16.7
Medicinal	3	0.0	0	0
Industrial	267	2.1	33	3.3
Public supply	645	5.2	76	7.6
Recreation	5	0.0	1	0.1
Stock	354	2.8	23	2.3
Institutional	42	0.3	2	0.2
Unused	1,582	12.7	189	18.9
Other	64	0.5	12	1.2
Total	12,495		998	
Data base total[a]	14,566		1,820	
Percentage		85.8[b]		54.8[b]

NOTE: U.S. Department of Energy (DOE, 1982, p. 5.1-192).

[a]U.S. Geological Survey Groundwater Site Inventory Data Base.

[b]Percentage of the data base total for which water-use information is available.

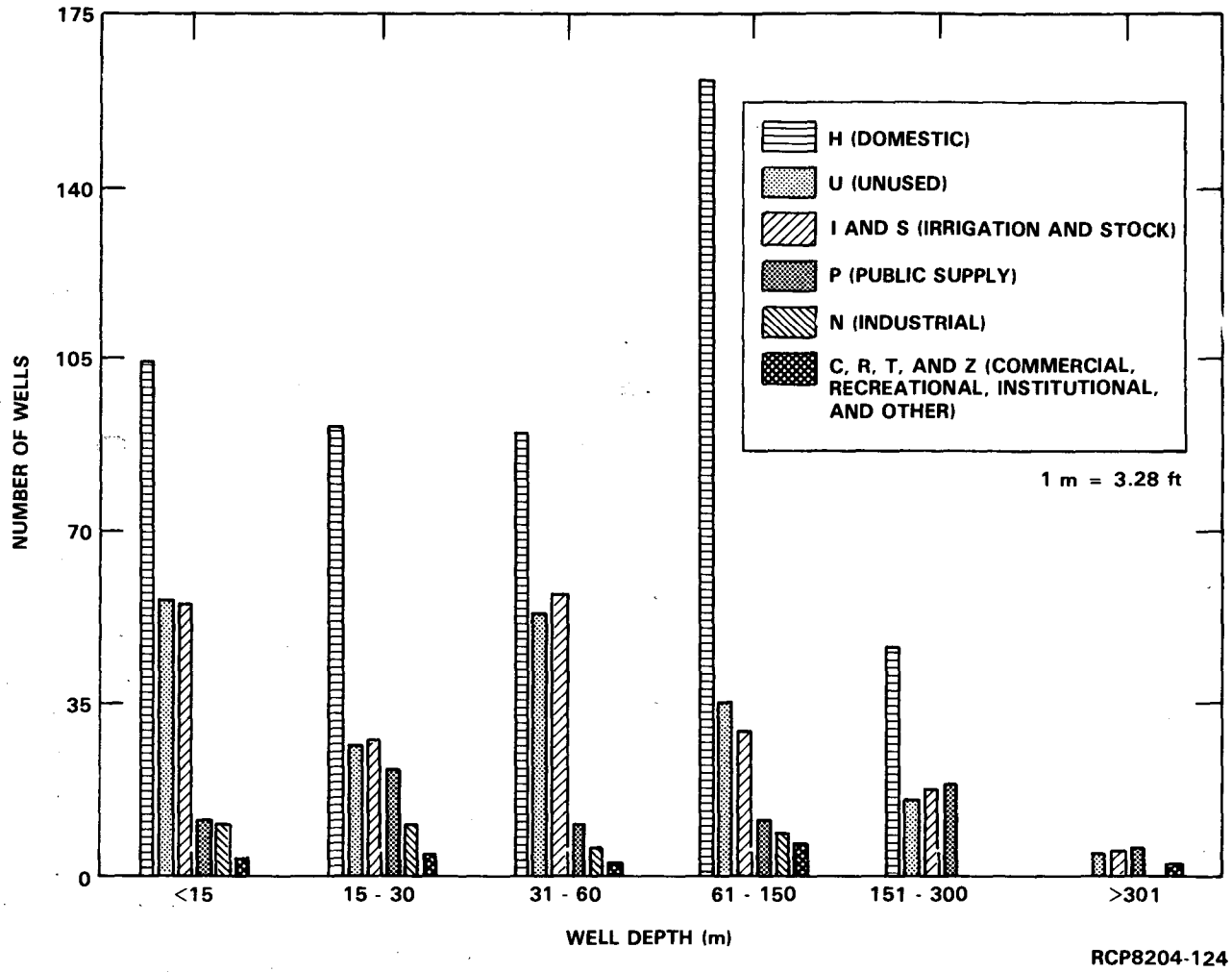


Figure 2-21. Frequency of well-use types listed in depth intervals for the Pasco Basin (taken from DOE, 1982, p. 5.1-193).

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Table 2-4. Ground-water use in the Pasco Basin

Ground-water users	Quantity, m^3 (ft^3)	Year
Agriculture (irrigation)	2.5×10^8 (8.8×10^9)	1980
Municipal (exclusive of industry)	1.1×10^7 (3.9×10^8)	1975
Industrial (self and municipally supplied)	1.9×10^{10} (6.7×10^{11})	1975
Domestic	7×10^5 (2.5×10^7)	1980

NOTE: U.S. Department of Energy (DOE, 1982, p. 5.1-193).

The long-term impacts of ground-water withdrawal throughout the Columbia Plateau have been predicted and observed (Foxworthy, 1979; Luzier and Burt, 1974; Luzier et al., 1968; Luzier and Skrivan, 1973). Predictions indicate that there will be water-level declines of several meters (feet) per year in aquifers of the Wanapum and Grande Ronde Basalts. These declines are predicted for areas outside the Pasco Basin, where the Wanapum and Grande Ronde Basalts are closer to the surface than they are within the Pasco Basin and are actively pumped for ground-water supplies.

Within the Pasco Basin, a similar phenomenon is seen in the upper Cold Creek Valley, lying on the western boundary of the Hanford Site, where irrigated agricultural activities have been expanding. The average water-level elevation within the Priest Rapids Member (Wanapum Basalt) in the Cold Creek Valley declined approximately 10 meters (30 feet) from 1979 to 1982 (DOE, 1982). Also, data show that over the past 50 years water levels in the Cold Creek Valley have declined approximately 60 meters (195 feet) because of ground-water development (Newcomb, 1961).

In other areas, various activities have contributed to an increase in water-level evaluations of shallow aquifers. Most notable is the Columbia Basin Irrigation Project, which lies north and east of the Pasco Basin and extends into the eastern and northern portions of the basin (see Fig. 2-14). Before irrigation began in the Columbia Basin Irrigation Project, there was little ground water in the shallow sands and gravels above the basalt, and ground-water levels in the basalt were a few tens of meters (feet) below ground surface. After irrigation commenced in 1952, the upper confined aquifers of the Columbia River Basalt Group experienced a water-level rise. Water levels in typical wells drilled into the basalt aquifers underlying the Columbia Basin Irrigation Project have increased

as much as 6 to 12 meters (20 to 40 feet) per year (DOE, 1982). This water-level rise is because of leakage of excess irrigation water from overlying unconfined aquifers across rock formations and probably along well casings and in open boreholes. Some researchers have estimated that approximately 20 to 40 percent of the water applied for irrigation (depending on location within the project) undergoes deep percolation into the water table (Gephart et al., 1979).

To manage ground-water use properly within the Columbia Plateau, the State of Washington Department of Ecology has established regional ground-water management areas. This is the topic of the following subsection.

2.1.4.3 Regional ground-water management

Regulation of public ground water within the State of Washington is an authority delegated to the State of Washington Department of Ecology. Specifically, Chapter 90.44 of the Revised Code of Washington extends the applicability of the state surface-water statutes to the appropriation and beneficial use of ground water within the State. The State of Washington Department of Ecology has thus far designated two ground-water management subareas within the Columbia Plateau under the authority of the Washington Administrative Code (WAC, 1973, Chapters 173-124; 173-128; 173-130; and 173-134) and is controlling ground-water development within certain portions of the Columbia Basin Project area (WAC, 1973, Chapter 508-14).

In general, the approach to regional ground-water management by the State of Washington Department of Ecology involves the following two activities:

1. Reconnaissance and evaluation of ground-water conditions.
2. Regulation of use.

The reconnaissance and evaluation activities consist of annual mass (water-level) measurements that are plotted to determine the rates of water-level decline for various zones. This is used as a basis for management and regulation. As a rule of thumb, the State of Washington Department of Ecology considers a situation serious when water-level declines in wells approach 9.2 meters (30 feet) within a 3-year period. This formula was established for the Odessa, Washington, subarea and reflects the type of agricultural practice there.

The Pasco Basin straddles the regional responsibility of the State of Washington Department of Ecology. The Eastern Regional Office in Spokane, Washington, is responsible for ground-water management activities east of the Columbia River; whereas, the Central Regional Office in Yakima, Washington, handles the area west of the Columbia River to approximately the crest of the Cascade Range (see Fig. 2-15). Ground-water withdrawal on the Hanford Site by the Federal Government has been very limited.

2.2 SITE-SCREENING PROCESS AND IDENTIFICATION OF A CANDIDATE HORIZON AT THE HANFORD SITE

Since 1976, the U.S. Department of Energy through the Basalt Waste Isolation Project has been responsible for investigating the Hanford Site to determine if a suitable location can be identified for geologic isolation of commercial high-level nuclear waste. Two primary factors led to the selection of the Hanford Site for exploration and screening to determine its suitability. First, the Hanford Site is situated in the center of a region covered by one of the largest (200,000 square kilometers (78,000 square miles)) crystalline rock types in the United States, the Columbia River Basalt Group. Second, the Hanford Site is a federally owned land tract that has been committed to nuclear activities for over 40 years (GAO, 1979; Congressional Record--House, 1979) (see Section 1.2.3). Because of these two factors, the Civilian Radioactive Waste Management Program included the basalts beneath the Hanford Site as one of the rock types considered for potential siting of a nuclear waste repository. Studies have been conducted since 1976 to determine the geologic and hydrologic characteristics of the Hanford Site and surrounding area (see Fig. 2-1), to assess the feasibility of disposing of these high-level nuclear wastes in basalt, and to provide the technology needed to design and construct such a repository in basalt should feasibility be proven (ARHCO, 1976; Myers, Price et al., 1979; Gephart et al., 1979; Smith et al., 1980; Myers and Price, 1981).

In 1978, a site-screening study was initiated to narrow systematically the Pasco Basin screening area (approximately 4,850 square kilometers (1,900 square miles)) (see Fig. 2-1) to a preferred candidate site. This study, which resulted in the identification of the reference repository location of approximately 47 square kilometers (18 square miles), was completed in May 1981 (WCC, 1981a). Principal borehole and exploratory shaft locations were then selected based on additional screening, using land use, surface contamination, ground-water contamination, and orientation of the exploratory shaft as criteria. These borehole and shaft locations were selected in 1982 (Rockwell, 1982). In mid-1982, screening of the basalt strata underlying the reference repository location was initiated to identify one of the basalt flows as a preferred candidate horizon. Such identification was necessary so that performance assessment, design studies, and planning for in situ testing could proceed on the basis of a single, specific horizon. This study was completed in September 1983 (Long and WCC, 1984). In June 1985, the Cohassett flow was designated the candidate horizon for a nuclear waste repository in basalt at the reference repository location at the Hanford Site.

Note that the reference repository location was selected before siting criteria were developed by the National Waste Terminal Storage Program (the predecessor to the Civilian Radioactive Waste Management Program) or the development of General Siting Guidelines (DOE, 1984) required by the Nuclear Waste Policy Act of 1982.

2.2.1 IDENTIFICATION OF A REFERENCE REPOSITORY LOCATION

Seven key assumptions guiding the site-identification study were important in establishing the objectives and development of screening guidelines. These are Hanford Site screening guidelines, not the General Siting Guidelines later developed by the U.S. Department of Energy (DOE, 1984). This process was completed before the Nuclear Waste Policy Act of 1982 was passed. These key assumptions were as follows:

- The repository will require licensing involving the U.S. Nuclear Regulatory Commission, other Federal agencies, and possibly State and local entities.
- The design and operation of most surface facilities will be governed by existing safety and environmental licensing requirements.
- The nominal design and performance characteristics for the repository have been established.
- The long-term safety-related characteristics of the host rock system can be estimated and can be used in the selection guidelines.
- The repository will be designed for two time frames: A relatively short emplacement and retrieval phase and a much longer isolation phase.
- The site-identification study will be based on available data; Hanford Site screening guidelines will be based on currently available technology.
- The repository-licensing requirements will be written in the style of those for other nuclear fuel cycle facilities.

On the basis of these assumptions, several objectives were established to reflect specific desired characteristics of the repository facilities, as well as conditions and concerns within the study area. The hierarchy of objectives provided the framework for choosing and applying guidelines to identify site localities. A proposed general statement of policy for licensing requirements for a repository, which was issued by the U.S. Nuclear Regulatory Commission (NRC, 1978), indicated that to be accepted as suitable a site must minimize the following:

- Effects on public health and safety.
- Adverse environmental and socioeconomic impacts.
- Cost necessary to attain the requisite levels of safety, and costs of mitigation.

The above objectives were then expanded and restated to bear on conditions or events that could be associated with an underground repository; thus, the expanded objectives are as follows:

- Minimize effects on public health and safety in relation to natural hazards, manmade hazards and events, and repository-induced events.
- Minimize adverse environmental and socioeconomic impacts related to construction, operation, closure, and surveillance.
- Minimize system costs related to construction and impact mitigation, operation, maintenance, closure, decommissioning, and surveillance.

For each of the objectives established, considerations or technical matters of concern were identified to describe the subject matter that would need to be addressed to orient the siting study so that it reflected characteristics, conditions, or processes in the study area. For example, one consideration related to a safety objective could be a fault rupture, which would then need to be addressed in the siting study.

For some considerations (technical matters of concern), a special level of achievement was required or implied by statute, regulation, technological limitations, or gross economic considerations. Again, using fault rupture as an example, a measure could be stated as the distance from capable faults and (or) those interpreted to be capable, thus indicating the degree to which a repository at any location could maximize safety in relation to fault rupture.

The choice of measures for the considerations was based on (1) prior U.S. Nuclear Regulatory Commission licensing experience and relevant regulatory positions, (2) the availability of data, and (3) the need to portray as many of the measures as possible on maps. In many cases, the measure was used as a proxy for the siting consideration or its associated effects. For example, the ground motion consideration was generally measured in kilometers (miles) from a fault. The motion itself is traditionally measured in terms of acceleration. In this study, the range of acceleration levels was inferred from a relationship between magnitude-acceleration attenuation, and the magnitude was estimated from a fault rupture length-magnitude relationship. On a map, this consideration was portrayed as a distance (in kilometers (miles)) from faults of different lengths; the distance represented a range of acceleration levels.

The value of the measure at which the limit was set was an inclusionary guideline. This limit was used to identify locations that met the minimum requirements for that consideration. In the fault rupture example, two considerations were evaluated based on two general viewpoints of the scientific community: (1) It is generally accepted that most effects of a fault rupture occur within 8 kilometers (5 miles) of the capable structure and (2) it is generally considered difficult to design an underground facility that will accommodate a fault rupture. Hence, a

limit was set on the measure of the fault rupture consideration, in that locations within 8 kilometers (5 miles) of capable faults were removed from consideration in the siting study.

For considerations where no specific level of achievement was required, the measure itself was used to identify groups of localities with similar characteristics. These guidelines were called classifying guidelines. The considerations, measures, and guidelines used for the site-identification study are found in a report by Woodward-Clyde Consultants (WCC, 1980, Vol. I, Appendix A), along with a detailed discussion of the background and rationale for selecting the various measures and guidelines.

2.2.1.1 Identification of site localities

A site screening was done as part of the U.S. Department of Energy activities to assess systematically the feasibility of constructing and operating a repository at the Hanford Site. The site-screening work to identify a suitable location for a repository at the Hanford Site was done by Woodward-Clyde Consultants (WCC, 1980). The Pasco Basin was selected for screening to provide a broader scope from which to study processes that might affect the Hanford Site, and to determine whether any obviously superior sites were located in a natural region outside, but contiguous to, the Hanford Site.

The first step in screening the study area was to define the candidate area. The considerations used at this step were active faults, ground motion, aircraft impact, transportation, operational radiation release, protected ecological areas, culturally important areas, and site-preparation costs. Figure 2-22 shows the candidate area defined by the composite overlay.

The second step in the screening of the Pasco Basin was to delineate subareas. Seven inclusionary considerations with more restrictive measures were used in this screening step: Fault rupture, flooding, ground failure, erosion denudation, hazardous facilities, induced seismicity, and site-preparation costs. When the overlays depicting these seven guidelines were compiled, the subareas shown in Figure 2-23 were identified. These subareas were then evaluated in the next step in the screening process to identify site locations. The evaluation of subareas was conducted in two steps: (1) Evaluation of subareas outside of the Hanford Site boundary and (2) evaluation of the subareas within the Hanford Site boundary.

The first step was designed to determine whether any obviously superior sites were located in the subareas outside the Hanford Site. The results of this evaluation indicated that three of the four subareas that were outside the Hanford Site (L, M, and N in Fig. 2-23) were used for irrigated farming and were near the Columbia River. The fourth subarea (P in Fig. 2-23), in addition to being used for irrigated farming, was an area where the bedrock dip was greater than 5 degrees; one of the baseline

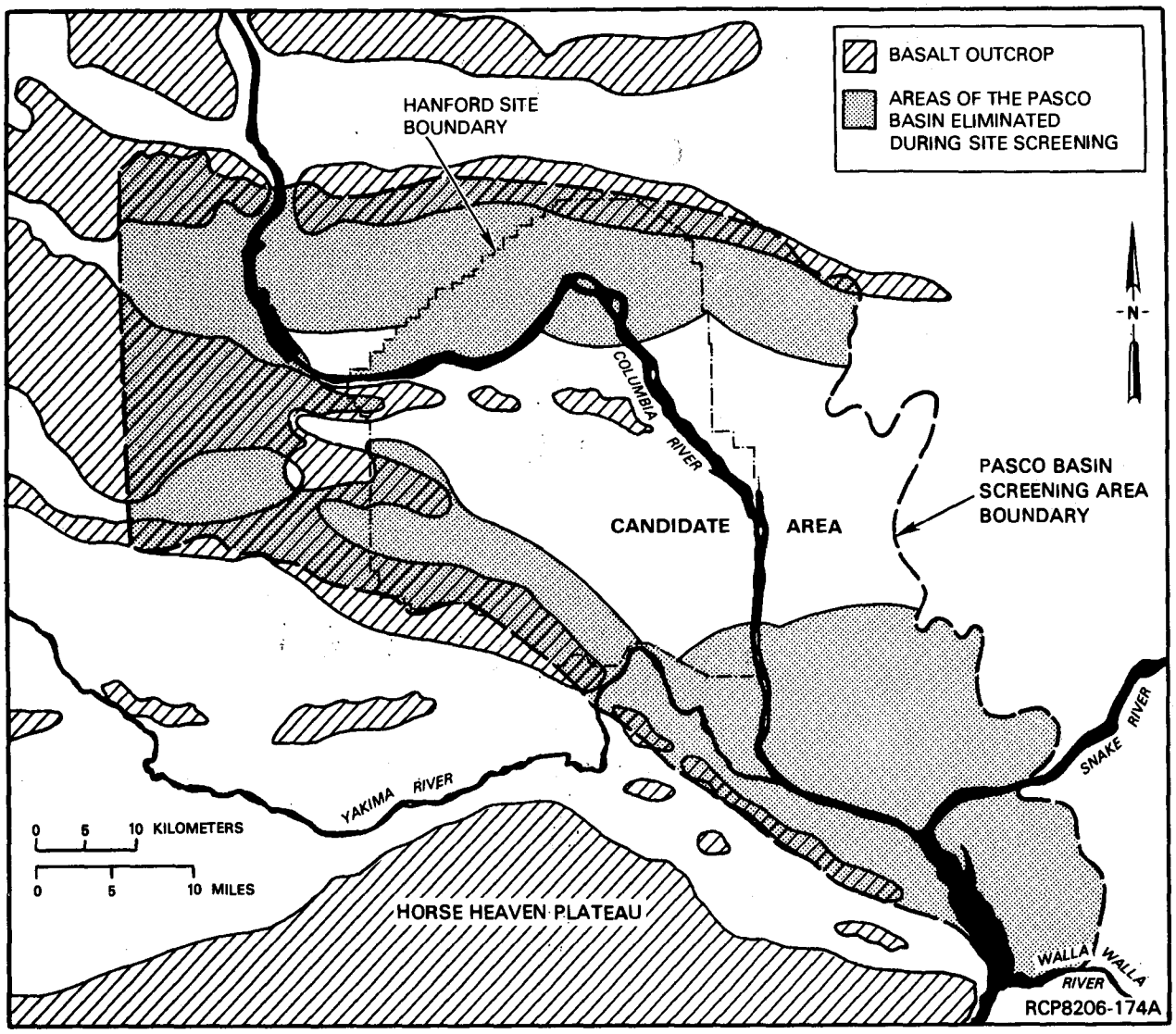

Figure 2-22. Candidate area within the Pasco Basin.

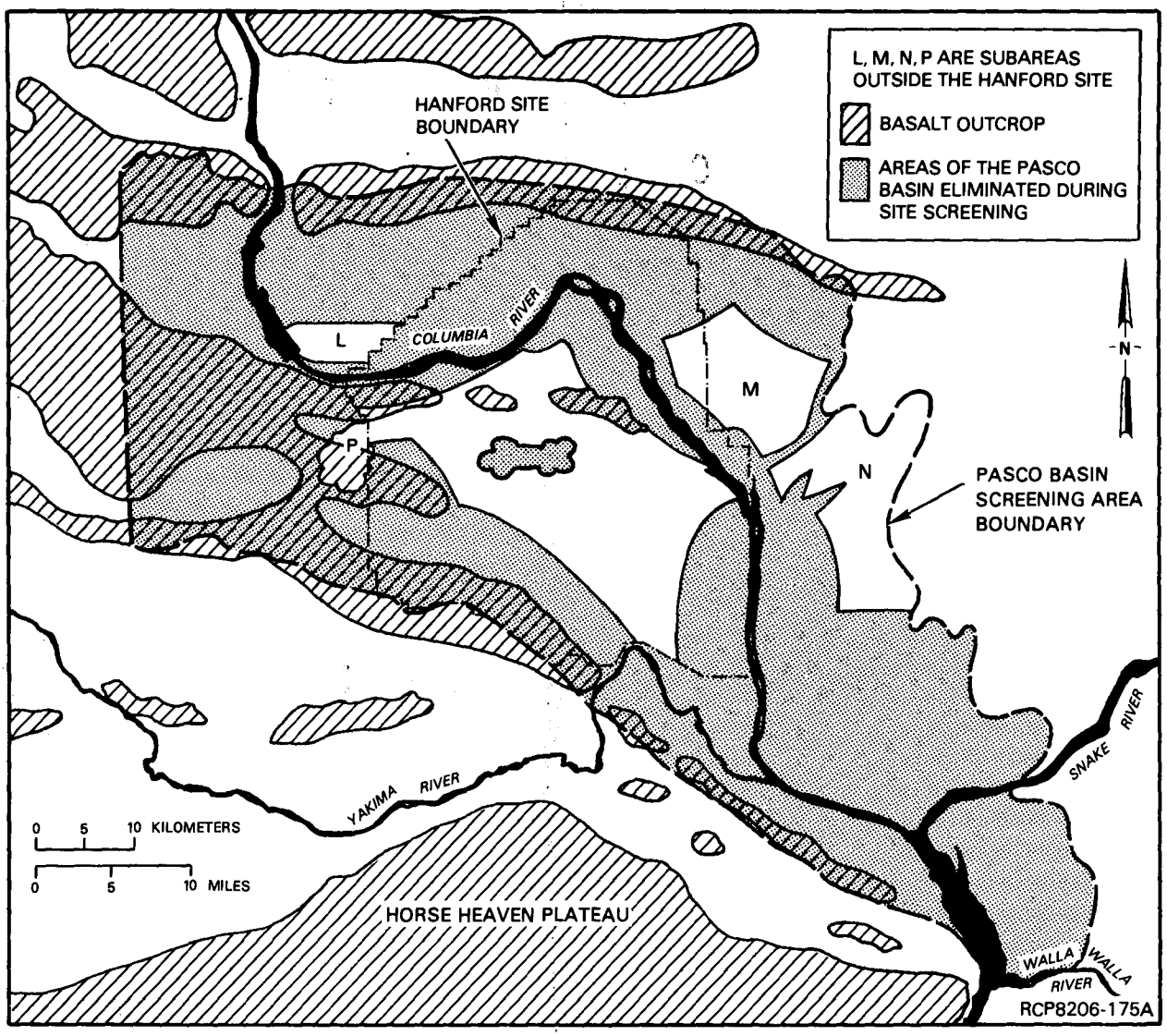

Figure 2-23. Subareas within the Pasco Basin.

conditions for the repository host rock was a flow dip of less than 5 degrees. On the basis of land use, hydrology, and bedrock dip, these sites were not obviously superior to those found within the Hanford Site and, therefore, were given no further consideration.

The next step in the evaluation of subareas within the Hanford Site (before the identification of site locations) was to study the available surface and subsurface areas separately and to evaluate surface and subsurface considerations. In all circumstances the subsurface considerations took precedence over the surface considerations; that is, when the subsurface screening showed obvious superiority, the surface screen was downgraded. The area that resulted by combining the surface and subsurface screens was judged to be more suitable and to have a higher likelihood of containing suitable waste repository sites.

The general size of a potential site was less than 130 square kilometers (50 square miles) and greater than 26 square kilometers (10 square miles); five potential sites were identified. Figure 2-24 shows the location of these five sites, designated H-1 through H-5. The boundaries of the three site localities south of Gable Mountain were defined somewhat arbitrarily to maintain equal size.

2.2.1.2 Identification and ranking of candidate sites

The initial step in identifying the reference repository location was to identify candidate sites within the five site localities. The size of a candidate site was determined from repository baseline conditions established at the beginning of the screening process. An area of approximately 26 square kilometers (10 square miles) was selected to include surface and subsurface facilities and an exclusion area buffer zone.

The candidate sites were identified through a selective and successive examination and evaluation of the range of conditions for 23 parameters that reflected the objectives of the siting study (WCC, 1981a).

Consideration was also given to established U.S. Nuclear Regulatory Commission reactor-siting criteria (NRC, 1984), the Office of Nuclear Waste Isolation draft site qualification criteria (ONWI, 1980, pp. 1 through 9), U.S. Nuclear Regulatory Commission draft repository criteria (NRC, 1980), and guidelines of the National Academy of Sciences-National Research Council (1978). The relationship of the Office of Nuclear Waste Isolation generic repository criteria and the site-specific consideration used for candidate site identification is given in two Rockwell Hanford Operations documents (Rockwell, 1980, 1981).

To identify candidate sites, screening overlays representing the range of conditions and the area affected by each parameter under consideration were superimposed. The results of this overlay process were used to identify the portion within each locality with the most desirable

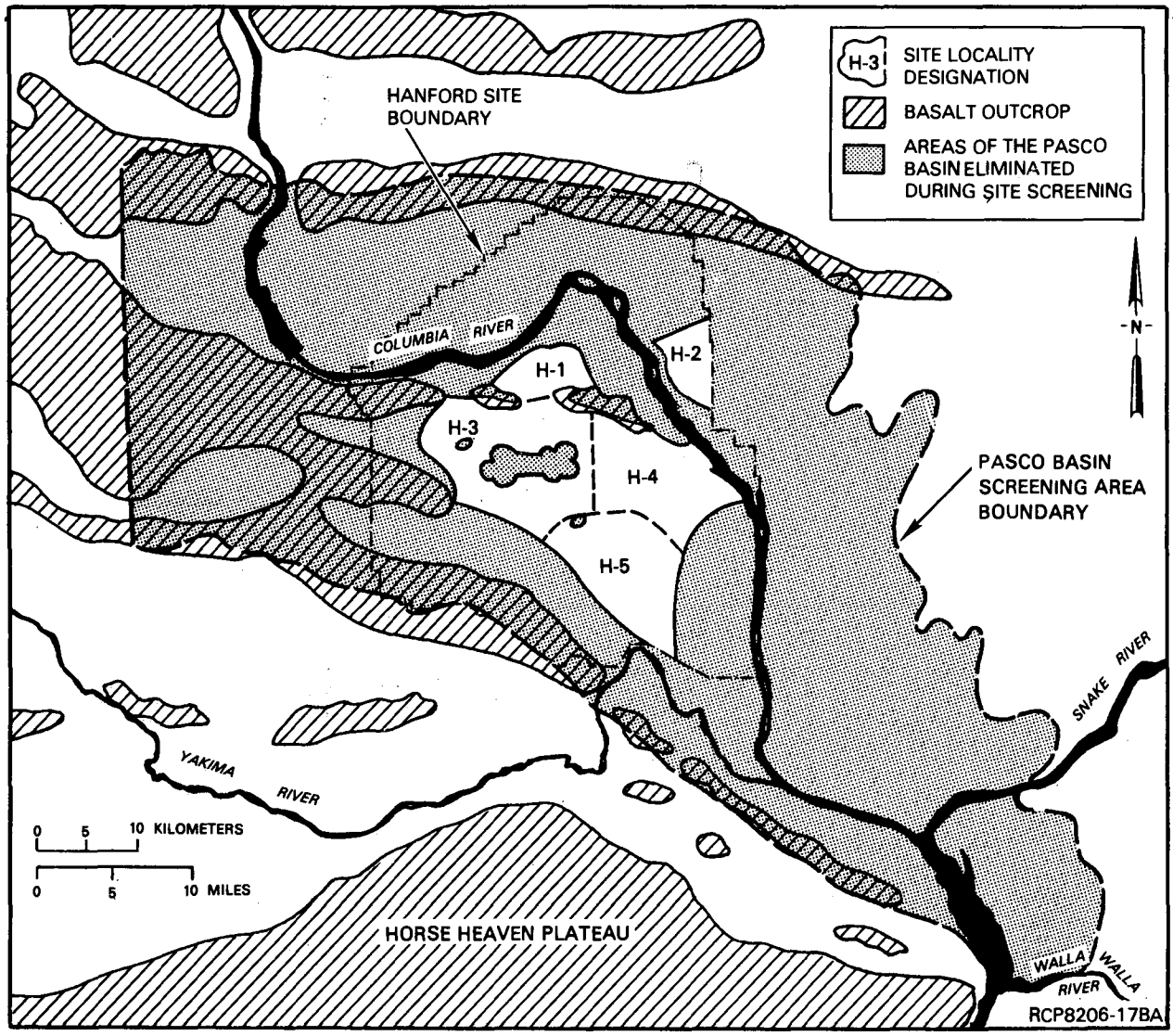

Figure 2-24. Site localities within the Pasco Basin.

characteristics with regard to the parameters. Nine candidate sites were thus identified within the site localities, designated R through Z in Figure 2-25. Seven of the nine candidate sites (R through X) lie in a group within the Cold Creek syncline, a major structural feature of the Pasco Basin. Two other candidate sites (Y and Z) lie outside this structure. Some of the candidate sites included parts of areas that previously had been excluded during site screening (i.e., the stippled areas within site locality H-3 (see Fig. 2-24)). This was allowed because the areas previously excluded were (1) the chemical separations and defense waste-management areas of the Hanford Site (surface facilities) and (2) steep terrain on the margin of the Umtanum Ridge bar (a surface feature). The facilities and terrain would not affect the repository at the 900-meter (3,000-foot) depth as long as the repository surface facilities were located away from the existing chemical separations and defense waste-management surface facilities and the Umtanum Ridge bar. The size and location of candidate sites were such that this condition was met.

A review of site conditions showed that candidate sites Y and Z were not technically superior to those in the Cold Creek syncline, were closer to the Columbia River, and were more distant from transportation, safety, and support facilities. For these reasons, candidate sites Y and Z were removed from further study.

The remaining seven contiguous candidate sites in the Cold Creek syncline displayed geological and physical similarities throughout the siting process. These sites were redesignated A through G (Fig. 2-26) and were further evaluated to identify a reference repository location. However, because the seven contiguous sites appeared to be so closely matched, further evaluation of the Cold Creek syncline was based on a more detailed study in the siting area. Results of the geologic field work were subsequently summarized in Myers and Price (1981).

Because of the linear trends identified during geophysical studies in the Cold Creek syncline (Myers and Price, 1981), the boundaries of the seven candidate sites were reevaluated. For ease of comparison with previous work, the original candidate site boundaries (A through G) were maintained and three additional candidate site boundaries were superimposed on portions of the original seven sites (but outside the influence of the more prominent geophysical lineaments). These additional sites were designated H, J, and K (Fig. 2-27).

Preliminary evaluation of the candidate sites (A through K) indicated that the sites were too closely matched to be differentiated by routine ranking. Thus, a decision analysis process was applied. An enlarged data base was compiled and referred to as the criteria matrix. The criteria matrix included a description of physical, socioeconomic, and biological conditions at the candidate sites using information available as of May 1980.

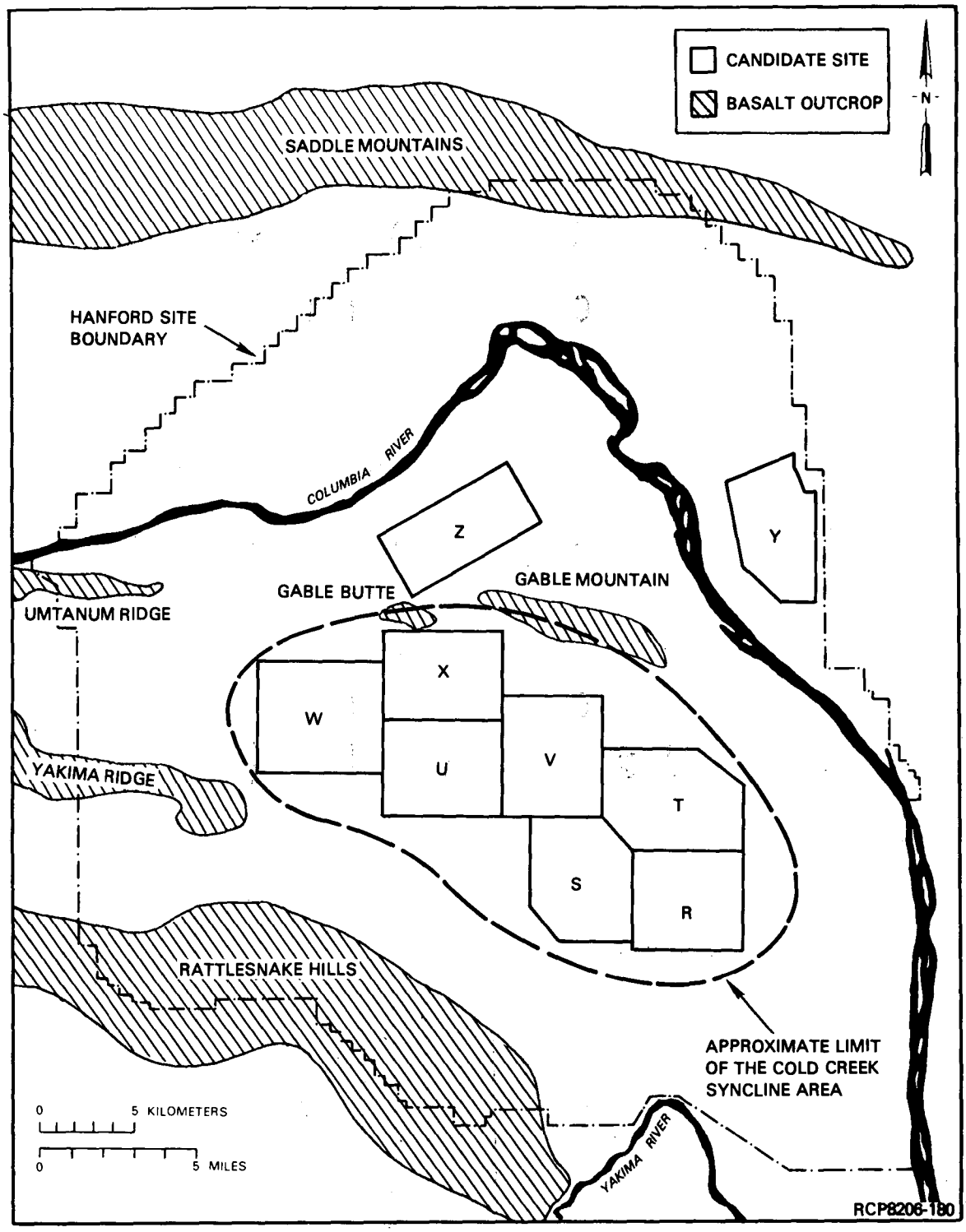

Figure 2-25. Candidate sites at the Hanford Site.

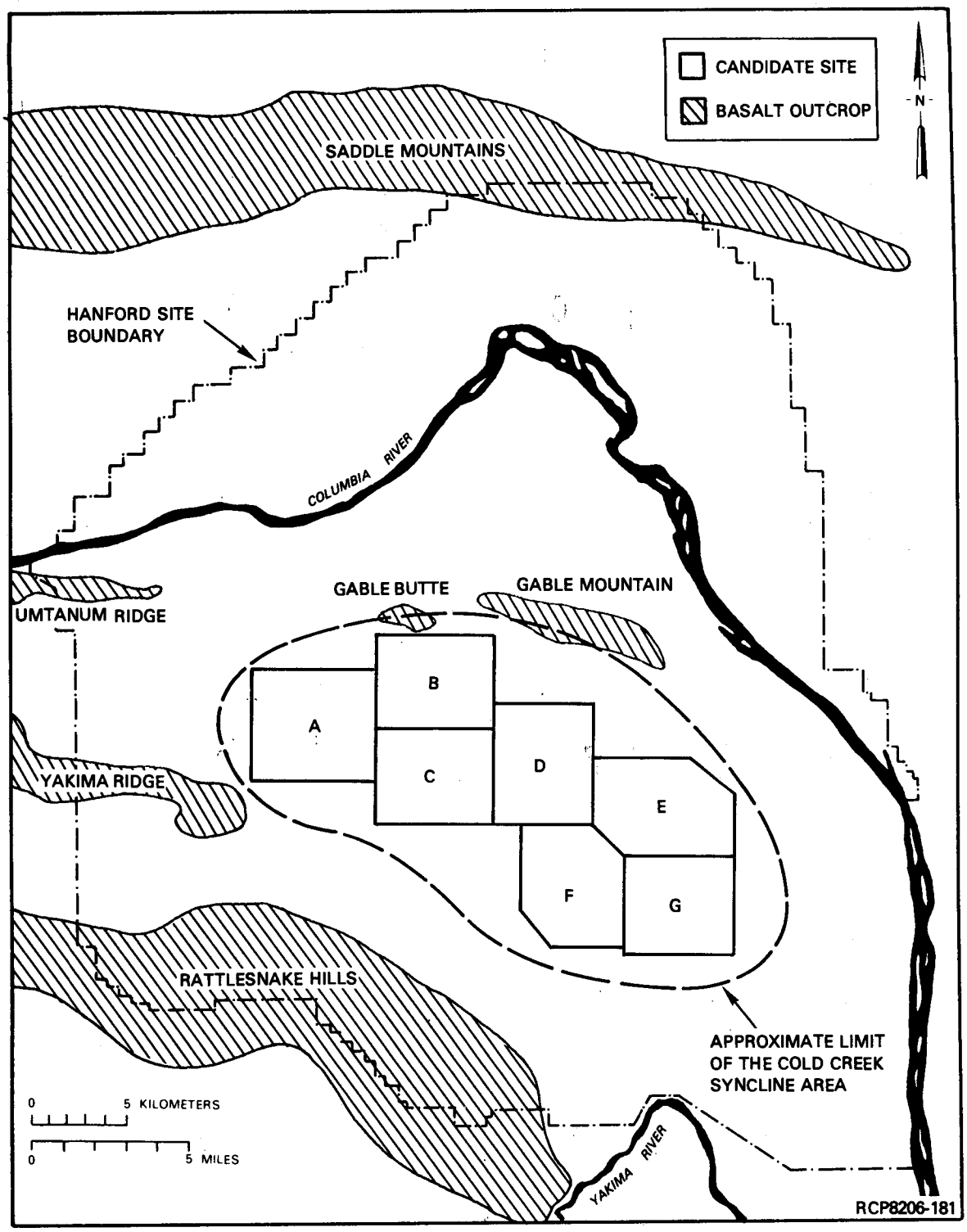

Figure 2-26. Initial candidate sites in the Cold Creek syncline area.

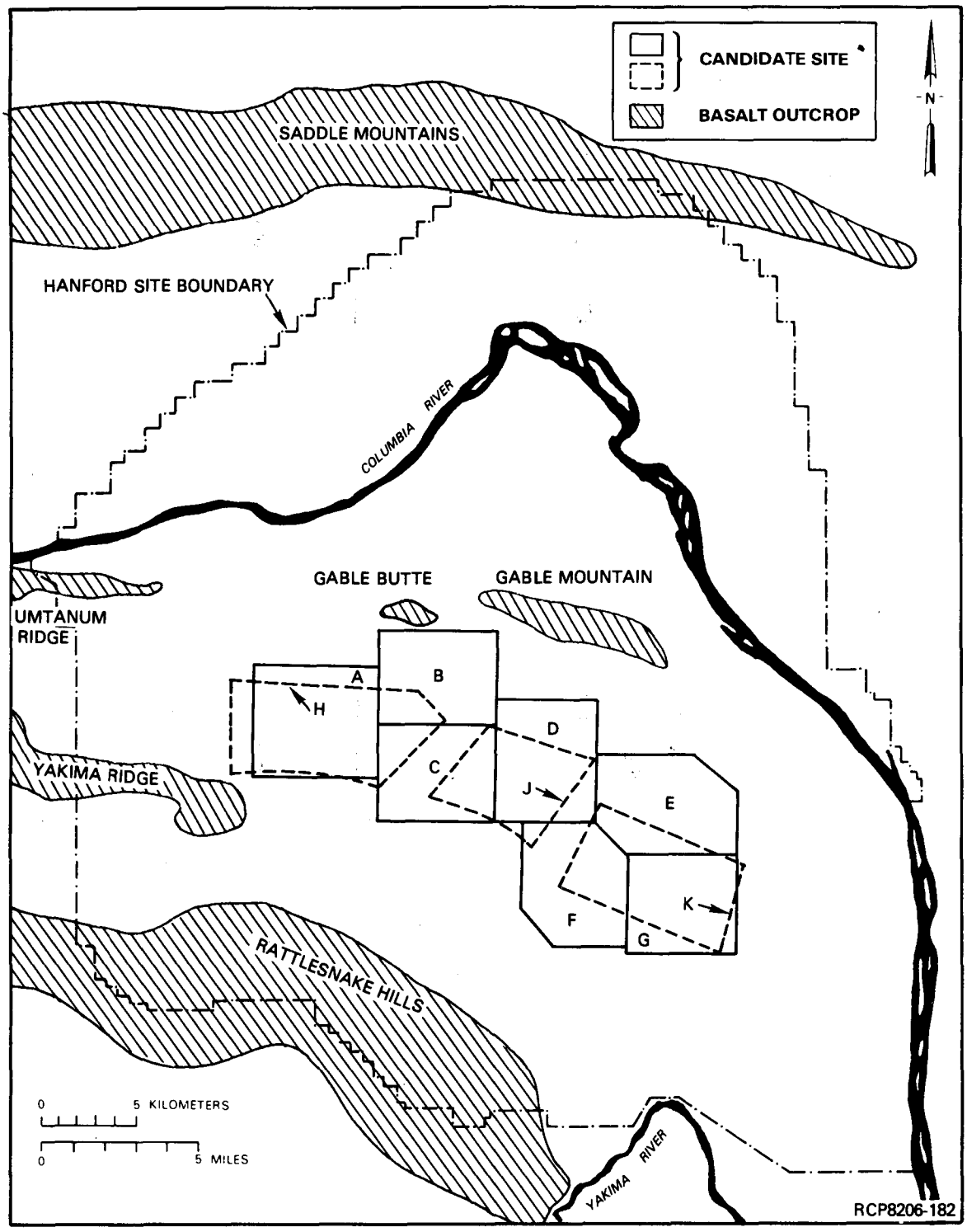

Figure 2-27. Candidate sites with three superimposed candidate sites (H, J, and K).

Criteria were selected from a detailed evaluation of the criteria matrix. The ten ranking criteria were as follows:

- Bedrock fractures and faults.
- Lineaments.
- Potential earthquake sources.
- Ground-water travel times.
- Contaminated soil and ground water incompatible with surface facilities.
- Thickness of the reference barrier interior (assumed to be the Umtanum flow).
- Tiering within the host flow.
- Vegetative natural communities.
- Unique microhabitats.
- Special species.

Dominance analysis was used for the site ranking and was carried out by a siting committee formed of technical representatives from Rockwell Hanford Operations and facilitated by Woodward-Clyde Consultants. For the purpose of the site-screening process, the Umtanum flow was selected as the target horizon. It exhibited promising repository characteristics, such as a relatively thick, dense flow interior with low porosity (based on recovered core and geophysical logs) and apparent lateral continuity (Myers and Price, 1981). The first step developed measures for ranking criteria that could be used to differentiate the candidate sites. The ranking criteria and their measures were derived from a detailed evaluation of criteria and data comprising the criteria matrix. Once the ranking criteria were defined, they were applied to each candidate site. The siting committee judged each site according to available published and unpublished data as outlined by the criteria matrix and their own professional judgment. The favorable or unfavorable consequence of each site in terms of the measures for each ranking criteria was then established.

The next step in the dominance analysis was to determine preference for a series of consequences. This became necessary because of the number of criteria and the fact that no one site had favorable consequences for all measures relative to all other sites. Thus, instead of simple dominance analysis, ordinal dominance analysis was used. Ordinal dominance analysis allowed the siting committee to assess trade-offs to determine the relative importance of the measures used in differentiating among candidate sites. These trade-offs were examined in two ways. First, if given a hypothetical site with all the criteria at the most

desirable levels, and given that one criterion had to be changed to its least desirable level, which one would be changed. The criterion selected for this question had the least weight. The question was then repeated progressively until all criteria were ranked.

The second way of assessing trade-offs required the determination of how much one was willing to give up from one criterion to enhance a second criterion. This rank ordering generally agreed with the first method. The information for ranking was then synthesized, which merely involved discussion and evaluation of all sites by the siting committee with respect to the ranking criteria, site characteristics, and analysis method.

The results of the ordinal dominance analysis are shown in Table 2-5. The additive numerical functions were determined based on the site-ranking value terms. The results of the ranking showed that site H was dominant over all other sites. Site A, which was almost totally included within Site H, had about the same dominance numerical value (0.834 and 0.860, respectively). These two sites were combined to form the reference repository location (Fig. 2-28). The screening guidelines used for selecting the reference repository location were not those now available as the General Siting Guidelines (DOE, 1984), although the elements were similar.

Because of the heavy weighting of the lineament and thickness criteria, the substitution of a thick Grande Ronde Basalt, other than the Umtamum flow, as the reference horizon would not be expected to alter the results of this ranking. Such a substitution has been made as the result of a study conducted specifically to identify the candidate horizon (Section 2.2.3).

2.2.2 IDENTIFICATION OF PRINCIPAL BOREHOLE AND EXPLORATORY SHAFT SITES

With the identification of the A-H site as the reference repository location, the U.S. Department of Energy and its contractors determined the site for a principal borehole for an exploratory shaft. Six shallow boreholes (designated by an RRL prefix, for reference repository location) (Fig. 2-29) were drilled to evaluate the overall dip of the basalt units. The results indicated an overall dip of less than 1 degree across the reference repository location. The axis of the Cold Creek syncline was also determined more precisely. Figure 2-29 is a contour map of the top of basalt beneath the reference repository location that is based on boreholes drilled for siting the principal borehole and exploratory shaft.

To help select a specific location for construction of a principal borehole for an exploratory shaft, exclusion-area criteria were developed. These criteria were land use, surface contamination, ground-water contamination, and the orientation of the exploratory shaft. A composite overlay of the reference repository location using the exclusion-area criteria is shown in Figure 2-30. This overlay shows that the area remaining for consideration was in sections 2, 3, 10, and 11 in the western half of the reference repository location. Within this area,

Table 2-5. Ordinal dominance analysis results

Candidate site	l'	l'+h	l'+t	l'+h+t	l'+h+t +p	l'+h+t +p+g'	l'+h+t +p+g'+b	Site ranking value	Site dominated by
A	1.84	2.51	2.84	3.51	4.26	4.39	4.66	0.834	H
B	0.50	1.50	1.17	2.17	2.79	3.05	3.15	0.496	A,H,J
C	1.00	1.58	1.67	2.25	2.72	2.97	3.47	0.550	A,H
D	0.66	1.41	0.99	1.74	2.62	3.12	3.28	0.495	A,H,J
E	0.66	1.33	0.66	1.33	2.33	2.83	2.95	0.442	A,C,D,H,J
F	0	0	0.33	0.33	0.33	0.46	0.92	0.088	All
G	0.84	0.84	0.84	0.84	1.25	1.25	1.25	0.255	A,C,H,J,K
H	2.00	2.67	3.00	3.67	4.36	4.49	4.68	0.860	—
J	1.16	1.83	1.49	2.17	2.79	3.28	3.70	0.584	A,H
K	1.16	1.33	1.16	1.33	1.71	1.84	1.84	0.366	A,H,J

l' = lineaments.
h = thickness of host flow.
t = tiering in host flow.
p = potential earthquake.
g' = ground-water travel time.
b = bedrock fracture.

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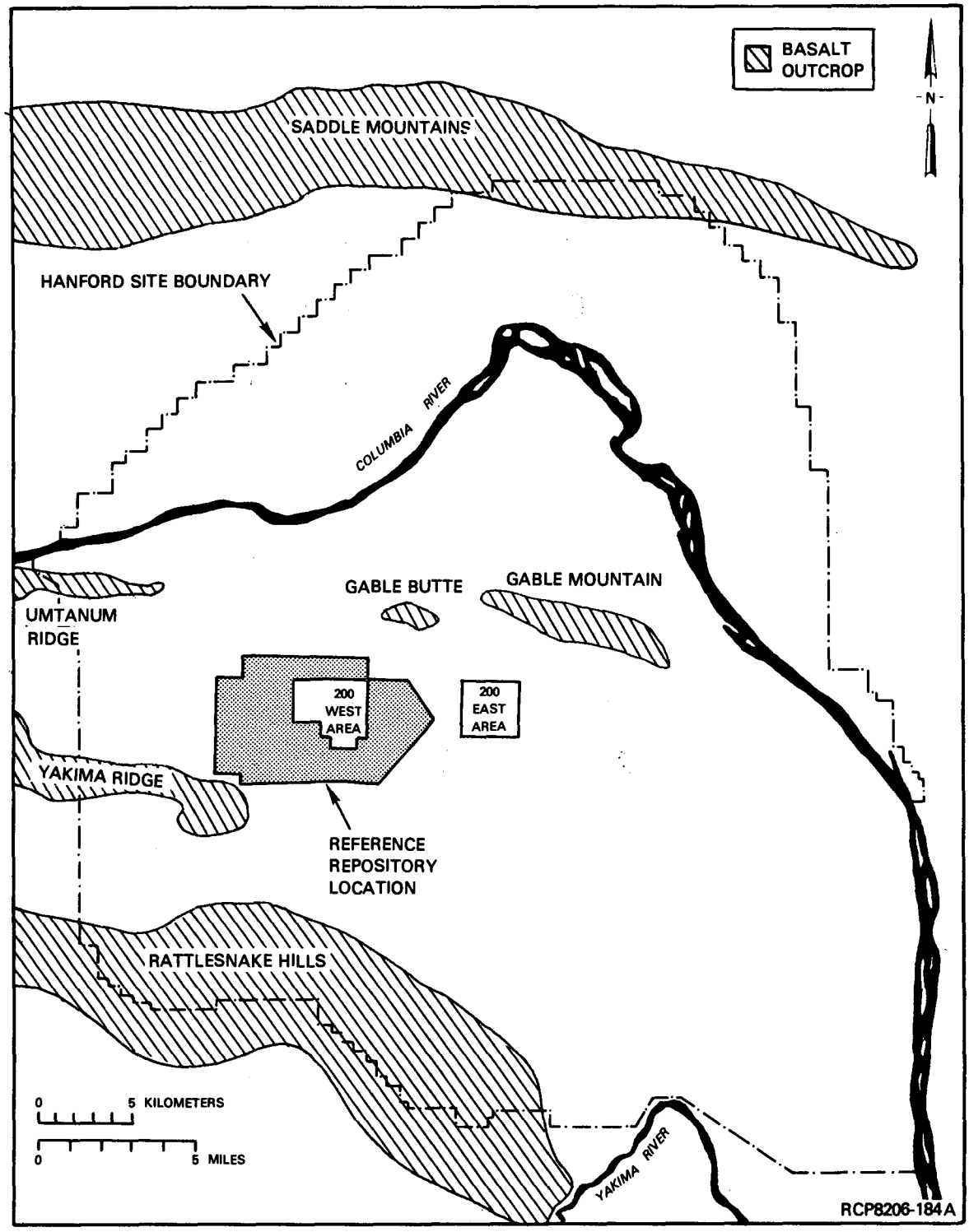

Figure 2-28. Reference repository location.

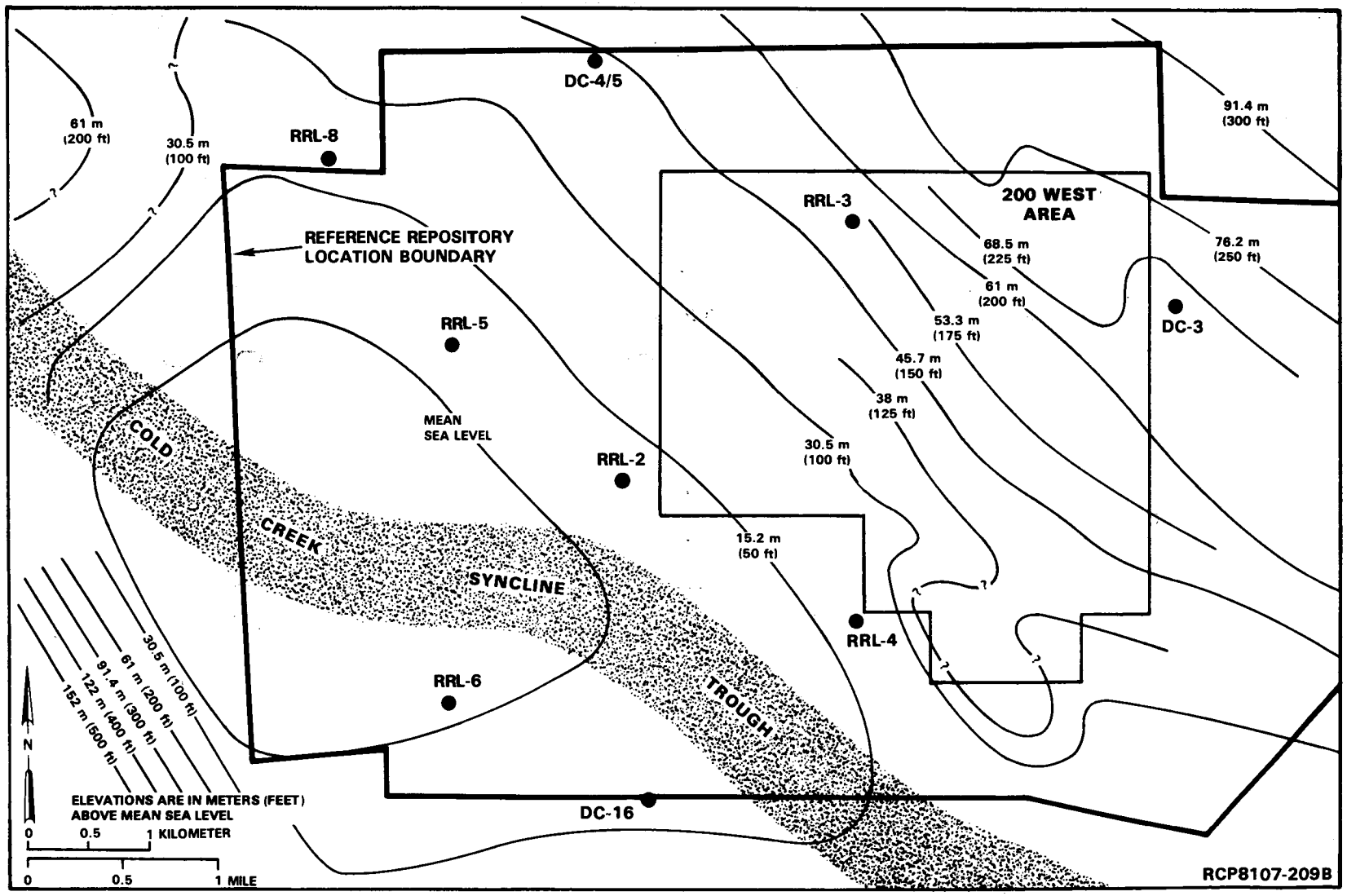

Figure 2-29. Contour map of reference repository location and boreholes drilled for characterization.

7 0 1 6 8 0 6 0 3

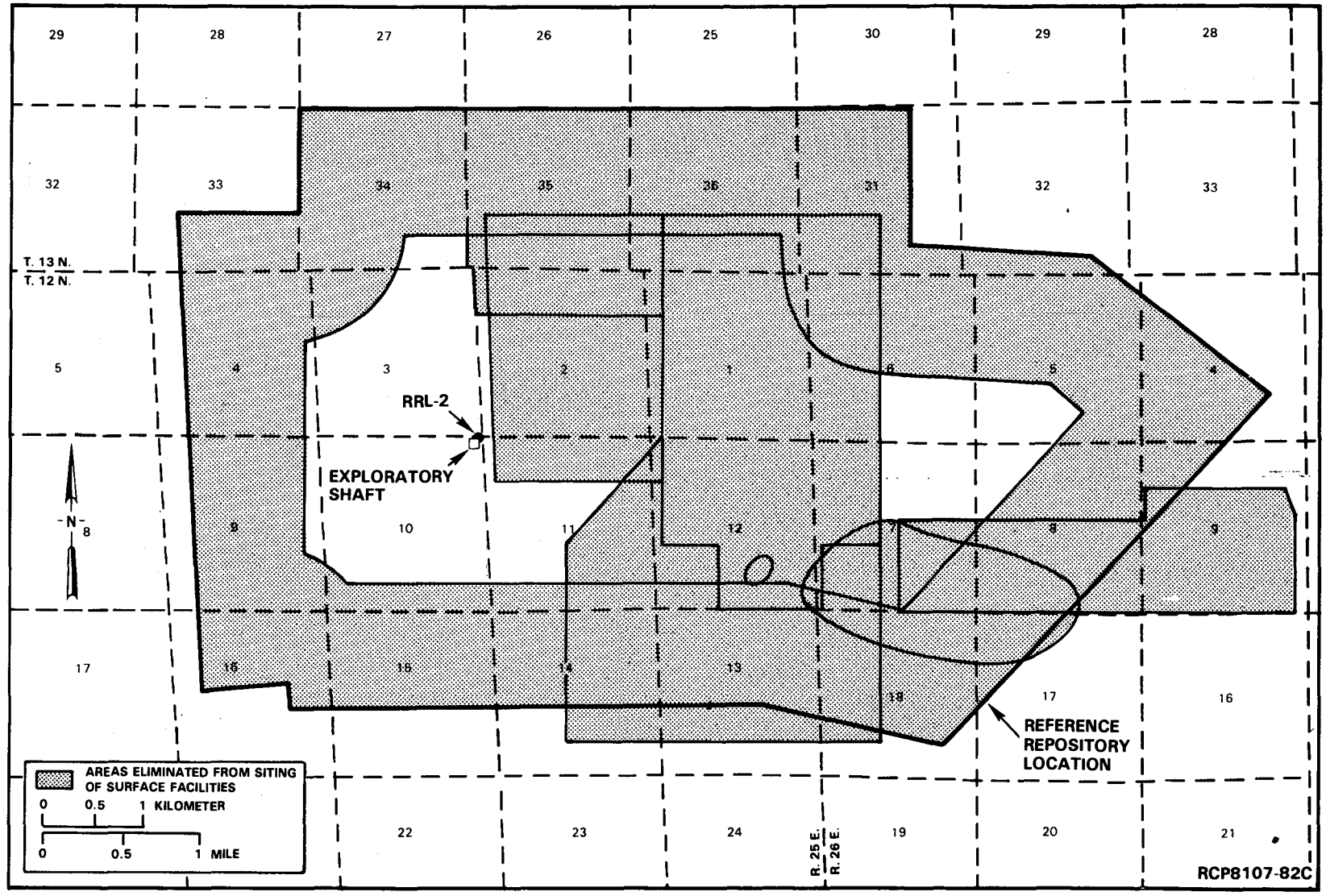

Figure 2-30. A composite overlay showing suitable areas for siting of the exploratory shaft (unshaded areas within the A-H Site).

7 0 1 6 8 0 6 0 4

adequate space existed for location of the exploratory shaft. The location of the principal borehole was selected near the intersection of these sections at the site of the existing borehole, RRL-2. This borehole had been cored to a depth of approximately 520 meters (1,700 feet) and was deepened to 1,177 meters (3,860 feet).

2.2.3 IDENTIFICATION OF A PREFERRED CANDIDATE HORIZON

During the initial phase of the Basalt Waste Isolation Project, geotechnical and engineering studies focused on the Umtanum flow as the reference horizon. This focus was based on a progressive accumulation and analysis of technical data starting as early as 1968. As the U.S. Department of Energy moved toward engineering design for an exploratory shaft, it became increasingly apparent that the actual identification of the horizon or flow in which shaft breakout would occur should be subject to more rigorous analysis, similar to the decision analysis technique used to identify the reference repository location. A decision analysis methodology (Keeney and Raiffa, 1976, Ch. 6) provided a quantitative approach for using available data and expert judgment to identify a preferred candidate horizon for a nuclear waste repository. Four steps guided the implementation of this methodology: (1) Structuring the analysis, (2) describing the consequences for each alternative candidate horizon, (3) assessing the preferences, and (4) ranking the alternative candidate horizons. These steps are summarized in this section and are discussed in detail in Long and Woodward-Clyde Consultants (Long and WCC, 1984).

The purpose of the analysis was to identify a preferred candidate horizon within the reference repository location. It was recognized throughout the study that new data resulting from ongoing site investigations could alter the outcome of the study. This was particularly true in the area of geohydrology, where there was considerable debate regarding the ground-water flow characteristics of the reference repository location. Thus, the preferred candidate horizon that was identified could be subject to revision until sufficient data were available to designate a single flow as the candidate horizon for a nuclear waste repository in basalt at the reference repository location.

In identifying the alternatives to be ranked, all stratigraphic horizons beneath the reference repository location shallower in depth than approximately 1,200 meters (3,940 feet) were considered as possible alternatives. A screening process was used to focus study on those horizons with higher potential for meeting the objectives of a nuclear waste repository in basalt. The screening process was designed to select systematically a manageable number of flows for detailed consideration in ranking. To do this, screening criteria were applied to each potential alternative; then professional judgment determined whether flows should be retained as candidates. As a result, three screening criteria were selected, the first of which was to exclude from further consideration any sedimentary interbeds and sediments overlying the basalt. The second criterion was to exclude flows with a minimum thickness of flow interior

(the relatively impermeable, dense middle part of a flow) of less than 24 meters (80 feet). The third criterion was to exclude flows above the deepest tapped aquifer within 10 kilometers (6 miles) of the reference repository location.

When these three criteria were applied, the following five flows were identified as proposed candidate horizons.

1. Frenchman Springs flow 6.
2. Rocky Coulee flow.
3. Cohassett flow.
4. McCoy Canyon flow.
5. Umtanum flow.

The Frenchman Springs flow 6 was excluded as a candidate, based on professional judgment, because it occurred in a formation with relatively high hydraulic conductivity of flow tops, it was closer to the land surface than the other candidate horizons, and there was less confidence in its stratigraphic correlation and continuity relative to the other candidates (Sections 3.2.2 and 3.3.2). The stratigraphic positions of the remaining four proposed candidate horizons are shaded in Figure 2-31.

The technical data compiled for identification of the preferred candidate horizon represented all data and interpretations on the proposed candidate horizons that were made available in mid-1983 (Long and WCC, 1984). These data were collected under field and laboratory conditions and encompassed current knowledge of geology, geohydrology, waste package environment, rock mechanics, waste package and repository design, and performance assessment.

Based on available data, the major geologic differences among the four proposed candidate horizons were (1) the depth of the flows below ground surface, (2) the thickness of flow interiors, and (3) the character and predictability of internal structures.

Available geohydrologic information indicated that the principal hydrologic differences among the proposed candidate horizons were (1) zones of relatively high hydraulic conductivity in the Umtanum flow top and (2) shorter vertical distance from the shallowest horizon (Rocky Coulee flow) to overlying zones of relatively high hydraulic conductivity in the Wanapum Basalt. Hydraulic heads and hydrochemistry were similar for the four flows. Insufficient data were available to compare dispersivity and porosity of the proposed candidate horizons.

Among the four proposed candidate horizons, the principal differences that could affect the waste package were temperature and pressure, although the temperature differences among horizons were not expected to affect the waste package design significantly. However, the respective hydrostatic pressures of the proposed candidate horizons would affect the thickness of the canister wall required for mechanical integrity.

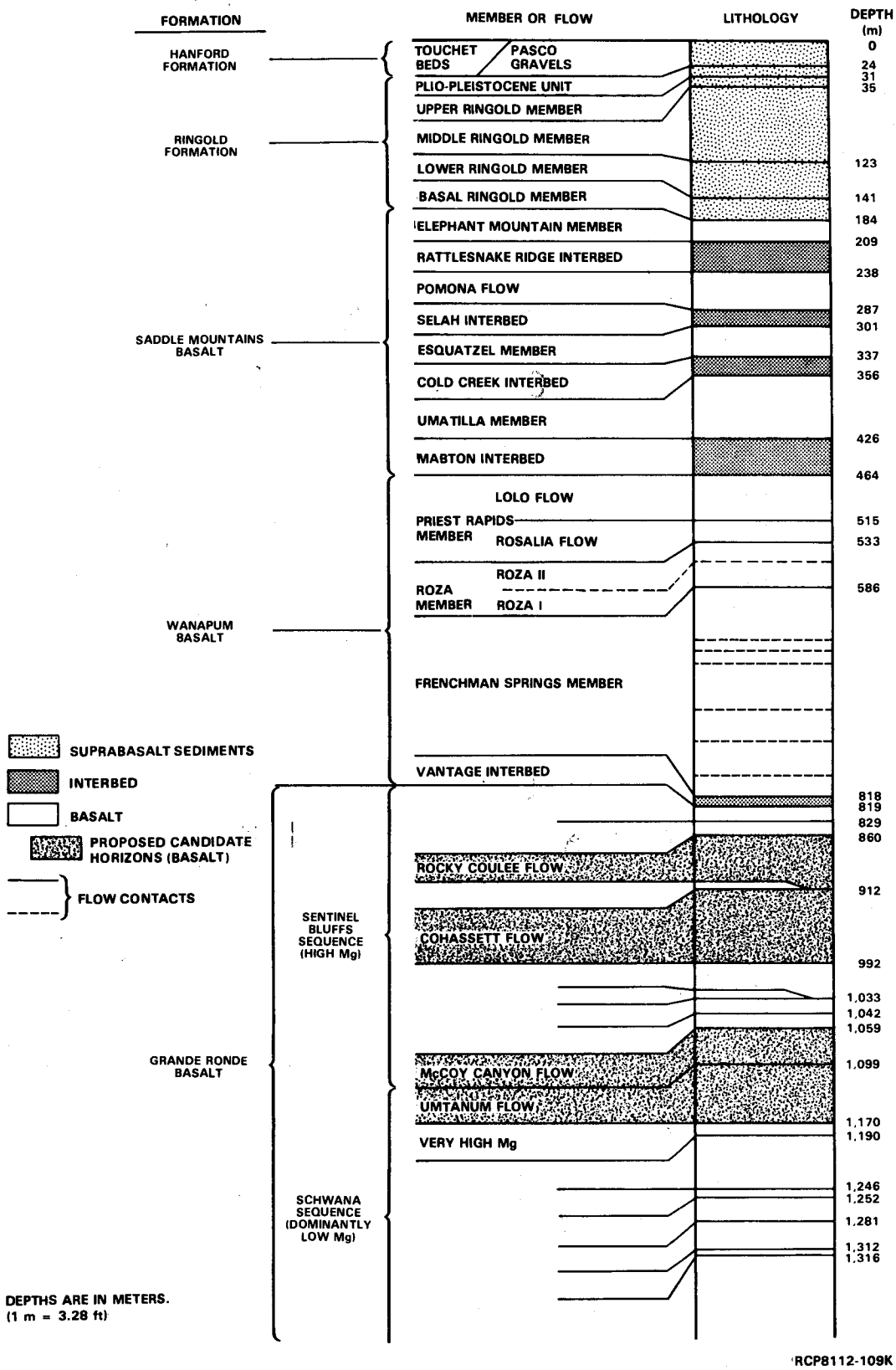

Figure 2-31. General stratigraphy of the reference repository location showing the positions of the proposed candidate horizons. Depths are from borehole RRL-2.

The rock mechanics characteristics considered were in situ stress, mechanical and thermal properties of intact rock, and rock mass properties. The in situ stress determined by hydraulic fracturing techniques indicated that the maximum principal stress was the horizontal stress acting approximately in the north-south direction, and the minimum principal stress was the vertical stress. The ratio of maximum horizontal to vertical stress measurements in borehole RRL-2 (see Fig. 2-28) ranged from approximately 2.2:1 to 2.7:1 (Kim et al., 1984). Some uncertainties were associated with stress measurements obtained by the hydrofracturing technique. In situ stress was not determined for all proposed candidate horizons in borehole RRL-2. Available data on mechanical and thermal properties of intact rock and rock mass properties for all four proposed candidate horizons were so similar that they did not form a basis for distinguishing between flows.

A preliminary performance assessment was conducted to compare the four proposed candidate horizons (Long and WCC, 1984). For comparison purposes, the cumulative activity of iodine-129 crossing a vertical boundary at 1.6 kilometers (1 mile) from the edge of a repository over 10,000 years was calculated for each proposed candidate horizon. The results, expressed in curies per 1,000 metric tons (1,100 tons) of heavy metal, are listed below.

Flow	Ci/1,000 t of heavy metal
Rocky Coulee	0.001
Cohassett	0.0001
McCoy Canyon	0.10
Umtanum	1.0

These estimates of radionuclide transport were preliminary, and were suitable for comparison purposes only. Methods and models used for the preliminary estimates of radionuclide transport as well as for ground-water travel time and vertical confinement of radionuclides are discussed in Long and Woodward-Clyde Consultants (Long and WCC, 1984). The results of a preliminary analysis of preclosure ground-water median travel times along the fastest pathline to a vertical boundary located 10 kilometers (6.2 miles) from the edge of the proposed repository are given below in stratigraphic order.

- Rocky Coulee flow (38,000 years).
- Cohassett flow (64,000 years).
- McCoy Canyon flow (34,000 years).
- Umtanum flow (36,000 years).

The calculated median travel times were useful only for comparative purposes because they reflected a limited hydrologic data base and a simplified conceptual model (Section 6.4.2 provides more recent ground-water travel-time estimates).

Another distinction among the four proposed candidate horizons was the distance between a given radionuclide concentration level in the dispersal plume and selected overlying aquifers. For comparison purposes, the positions of the maximum permissible concentration of iodine-129 in the dispersal plume at 10,000 years with respect to the base of the Priest Rapids Member are given as follows:

Flow	Position, m (ft)
Rocky Coulee	285 (935)
Cohassett	335 (1,099)
McCoy Canyon	460 (1,509)
Umtanum	510 (1,673)

These values represented a relative safety factor against radionuclide contamination of the Priest Rapids Member. The base of the Priest Rapids Member was used solely for purposes of comparison; another stratigraphic datum, such as the Vantage interbed or even the upper contact of the Rocky Coulee flow, might well have been chosen. The significant aspect of these data was that they provided a consistent relative comparison of the depth to which radionuclides could be confined in each of the proposed candidate horizons. As with the other estimates of repository performance, these data were preliminary and continue to be evaluated.

2.2.3.1 Application of decision analysis to the proposed candidate horizons

Once the proposed candidate horizons were identified and available data for them compiled, a multidisciplinary study team developed a set of measures for ranking the four proposed candidate horizons. The principal ranking objectives were to (1) maximize repository performance, (2) maximize ease of construction, and (3) minimize costs. These objectives provided a guideline for developing the following eight ranking measures.

- Performance-related measures
  - Cumulative releases of iodine-129 across a vertical boundary at 1.6 kilometers (1 mile) over 10,000 years
  - Ground-water travel times from the repository to the accessible environment along the fastest likely pathline
  - Vertical distance between the 1.0 maximum-permissible-concentration plume for iodine-129 and the base of the Priest Rapids Member after 10,000 years.

- Construction-related measures
  - Mean thickness of flow interior (constructibility)
  - Minimum thickness of flow interior (variability-predictability)
  - Mean percent of the flow interior exhibiting vesiculation.
- Cost-related measures
  - Savings in construction costs relative to the Umtanum flow
  - Savings in construction schedule relative to the Umtanum flow.

The next step in the decision analysis was to assign the appropriate numerical level for each ranking measure for each proposed candidate horizon. The numerical estimates were used as the basis for ranking the alternatives. Numerical levels were assigned in two evaluations. The first was deterministic, using single numbers as the levels of the ranking measures. The second was probabilistic, using probability distributions to describe the levels of the ranking measures. The probabilistic evaluation quantitatively described the uncertainties in the levels assigned to the ranking measures. The uncertainties for each measure level were derived either from the technical data available (Long and WCC, 1984) or by structured interview techniques with Rockwell Hanford Operations scientists and engineers.

The numerical estimates indicated that none of the proposed candidate horizons were obviously superior on all ranking measures. The next step in the decision analysis was to assess the preferences and develop trade-offs between the ranking measures that established the relative importance of each measure.

Trade-offs were developed by the multidisciplinary study team in structured group and individual meetings with decision analysts from Woodward-Clyde Consultants. Team members were asked specific questions regarding their preferences for one measure level versus another over the range of levels covered by all four proposed candidate horizons. These preferences were then combined to calculate scaling constants for each measure that would consistently relate one measure to another and reflect the relative importance and the range of values for each measure.

The last step in the decision analysis was to compute the expected utility of the four proposed candidate horizons from the information developed. Two sets of expected utilities were computed: One used the deterministic ranking measure levels and the other used the probability distribution developed for the ranking measure levels.

The Cohassett flow ranked the highest of the four proposed candidate horizons under the deterministic and the probabilistic cases (Fig. 2-32). In the deterministic case, the Rocky Coulee, McCoy Canyon, and Umtanum flows all rank closely. In the probabilistic case, there was a distinct difference in the ranking of the flows. The multidisciplinary study team

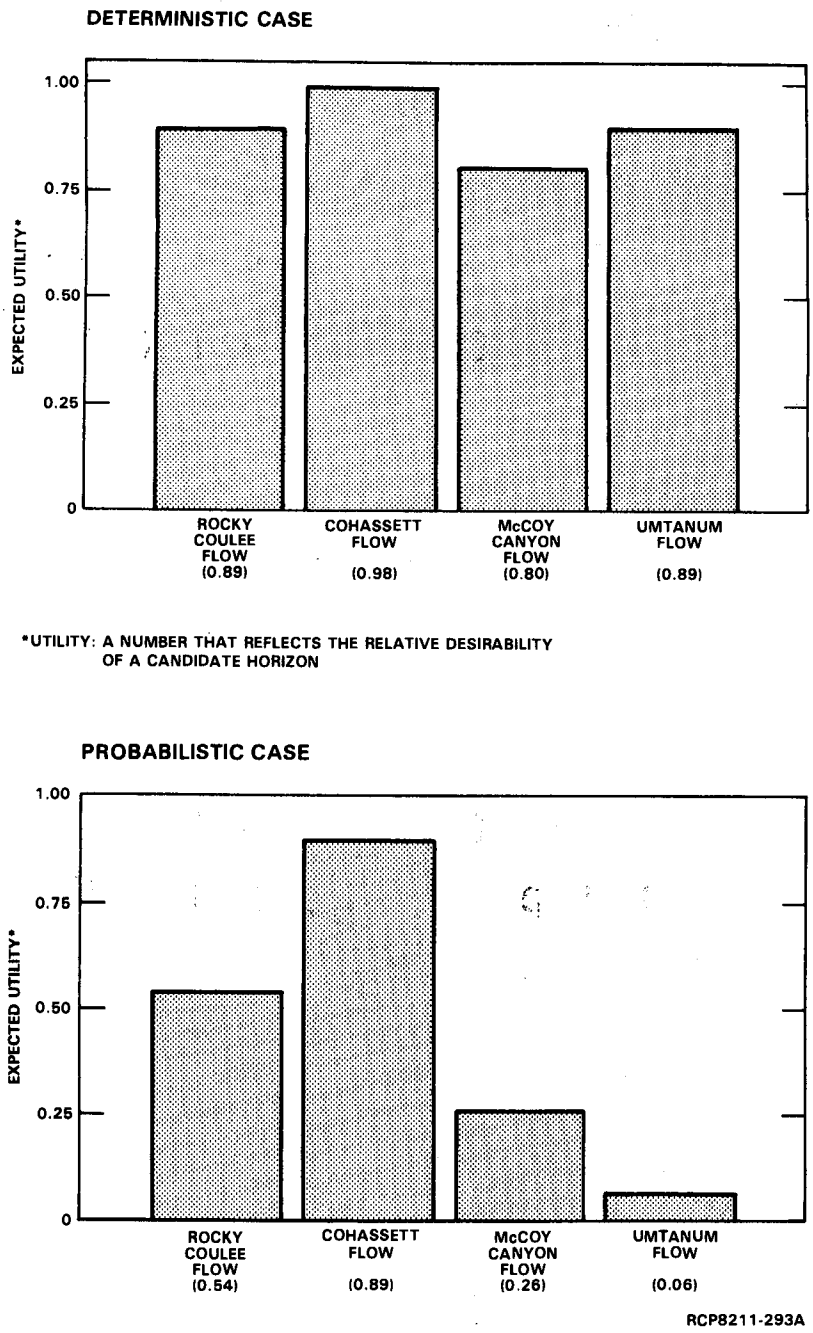

Figure 2-32. Comparison of the proposed candidate horizons ranking results for the deterministic and the probabilistic cases (after Long and WCC, 1984).

believed that the probabilistic ranking best represented the comparison of horizons. In addition, the Cohassett flow ranked highest under a variety of assumptions about the relative importance of the ranking measures. Moreover, the highest rank for the Cohassett flow was not sensitive to wide variations in levels of the measures.

2.2.3.2 Application of expert judgment to the proposed candidate horizons

Members of the U.S. Department of Energy-Richland Operations Office Basalt Waste Isolation Project Overview Committee and their consultants (Bartlett, 1983) in conjunction with the Basalt Waste Isolation Project staff assessed the proposed candidate horizons based on the technical data available (Long and WCC, 1984). The assessment presupposed identification of the four proposed candidate horizons and was mainly deductive.

The principal conclusion from this review was that the Cohassett flow, with few exceptions, had characteristics that appeared to be more favorable for a repository than those of the other proposed candidate horizons. The main exception was that the Cohassett flow, because of its stratigraphic position, did not confine radionuclides to as great a depth as the McCoy Canyon or Umtanum flows. However, the Cohassett flow still provided vertical confinement that, based on preliminary modeling results, prevented significant contamination of the overlying, relatively high-permeability zones in the Wanapum and Saddle Mountains Basalts (Long and WCC, 1984). Vertical confinement thus appeared adequate. Consequently, the other two performance comparisons (radionuclide release and ground-water travel time) for which the Cohassett flow showed better performance than the other proposed candidate horizons, tended to offset its lesser performance on vertical confinement.

In summary, based on the recognized differences among the proposed candidate horizons, application of expert judgment identified the Cohassett flow as the preferred candidate horizon for a nuclear waste repository. This result corroborated the result obtained using the decision analysis approach.

It was recognized that the selection of the preferred candidate horizon was subject to review and revision as new data were acquired and analyzed. Based on the Long and Woodward-Clyde Consultants (Long and WCC, 1984) study, all four proposed candidate horizons identified were considered to be suitable as a host rock. In June 1985, the preferred candidate horizon, the Cohassett flow, was designated as the candidate horizon for a nuclear waste repository in basalt at the reference repository location.

2.3 SUMMARY OF THE EVALUATION OF THE POTENTIALLY ACCEPTABLE SITE WITHIN THE GEOHYDROLOGIC SETTING

This section presents a short summary of the evaluation of the reference repository location relative to the disqualifying conditions contained in the General Siting Guidelines (DOE, 1984). The preceding section (Section 2.2) summarizes the screening process by which the reference repository location was identified for consideration as a potentially acceptable site for a nuclear waste repository. The process for the selection of the first national site for a repository was established by the Nuclear Waste Policy Act of 1982. In accordance with the Act, on February 2, 1983, the Secretary of Energy notified the State of Washington that the reference repository location on the Hanford Site had been selected as a potentially acceptable site for a nuclear waste repository. The next step in the site-selection process is the submission of this site-nomination environmental assessment. This environmental assessment will be used to reduce the number of potentially acceptable sites, which are under consideration for nomination as candidate sites, to a minimum of three. It is prudent to ensure that at this step in the siting process none of the disqualifying conditions identified in Appendix III of the General Siting Guidelines (DOE, 1984) exist at any of the potentially acceptable sites. Table 2-6 summarizes the evaluation of the reference repository location with respect to the disqualifying conditions set forth in the General Siting Guidelines (DOE, 1984). Based on current knowledge, disqualifying conditions have not been identified that would result in rejecting the reference repository location from further consideration as a site for a nuclear waste repository. The detailed analysis of each disqualifying condition is presented in Chapter 6 in conjunction with the evaluation of qualifying, favorable, and potentially adverse conditions of the appropriate siting guideline.

2.3.1 GEOHYDROLOGY (Section 960.4-2-1(d))

2.3.1.1 Disqualifying condition

"A site shall be disqualified if the pre-waste-emplacement ground-water travel time from the disturbed zone to the accessible environment is expected to be less than 1,000 years along any pathway of likely and significant radionuclide travel."

2.3.1.2 Summary of the geohydrology disqualifier analysis

Based on data and current understanding of the ground-water system, the pre-waste-emplacement ground-water travel time to the accessible environment is expected to be greater than 1,000 years. The evidence does not support a finding that the reference repository location is disqualified (Level 1).

Refer to Subsection 6.3.1.1.11 for a detailed discussion of this disqualifying condition.

Table 2-6. Evaluation of summary findings at the reference repository location with respect to the disqualifying conditions (sheet 1 of 2)

Disqualifying condition[a]	Conclusion[b]	Reference[c]	Synopsis[d]
1. 10 CFR 960.4-2-1: GEOHYDROLOGY – Less than 1,000 years ground-water travel time (unless releases of radionuclides are less than those allowed by system guidelines)	NOT DISQUALIFIED	6.3.1.1.11	The evidence does not support a finding that the reference repository location is disqualified (Level 1). Most likely flow time to the accessible environment is expected to exceed 1,000 years and likely to exceed 10,000 years
2. 10 CFR 960.4-2-5: EROSION – Any portion of the underground facility less than 200 meters (656 feet) deep	NOT DISQUALIFIED	6.3.1.5.8	The evidence supports a finding that the reference repository location is not disqualified and is not likely to be disqualified (Level 2). The candidate horizon for a repository is greater than 870 meters (2,850 feet) deep
3. 10 CFR 960.4-2-6: DISSOLUTION – Dissolution during first 10,000 years causing hydraulic pathway with releases greater than allowed by system guidelines	NOT DISQUALIFIED	6.3.1.6.5	The evidence supports a finding that the reference repository location is not disqualified and is not likely to be disqualified (Level 2). Basalt is not generally considered soluble; disqualifier is more appropriate for evaporites
4. 10 CFR 960.4-2-7: TECTONICS (POSTCLOSURE) – Nature and rates of fault movement or other ground motion expected such that loss of waste isolation is likely to occur	NOT DISQUALIFIED	6.3.1.7.10	The evidence does not support a finding that the reference repository location is disqualified (Level 1). Fault movement or other ground motion are not expected to result in a loss of waste isolation
5. 10 CFR 960.4-2-8-1: NATURAL RESOURCES – Previous mineral exploration creating significant pathways between repository and accessible environment – Future activities outside the controlled area expected to cause loss of waste isolation	NOT DISQUALIFIED	6.3.1.8.9 6.3.1.8.10	The evidence does not support a finding that the reference repository location is disqualified (Level 1). No identified at-depth exploration occurs in the reference repository location and exploration for natural resources away from the reference repository location are not expected to cause loss of waste isolation
6. 10 CFR 960.5-2-1: POPULATION DENSITY AND DISTRIBUTION – Any surface facility in a highly populated area – Any surface faciiity adjacent to a 1.6- by 1.6-kilometer (1- by 1-mile) area with 1,000 people – Inability to develop an emergency preparedness plan	NOT DISQUALIFIED	6.2.1.2.5	The evidence supports a finding that the reference repository location is not disqualified and is not likely to be disqualified (Level 2). The reference repository location is located in the central Hanford Site within a controlled access area with a very low population density within 16 kilometers (10 miles) and distant (24 kilometers (15 miles)) from densely populated areas. An emergency response plan and procedures are currently in place for the Hanford Site
7. 10 CFR 960.5-2-4: OFFSITE INSTALLATIONS AND OPERATIONS – Atomic energy defense activities that would irreconcilably conflict with repository activities	NOT DISQUALIFIED	6.2.1.5.6	The evidence does not support a finding that the reference repository location is disqualified (Level 1). Irreconcilable conflicts due to current atomic energy defense activities are not anticipated

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Table 2-6. Evaluation of summary findings at the reference repository location with respect to the disqualifying conditions (sheet 2 of 2)

Disqualifying condition[a]	Conclusion[b]	Reference[c]	Synopsis[d]
8. 10 CFR 960.5-2-5: ENVIRONMENTAL QUALITY – Unacceptable impacts – Repository or support facility in National Park, National Wildlife Refuge, or National Wild and Scenic River System – Irreconcilable conflict with previously designated land use	NOT DISQUALIFIED	6.2.1.6.11	The evidence supports a finding that the reference repository location is not disqualified and is not likely to be disqualified (Level 2). No unacceptable adverse impacts have been identified and the repository would not conflict with any other land use
9. 10 CFR 960.5-2-6: SOCIOECONOMIC IMPACTS – Repository activities significantly degrading water quality or significantly reducing water quantity available	NOT DISQUALIFIED	6.2.1.7.11	The evidence does not support a finding that the reference repository location is disqualified (Level 1). No significant reduction in water quality or quantity is anticipated
10. 10 CFR 960.5-2-9: ROCK CHARACTERISTICS – Significant risk to health and safety of operating personnel	NOT DISQUALIFIED	6.3.3.2.10	The evidence does not support a finding that the reference repository location is disqualified (Level 1). No rock characteristics that could cause or lead to significant health or safety risks, which could not be compensated for by suitable engineering, have been identified
11. 10 CFR 960.5-2-10: HYDROLOGY – Control of expected ground-water conditions beyond reasonably available technology	NOT DISQUALIFIED	6.3.3.3.7	The evidence does not support a finding that the reference repository location is disqualified (Level 1). Engineering technology is reasonably available for controlling ground-water conditions encountered during exploratory shaft construction or during repository construction and operation
12. 10 CFR 960.5-2-11: TECTONICS (PRECLOSURE) – Nature and rates of fault movement or ground motion such that complex engineering measures will be required for exploratory shaft construction or repository construction, operation, or closure	NOT DISQUALIFIED	6.3.3.4.7	The evidence does not support a finding that the reference repository location is disqualified (Level 1). Probability of ground motion in preclosure period is low. It is expected that reasonably available technology can be utilized in construction of shafts and subsurface facilities; repository operations and closure are not expected to require complex engineering measures

[a]General Siting Guidelines (DOE, 1984).
[b]Not disqualified--no obvious disqualifying conditions have been identified.
[c]Subsection in this environmental assessment containing detailed analysis of disqualifying condition.
[d]Synopsis from detailed analysis of disqualifying condition given in Chapter 6.

2.3.2 EROSION (Section 960.4-2-5(d))

2.3.2.1 Disqualifying condition

"The site shall be disqualified if site conditions do not allow all portions of the underground facility to be situated at least 200 meters below the directly overlying ground surface."

2.3.2.2 Summary of the erosion disqualifier analysis

The depth of the Cohassett flow is greater than 870 meters (2,850 feet) below the ground surface at the reference repository location. Potential erosion scenarios suggest this depth is more than sufficient to maintain greater than 440 meters (1,443 feet) between the ground surface and a repository. Therefore, the evidence supports a finding that the reference repository location is not disqualified on the basis of this evidence and is not likely to be disqualified (Level 2).

Refer to Subsection 6.3.1.5.8 for a detailed discussion of this disqualifying condition.

2.3.3 DISSOLUTION (Section 960.4-2-6(d))

2.3.3.1 Disqualifying condition

"The site shall be disqualified if it is likely that, during the first 10,000 years after closure, active dissolution, as predicted on the basis of the geologic record, would result in a loss of waste isolation."

2.3.3.2 Summary of the dissolution disqualifier analysis

Active dissolution fronts do not occur in basalt. Therefore, the reference repository location is not disqualified on the basis of evidence and is not likely to be disqualified (Level 2).

Refer to Subsection 6.3.1.6.5 for a detailed discussion of this disqualifying condition.

2.3.4 TECTONICS (Section 960.4-2-7(d))

2.3.4.1 Disqualifying condition

"A site shall be disqualified if, based on the geologic record during the Quaternary Period, the nature and rates of fault movement or other ground motion are expected to be such that a loss of waste isolation is likely to occur."

2.3.4.2 Summary of the tectonics disqualifier analysis

The nature and rates of fault movement or other ground motion at the reference repository location are not expected to result in a loss of waste isolation. Therefore, the evidence does not support a finding that the reference repository location is disqualified (Level 1).

Refer to Subsection 6.3.1.7.10 for a detailed discussion of this disqualifying condition.

2.3.5 NATURAL RESOURCES (Section 960.4-2-8-1(d))

2.3.5.1 Disqualifying conditions

"A site shall be disqualified if--

"(1) Previous exploration, mining, or extraction activities for resources of commercial importance at the site have created significant pathways between the projected underground facility and the accessible environment; or

"(2) Ongoing or likely future activities to recover presently valuable natural mineral resources outside the controlled area would be expected to lead to an inadvertent loss of waste isolation."

2.3.5.2 Summary of the natural resources disqualifier analysis

The data show a lack of major previous exploration, mining, or extraction of resources in the reference repository location. This data base is not expected to change. Therefore, the reference repository location is not disqualified on the basis of available evidence.

Refer to Subsection 6.3.1.8.9 for a detailed discussion of disqualifying condition (1).

In addition, possible future activities to recover presently valuable natural mineral resources (high-unit value or oil and gas) outside the controlled area are not expected to lead to an inadvertent loss of waste isolation. Therefore, the evidence does not support a finding that the reference repository location is disqualified (Level 1).

Refer to Subsection 6.3.1.8.10 for a detailed discussion of disqualifying condition (2).

2.3.6 POPULATION DENSITY AND DISTRIBUTION (Section 960.5-2-1(d))

2.3.6.1 Disqualifying conditions

"A site shall be disqualified if—

"(1) Any surface facility of a repository would be located in a highly populated area; or

"(2) Any surface facility of a repository would be located adjacent to an area 1 mile by 1 mile having a population of not less than 1,000 individuals as enumerated by the most recent U.S. census; or

"(3) The DOE could not develop an emergency preparedness program which meets the requirements specified in DOE Order 5500.3 (Reactor and Non-Reactor Facility Emergency Planning, Preparedness, and Response Program for Department of Energy Operations) and related guides or, when issued by the NRC, in 10 CFR Part 60, Subpart I, 'Emergency Planning Criteria.' "

2.3.6.2 Summary of the population density and distribution disqualifier analysis

The reference repository location is not disqualified for any of the above three disqualifying conditions. The reference repository location is not located in or adjacent to a highly populated area, and an emergency preparedness program is already in place for the Hanford Site. Therefore, the evidence supports a finding that the reference repository location is not disqualified on this basis and is not likely to be disqualified (Level 2).

Refer to Subsection 6.2.1.2.5 for a detailed discussion of these disqualifying conditions.

2.3.7 OFFSITE INSTALLATIONS AND OPERATIONS (Section 960.5-2-4(d))

2.3.7.1 Disqualifying condition

"A site shall be disqualified if atomic energy defense activities in proximity to the site are expected to conflict irreconcilably with repository siting, construction, operation, closure, or decommissioning."

2.3.7.2 Summary of the offsite installations and operations disqualifier analysis

The reference repository location is not disqualified on the basis of the potentially disqualifying condition. The proximity of the reference repository location to defense facilities is not expected to pose irreconcilable conflicts. Actual and projected radioactive releases from atomic energy defense activities are substantially less than federally established exposure standards (Price et al., 1985). Therefore, the evidence does not support a finding that the reference repository location is disqualified (Level 1).

Refer to Subsection 6.2.1.5.6 for a detailed discussion of this disqualifying condition.

2.3.8 ENVIRONMENTAL QUALITY (Section 960.5-2-5(d))

2.3.8.1 Disqualifying conditions

"Any of the following conditions shall disqualify a site:

"(1) During repository siting, construction, operation, closure, or decommissioning the quality of the environment in the affected area could not be adequately protected or projected environmental impacts in the affected area could not be mitigated to an acceptable degree, taking into account programmatic, technical, social, economic, and environmental factors.

"(2) Any part of the restricted area or repository support facilities would be located within the boundaries of a component of the National Park System, the National Wildlife Refuge System, the National Wilderness Preservation System, or the National Wild and Scenic Rivers System.

"(3) The presence of the restricted area or the repository support facilities would conflict irreconcilably with the previously designated resource-preservation use of a component of the National Park System, the National Wildlife Refuge System, the National Wilderness Preservation System, the National Wild and Scenic Rivers System, or National Forest Lands, or any comparably significant State protected resource that was dedicated to resource preservation at the time of the enactment of the Act."

2.3.8.2 Summary of the environmental quality disqualifier analysis

The siting of a repository at the reference repository location is not projected to have unacceptable adverse impacts on the quality of the environment. The two primary factors that indicate these disqualifying conditions are not present at the reference repository location are (1) no adverse environmental impacts have been projected that could not be mitigated to an acceptable degree, including the absence of any federally recognized threatened and endangered species at the reference repository location and (2) significant Federal- or State-protected resources do not exist at the reference repository location. The nearest Federal- or State-protected resource is the Columbia National Wildlife Refuge located 20 kilometers (12.5 miles) north of the reference repository location. Therefore, the evidence supports a finding that the reference repository location is not disqualified on the basis of that evidence and is not likely to be disqualified (Level 2).

Refer to Subsection 6.2.1.6.11 for a detailed discussion of these disqualifying conditions.

2.3.9 SOCIOECONOMIC IMPACTS (Section 960.5-2-6(d))

2.3.9.1 Disqualifying condition

"A site shall be disqualified if repository construction, operation, or closure would significantly degrade the quality, or significantly reduce the quantity, of water from major sources of offsite supplies presently suitable for human consumption or crop irrigation and such impacts cannot be compensated for, or mitigated by, reasonable measures."

2.3.9.2 Summary of the socioeconomic impacts disqualifier analysis

Based on projected repository construction and operation methods and projected waste isolation performance, a repository built in the reference repository location is not expected to degrade significantly water quality or to reduce water quantities from major sources of offsite supplies. Therefore, the evidence does not support a finding that the reference repository location is disqualified (Level 1).

Refer to Subsection 6.2.1.7.11 for a detailed discussion of this disqualifying condition.

2.3.10 ROCK CHARACTERISTICS (Section 960.5-2-9(d))

2.3.10.1 Disqualifying condition

"The site shall be disqualified if the rock characteristics are such that the activities associated with repository construction, operation, or closure are predicted to cause significant risk to the health and safety of personnel, taking into account mitigating measures that use reasonably available technology."

2.3.10.2 Summary of the rock characteristics disqualifier analysis

Geomechanics data obtained from laboratory, field, and in situ testing and case history studies of similar underground construction projects suggest that the effects of potentially hazardous conditions on the construction, operation, and closure of a repository at the reference repository location are not expected to cause significant risk to the health and safety of repository personnel and (or) members of the general public. This takes into account mitigating measures that use reasonably available technology. Therefore, the evidence does not support a finding that the reference repository location is disqualified (Level 1).

Refer to Subsection 6.3.3.2.10 for a detailed discussion of this disqualifying condition.

2.3.11 HYDROLOGY (Section 960.5-2-10(d))

2.3.11.1 Disqualifying condition

"A site shall be disqualified if, based on expected ground-water conditions, it is likely that engineering measures that are beyond reasonably available technology will be required for exploratory-shaft construction or for repository construction, operation, or closure."

2.3.11.2 Summary of the hydrology disqualifier analysis

Current construction data, case history studies of underground construction projects, and understanding of the basalt geohydrologic environment suggest that the ground-water conditions likely encountered in basalt during exploratory shaft construction and repository construction, operation, or closure will only require reasonably available technology. Therefore, the evidence does not support a finding that the reference repository location is disqualified (Level 1).

Refer to Subsection 6.3.3.3.7 for a detailed discussion of this disqualifying condition.

2.3.12 TECTONICS (Section 960.5-2-11(d))

2.3.12.1 Disqualifying condition

"A site shall be disqualified if, based on the expected nature and rates of fault movement or other ground motion, it is likely that engineering measures that are beyond reasonably available technology will be required for exploratory-shaft construction or for repository construction, operation or closure."

2.3.12.2 Summary of the tectonics disqualifier analysis

Existing engineering measures could be used, if needed, in exploratory shaft construction or repository construction, operation, or closure. The basis for this statement stems from the fact that the probability of ground motion that could adversely affect a repository in the reference repository location during the preclosure period is considered to be low. Therefore, the evidence does not support a finding that the reference repository location is disqualified (Level 1).

Refer to Subsection 6.3.3.4.7 for a detailed discussion of this disqualifying condition.

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CHAPTER 3 SUMMARY

While Chapter 2 describes the general geologic and hydrologic setting of the Columbia Plateau, Chapter 3 is focused on the Pasco Basin and the Hanford Site where the reference repository location is situated. This chapter provides background information on the geology and hydrology (Sections 3.2 and 3.3), the environmental setting (Section 3.4), and the transportation and socioeconomic conditions of this area (Sections 3.5 and 3.6) the information contained in this chapter provides much of the basis for decisions and findings reported in Chapters 4, 5, and 6. Table 3-A provides a cross-reference matrix to help the reader locate the sections in this document that are related to topics discussed in Chapter 3.

The reference repository location is situated near the center of the 1,500-square-kilometer (570-square-mile) Hanford Site in south-central Washington in a broad area known as the Cold Creek syncline. The area lies within the Pasco Basin, the structural and topographic low of the Columbia Plateau, approximately 55 kilometers (34 miles) northwest of the junctions of the Snake and Yakima Rivers with the Columbia River. The Pasco Basin is bordered on the north by the Saddle Mountains, on the south by the Rattlesnake Hills, and on the west by the eastern ends of the Umtanum and Yakima Ridges. Gable Mountain and Gable Butte, two prominent anticlinal ridges of basalt within the Hanford Site, appear to be on the structural trend with the eastern segment of Umtanum Ridge. The eastern boundary of the basin is defined by a southwest-dipping homocline.

The Pasco Basin is divided into three major landform systems (i.e., areas of recurring landforms, processes, and effects): Ridge terrain, lower slope terrain, and basin and valley terrain. The latter terrain system describes the reference repository location.

The major stratigraphic units in the reference repository location are the Grande Ronde, Wanapum, and Saddle Mountains Basalts of the Columbia River Basalt Group and the Ellensburg, Ringold, and Hanford Formations. Over 50 basalt flows within the Pasco Basin have been identified, totaling perhaps as much as 5,000 meters (16,000 feet) in thickness. Sedimentary deposits overlie the basalt sequence and are commonly interbedded with the uppermost basalt flows. The Cohassett flow has been identified as the candidate horizon for a nuclear waste repository and lies within the Grande Ronde Basalt, the thickest basalt sequence of the Columbia River Basalt Group. The Cohassett flow is continuous throughout the Pasco Basin.

Structurally, the Cold Creek syncline, in which the reference repository location is situated, occupies the low area between the Umtanum Ridge-Gable Mountain structure and the Yakima Ridge anticline. The top of the basalt and the deeper horizons are interpreted as nearly flat, with very gentle dips toward the trough of the Cold Creek syncline. Based on geophysical surveys and surface and subsurface mapping, the reference repository location appears to be relatively free of potentially adverse bedrock features.

Table 3-A. Sections related to Chapter 3 discussions

	Chapter 2	Chapter 3	Chapter 4	Chapter 5	Chapter 6
Geology	2.1.1	3.2	4.2.1.1	5.2.1.1	
Physiography and geomorphology		3.2.1			
Stratigraphy	2.1.1.1	3.2.2	4.1.1.1		
Structure and tectonics	2.1.1.2/2.1.2	3.2.3	4.1.1.1/4.1.1.2		6.3.1.7/6.3.3.4
Seismicity	2.1.1.3	3.2.4			
Surface-water hydrology	2.1.3	3.3.1	4.1.1.7/4.2.1.2.1	5.2.1.2.1	6.3.3.3
Pasco Basin		3.3.1.1			
Hanford Site		3.3.1.2			
Surface flooding potential		3.3.1.3			6.3.3.1
Surface-water use in Pasco Basin		3.3.1.4			
Surface-water demand		3.3.1.5			
Surface-water intakes in Pasco Basin		3.3.1.6			
Ground-water hydrology	2.1.4	3.3.2	4.1.1.3/4.2.1.2.2	5.2.1.2.2	6.3.1.1
Potential pathways		3.3.2.1	4.1.1.4		6.4.2.3.5
Alternative flow concepts		3.3.2.2	4.1.1.5		6.3.1.1
Environmental setting		3.4	4.1.2.3/4.2.1.3	5.2.1.3	6.2.1.6/6.2.2.2
Land use		3.4.1	4.2.2.6	5.2.3.6	6.2.1.1/6.2.1.3
Terrestrial and aquatic ecosystems		3.4.2	4.2.1.3.1	5.2.1.3.1	
Meteorology and air quality		3.4.3	4.2.1.3.2	5.2.1.3.2	6.2.1.4
Noise		3.4.4	4.2.1.3.3	5.2.1.3.3	
Aesthetic resources		3.4.5	4.2.1.3.4	5.2.1.3.4	
Archaeological, cultural, and historical resources		3.4.6	4.2.1.3.5	5.2.1.3.5	
Transportation		3.5	4.2.3	5.2.2/5.1.7	6.2.1.8/6.2.2.2
Railroad service		3.5.1		5.2.2.3.2	
Highway service		3.5.2		5.2.2.3.1	
Repository access routes		3.5.3		5.2.3.6	
Socioeconomic conditions	2.3.9*	3.6	4.1.2.2/4.2.2	5.2.3	6.2.1.7/6.2.2.2
Population density and distribution	2.3.6*	3.6.1	4.2.2.1	5.2.3.1	6.2.1.2
Economic conditions		3.6.2	4.2.2.2	5.2.3.2	
Community services		3.6.3	4.2.2.3	5.2.3.3	
Social conditions		3.6.4	4.2.2.4	5.2.3.4	
Fiscal conditions and government structure		3.6.5	4.2.2.5	5.2.3.5	
Affected Indians		3.6.6			

*Disqualifier analysis.

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The seismicity of the Pasco Basin (instrumentally monitored since 1969) is low to moderate. No shallow-depth earthquakes--less than 4 kilometers (2 miles)--have been recorded within the boundaries of the reference repository location, but such swarms have been recorded in the Cold Creek syncline. Microearthquake activity in the area around the reference repository location has been largely confined to a crust 28 kilometers (17 miles) thick, and has been characterized by swarms of low-magnitude earthquakes that occur predominantly in the basalts.

Section 3.3 discusses the surface and subsurface hydrologic systems within and in the vicinity of the Hanford Site. Studies of surface drainage patterns, and evaluations of the potential for seasonal or catastrophic flooding, indicate that expected surface-water conditions from the Columbia, Snake, and Yakima Rivers do not pose a problem to the reference repository location. A potential for a shallow, probable maximum flood originating from the Cold Creek watershed does exist along the southwestern boundary of the reference repository location.

Understanding ground-water recharge and discharge patterns and ground-water movement is in a preliminary state. Additional hydrologic testing and analyses are required to characterize adequately the ground-water flow system of the reference repository location. Ground water occurs in confined aquifers within basalt flow tops and interbedded sediments and in a shallow sedimentary unconfined aquifer. Ground-water movement in the basalts most likely takes place along flow pathways found in three groups of geologic features:

- Discontinuities (fractures) within basalt layers.
- Contacts (flow tops and sedimentary interbeds) between basalt layers.
- Bedrock structural discontinuities (fault or fracture zones) crossing basalt layers.

Four conceptual models were developed to describe ground-water movement in a basalt medium. Differences between models center on the extent of vertical leakage across basalt flow interiors and the influence of structural discontinuities in vertically interconnecting flow systems. The bedrock structural discontinuities that cross basalt layers could have larger vertical hydraulic conductivities than the confining aquitards. Such discontinuities could vertically connect shallow and deep ground-water flow systems. The discontinuities investigated thus far appear to restrict lateral flow.

Section 3.4 details the environmental setting of the Hanford Site in terms of land use, terrestrial and aquatic ecosystems, meteorological conditions and air quality, noise, aesthetics, and archaeological, cultural, and historical resources. The Hanford Site has been used for Federal nuclear activities for over 40 years and currently includes the Arid Lands Ecology Reserve and areas provided by the U.S. Department of Energy under revocable permits to the U.S. Fish and Wildlife Service and to the State of Washington Department of Game.

The Hanford Site is characterized as a shrub-steppe grassland, dominated by the sagebrush-cheatgrass community, which provides food, cover, and shelter to many species of wildlife. Aquatic habitats on the Hanford Site are primarily limited to the Columbia River system, although several ponds, springs, and manmade ditches also provide some aquatic habitat. No federally recognized threatened or endangered animal species are known to nest or reproduce within the reference repository location. However, one threatened bird species, the bald eagle, and one endangered bird species, the peregrine falcon, have been infrequently sighted within the reference repository location boundaries. Three additional bird species that are found within the reference repository location are being considered as potential candidates for protection on the Federal threatened and endangered species list: The ferruginous hawk, the Swainson's hawk, and the long-billed curlew. No federally recognized threatened or endangered plant species are known to occur within the reference repository location; however, two State-sensitive plant species, Cryptantha levcophaea and Arenaria franklinii variety thompsonii, have been observed near the reference repository location.

Environmental data are collected at a number of locations on and near the Hanford Site. Complete climatological data have been monitored at the Hanford Meteorological Station since 1945. Temperature and precipitation data from a nearby location are available from 1912 through 1943. Reports of environmental monitoring data (e.g., air, ground water, foodstuffs, soil, vegetation) have been issued for each of the last 25 years, and the data for the last 15 years have been placed in a computerized data base. These reports establish a baseline of environmental conditions for historically monitored media, parameters, and locations.

Section 3.5 details the extensive transportation network that facilitates travel and the marketing of goods and commodities within the Tri-Cities region (Richland, Kennewick, and Pasco, Washington—located approximately 35 kilometers (22 miles) from the reference repository location). The Tri-Cities are served by the Burlington Northern and the Union Pacific Railroads and by major highway routes.

The discussion of socioeconomic conditions in this chapter (Section 3.6) is based on data from approximately 1965 to 1984 and covers population density and distribution, economic conditions, community services, social conditions, and fiscal conditions and government structure. The study region for this analysis is defined as Benton and Franklin Counties, with special consideration of the Tri-Cities, West Richland, Benton City, and the contiguous unincorporated areas. The study region was characterized during the decade of the 1970's as one of the most rapidly growing metropolitan areas in the nation. Since 1981, the region is experiencing a major economic downswing and accompanying population decline. The analysis in this chapter addresses the socioeconomic effects of that decline and the prognosis for future recovery.

Chapter 3

THE SITE

3.1 LOCATION AND TOPOGRAPHY

The reference repository location is situated near the center of the 1,500-square-kilometer (570-square-mile) Hanford Site in the south-central portion of the State of Washington (Fig. 3-1). The area lies within the Pasco Basin, the structural and topographic low part of the Columbia Plateau, and approximately 55 kilometers (34 miles) northwest of the junctions of the Snake and Yakima Rivers with the Columbia River. The terrain of the central and eastern Hanford Site, including the reference repository location, is relatively flat (Fig. 3-2) with subtle topographic features primarily formed by large, glacially related floods (see Subsections 2.1.1.1 and 3.2.2.7) that inundated the Pasco Basin prior to approximately 13,000 years ago. These topographic features have been locally masked by east-west-trending sand dunes that attest to the semiarid climate of the region. The reference repository location is approximately 195 meters (640 feet) above mean sea level and approximately 73 meters (240 feet) above the current level of the Columbia River. The terrain of the northern and western Hanford Site has moderate to steep topographic ridges composed of basalt and locally veneered with sediments.

3.2 GEOLOGIC CONDITIONS

3.2.1 PHYSIOGRAPHY AND GEOMORPHOLOGY

The Columbia Basin subprovince of the Columbia Intermontane Physiographic Province, discussed in Section 2.1.1, is divided into six sections on the basis of general morphology: (1) Central Plains, (2) Yakima Folds, (3) Waterville Plateau, (4) Channeled Scablands, (5) Palouse Hills, and (6) North-Central Oregon Plateau (Fig. 3-3) (Myers, Price et al., 1979; WPPSS, 1981; PSPL, 1982).

The reference repository location is situated in the west-central portion of the Pasco Basin near the western boundary of the Central Plains section of the Columbia Basin subprovince (see Fig. 3-3). The basin is divided into three major landform systems or areas of recurring landforms, processes, and effects (Myers, Price et al., 1979, pp. III-166 through III-171). These are the ridge, lower slope, and basin and valley terrains (Fig. 3-4). The ridge terrain consists of prominent anticlinal basalt ridges and is located in the Yakima Folds section of the Columbia Basin subprovince. The lower slope terrain consists primarily of middle and lower slopes of anticlinal basaltic ridges of the Yakima Folds section,

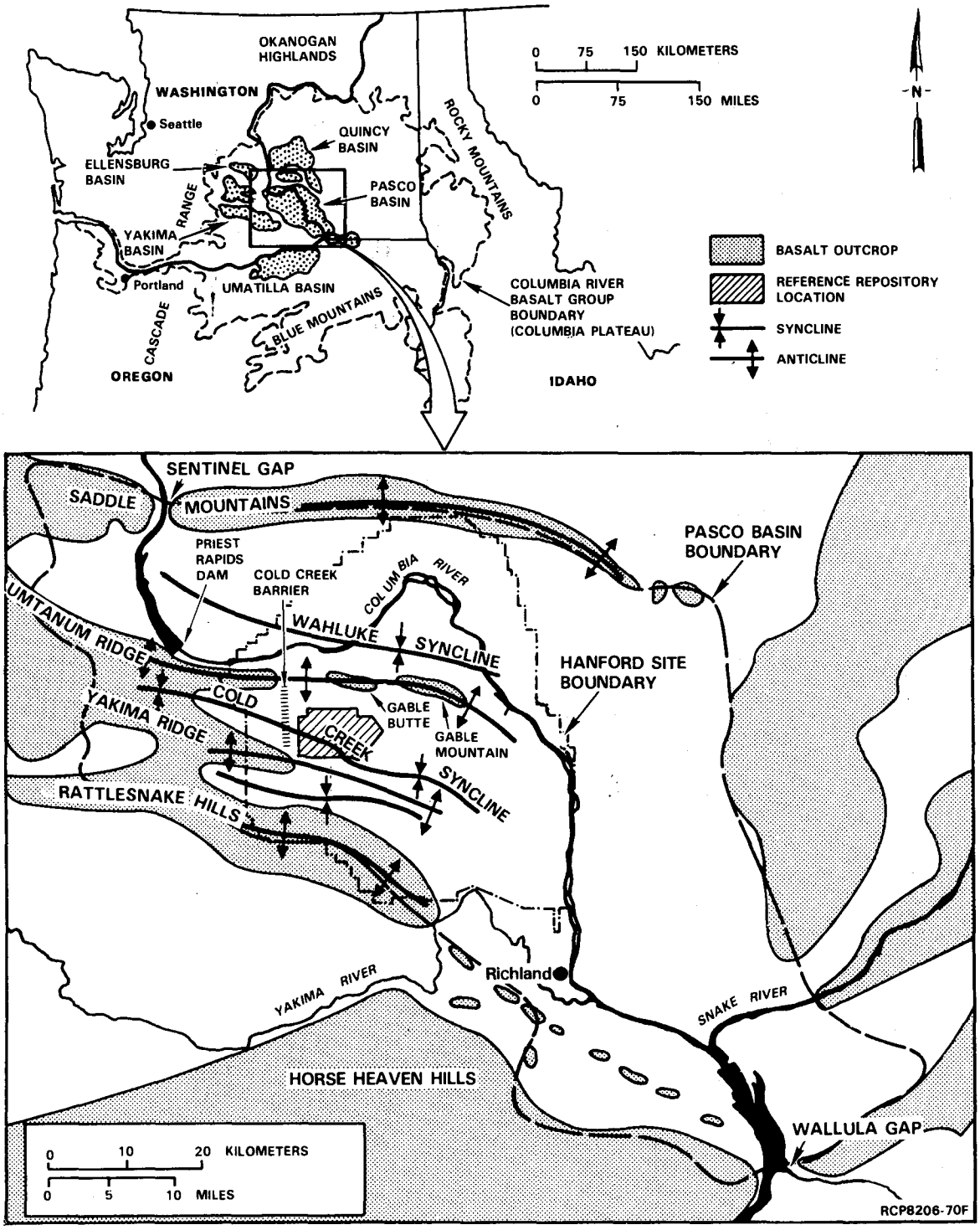

Figure 3-1. Extent of the Columbia River Basalt Group, Pasco Basin, and reference repository location.

Figure 3-2. A view the reference repository location, looking south from Umtanum Ridge Bar. Rattlesnake Hills are in the background.

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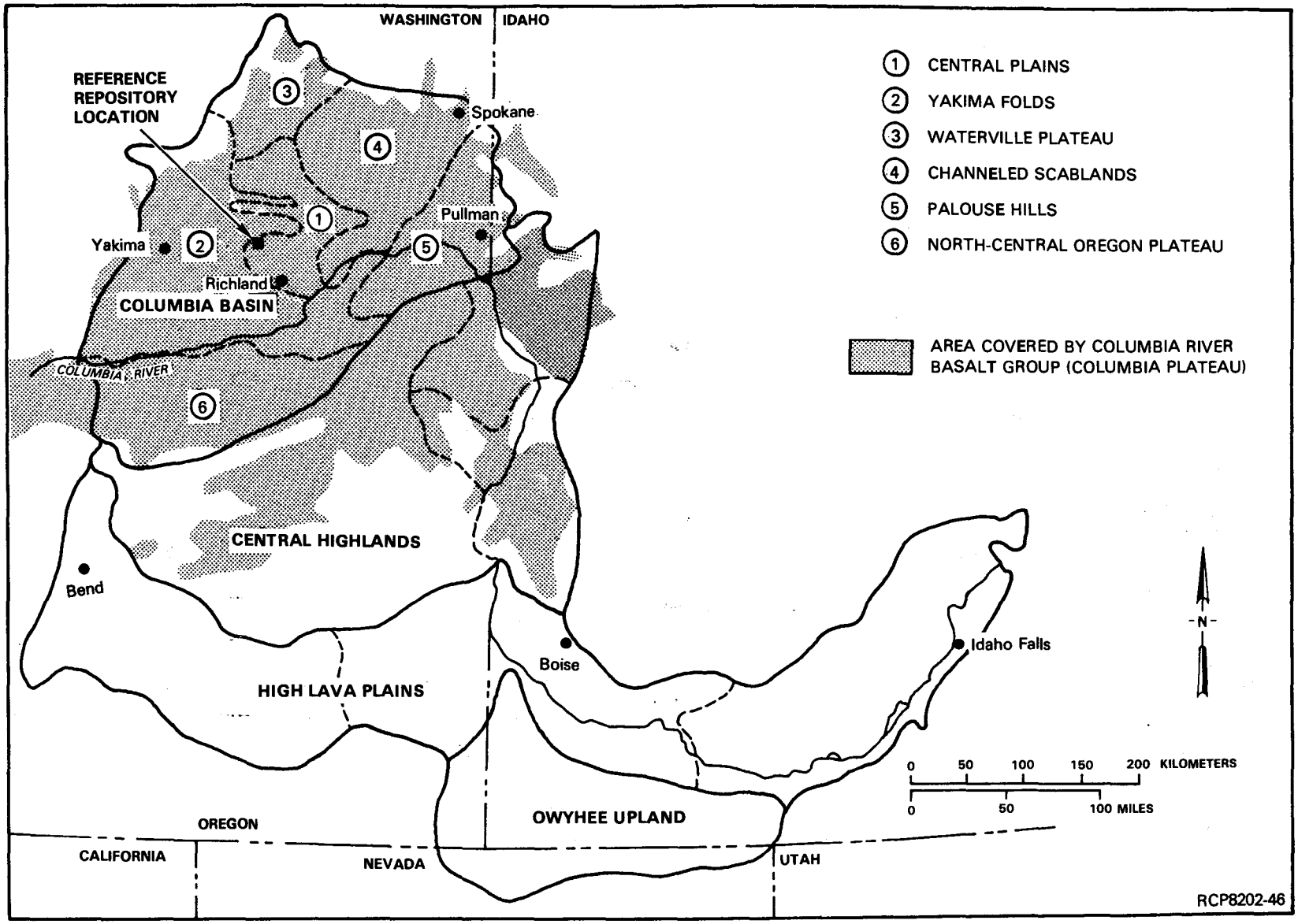

Figure 3-3. Divisions of the Columbia Intermontane Physiographic Province (after Freeman et al., 1945).

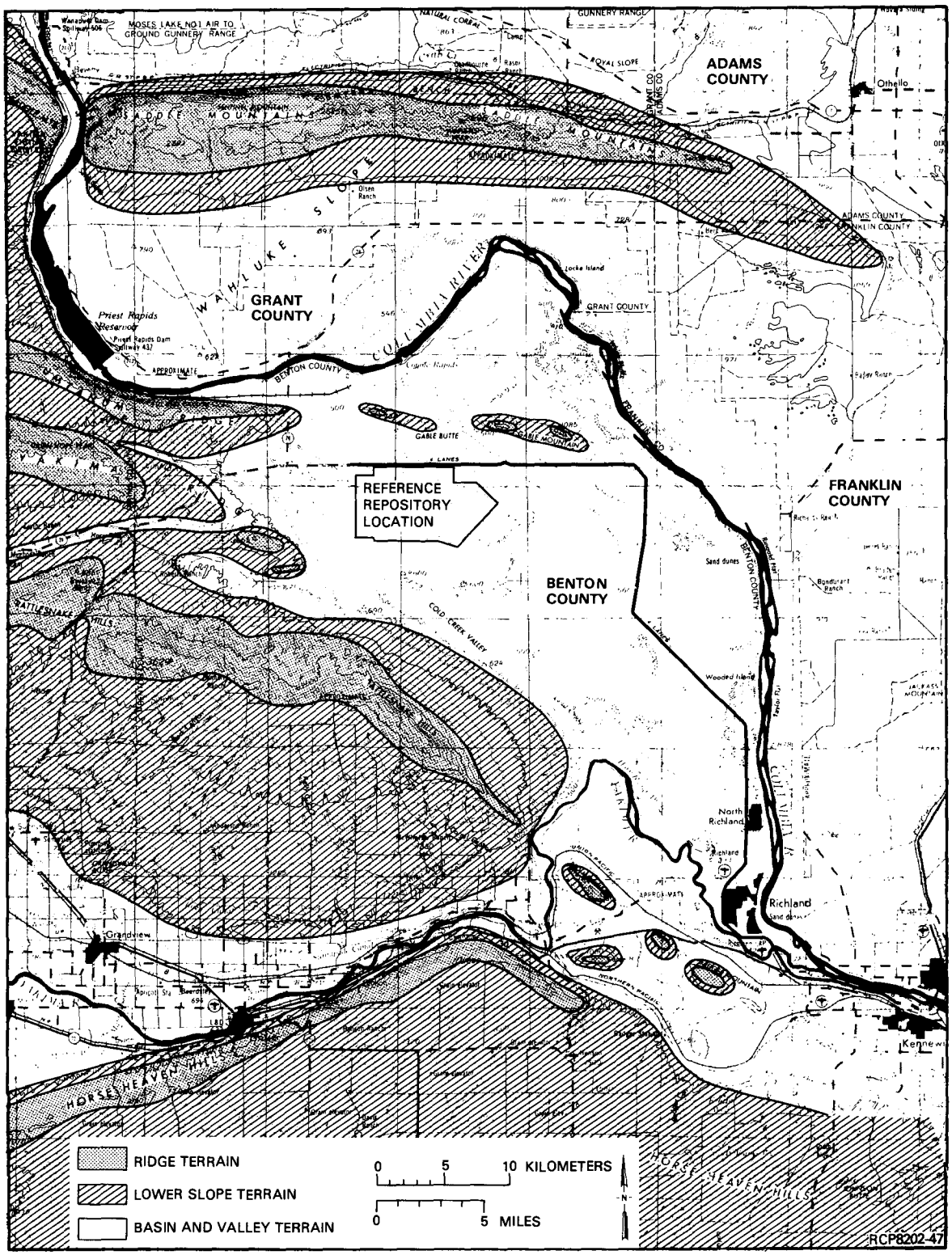

Figure 3-4. Map of major landform systems of the Pasco Basin.

but also includes portions of the bordering Central Plains section. The basin and valley terrain, including the reference repository location, consists of the low-relief, sediment-filled portion of the basin in the Central Plains section and the synclinal valleys of the Yakima Folds section. A more detailed description of these three landform systems is given in Myers, Price et al. (1979, pp. III-166 through III-171).

The reference repository location is located in the western portion of the basin and valley terrain and is divided into four geomorphic units: (1) Umtanum Ridge bar, (2) 200 Areas bar, (3) central Hanford sand plain, and (4) Cold Creek alluvial plain (Fig. 3-5). These units are defined topographically and by sediment texture. Judging by the undissected nature of these units, with the exception of the Cold Creek alluvial plain, minimal erosion has occurred since formation by catastrophic floodwaters in the late Pleistocene (approximately 13,000 years ago).

Two gravel bars of catastrophic flood origin are present within the reference repository location (see Fig. 3-5). Based on a description of flood bars by Baker (1983, pp. 35 through 42), the Umtanum Ridge bar is classified as an eddy bar, while the 200 Areas bar represents an expansion bar. The southeast-extending Umtanum Ridge bar covers an area of approximately 6 square kilometers (2.5 square miles) and is the highest topographic feature in the reference repository location. It represents a Pleistocene eddy bar that developed behind the east end of Umtanum Ridge. The bar is relatively flat and streamlined in shape. Locally steep gradients (up to 15 percent) on south-facing slopes of the bar occur within the reference repository location. The relief on the bar within the reference repository location is approximately 30 meters (100 feet) and the bar elevations range from approximately 215 meters (705 feet) at the base of the south slope to approximately 245 meters (800 feet) at the crest of the bar.

The 200 Areas bar is a lower elevation, down-valley continuation of the Umtanum Ridge bar, trending southeast. This bar is the most extensive geomorphic unit in the reference repository location, covering approximately 20 square kilometers (8 square miles). The 200 Areas bar formed as the result of the decelerating flow of catastrophic floodwaters in the expanded reach south of the Umtanum Ridge-Gable Mountain structure (see Fig. 3-1). The general form of the bar is very broad and relatively flat and not streamlined like the Umtanum Ridge bar. The maximum elevation of the bar is approximately 245 meters (800 feet) and the lowest elevation in the reference repository location is approximately 195 meters (640 feet) along the north slope of the bar. The 200 Areas bar is mantled by coarse sand and gravel in the northern and eastern portions of the reference repository location and laterally grades to silty, medium to coarse sand at the southwestern limit of the bar. Modification of the bar by Holocene geomorphic processes is minor and mainly from wind action.

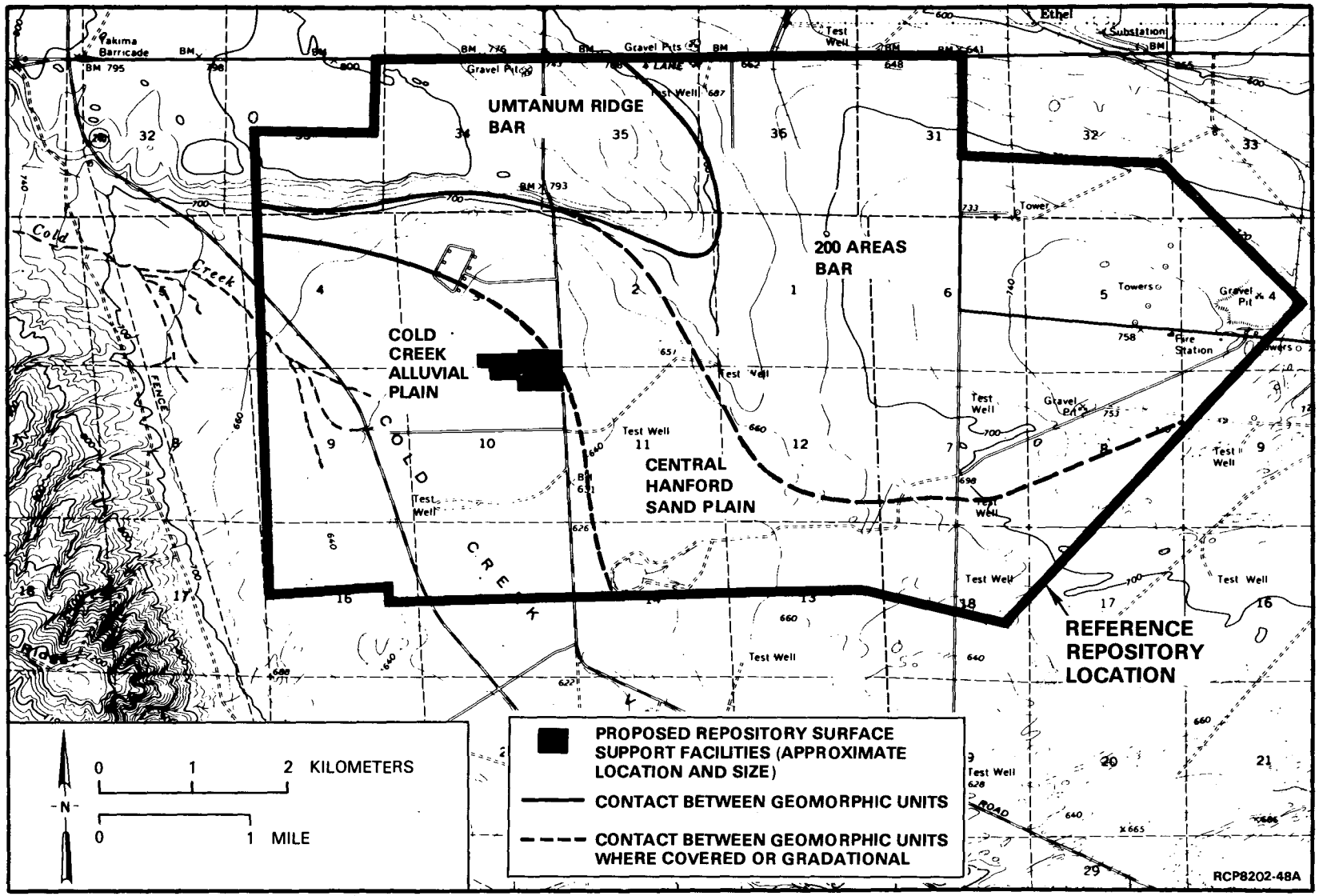

Figure 3-5. Geomorphic map of the reference repository location.

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The central Hanford sand plain is located south of the flood bars in the southern part of the reference repository location. This plain was formed during late-Pleistocene flooding by the deposition of fine-grained sediments on the lee of the Umtanum Ridge bar. The sand plain, which covers approximately 15 square kilometers (6 square miles) of the reference repository location, is relatively flat, sloping gently toward the center of Cold Creek Valley.

Holocene alluvium deposited along Cold Creek is superimposed on the western portion of the central Hanford sand plain. Sloping slightly to the southeast down Cold Creek Valley, the Cold Creek alluvial plain ranges in elevation from approximately 205 meters (675 feet) to the northwest to 190 meters (625 feet) to the southeast.

Sediments on the alluvial plain are composed mostly of fine sand and silt. The active portions of this plain can be distinguished by dendritic and distributary drainage patterns. Parts of the inactive alluvial plain surface have been slightly modified by winds that have formed a thin sandy soil cover. Additional information on soils in and around the reference repository location can be found in Hajek (1966).

3.2.2 STRATIGRAPHY

The Pasco Basin, located near the center of the Columbia Plateau (see Fig. 3-1), is underlain by (1) a thick sequence of Cretaceous-Miocene sedimentary rocks and (2) a thick sequence of Miocene tholeiitic basalt flows that are, in places, interbedded with and overlain by clastic sediments of Miocene or younger age (Fig. 3-6). These basalt flows collectively form the Columbia River Basalt Group (see Section 2.1.1) that beneath the Pasco Basin and vicinity consists of three formations: Grande Ronde, Wanapum, and Saddle Mountains Basalts (Swanson et al., 1979b). Sedimentary rocks of Miocene age interbedded with the basalts in the basin are designated the Ellensburg Formation (Brown, 1959; Newcomb et al., 1972).

Overlying the basalts and interbedded sediments in topographic and structural lows of the central Columbia Plateau are semiconsolidated sediments of the Miocene-Pliocene Ringold Formation (Merriam and Buwalda, 1917). The thickest sequence of Ringold Formation sediments occurs in the Pasco Basin, where approximately 365 meters (1,200 feet) of coarse to fine-grained clastic sediments were deposited by ancestral rivers and lakes. In the central Pasco Basin, the Ringold Formation is informally subdivided into four fluvial facies: basal, lower, middle, and upper Ringold units (Tallman et al., 1981; Bjornstad, 1984). A unit of Pliocene to Pleistocene age overlies the Ringold Formation in the reference repository location, which is characterized by locally derived alluvium and paleosol development.

The Quaternary Period in the central Columbia Plateau is dominated by Pleistocene catastrophic floods that scoured the Channeled Scablands and deposited glaciofluvial sediments in topographic lows. In the Pasco Basin, the glaciofluvial sediments are designated the Hanford Formation.

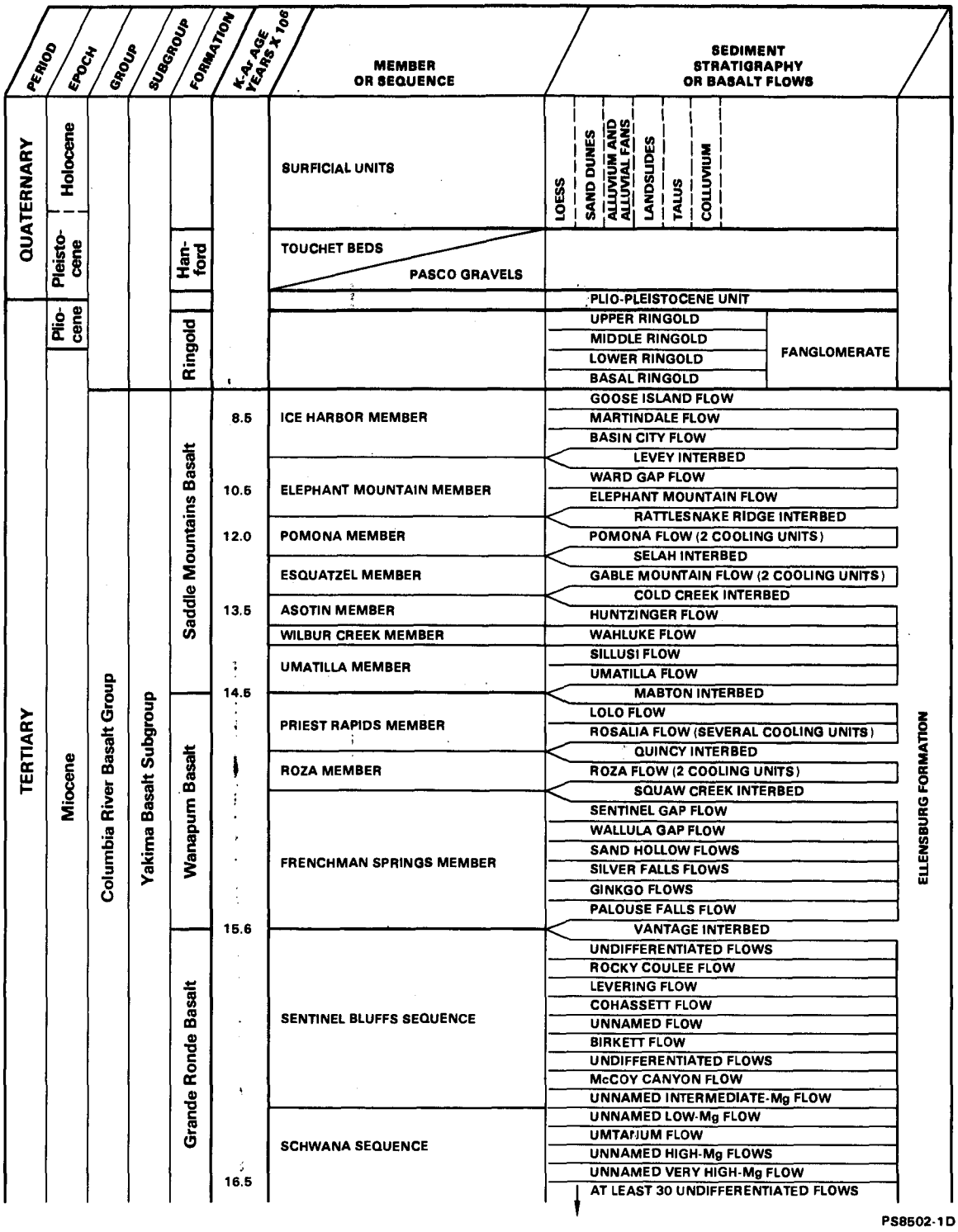

Figure 3-6. Stratigraphic units present in the Pasco Basin.

Loess, dune sand, alluvium, as well as landslide debris, colluvium, and talus form a thin cover on the flanks of the basaltic ridges bounding the Pasco Basin. These deposits range from Pleistocene to present in age (Myers, Price et al., 1979).

The major stratigraphic units present in the reference repository location are the Grande Ronde, Wanapum, and Saddle Mountains Basalts of the Columbia River Basalt Group and the Ellensburg, Ringold, and Hanford Formations, which are major fluvial units (see Fig. 3-6). A thin veneer of surficial sediments is present over much of the area. Stratigraphic descriptions of the geologic units in the reference repository location are given below.

The data base for developing the stratigraphy of the reference repository location includes both site-specific and Hanford Site information. The site-specific information includes (1) approximately 40 U.S. Department of Energy-drilled boreholes and core holes that total greater than 13,000 linear meters (44,000 linear feet) (key boreholes in the reference repository location are given in Fig. 3-7) and (2) approximately 700 other U.S. Department of Energy-drilled boreholes that total greater than 30,000 linear meters (100,000 linear feet) (McGhan and Damschen, 1979; Fecht and Lillie, 1982).

The definition of the reference repository location stratigraphy from this data base has been achieved by a variety of techniques, including geophysical logging (especially neutron-epithermal-neutron, gamma-gamma, natural gamma, sonic, caliper, and resistivity logs), paleomagnetic data, major and trace-element chemistry, and sediment grain size analysis. These techniques are discussed where appropriate in the remainder of this section or in referenced documents.

3.2.2.1 Pre-Columbia River basalt rocks

The Columbia River basalt overlies a geologically diverse terrain as judged from the age, lithology, and structure of rocks exposed along the plateau margin. There are no exposures of rocks beneath the thick basalts and few boreholes have penetrated the subbasalt strata; therefore, the age, rock types, and structures that might be present beneath the central Columbia Plateau must be primarily inferred from extrapolation of exposures along the margins of the plateau. The diversity of lithology and structure along the plateau margins does not permit simple extrapolation; thus, geophysical techniques have been extensively used to study the rocks and structure beneath the basalt. The method proving best suited for deep exploration in the Columbia Plateau is magnetotelluric. Like most geophysical techniques, interpretation of magnetotelluric data relies on geological and other geophysical information.

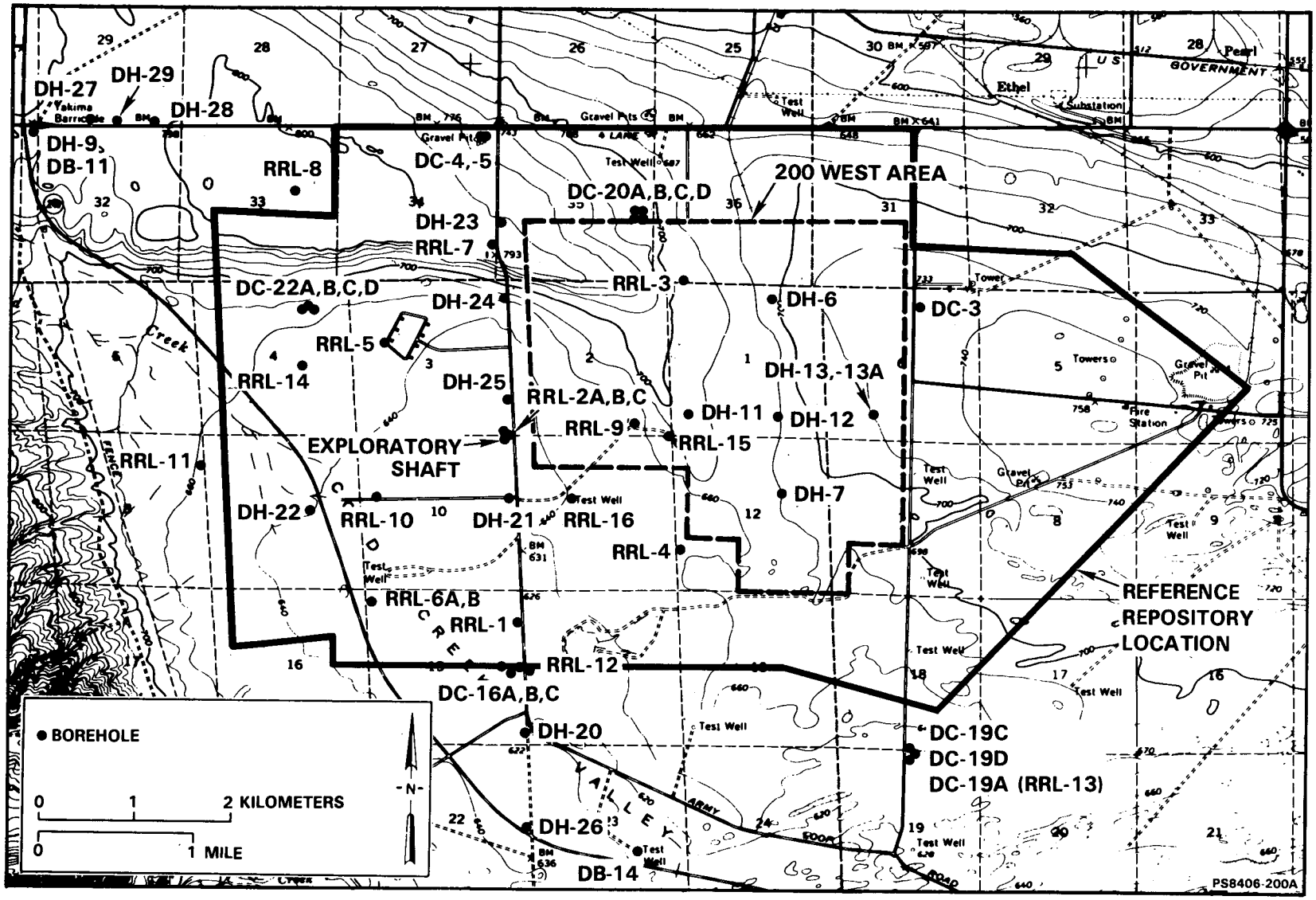

Figure 3-7. Key boreholes in and around the reference repository location.

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The observed changes in the magnetotelluric data from the central Columbia Plateau, supplemented by borehole data, are interpreted to represent five primary rock units from the surface down are (1) low-resistivity (5 to 50 ohm-meter) rocks, (2) high-resistivity (100 to 200 ohm-meter) rocks, (3) low-resistivity (2 to 20 ohm-meter) rocks, (4) a more resistive (100 to 1,000 ohm-meter) electrical basement, which includes geologic basement and possibly more resistive sediments, and (5) a deep (5 to 15 ohm-meter) lower crustal layer. The upper two rock units (rock units 1 and 2) can be related to rocks of Columbia River basalt age and younger.

Rock unit 3 is interpreted to be a sedimentary unit that ranges in age from lower Miocene through Cretaceous (Campbell, 1985). The rock unit has been subdivided into two subunits, based on borehole data from outside the Pasco Basin (Orange and Berkman, 1985). These boreholes include the Standard Kirkpatrick No. 1 well (T.4S., R21E., section 6) in north-central Oregon, and three Shell Oil Company wells (Yakima mineral 1-33 and 2-33, sec. 33, T. 15 N., R. 19 E., and Bissa I-29, sec. 29, T. 18 N., R. 21 E.) in central Washington. The sedimentary rocks encountered immediately beneath the basalt are interpreted to be lower Miocene and Oligocene strata with resistivities of 1 to 4 ohm-meters. These rocks are of continental origin and consist of volcaniclastic units with interbedded basalts, pyroclastics, tuffs, and epiclastic deposits. Underlying these 1- to 4-ohm-meter rocks are Eocene and (or) Cretaceous strata with resistivities of 10 to 20 ohm-meters. The Eocene and Cretaceous rocks consist primarily of continental fluvial sandstones with interbedded carbonaceous shales. The Bissa well encountered marine sandstones and shales near the base of the well.

Rock unit 4, the electrical basement, could correlate with a variety of geologic terrains as observed around the edges of the Columbia Basin. In all cases the unit exhibits resistivities in the range of 100 to 1,000 ohm-meters. A metamorphic basement would relate to resistivities of approximately 100 ohm-meters and a granitic basement would relate to resistivities closer to 1,000 ohm-meters. The electrical basement also might contain older, more resistive sediments similar to those cropping out in the Blue Mountains.

Rock unit 5, the lower crustal layer, consisting of low-resistivity crustal materials, is deep and is not detected in most magnetotelluric data. The rock types of this rock unit are not known.

3.2.2.2 Grande Ronde Basalt

As was previously summarized in Chapter 2, the Grande Ronde Basalt erupted 16.5 to 15.5 million years ago. It is a thick sequence of at least 56 basalt flows in the Pasco Basin that are typically fine grained and aphyric or sparsely microphyric with few consistent textural differences among flows. The flows are correlated regionally on the basis

of magnetostratigraphic units (from oldest to youngest: R_1, N_1, R_2, N_2) (see Fig. 2-4) (Swanson et al., 1979b). Flows exposed or encountered in boreholes within the Pasco Basin are of the N_2 and R_2 magnetostratigraphic units. However, the entire Grande Ronde Basalt section has not been penetrated. In addition, two major informal sequences of flows distinguished on the basis of chemical composition (primarily differences in magnesium) have been recognized in the Pasco Basin and reference repository location: Schwana and Sentinel Bluffs sequences (Myers, Price et al., 1979). The boundary between the Schwana and the Sentinel Bluffs sequences is termed the magnesium horizon (ARHCO, 1976). Grande Ronde Basalt within the reference repository location is overlain by up to 20 flows of Wanapum and Saddle Mountains Basalts and interbedded sediments of the Ellensburg Formation (see Fig. 3-6 and 3-8).

The Schwana sequence lies within the R_2 and N_2 magnetostratigraphic units and consists of dominantly low-magnesium flows (less than 4.0 weight percent magnesium oxide) (Long and Landon, 1981, pp. 4-14, 4-37, and 4-38). Several flows of high-magnesium chemistry (greater than 4.0, less than 5.5 weight percent magnesium oxide) are found in the Schwana sequence and a single flow of very high-magnesium oxide content (greater than 5.5 weight percent magnesium oxide) is found near the top of the sequence (Long and Landon, 1981).

Basalts of the Schwana sequence extend much deeper than most boreholes in the Pasco Basin have penetrated. Borehole RSH-1, located in the Rattlesnake Hills approximately 13 kilometers (8 miles) southwest of the reference repository location, encountered basalt to a depth of approximately 3,250 meters (10,650 feet). This is approximately 1,500 meters (5,000 feet) deeper than other deep boreholes in the basin, except for the Shell Oil Company borehole (Bissa well 1-29) in the Saddle Mountains. Information from the Shell Oil Company borehole is proprietary. Borehole RSH-1 did not reach the base of the basalts, so a total thickness for the Schwana sequence in the basin is known only from estimates based on geophysical data. Its thickness beneath the reference repository location is estimated to be approximately 3,600 to 4,600 meters (12,000 to 15,000 feet) based on data from Orange and Berkman (1985, Plate 12). Moreover, it is likely that the deeper parts of the Schwana sequence contain R_1 and N_1 magnetostratigraphic units.

The Sentinel Bluffs sequence consists of 8 to 9 flows in the reference repository location, all of high-magnesium chemical type (greater than approximately 4.0 weight percent magnesium oxide). Basalt flows in this sequence lie within the N_2 magnetostratigraphic unit (Long and Landon, 1981). Individual flows within the sequence vary in thickness from 5.3 to 81.4 meters (17.5 to 267 feet). The Cohassett flow, which has been identified as the candidate horizon for a nuclear waste repository in the reference repository location, is located in the Sentinel Bluffs sequence (Section 3.2.2.3; see Fig. 3-6 and 3-8).

Flows of the Sentinel Bluffs sequence and flows from the upper portion of the Schwana sequence have been correlated from one location to another across the Pasco Basin (Long and WCC, 1984). The geographic

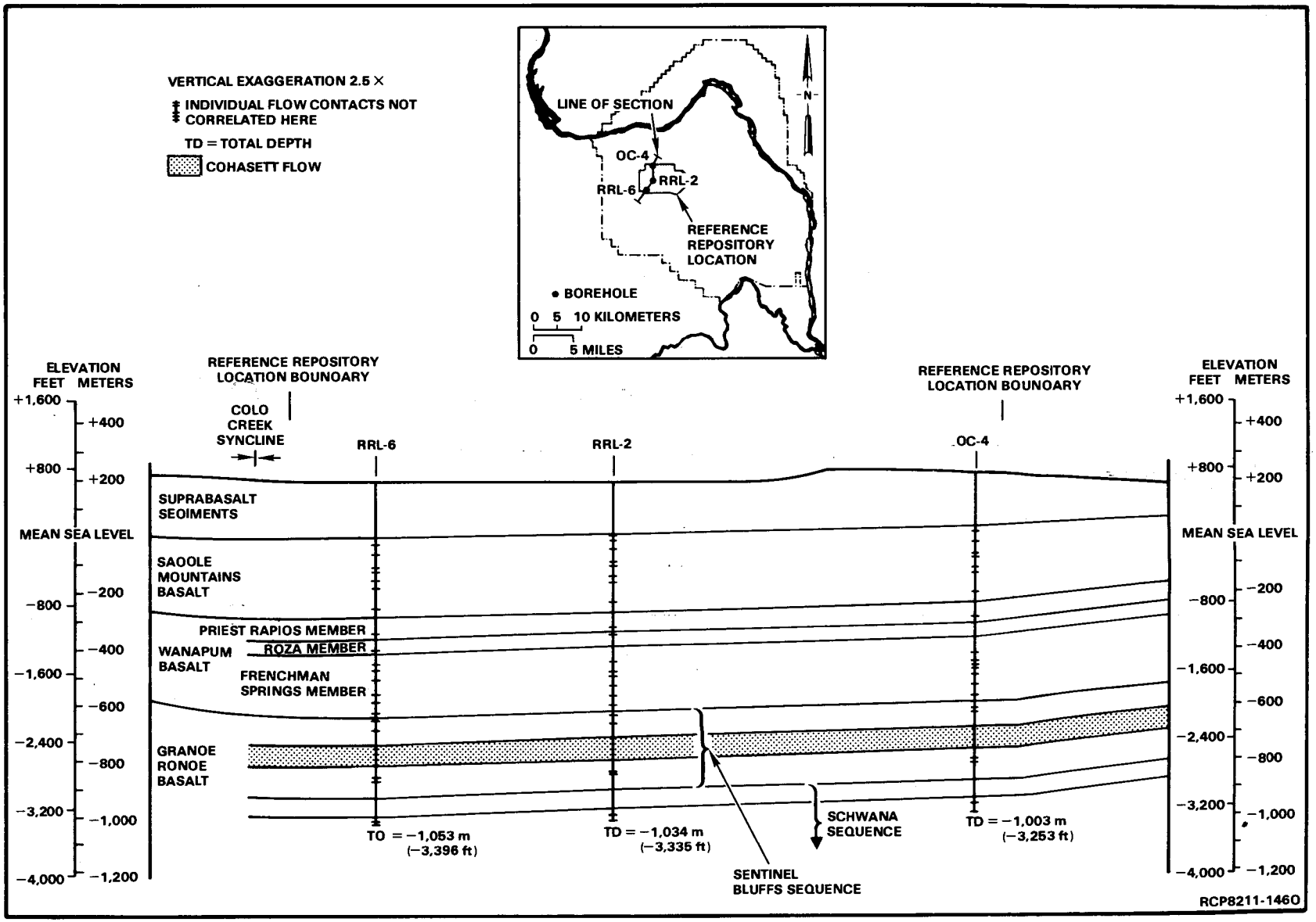

Figure 3-8. Generalized geologic cross section through the reference repository location.

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distribution of the thickness of the total Sentinel Bluffs sequence in the basin is shown in Figure 3-9. The sequence is thinner to the east and northeast, probably the result of the regional southwest-dipping paleoslope (Swanson and Wright, 1976) that flattens out in the area now occupied by the basin. This flattening resulted in ponding of flows in part of the area now occupied by the Pasco Basin. In the vicinity of the reference repository location, the Sentinel Bluffs sequence maintains a relatively consistent thickness.

3.2.2.3 Cohassett flow

The Cohassett flow is the candidate horizon for a nuclear waste repository in the reference repository location. This flow is stratigraphically positioned near the center of the Sentinel Bluffs sequence (see Fig. 3-6) and can be correlated throughout the entire Pasco Basin. Correlations of the Cohassett flow are based on stratigraphic position and thickness (Long and WCC, 1984). The flow is of the high-magnesium Grande Ronde chemical type (Table 3-1) and has a similiar paleomagnetic inclination to the McCoy Canyon flow (Fig. 3-10). The Cohassett flow, as illustrated in Figure 3-11, is thickest in the central Pasco Basin, maintains a fairly consistent thickness in the reference repository location (ranging from approximately 73 to 81 meters (240 to 266 feet)), and thins in the southeastern portion of the map area. The thinning of the flow in the southeast is thought to be related to the mechanics of flow emplacement and not related to thinning over a topographic high, either structural or constructional. The top of the flow in the reference repository location lies 869 to 943 meters (2,850 to 3,093 feet) below the ground surface and at an elevation of 645 to 746 meters (2,117 to 2,450 feet) below sea level.

The internal characteristics (intraflow structures) of the Cohassett flow are a flow top, a flow interior, and a flow bottom. The flow interior contains a laterally extensive zone of vesicular basalt and exhibits alternating tiers of entablature and colonnade. These features are illustrated in Figure 3-12.

The Cohassett flow-top thickness ranges from 4 to 26 meters (13 to 85 feet) across the Pasco Basin (Fig. 3-13) and from 4.0 to 10.4 meters (13 to 34 feet) within the reference repository location. The flow top is typically comprised of flow-top breccia and rubble overlying vesicular and vuggy rock. Field studies show that flow-top thickness variations of approximately 10 meters (33 feet) occur over distances of approximately 100 meters (300 feet). Generally, where thicknesses change, the increase is primarily in the vesicular and vuggy portion of the flow top and not in the breccia. Flow-top breccia and rubble typically make up one-half of the total flow-top thickness, with vesicular and vuggy rock comprising the remainder of the flow top. The breccia and rubble are typically composed of subangular clasts 1 to 6 centimeters (0.4 to 2.4 inches) in diameter with occasional clasts to about 40 centimeters (16 inches). The clasts occupy 60 to 75 percent of the rock mass in a matrix filled with clay,

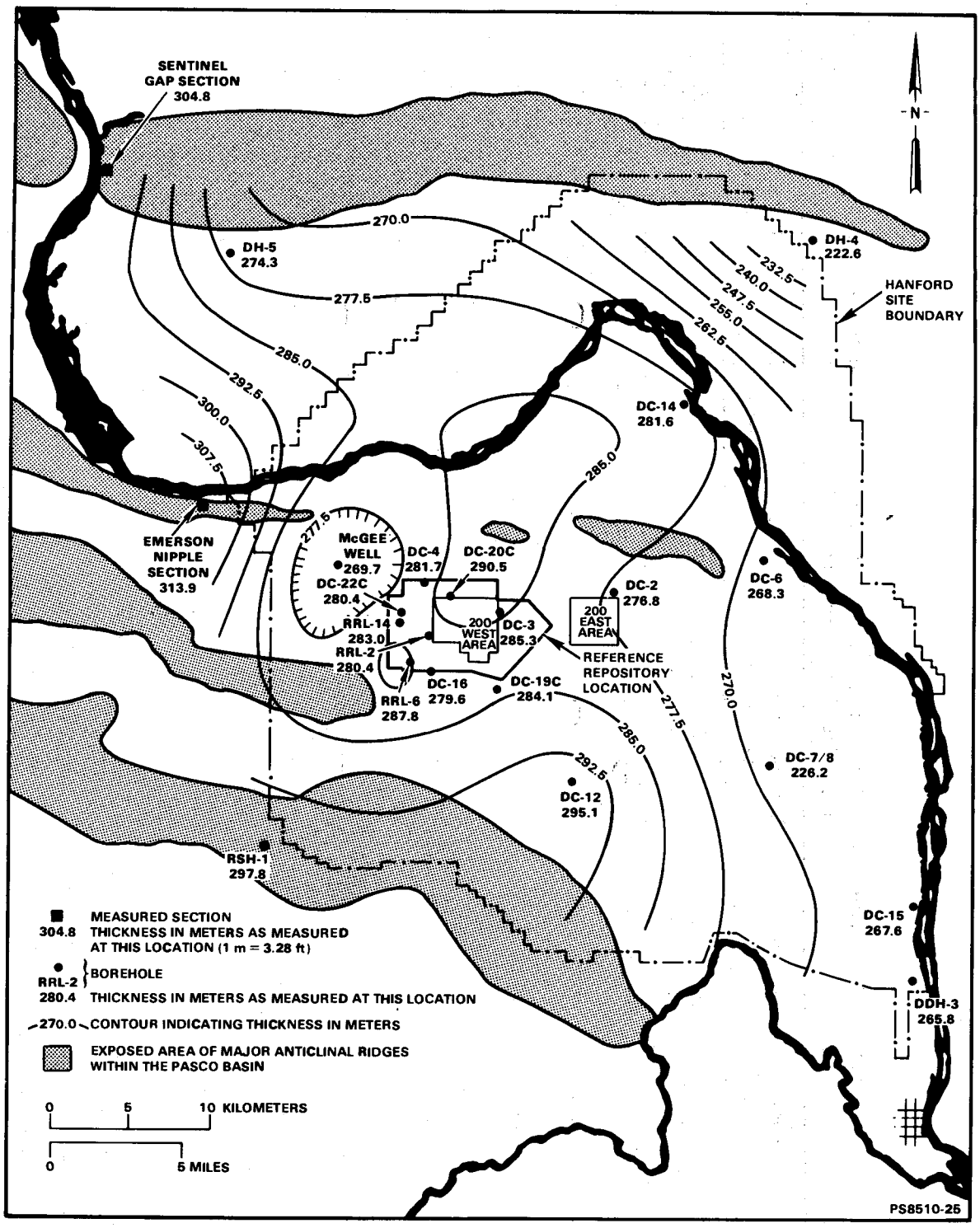

Figure 3-9. Isopach map of Sentinel Bluffs sequence.

Table 3-1. Means of major oxides of the proposed candidate horizons in Grande Ronde Basalt (wt%)

Oxide	Rocky Coulee flow (34 samples)		Cohassett flow (42 samples)		McCoy Canyon flow (38 samples)		Umtanum flow (53 samples)	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
SiO_2	54.10	0.63	53.58	0.43	53.58	0.51	54.65	0.79
Al_2O_3	15.13	0.36	15.07	0.39	14.96	0.33	14.68	0.31
FeO	11.42	0.29	11.70	0.32	12.30	0.25	12.91	0.28
MgO	4.81	0.20	5.04	0.20	4.62	0.25	3.53	0.19
CaO	8.54	0.29	8.82	0.29	8.44	0.22	7.19	0.28
K_2O	1.14	0.09	1.01	0.12	1.01	0.12	1.52	0.24
Na_2O	2.43	0.35	2.49	0.32	2.45	0.39	2.55	0.40
TiO_2	1.73	0.06	1.78	0.07	1.95	0.08	2.18	0.07
MnO	0.21	0.01	0.21	0.01	0.21	0.01	0.22	0.01
P_2O_5	0.30	0.02	0.28	0.03	0.29	0.02	0.35	0.01

NOTE: All standard deviations are one sigma.

7 0 1 6 8 0 6 5 6

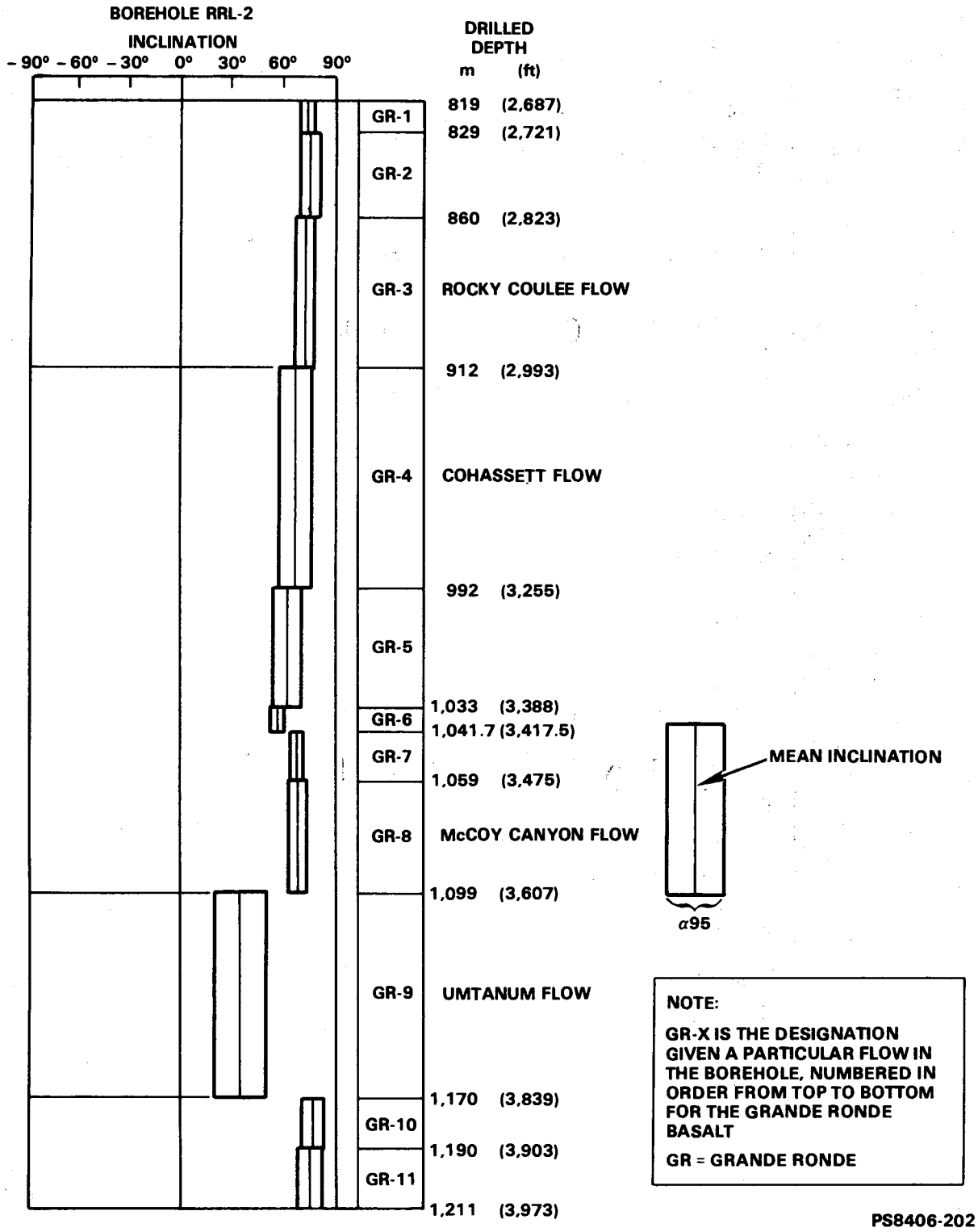

Figure 3-10. Paleomagnetic data from Grande Ronde Basalt in borehole RRL-2.

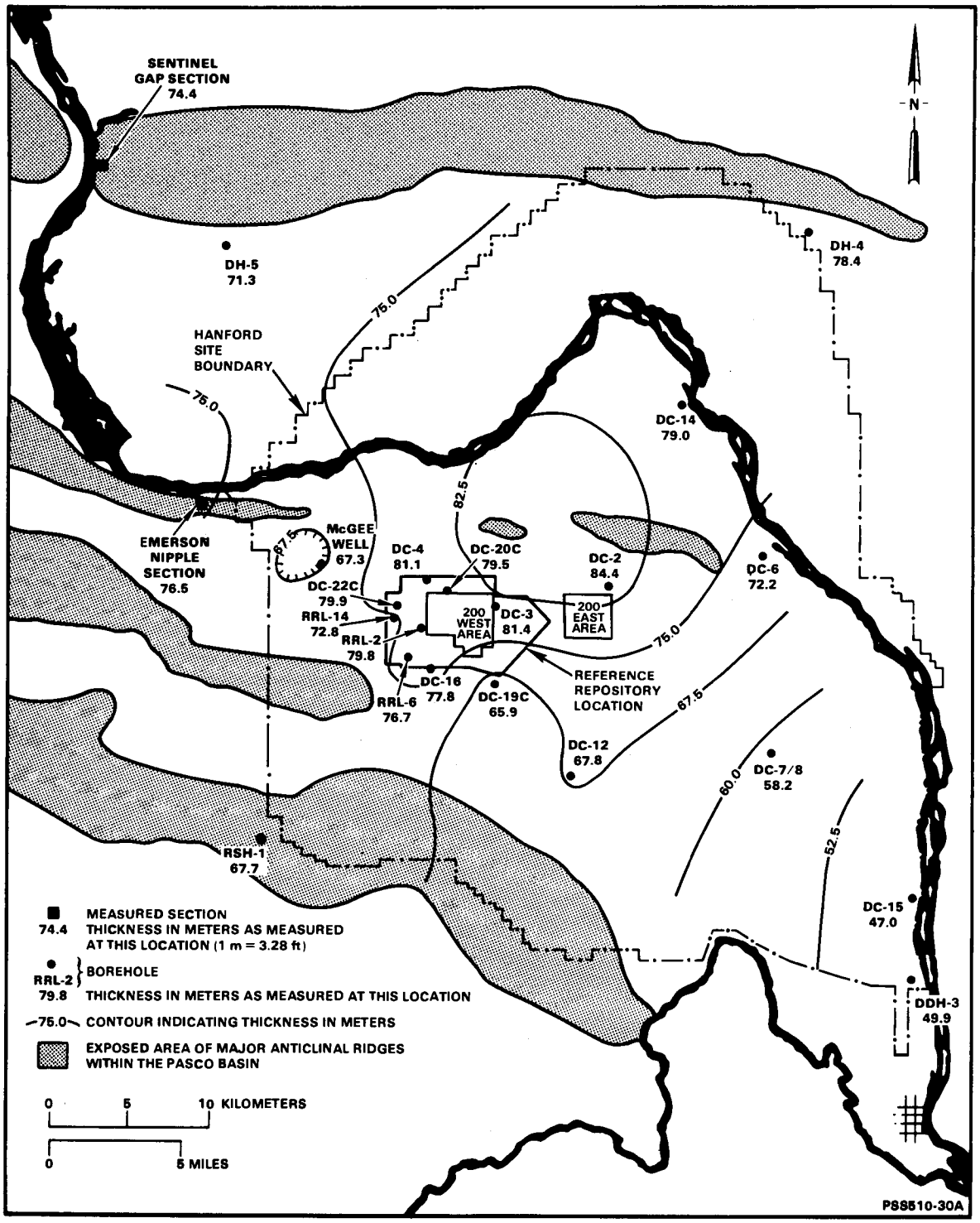

Figure 3-11. Isopach map of Cohassett flow.

7 0 1 6 8 8 0 1 6 5 9

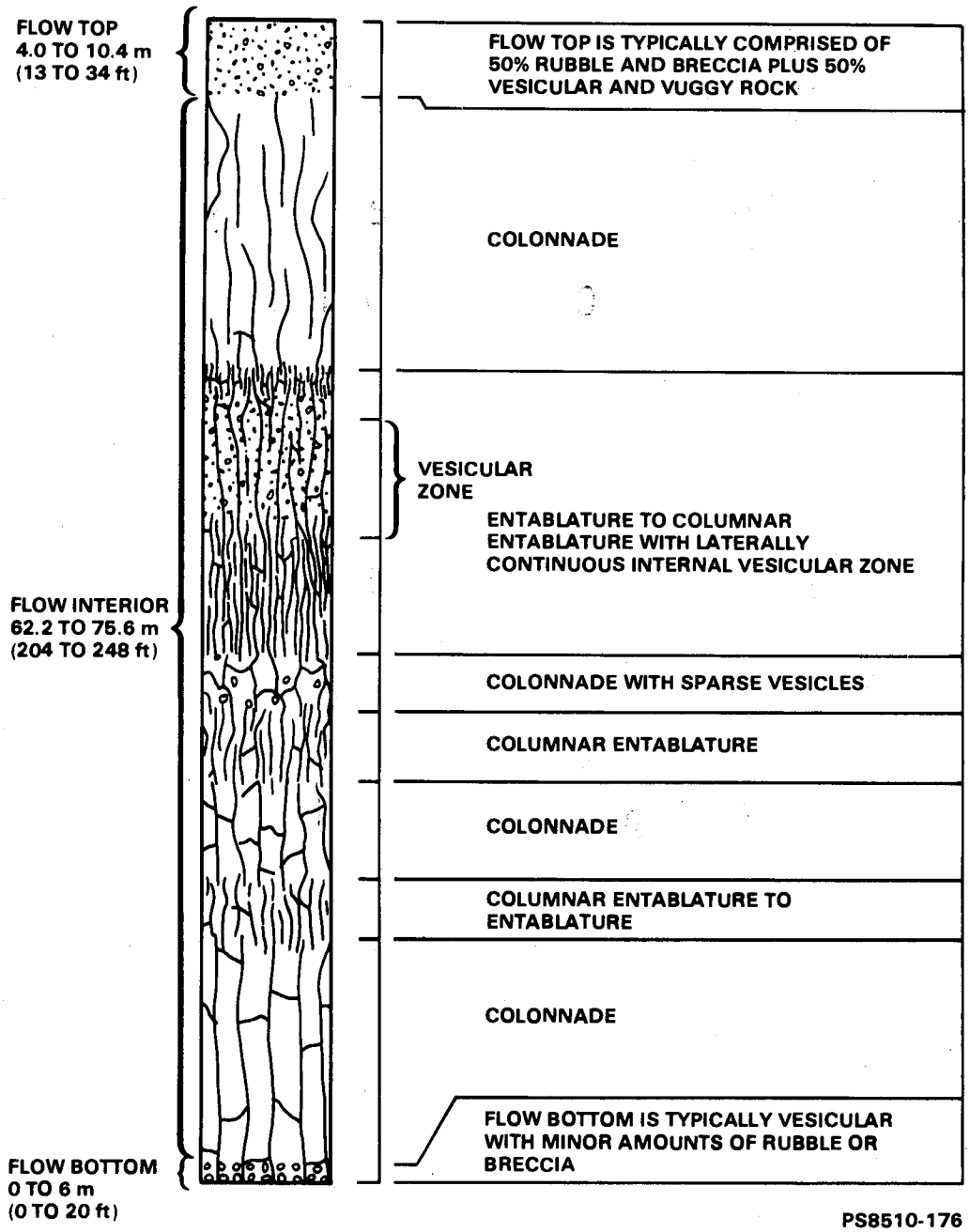

Figure 3-12. Cohassett flow total thickness ranging from 73 to 81 meters (240 to 266 feet) within the reference repository location.

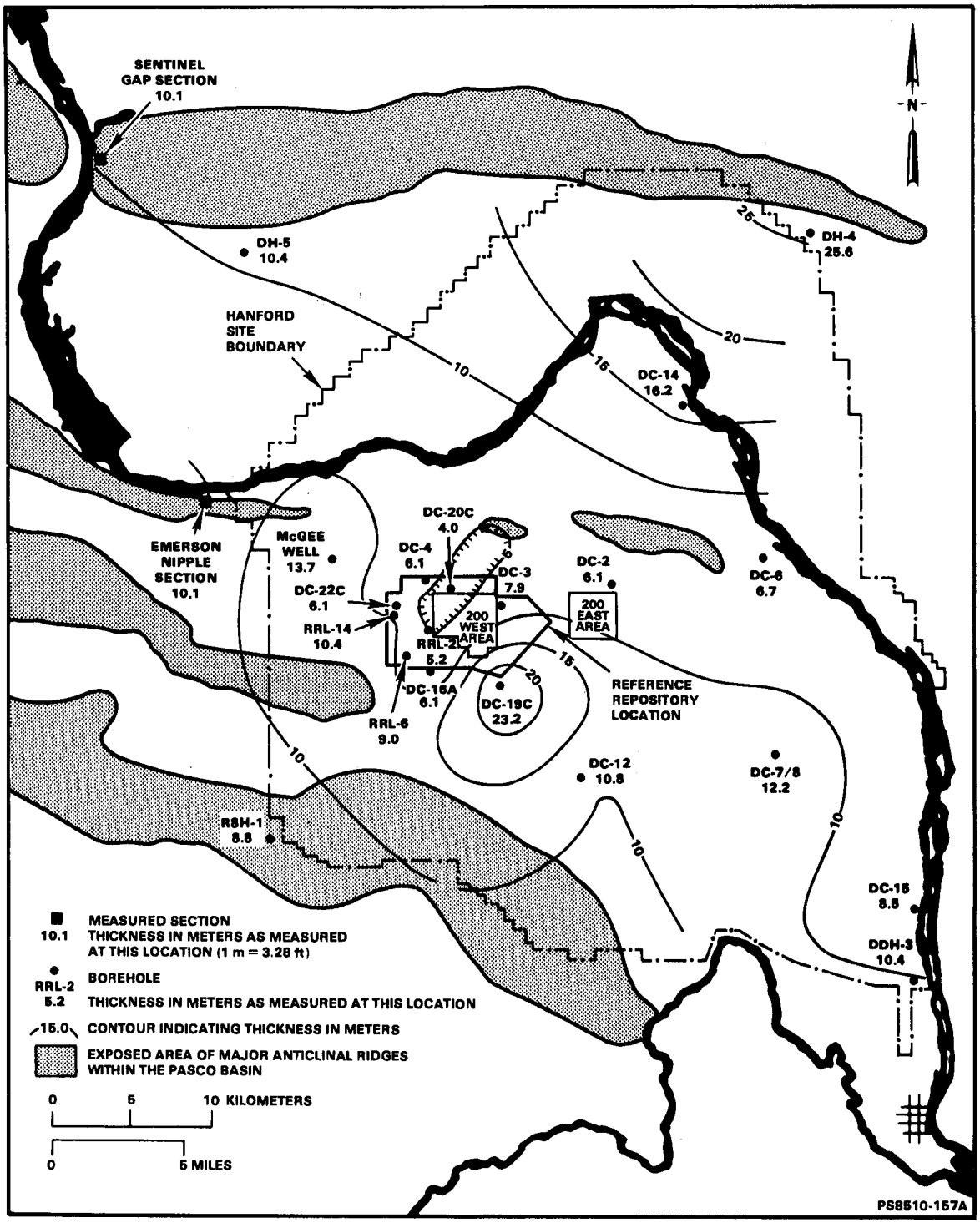

Figure 3-13. Isopach map of Cohassett flow top.

silica, zeolite, or basalt. Vesicles and vugs range from 2 to a maximum of 40 percent of the rock mass. Vesicles vary in size from 1 to 8 millimeters (0.04 to 0.3 inch), and are unfilled or partially filled with clay, silica, or zeolites.

The interior of the Cohassett flow extends from the bottom of the flow top to the top of the flow bottom. It ranges in thickness from 62.2 to 75.6 meters (204 to 248 feet) within the reference repository location (Fig. 3-14). A laterally extensive vesicular zone is found within the flow interior of the Cohassett flow. This zone is defined as having greater than 2 percent vesicles by volume. The flow interior above the vesicular zone and below the base of the flow top ranges from approximately 16 to 21 meters (53 to 68 feet) within the reference repository location. The flow interior below the vesicular zone and above the flow bottom ranges from 36 to 46 meters (120 to 149 feet). The interior of the flow is fractured from contraction during cooling of the basalt flow. Virtually all (99.4 percent) cooling joints are completely filled with clays, silica, or zeolite (Lindberg, 1986). Current repository design uses the entire flow interior, including the vesicular zone.

Entablature-colonnade tiers occur within the interior of the Cohassett flow. These tiers have not been correlated from borehole to borehole within the reference repository location. However, based on recent field work at Sentinel Gap in the Saddle Mountains north of the Pasco Basin, tiers have been traced across distances of up to 3.2 kilometers (2 miles). Gradual variations in thickness of tiers are recognized at this location. While entablatures differ from colonnades in primary fracture patterns and microscopic textures, both intraflow structures are within the interior of the flow. Moreover, contacts between entablature and colonnade tiers are distinct in some places but gradational in others. In no case, however, do contacts between these intraflow structures represent a change in lithology, which could be potential zones of higher hydraulic conductivities.

The vesicular zone in the Cohassett flow is consistently located approximately 24 meters (79 feet) below the base of the flow top in the reference repository location. The vesicular zone is typically within a columnar-entablature portion of the flow interior. Thickness of the vesicular zone ranges from 3.0 to 15.8 meters (10 to 52 feet) within the reference repository location and is interpreted to be continuous throughout the reference repository location and much of the Pasco Basin (Fig. 3-15). This zone is composed of vesicular and vuggy rock with vesicles being prevalent. In general, vesiculation ranges from 2 to 15 percent by volume and vugs range from 2 to 10 percent by volume. Vesicle size ranges from 1 to 9 millimeters (0.04 to 0.35 inch) with an average size of approximately 5 millimeters (0.2 inch). Vugs range from 1 to 3 centimeters (0.4 to 1.2 inches), with an average size of approximately 1.5 centimeters (0.6 inch). When vesicular and vuggy rock occur together, the average percent open space is approximately 15 percent. Vesicles and vugs within this zone are predominantly unfilled. When filled, the principal infilling mineral is clay with minor amounts of

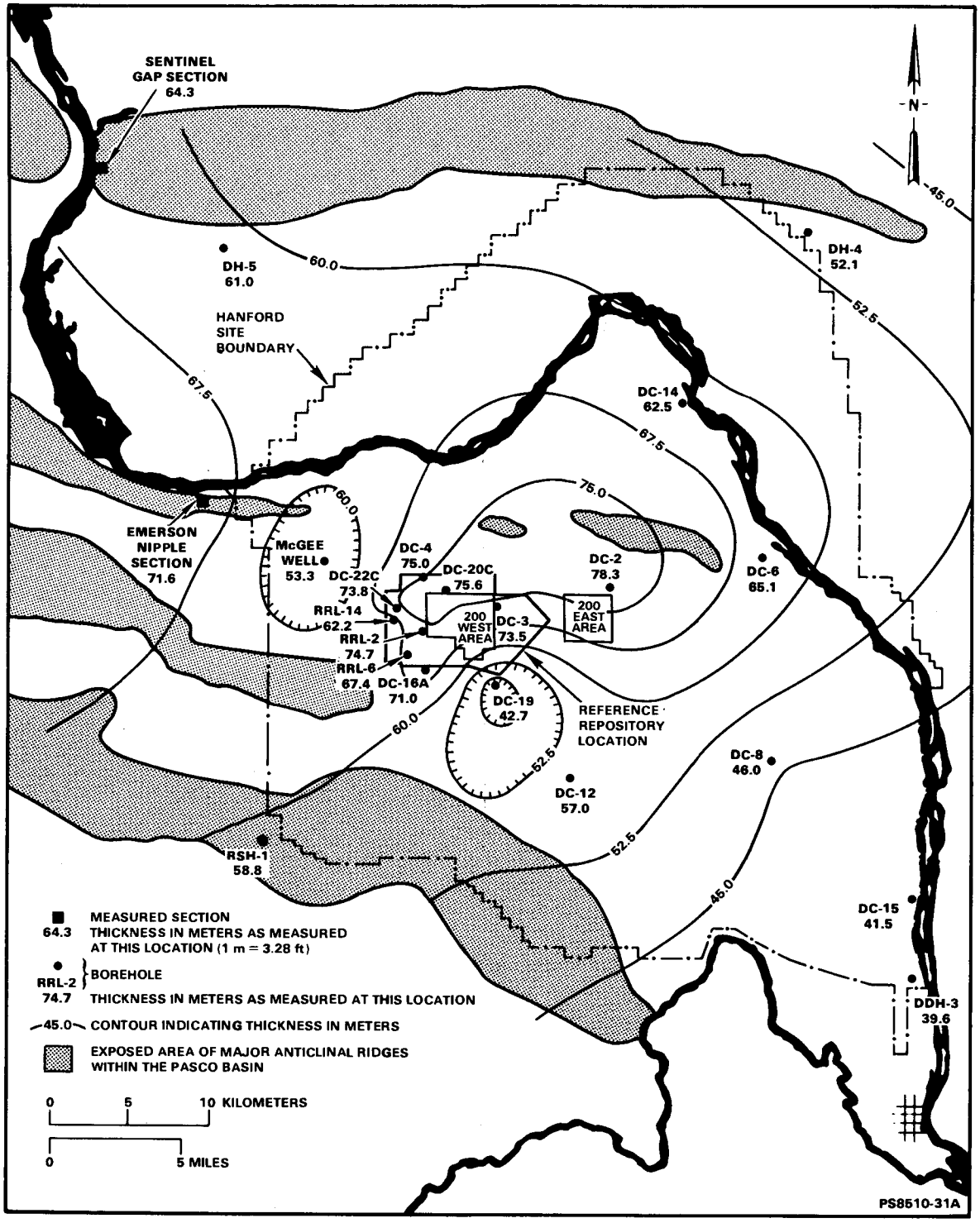

Figure 3-14. Isopach map of the total flow interior of the Cohassett flow.

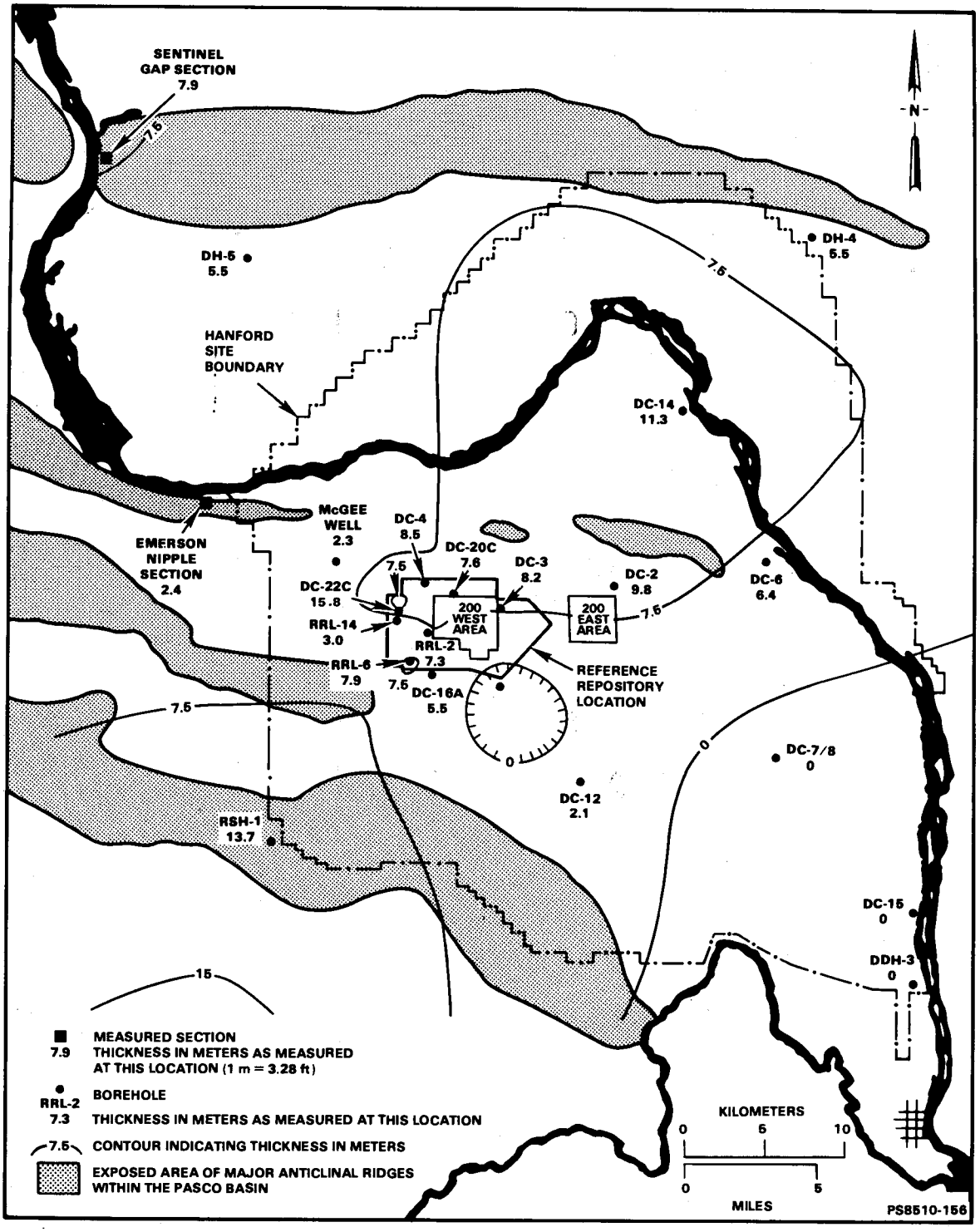

Figure 3-15. Isopach map of the internal vesicular zone in the Cohassett flow.

other infilling minerals. Vesicles and vugs are not interconnected except where transected by fractures. The amount of vesicles in the vesicular zone commonly increases in abundance upward from the base; the largest abundance of vesiculation and vugginess is commonly found at the top of the zone. An internal stratification of vesicles and vugs also may occur within the vesicular zone. The upper surface of the vesicular zone is planar and is consistently defined by an abrupt decrease in vesiculation. Brecciated rock that occurs in flow tops has not been observed within the vesicular zone. Preliminary results of outcrop studies of the Cohassett flow are consistent with the characteristics discussed above that were based on boreholes in the reference repository location.

Means of fracture width were compared between fractures in the Cohassett flow vesicular zone and fractures elsewhere in the Cohassett flow interior. The results showed that mean fracture width of Cohassett flow vesicular zone fractures are indistinguishable from other mean widths.

Southeast of the reference repository location at borehole DC-19C, flow-top and interior thicknesses for the Cohassett flow are different than those within the reference repository location (see Fig. 3-7). At this location, the Cohassett flow is approximately 12 meters (39 feet) thinner than at locations within the reference repository location. Additionally, flow-top thickness at borehole DC-19C is thicker than has been encountered in the reference repository location (see Fig. 3-13). Interior thickness at borehole DC-19C is 42.7 meters (140 feet) and no internal vesicular zone is present. The absence of the internal vesicular zone is interpreted to be related to the thinner total flow thickness. The internal vesicular zone of the Cohassett flow in the vicinity of borehole DC-19C may either gradually disappear laterally as the flow thins or it may merge with the vesiculation associated with the flow top. The thickness of the interior of the flow in borehole DC-19C is of comparable thickness to the interior below the vesicular zone in boreholes within the reference repository location.

The internal vesicular zone of the Cohassett flow (see Fig. 3-12) was formed after flow emplacement by the upward migration, coalescence, and entrapment of vapor bubbles (McMillan et al., 1985). The zone gradually changes from dense, sparsely vesicular rock in the lower portion of the zone to highly (approximately 15 percent) vesicular and vuggy in the upper portion of the zone. The upper margin of the zone is defined by an abrupt transition to slightly vesicular and nonvesicular rock. The upper margin is defined by an abrupt transition from nonvesicular to highly vesicular rock. However, downward-propagated cooling joints traced continuously through the zone from above demonstrate that the zone neither represents nor is associated with a stratigraphic or structural discontinuity. During cooling of the flow, the upper and lower solidification fronts advancing inward serve as sites for the formation of aqueous vapor. Vapor bubbles, formed at the upward-advancing solidification front, rise buoyantly until the higher viscosities are encountered preceding the upper solidification front. The bubbles become trapped by the downward passage

of the front. Vapor bubbles, formed at the upper solidification front, cannot migrate and are trapped as thin diktytaxitic laminae marking increments of the downward advance.

The flow bottom of the Cohassett flow is typically a thin zone of vesicular basalt. Brecciated flow bottom has not been observed within the reference repository location. Vesicles are typically 1 to 8 millimeters (0.04 to 0.3 inch) in diameter and represent approximately 2 to 15 percent of the rock mass. Flow-bottom thicknesses of the Cohassett flow range from 0 to 0.6 meter (0 to 2 feet) in the reference repository location, with the exception of rotary-drilled borehole RRL-2C (see Fig. 3-7). At this location, borehole video logs and geophysical logs indicate two emplacement lobes at the base of the flow. Each of the lobes is approximately 3 meters (10 feet) thick. Each lobe has a dense lower half and a vesicular upper half. These two lobes are considered to be flow bottom with a total thickness of 6 meters (20 feet). Borehole RRL-2A, located approximately 100 meters (300 feet) southwest of borehole RRL-2C, has no flow-bottom material present; therefore, the borehole RRL-2C flow bottom is interpreted to be of limited lateral extent.

Studies of primary fractures in upper Grande Ronde Basalt core samples (including Cohassett flow core samples) from boreholes RRL-2, RRL-6, RRL-14, and DC-16A show that the basalt flows studied cannot be differentiated on the basis of fracture width (Lindberg, 1986). Intraflow structures within flow interiors also are similar in fracture width. Therefore, the primary fracture widths in the Cohassett flow interior may be classified as members of a larger population of primary fracture width. The mean width of this larger population is 0.23 millimeter (0.01 inch) and the standard deviation is 0.49 millimeter (0.02 inch). Only 19 (0.6 percent) of the 3,194 randomly selected fractures in the study have measurable void space (Lindberg, 1986). Most of the fractures in the Cohassett flow (89 percent) are filled predominantly with clay, but fractures with silica (4 percent) and zeolite (7 percent) as the predominant filling also are observed. Fractures in this population that have a lack of secondary mineral infilling (i.e., have measurable void space) are rare.

Table 3-2 shows abundances of primary fractures and mechanical handling breaks per meter (foot) for the Cohassett flow from the McGee well and borehole DC-16A core samples (see Fig. 3-15). Intraflow structures in the flow interior in both boreholes have primary fracture abundances that range from about 14 to 38 per meter (4 to 12 per foot). Generally, the colonnades have the lowest abundance, entablatures the highest, and columnar entablatures intermediate. The vesicular zone, which is a portion of the columnar entablature, has a primary fracture abundance about the same or slightly lower than the colonnade. Primary fracture abundance in flow tops and bottoms vary over the range of abundances encountered in entablature and colonnade. The flow top in borehole DC-16A has a fracture abundance like that of a colonnade, but the flow bottom in the McGee well has a fracture abundance similar to an entablature.

Table 3-2. Primary fracture abundance and breaks[a] per meter for intraflow structures of the Cohassett flow in core hole samples from McGee well and borehole DC-16A

Intraflow structure	McGee well		Borehole DC-16A	
	Primary fractures per meter (per foot)	Breaks per meter (per foot)	Primary fractures per meter (per foot)	Breaks per meter (per foot)
Flow top[b]	25.3 (7.7)	4.3 (1.3)	14.1 (4.3)	2.5 (0.8)
Entablature	38.5 (11.7)	5.6 (1.7)	36.6 (11.2)	13.8 (4.2)
Columnar entablature	21.9 (6.7)	4.5 (1.4)	26.3 (8.0)	9.8 (3.0)
Vesicular zone	14.4 (4.4)	2.9 (0.9)	15.9 (4.8)	6.2 (1.9)
Colonnade	20.5 (6.2)	5.2 (1.6)	14.1 (4.3)	6.5 (2.0)
Flow bottom*	45.3 (13.8)	9.8 (3.0)	21.0 (6.4)	3.3 (1.0)

[a]Mechanical breaks that occur along primary fractures due to normal coring and core-handling procedures.

[b]Primary fracture frequency and breaks per meter (foot) were calculated only for portions without breccia or rubble.

Table 3-2 also shows that actual core breaks per meter (foot) (mechanical breaks that occur along primary fractures due to normal coring and core-handling procedures) are significantly lower than the number of primary fractures per meter (foot). The ratios range from approximately 2 to 7. This difference demonstrates that secondary mineral infillings play a significant role in holding fractures intact during normal coring and handling operations.

Frequency of actual breaks per meter (foot) in the flow interior of the borehole DC-16A core samples is, in general, about twice that of the McGee well (see Table 3-2). The flow top and bottom of borehole DC-16A do not have a higher number of breaks than the flow top and flow bottom in the McGee well. The incidence of higher number of breaks per meter (foot) in the flow interior of borehole DC-16A is probably related to disking, which in turn is correlated to in situ stress. The flow interior of the Cohassett flow in borehole DC-16A has a moderate amount of disking, compared to the Cohassett flow in the McGee well core samples that are relatively free of disking (Cross and Fairchild, 1985).

3.2.2.4 Wanapum Basalt

The Wanapum Basalt in the Pasco Basin consists of the Frenchman Springs, Roza, and Priest Rapids Members. The Vantage interbed separates this formation from the underlying Grande Ronde Basalt; the Mabton interbed separates the Wanapum Basalt from the overlying Saddle Mountains Basalt (see Fig. 3-6).

The Wanapum Basalt is typically fine to medium grained with some flows containing olivine and plagioclase phenocrysts. The petrographic characteristics combined with distinct compositional differences permit distinction of the Wanapum Basalt from the Grande Ronde Basalt.

The Wanapum Basalt is between 15.5 and 14.5 million years old (Long and Duncan, 1982; Watkins and Baksi, 1974) and was erupted from linear vents in the east half of the Columbia Plateau (Swanson et al., 1979a). It is thickest in the central area of the Cold Creek syncline around the reference repository location, but thins from west to east and over the Rattlesnake Hills and Umtanum Ridge-Gable Mountain structures (see Fig. 3-1). The Wanapum Basalt in the reference repository location consists of 10 to 11 flows and is approximately 335 meters (1,100 feet) thick.

3.2.2.4.1 Frenchman Springs Member

The Frenchman Springs Member is the oldest member of the Wanapum Basalt in the Pasco Basin and consists of seven to nine flows in the Cold Creek syncline. It is approximately 230 meters (775 feet) thick in the reference repository location. The flows are all medium to fine grained

and contain plagioclase phenocrysts. Regionally, the Frenchman Springs Member can be grouped into six stratigraphic units based on chemical composition, paleomagnetic data, and, to a lesser extent, lithology (Beeson et al., 1985). These units are basalt of Palouse Falls, basalt of Ginkgo, basalt of Silver Falls, basalt of Sand Hollow, basalt of Sentinel Gap, and basalt of Lyons Ferry. All but basalt of Lyons Ferry are found in the reference repository location. The average chemical composition of the Frenchman Springs Member is given in Table 3-3. The composition falls within the Frenchman Springs chemical type of Wright et al. (1973).

The flows of the Frenchman Springs Member north of the Pasco Basin were sampled for remanent magnetic polarity by Van Alstine and Gillett (1981) as part of the Basalt Waste Isolation Project stratigraphic studies. Their findings are comparable with those of Rietman (1966, p. 67), Kienle et al. (1978), and Sheriff and Bentley (1980) (Table 3-4).

The total thickness of the Frenchman Springs Member thins from south to north and from east to west across the Pasco Basin (Reidel et al., 1980). The greatest number of flows is present in the southeastern part of the basin and the least number in the northwestern part. In the central part of the Cold Creek syncline, there are between seven and nine flows or flow lobes. An abrupt thinning occurs onto the Rattlesnake Mountain structure to the south of the Cold Creek syncline. The greatest thickness occurs on the east side of the Cold Creek syncline.

3.2.2.4.2 Roza Member

One to two flows or flow lobes of similar physical and chemical composition comprise the Roza Member in the Pasco Basin and reference repository location. The member is approximately 53 meters (175 feet) thick in the reference repository location. It is distinguished in hand specimen, typically by the presence of single plagioclase phenocrysts up to 1.5 centimeters (0.6 inch) in size set in a fine-grained groundmass.

The average chemical composition of the Roza Member from the Pasco Basin is given in Table 3-3. It generally falls within the Frenchman Springs chemical type of Wright et al. (1973) and cannot be distinguished from the flows of Frenchman Springs Member on chemical composition alone.

The magnetic polarity of the Roza Member was determined by Rietman (1966) to be transitional. However, Choiniere and Swanson (1979) found a reversed dike that they interpreted to be perhaps the youngest Roza unit. Van Alstine and Gillett (1981) found that the two Roza flows in core samples from a borehole south of the Saddle Mountains have low-mean inclinations (plus 3.3 and 7.5 degrees); lower than those reported by Choiniere and Swanson (1979) (see Table 3-4). Packer and Petty (1979) sampled the Roza flow in core drilled from the central Hanford Site and found results similar to those of Van Alstine and Gillett (1981).

Table 3-3. Average chemical composition of flows from the Wanapum and Saddle Mountains Basalts, Pasco Basin

Oxide	Frenchman Springs Member (103 samples)		Roza Member (16 samples)		Priest Rapids Member Rosalia flow (15 samples)		Priest Rapids Member Lolo flow (20 samples)		Umatilla Member Sillusi flow (19 samples)	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
SiO_2	51.35	0.51	50.60	0.40	49.95	0.36	49.85	0.49	54.70	0.48
Al_2O_3	14.22	0.39	14.36	0.37	13.72	0.21	14.31	0.30	14.61	0.27
TiO_2	3.00	0.09	3.03	0.15	3.49	0.05	3.14	0.08	2.69	0.12
FeO	14.51	0.58	14.37	0.56	15.31	0.31	14.10	0.42	12.37	0.71
MnO	0.23	0.01	0.24	0.01	0.25	0.01	0.24	0.01	0.22	0.03
CaO	8.27	0.24	8.63	0.21	8.57	0.19	9.05	0.59	6.31	0.30
MgO	4.18	0.30	4.57	0.29	4.50	0.22	5.23	0.29	2.61	0.24
K_2O	1.18	0.16	1.18	0.12	1.05	0.20	1.00	0.11	2.77	0.13
Na_2O	2.53	0.22	2.48	0.21	2.50	0.22	2.42	0.16	2.88	0.13
P_2O_5	0.54	0.05	0.55	0.04	0.66	0.02	0.65	0.02	0.84	0.03

Oxide	Umatilla Member Umatilla flow (36 samples)		Esquatzel Member (50 samples)		Pomona Member (71 samples)		Elephant Mountain Member (91 samples)	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
SiO_2	53.78	0.72	52.85	0.48	51.90	0.38	50.91	0.53
Al_2O_3	14.59	0.28	14.28	0.26	15.44	0.28	14.00	0.30
TiO_2	2.98	0.15	3.03	0.11	1.63	0.06	3.50	0.08
FeO	12.73	0.69	13.52	0.49	10.51	0.38	14.71	0.66
MnO	0.23	0.04	0.21	0.02	0.19	0.01	0.22	0.02
CaO	6.76	0.45	7.69	0.22	10.66	0.32	8.49	0.29
MgO	2.97	0.43	3.78	0.22	6.74	0.29	4.18	0.19
K_2O	2.48	0.35	1.76	0.15	0.53	0.10	1.20	0.22
Na_2O	2.77	0.31	2.49	0.14	2.17	0.13	2.30	0.15
P_2O_5	0.74	0.03	0.38	0.02	0.24	0.02	0.49	0.05

NOTE: All standard deviations are one sigma. Total Fe expressed as FeO.

7 0 1 6 8 0 6 6 9

Table 3-4. Paleomagnetic polarity of Wanapum Basalt and Saddle Mountains Basalt

Member	Flow or location	Mean declination	Mean inclination	Alpha 95[a]	Source of information
Saddle Mountains Basalt					
Ice Harbor	Goose Island	51.3	+19.2	11.7	(b)
		33.5	+31.9	13.3	(b)
	Martindale	185.1	-55.1	3.0	(b)
		168.2	-65.0	3.3	(b)
	Basin City	317.0	+34.7	4.2	(b)
		319.3	+49.5	6.3	(b)
Elephant Mountain	Site 1	6.9	+59.6	4.2	(b)
	Site 2	14.2	+62.5	8.3	(b)
	Site 3	111.5	-25.6	9.3	(b)
	Site 4	127.9	-39.5	9.8	(b)
		133.2	-39.2	8.6	(c)
Pomona	Site 1	187.8	-51.9	1.7	(b)
	Site 2	186.3	-53.4	2.2	(b)
	Site 3	203.4	-54.6	2.0	(b)
	Site 4	195.4	-50.6	2.9	(b)
		193.5	-52.7	9.5	(c)
Esquatzel	Site 1	340.8	+63.0	3.6	(b)
	Site 2	308.0	+81.0	11.4	(b)
		348.4	+64.8	8.6	(c)
Asotin	Huntzinger	23.7	+80.6	4.5	(c)
Wilbur Creek	Wahluke	345.7	+72.1	3.4	(c)
Umatilla	Sillusi	321.7	+32.2	2.6	(c)
	Umatilla	324.3	+31.7	3.4	(c)
Wanapum Basalt					
Priest Rapids	Lolo	190.5	-64.9	2.8	(c)
Roza	Site 1	214.2	-14.7	7.3	(b)
	Site 2	184.7	-38.7	7.0	(b)
Frenchman Springs	Sentinel Gap	5.0	+62.8	2.2	(c)
	Sand Hollow	144.7	+39.8	3.6	(c)
	Ginkgo	146.1	+42.1	2.6	(c)

[a]A measure of how well the average direction of magnetism is determined.

[b]Choiniere and Swanson (1979).

[c]Van Alstine and Gillett (1981).

The Roza Member reaches its greatest thickness in the central part of the Cold Creek syncline and just north of Gable Mountain. It thins across Rattlesnake Mountain and the Umtanum Ridge-Gable Mountain structure, but thickens along the northern flank of the Umtanum Ridge-Gable Mountain structure in the Wahluke syncline.

3.2.2.4.3 Priest Rapids Member

The Priest Rapids Member is the youngest member of the Wanapum Basalt (Swanson et al., 1979b) and consists of two distinct flows in the Cold Creek syncline as elsewhere in the Pasco Basin. In core from the Priest Rapids Dam site (see Fig. 3-1), four flows are present, but the three lowest are now considered to be flow lobes of the same flow (Reidel et al., 1980). The member is approximately 46 meters (150 feet) thick in the reference repository location. The older flow is typically coarser grained with rare olivine and plagioclase phenocrysts. The younger flow has small olivine phenocrysts (less than 5 millimeters (0.2 inch)) and rare glomerocrysts or phenocrysts of plagioclase. This texture varies from glassy to fine grained with distinct zones having a diabasic texture.

Both flows have distinct chemical compositions (see Table 3-3). The older flow is chemically similar to the Rosalia chemical type of Swanson et al. (1979b), while the younger flow is chemically similar to the Lolo chemical type of Wright et al. (1973). The Lolo flow has lower titanic oxide and higher iron oxide than the Rosalia flow.

Van Alstine and Gillett (1981) sampled a surface exposure of the Lolo flow in the Saddle Mountains for magnetic polarity. The flow was found to have a mean declination of 190.5 degrees and a mean inclination of minus 64.9 degrees (see Table 3-4). These data are comparable to the inclination of the Lolo flow in core drilled from the central Hanford Site sampled by Packer and Petty (1979). Packer and Petty (1979) also found the Rosalia flow from this core to have reversed magnetic polarity.

The Priest Rapids Member reaches its greatest thickness in an area between the northern flank of Rattlesnake Mountain and the Cold Creek syncline; it thins abruptly across the crest of Rattlesnake Mountain, along the Umtanum Ridge-Gable Mountain structure, and along a small, northwest-trending zone on the east side of the Cold Creek syncline.

The Rosalia and Lolo flows of the Priest Rapids Member are present throughout most of the Cold Creek syncline area. The lower flow, the Rosalia, is thickest in the trough of the Wahluke and Cold Creek synclines and thins across the Umtanum Ridge-Gable Mountain structure and Rattlesnake Mountain (see Fig. 3-1) (Reidel et al., 1980). It is thicker on the south side of the Cold Creek syncline and thins northward, abruptly pinching out near the southeast boundary of the Hanford Site.

The Lolo flow is also thicker on the southern margin of the Cold Creek syncline and thins across the Umtanum Ridge-Gable Mountain structure and Rattlesnake Mountain. The maximum thickness occurs in a northwest-southeast zone that parallels the present axis of the Cold Creek syncline. Evidence for ponding and slow cooling along the north side of Rattlesnake Mountain is apparent from areas where the basalt has a diabasic texture. The Lolo flow also pinches out on the east side of the Pasco Basin beyond the limits of the Hanford Site (Reidel et al., 1980).

3.2.2.5 Saddle Mountains Basalt

The Saddle Mountains Basalt in the Pasco Basin consists of the Umatilla, Wilbur Creek, Asotin, Esquatzel, Pomona, Elephant Mountain, and Ice Harbor Members (see Fig. 3-6). The Umatilla, Esquatzel, Pomona, and Elephant Mountain are the only members of the Saddle Mountains Basalt present in the reference repository location. The Saddle Mountains Basalt in the basin ranges in age from 13.5 to 8.5 million years before present (Watkins and Baksi, 1974; McKee et al., 1977; ARHCO, 1976).

The Saddle Mountains Basalt flows were erupted over a much greater interval of time than the flows of any other formation of the Columbia River Basalt Group (Swanson et al., 1979b) and contain widely diverse petrographic characteristics, chemical types, and magnetic inclinations. Vents for the Saddle Mountains Basalt have been recognized in eastern Washington, northeastern Oregon, and western Idaho (Taubeneck, 1970; Price, 1977; Ross, 1978; Swanson et al., 1979a).

Thickness variations in the Saddle Mountains Basalt are greater and more complex than in the Wanapum Basalt because of (1) thinning over structures, (2) greater time between eruptions, and (3) limited extent of many flows. Variations in data could also be attributable, in part, to the greater amount of information available for the Saddle Mountains Basalt than for other formations (Reidel et al., 1980).

Only the members of the Saddle Mountains Basalt present in the reference repository location (i.e., Umatilla, Esquatzel, Pomona, and Elephant Mountain) are discussed below. Information on those members not present in the reference repository location can be found in Swanson et al. (1979b) and Reidel and Fecht (1981).

3.2.2.5.1 Umatilla Member

The Umatilla Member is approximately 70 meters (225 feet) thick in the reference repository location and consists of two flows in the Pasco Basin. Based on chemical correlations with the type localities described by Laval (1956), the younger flow is the Sillusi flow and the older flow

is the Umatilla flow (see Fig. 3-6). Both flows are fine grained to glassy with rare microphenocrysts of plagioclase and olivine and even rarer silicic xenoliths of basement rock.

The Umatilla and Sillusi flows have similar overall chemical compositions and fall into the Umatilla chemical type of Wright et al. (1973). Distinct differences in chemical composition, however, allow the flows to be distinguished. The Umatilla flow has higher titanic oxide, magnesium oxide, and lower phosphorus pentoxide than the Sillusi flow (see Table 3-3).

Rietman (1966, p. 33) found that the Umatilla Member has normal magnetic polarity. Van Alstine and Gillett (1981) found that the Umatilla and Sillusi flows have nearly identical mean declinations of 324.3 and 321.7 degrees and mean inclinations of plus 31.7 degrees and plus 32.2 degrees, respectively (see Table 3-4). They suggest that this indicates that the flows were erupted nearly contemporaneously.

The flows of the Umatilla Member entered the Pasco Basin from the south and filled the Cold Creek syncline. The overall geometry of the Umatilla Member is that of a wedge that thins to the north. The member pinches out just north of the Umtanum Ridge-Gable Mountain structure and just east of the Cold Creek syncline (Reidel et al., 1980). It is much thinner on the crest of Rattlesnake Mountain and Yakima Ridge (see Fig. 3-1). Thinning is also apparent across the subsurface extensions of Gable Mountain and Gable Butte.

The Umatilla and Sillusi flows are present throughout most of the Cold Creek syncline. The Umatilla flow is the thicker flow in the western and southern parts of the syncline, but the Sillusi flow is the only flow present in the eastern part and is the thicker flow in the northern part of the syncline. The western part of the Cold Creek syncline was covered first by the Umatilla flow; the Sillusi flow was later directed along the northern and eastern margins of the Umatilla flow with some onlap. This distribution was probably a result of the Sillusi flow filling the low area formed between the gently westward-dipping regional paleoslope and the northward-tapering margin of the Umatilla flow.

3.2.2.5.2 Esquatzel Member

The Esquatzel Member in the Pasco Basin consists of one to two flows or flow lobes that total approximately 70 meters (225 feet) thick in the reference repository location. In the eastern Cold Creek syncline, there are two Esquatzel flows or flow lobes that occur locally with a vitric tuff between them.

The Esquatzel Member is plagioclase-phyric to glomerophyric and contains microphenocrysts of clinopyroxene. The abundance of phenocrysts varies throughout the Cold Creek syncline area; some localities are completely void of phenocrysts.

The average chemical composition of the Esquatzel Member is given in Table 3-3 and falls within the Esquatzel chemical type of Swanson et al. (1979b). Van Alstine and Gillett (1981) indicated that flows of the Esquatzel Member have normal polarity with a mean declination of 348.4 degrees and a mean inclination of plus 64.8 degrees (see Table 3-4). These results are similar to those determined by Choiniere and Swanson (1979).

Flows of the Esquatzel Member entered the Pasco Basin from the east near Mesa, Washington, in a channel that was cut into the Priest Rapids Member (Swanson et al., 1979a; Reidel et al., 1980). It is confined to the southern and eastern parts of the Pasco Basin and pinches out along and north of the Umtanum Ridge-Gable Mountain structure. It is thicker in the western Cold Creek syncline area north of the eastern extension of the Yakima Ridge anticline. It also thins across the extension of the Yakima Ridge and Rattlesnake Mountain structures and pinches out just south of the present crest of Rattlesnake Mountain. The Esquatzel Member flowed out of the Pasco Basin in channels to the west (Goff, 1981; Goff and Myers, 1978; Reidel et al., 1980).

Several factors probably controlled the distribution of the Esquatzel Member in the Cold Creek syncline. First, the margin of the Huntzinger flow of the Asotin Member (see Fig. 3-6) formed a barrier that prevented the Esquatzel Member from spreading across the northern Pasco Basin. The channel that the Esquatzel Member occupies near Mesa, Washington, is probably part of the same channel that is now filled by sediments along the southern margin of the Huntzinger flow in the Cold Creek syncline. The Umtanum Ridge-Gable Mountain structure was a structural high that influenced the spread of the Esquatzel Member to the west, as indicated by the absence of this member west of Gable Butte. Rattlesnake Mountain was also important in controlling flows of the Esquatzel Member, as evidenced by its pinchout near the present crest.

3.2.2.5.3 Pomona Member

The Pomona Member has been dated at 12 million years before present (McKee et al., 1977). The member consists of one to two flows or flow lobes in the Pasco Basin, but only one flow approximately 80 meters (260 feet) thick is present in the reference repository location.

The texture of the Pomona Member is relatively uniform across the Pasco Basin. It typically is fine grained to glassy with wedge-shaped plagioclase phenocrysts and rare olivine.

The Pomona Member has a distinct chemical composition (Pomona chemical type of Wright et al., 1973) with little overall variance (see Table 3-3). The member has reversed magnetic polarity (Rietman, 1966, p. 67; Choiniere and Swanson, 1979). This polarity was corroborated by Van Alstine and Gillett (1981), who also found that the Pomona Member has the tightest inclination and declination grouping of any flow analyzed

from the Columbia River Basalt Group. The Pomona Member has a mean declination of 193.5 degrees and a mean inclination of minus 52.7 degrees (see Table 3-4).

The Pomona Member is present throughout most of the Pasco Basin and reaches its greatest thickness in the southeast portion of the Cold Creek syncline and just north of Gable Mountain in the Wahluke syncline. The Pomona Member thins over the Umtanum Ridge-Gable Mountain structure, Rattlesnake Mountain, and Yakima Ridge.

The volume of Pomona lava that was flowing into the Pasco Basin was considerably greater than that of the Umatilla and Esquatzel Members. This volume overcame any effects of flow edges and topography; the Pomona flow buried the topography of the Cold Creek syncline and much of the Pasco Basin.

3.2.2.5.4 Elephant Mountain Member

The Elephant Mountain Member has been dated at 10.5 million years before present (McKee et al., 1977) and consists of two separate flows: (1) Elephant Mountain flow (Waters, 1955, 1961) and (2) Ward Gap flow (Schmincke, 1967b). Only the Elephant Mountain flow is present in the reference repository location and is approximately 25 meters (80 feet) thick.

The texture of these flows is medium to fine grained with abundant microphenocrysts of plagioclase. Where lava ponded, the flows exhibit a coarse-grained texture. Both flows (see Table 3-3) fit the Elephant Mountain chemical type of Wright et al. (1973).

Choiniere and Swanson (1979) and Rietman (1966) reported that the Elephant Mountain Member has transitional to normal magnetic polarity. Van Alstine and Gillett (1981) sampled surface exposures and found that both flows yielded a mean declination of 133.2 degrees and a mean inclination of minus 39.2 degrees (see Table 3-4).

The Elephant Mountain Member is stratigraphically younger than the Rattlesnake Ridge interbed of the Ellensburg Formation, but in many areas an invasive relationship between basalt and sediment has been observed. Both Elephant Mountain Member flows pinch out in the northwest part of the Cold Creek syncline. The member is thicker in the eastern part of the Cold Creek syncline area and thins toward Rattlesnake Mountain. The Elephant Mountain flow has a greater lateral extent than the Ward Gap flow, but both flows pinch out near the northwest corner of the reference repository location. The Elephant Mountain Member is the uppermost basalt unit over most of the Cold Creek syncline on the Hanford Site.

3.2.2.6 Ellensburg Formation

The Ellensburg Formation is a Miocene fluvial sequence with local volcanic lahars. The formation is relatively thick along the western margin of the Columbia Plateau and thins eastward onto the central portion of the plateau. Within the Pasco Basin and reference repository location, Ellensburg Formation sediments are primarily interbedded with the Wanapum and Saddle Mountains Basalts. The nomenclature for the Ellensburg Formation in the Pasco Basin is presented in Figure 3-6. The lateral extent and thickness of the sediments generally increase upward in the section.

The Ellensburg Formation of the central Columbia Plateau is interbedded with the Columbia River Basalt Group and is composed of two major and distinct lithologies of different provenance (Schmincke, 1964, 1967a; Swanson et al., 1979b). One includes volcaniclastic sediments deposited as ashfall and by tributary rivers flowing onto the central portion of the plateau. The other includes clastic, plutonic, and metamorphic rock derived from Rocky Mountain terrain that was carried onto the plateau by westward-flowing ancestral rivers. These two major lithologies occur either as distinct or mixed deposits within the Ellensburg Formation of the Pasco Basin. Additional data on the Ellensburg Formation in the Pasco Basin, including the major interbeds (i.e., Vantage, Mabton, Cold Creek, Selah, and Rattlesnake Ridge), are discussed in Myers, Price et al. (1979) and Reidel and Fecht (1981). The stratigraphic and geochemical characteristics of the Ellensburg Formation in the Pasco Basin have not as yet been studied in detail. Determination of these characteristics is included in plans for site characterization (Section 4.1.1).

3.2.2.7 Ringold Formation

The Ringold Formation overlies the Columbia River Basalt Group in the central Columbia Plateau and within most of the Pasco Basin (see Fig. 3-6), except where (1) basalt crops out, (2) glaciofluvial Hanford Formation laps onto ridges above the margin of the Ringold Formation, or (3) Ringold Formation has been eroded and Hanford Formation sediments have been deposited directly on basalt. Ringold Formation sediments were deposited in a fluvial environment with some lacustrine and fanglomerate facies. Based on fossils and paleomagnetic data in the Pasco Basin, the Ringold Formation has been interpreted to range from 8.5 million years (post-Ice Harbor Member) to 3.7 million years in age (Tallman et al., 1981, pp. 2-25). A minimum age for the Ringold Formation may be as young as 3 million years before present. This age is based on a major paleomagnetic boundary (Gauss-Gilbert epoch boundary) that is dated at 3.4 million years before present (Mankinen and Dalrymple, 1979) and lies approximately 30 meters (100 feet) below the top of the Ringold Formation along the White Bluffs.

The Ringold Formation in the Pasco Basin is classified into three section types (Tallman et al., 1981, pp. 2-3 through 2-7) (Fig. 3-16). The Ringold Formation in the reference repository location is represented primarily as section Type I, which is composed of basal, lower, middle, and upper textural units (Fig. 3-17). Within the reference repository location the Ringold Formation ranges from approximately 105 to 215 meters (350 to 700 feet) in thickness. The following discussion is based on borehole studies by Bjornstad (1984) of the Ringold Formation and other suprabasalt sediments in the reference repository location. The suprabasalt stratigraphy was developed using the potassium-argon age-dating technique on core from boreholes within and adjacent to the reference repository location (see Fig. 3-7).

In the reference repository location, the basal Ringold unit overlies the Elephant Mountain Member of the Saddle Mountains Basalt (see Fig. 3-17). The basal Ringold unit represents a complete fining-upward, fluvial cycle consisting of three correlative subunits. These are from oldest to youngest: (1) A coarse facies, (2) a fine facies, and (3) a paleosol. The coarse facies is composed of an angular medium to coarse sand and well-rounded, polished, cobble gravel. Secondary fining-upward cycles are common within the basal Ringold unit coarse facies, but occur locally and are not usually correlative from one borehole to another.

Overlying the basal Ringold unit, coarse facies is a conformable sequence of cross-laminated and micaceous, light-colored mud (i.e., mixture of silt and clay) and sand that marks the transition to a lower energy fluvial environment. This facies grades upward into and is capped by a well-developed laterally extensive paleosol. The paleosol is composed of massive, olive-colored, bioturbated mud. Caliche stringers and nodules are common in the lower part of the paleosol.

Laminated silt and clay of the lower Ringold unit overlie the basal Ringold unit in the reference repository location where the lower Ringold is disconformable with the basal Ringold unit paleosol and is distinguishable by (1) the presence of primary sedimentary structures, (2) a distinct gray versus olive color, and (3) a significantly higher natural gamma response in geophysical logs.

The middle Ringold unit, the thickest of the suprabasalt units, is unconformable with the lower Ringold unit with up to several meters (feet), locally, of erosional relief. The middle Ringold unit is texturally and mineralogically similar to sandy gravel of the basal Ringold facies (Tallman et al., 1981, pp. 2-13 through 2-19), except for a higher proportion of quartzite to volcanic porphyry lithologies for the middle Ringold unit. Locally, the middle Ringold unit sequence is intercalated with thin zones of current-laminated sand and mud.

The upper Ringold unit conformably overlies the middle Ringold unit in the reference repository location (see Fig. 3-17). It consists of alternately bedded and laminated sand and mud representative of a low-energy fluvial environment. The maximum elevation of the upper Ringold unit over the reference repository location was probably much

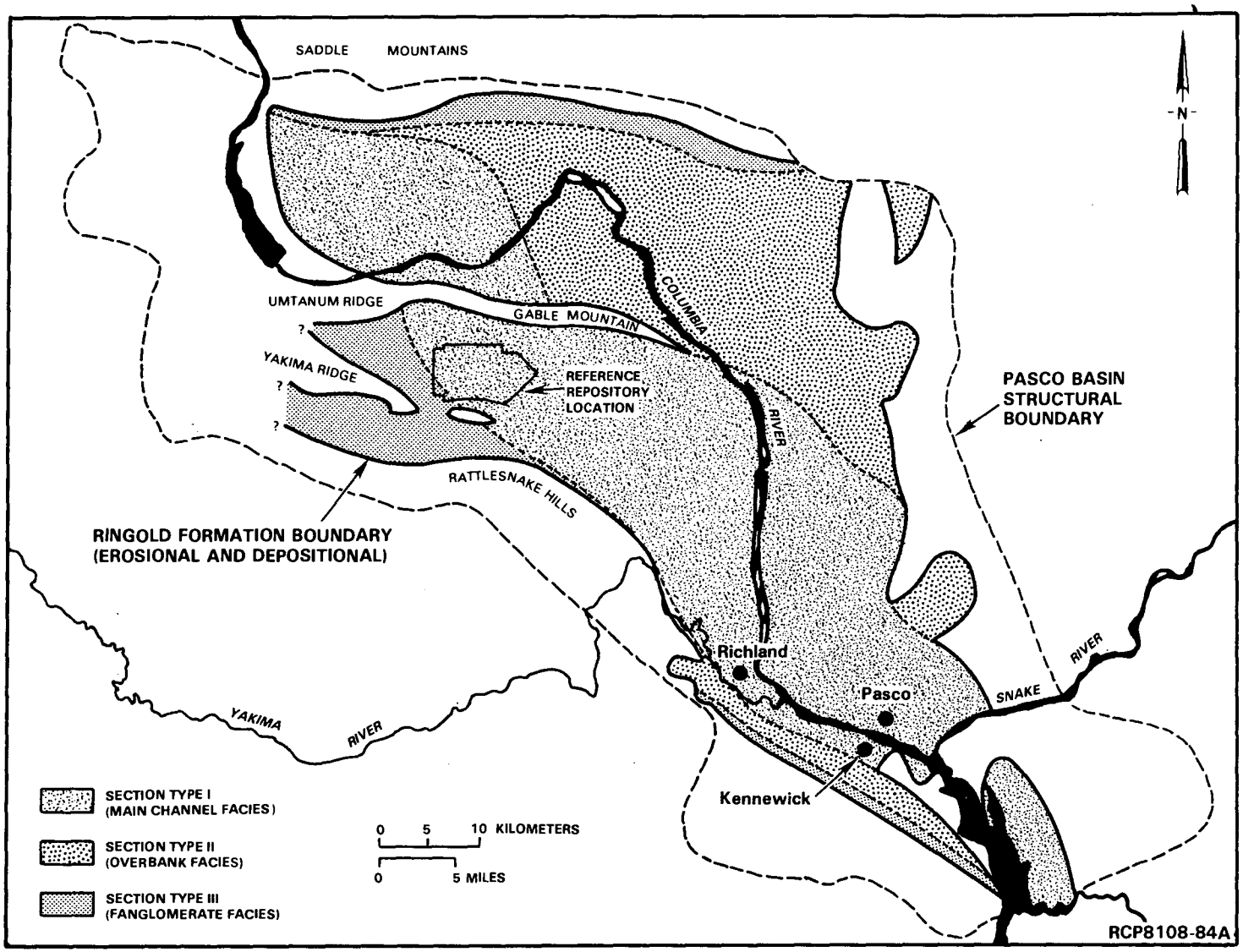

Figure 3-16. Distribution of Ringold Formation section types.

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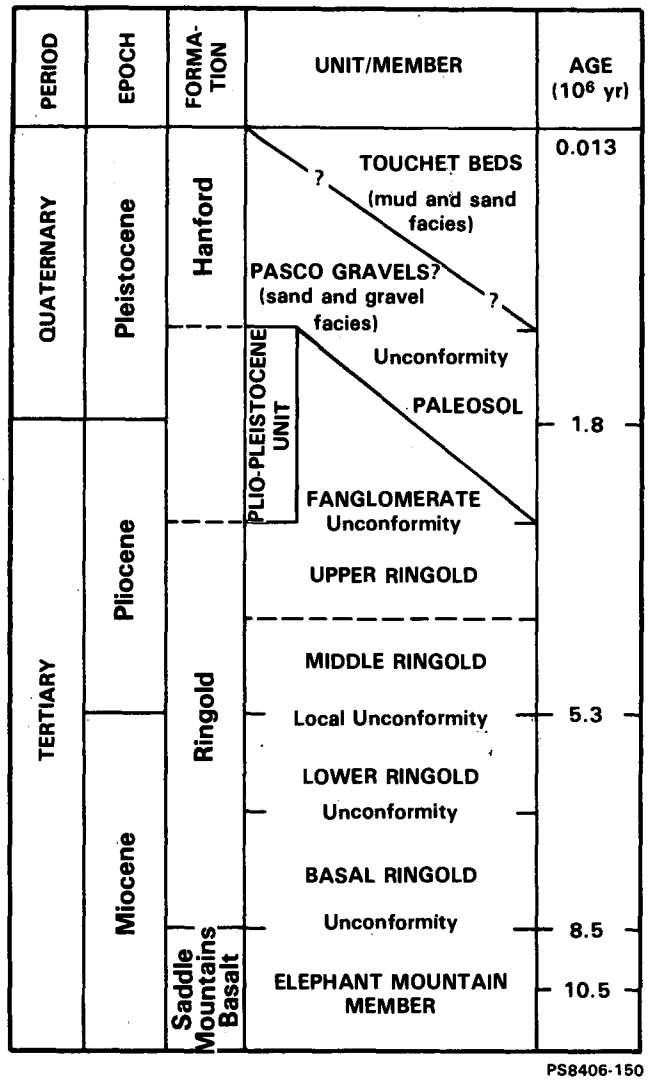

Figure 3-17. Suprabasalt stratigraphy in the reference repository location.

higher at one time as indicated by the present elevation (277 meters (900 feet)) of the upper Ringold unit preserved in the White Bluffs to the east. The large variations in thickness of the upper Ringold unit in the reference repository location are primarily due to erosion by more recent local streams. Figure 3-18 shows an incised paleostream channel in the Ringold Formation that generally parallels the axis of the Cold Creek syncline.

3.2.2.8 Plio-Pleistocene unit

Overlying the Ringold Formation in the reference repository location is the Plio-Pleistocene unit that consists of two subunits: A fanglomerate and a paleosol (see Fig. 3-17) (Bjornstad, 1984). The fanglomerate facies is generally composed of angular, poorly sorted gravel derived from the mass wastage off the ridges surrounding the Cold Creek syncline. The basaltic gravel is often intercalated with zones of loess and caliche, which represent intermittent periods of alluvial fan stabilization. The fanglomerate facies is thickest (up to 24 meters (80 feet)) beneath the present Cold Creek Valley where coarse-grained sidestream facies partially filled a paleochannel. Within the reference repository location, the fanglomerate facies becomes thinner and finer grained to the northeast where it grades into a paleosol, which developed after incision of the Ringold surface. The Plio-Pleistocene unit appears to correlate with fanglomerate sequences present along the flanks of the basaltic ridges that bound the Pasco Basin on the north, west, and south.

3.2.2.9 Hanford Formation

Catastrophic flood deposits of the Hanford Formation were deposited when ice dams in western Montana and northern Idaho were breached, allowing large volumes of water to spill across eastern and central Washington (Bretz, 1923, pp. 51 through 55). Evidence exists for multiple floods; however, the exact timing and frequency of these floods are undetermined (Baker, 1973, pp. 123 and 124; Waitt, 1980). Most of the sediments are late Pleistocene, with the last major flood sequence dated at approximately 13,000 years before present (Mullineaux et al., 1977, p. 1105). These deposits (referred to as the Hanford Formation in the Pasco Basin), which are up to 50 meters (165 feet) thick, are composed of two facies: A flood facies (Pasco gravels) and slackwater facies (Touchet Beds) (see Fig. 3-6 and 3-17).

Pasco gravels are composed of coarse sand and gravel. They are restricted mainly to the Pleistocene flood bars that developed along high-energy flood channel ways. Two such flood bars are present within the reference repository location: The Umtanum Ridge bar to the north and the 200 Areas bar, which is a continuation of the Umtanum Ridge bar, to the southeast (see Section 3.2.1). The Pasco gravels have been subdivided

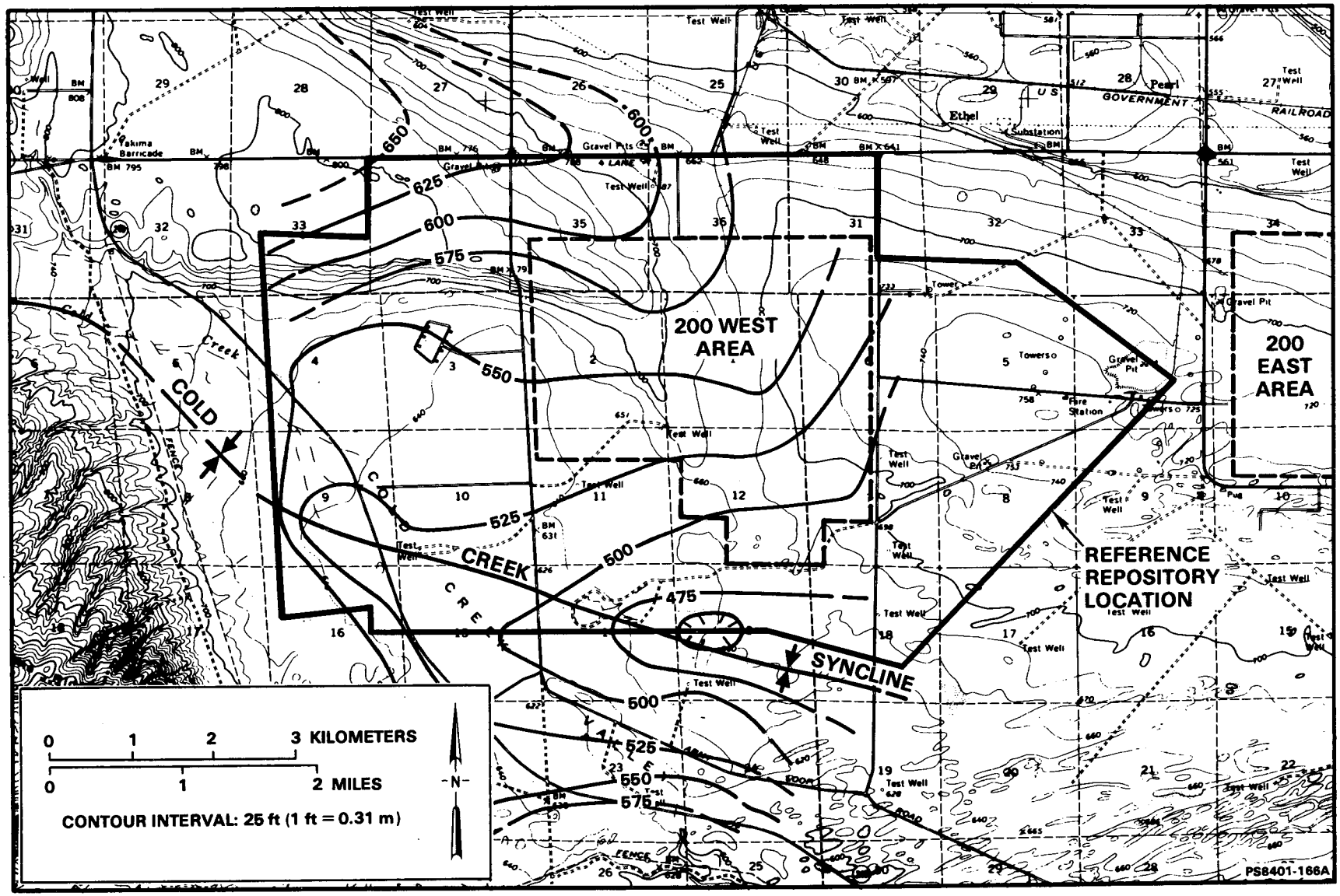

Figure 3-18. Top of the Ringold Formation. Contour pattern indicates maximum post-Ringold incision occurred near the trend of the present Cold Creek Valley.

7 0 1 6 8 0 6 9 0

into the Missoula and pre-Missoula gravels by Puget Sound Power & Light Company (PSPL, 1982, pp. 2R-22 and 2R-23) in the central Hanford Site. There is no evidence for pre-Missoula gravels in the reference repository location.

Touchet beds are a rhythmically bedded and fine-grained slackwater flood facies deposited away from the flood bars and generally coeval with the Pasco gravels. They are most common in the southern and western parts of the reference repository location and to the east where they underlie Pasco gravels associated with the 200 Areas flood bar.

3.2.3 STRUCTURE AND TECTONICS

The data base for interpreting the geologic structure in and around the reference repository location includes site-specific and Pasco Basin information. The site-specific information includes the following:

- Approximately 32 kilometers (20 miles) of seismic refraction lines.
- Approximately 22 kilometers (14 miles) of seismic reflection lines.
- Approximately 130 kilometers (80 miles) of ground magnetic lines.
- Approximately 2,000 gravity measurement stations.
- Borehole data (see Section 3.2.2).

Pasco Basin information includes:

- Geologic mapping of 5,180 square kilometers (2,000 square miles) of the Pasco Basin at a scale of 1:62,500.
- More than 1,600 kilometers (1,000 miles) of geophysical lines.
- Approximately 12,000 gravity measurement stations.
- Extensive borehole data (see Section 3.2.2).

The Pasco Basin and reference repository location are located along the eastern boundary of the Yakima Fold Belt structural subprovince (see Fig. 2-7). Structures in the Pasco Basin area are characterized by long, narrow anticlines and broad synclines extending generally eastward from the western Columbia Plateau to the Pasco Basin where they generally die out (Fig. 3-19, Table 3-5). Most known faults within the region are associated with anticlinal fold axes, thrust to reverse faults (although normal faults are also present), and probably developed concurrently with folding. Anticlinal folds bound the Pasco Basin on the north (Saddle Mountains) and south (Rattlesnake Hills) and plunge eastward to the Pasco Basin from the west (Umtanum and Yakima Ridges) (see Fig. 3-18).

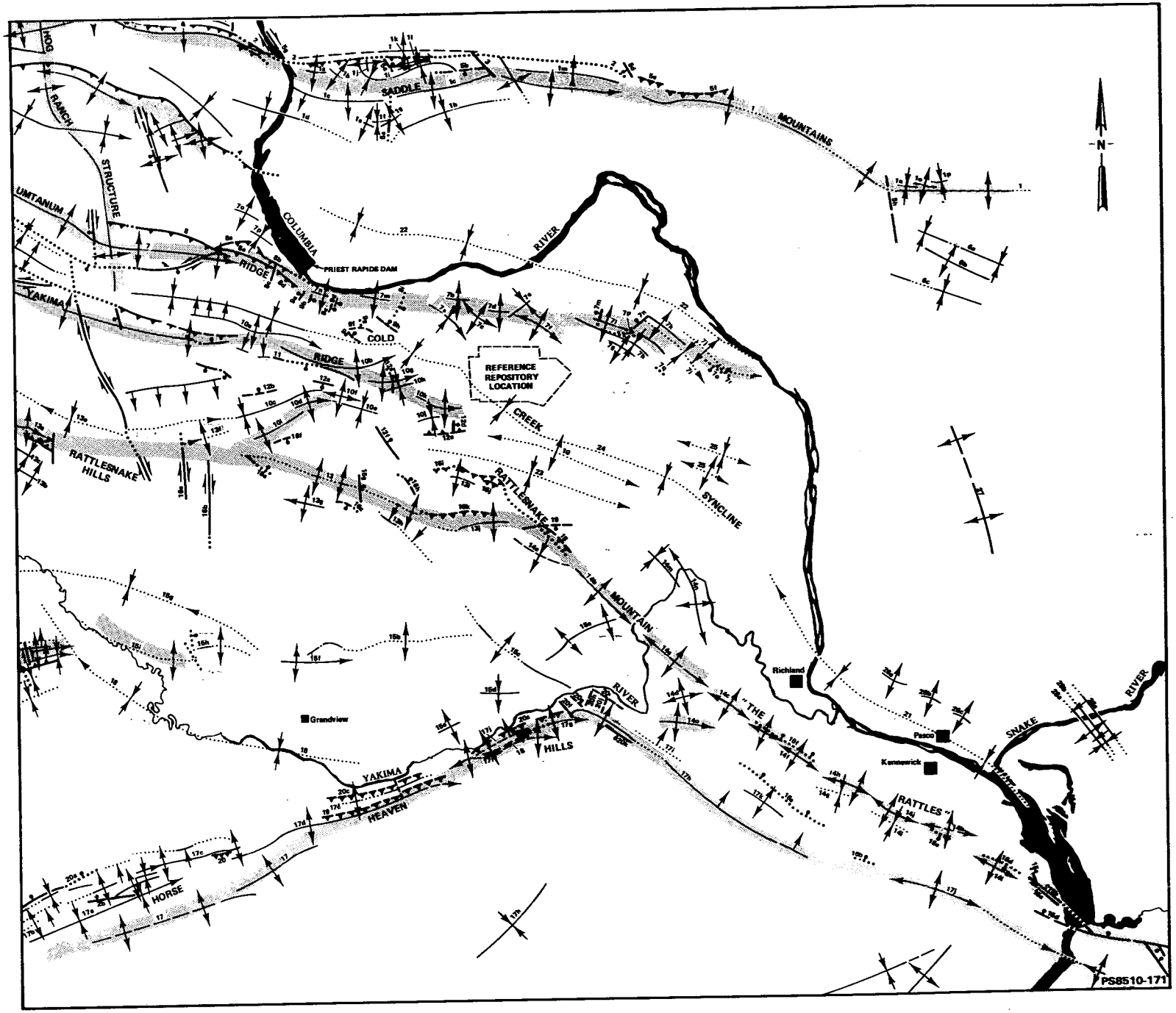

Figure 3-19. Generalized geologic structure map of central Columbia Plateau. Numbers on this map are keyed to Table 3-5. (sheet 1 of 2)

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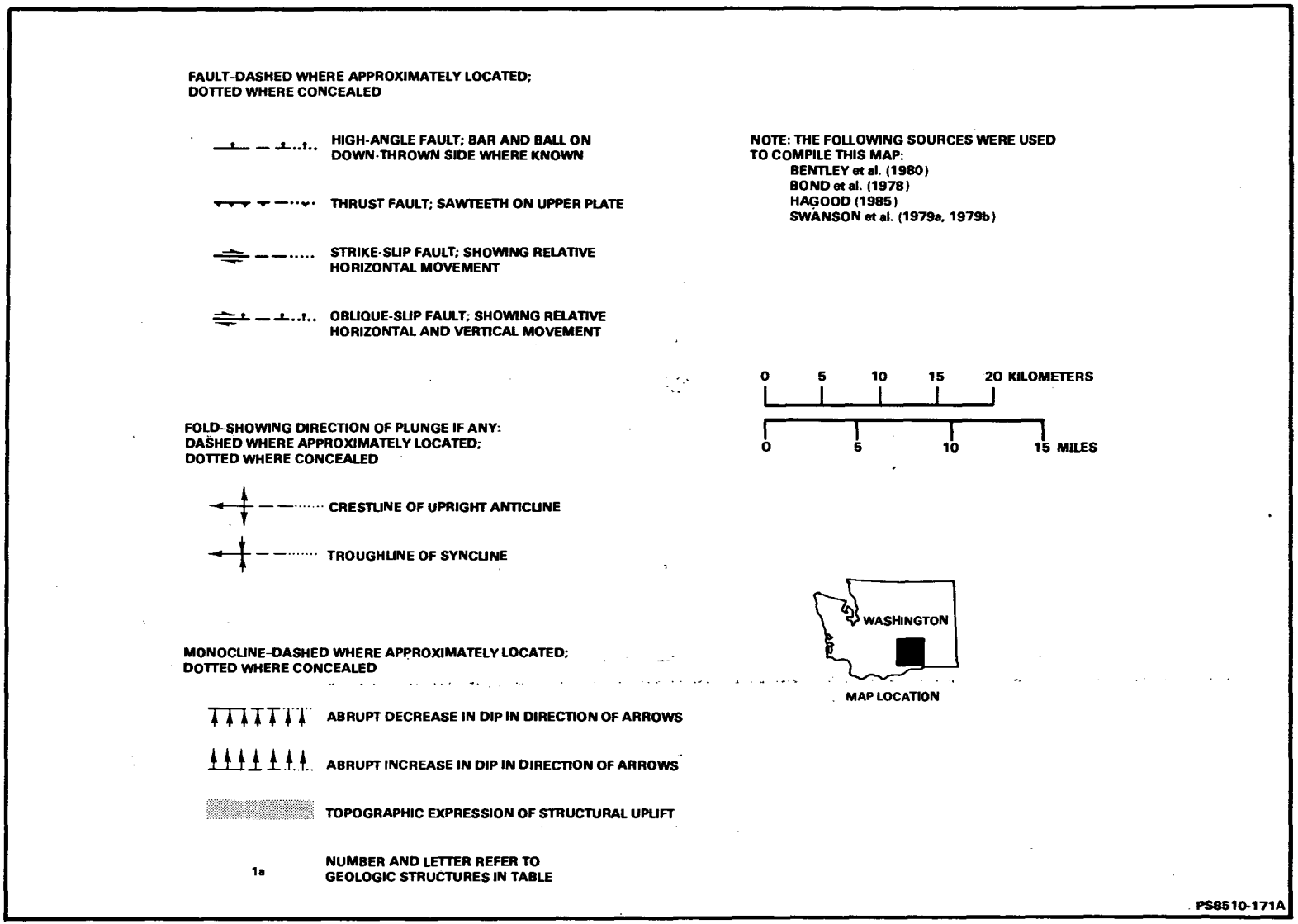

Figure 3-19. Generalized geologic structure map of central Columbia Plateau. Numbers on this map are keyed to Table 3-5. (sheet 2 of 2)

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Table 3-5. Characteristics of folds and faults within or near the Pasco Basin (sheet 1 of 9)

Primary structure	Secondary structure	Map number (Fig. 3-19)	Minimum distance from RRL (km)	Fold characteristics		Fault characteristics				References
				Length (km)	Geometry	Length (km)	Strike/dip	Type of displacement	Age of latest displacement	
Saddle Mountains anticline		1	26	110	Asymmetric, amplitude to 600 m, plunges to E., E.-SE. trend, gentle to open, box fold in part, faulted on north side, second-order folds trend E.-W. to NW.-SE.					Myers, Price et al. (1979), Price (1982), Reidel (1978, 1984)
	Related folds or structure	1a-1p	23	3-11						
	Saddle Mountains fault	2	29			>40	E.-W./ 45° or less west side Sentinel Gap; 45° at Smyrna Bench	Reverse fault at base of the Saddle Mountains structure. Maximum stratigraphic displacement 600 m; maximum shortening 3 km on west side of Sentinel Gap	<10.5 m.y.	Reidel (1978, 1984), Grolier and Bingham (1978)
	Smyrna fault	3	26			2	NW./vertical	Tear fault that separates Smyrna Bench and Sentinel Gap segments of Saddle Mountains	<10.5 m.y.	Reidel (1978, 1984)
	Hansen Creek fault	4	29			~5	E.-W./S.	Interpreted to be a high-angle reverse fault, displaces Priest Rapids against Frenchman Springs flows	<14 m.y.	Bentley (1977), Myers, Price et al. (1979)
	Unnamed faults	5a-5h	23			4-5	E.-W./ unknown and N.-S./ unknown	High-angle normal; high-angle reversed; tear faults. See Grolier and Bingham (1971) for alternative mapping; superseded by Reidel (1984)	<12 m.y.	Myers, Price et al. (1979), Reidel (1984)

7 0 1 6 8 0 6 8 5

Table 3-5. Characteristics of folds and faults within or near the Pasco Basin (sheet 2 of 9)

Primary structure	Secondary structure	Map number (Fig. 3-19)	Minimum distance from RRL (km)	Fold characteristics		Fault characteristics				References
				Length (km)	Geometry	Length (km)	Strike/dip	Type of displacement	Age of latest displacement	
Saddle Mountains anticline (cont.)	Related folds on south side of structure	6a-6c	34	3	Low amplitude <30 m; >1-km wavelength					Reidel (1984)
Umtanum Ridge-Gable Mountain structure		7	3	130	Asymmetric, E.-W. trend, first-order fold, segmented, plunging at east end, open to tight					Myers, Price et al. (1979), PSPL (1982)
	Folds related to Umtanum Ridge	7a-7p	2	2-5	Asymmetric, amplitude to 750 m, variable plunge, E.-W. to W.-NW., E.-SE. trend, open to tight, box fold in parts					Goff (1981), Myers, Price et al. (1979), Price (1982)
	Umtanum fault and fault zone	8 8b-8e	18			>12	N. 60° W./30° to 40°S.	Reverse, dip-slip, displacement on order of 150 m vertical and 300 m horizontal	>13,000 yr B.P.	Goff and Myers (1978), Price (1982), PSPL (1982)
	North reverse fault	8a	24			1.5	NW./inferred toward S.	Reverse, inferred	Post-Wanapum Basalt/pre-Ellensburg growth	PSPL (1982)
	Reverse (?) fault	8b	18			Un-known	Unknown	Reverse, inferred	<14 m.y.	PSPL (1982)
	Twin fault	8c	21			>0.6	NE./ unknown	Interpreted to be tear fault within Umtanum anticline	<14 m.y.	Myers, Price et al. (1979), PSPL (1982)
	Buck thrust	8d	19			2.6	N. 50°-N. 80° W./gently NE.	Thrust, zone 9 to 15 m thick, dies out in Umtanum anticline, 250-m displacement	<15.5 m.y.	Price (1982)
	Upper reverse	8e	21			~2.4	N. 60°E./S.	Thrust, similar to Buck thrust	<15.5 m.y.	PSPL (1982)

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Table 3-5. Characteristics of folds and faults within or near the Pasco Basin (sheet 3 of 9)

Primary structure	Secondary structure	Map number (Fig. 3-19)	Minimum distance from RRL (km)	Fold characteristics		Fault characteristics				References
				Length (km)	Geometry	Length (km)	Strike/dip	Type of displacement	Age of latest displacement	
Umtanum Ridge-Gable Mountain structure (cont.)	Umtanum Ridge cross faults	9a-9i	8			<1	NW.-SE. and N.-S./ unknown	All normal cross faults of the Umtanum anticline, displacements of a few meters	<12 m.y.	Goff (1981)
		9j	27			7 km		Tear fault		Swanson et al. (1979a)
	Folds related to Gable Butte	7a-7f	2	1-5	Symmetric, amplitude to 150 m, generally plunge to SE., W.-NW., E.-SE. to E.-NE., W.-SW. trend, open, rounded hinges					Fecht (1978), PSPL (1982)
	Folds related to Gable Mountain	7g-7l	5	≤13	Asymmetric to symmetric, amplitude to 300 m, most plunge to SE., W.-NW., E.-SE. to NW.-SE. trend, open to tight, rounded to angular hinges					Fecht (1978), PSPL (1982)
	West fault, Gable Mountain	7m	5			~0.8	N. 34°E./ steeply W.	Normal, stratigraphic throw <5 m	<10.5 m.y.	Fecht (1978), PSPL (1982)
	Central fault, Gable Mountain	7n	8			<3.2	N. 55°E./30°S.	Reverse, 50-m dip-slip displacement, variable displacement with depth	13,000 yr B.P.	Fecht (1978), PSPL (1982)
	South fault, Gable Mountain	7o	13			≤1.2	E.-W./35° to 40°S.	Reverse, displacement 12 m	<10.5 m.y.	PSPL (1982)
	North-dipping fault, Gable Mountain	7p	6			Unknown	N. 65°W./ 13°N.	Reverse, 9.1 to 15.2 m wide in drill holes, stratigraphic throw 98 m	<10.5 m.y.	PSPL (1982)

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Table 3-5. Characteristics of folds and faults within or near the Pasco Basin (sheet 4 of 9)

Primary structure	Secondary structure	Map number (Fig. 3-19)	Minimum distance from RRL (km)	Fold characteristics		Fault characteristics				References
				Length (km)	Geometry	Length (km)	Strike/dip	Type of displacement	Age of latest displacement	
Umtanum Ridge-Gable Mountain structure (cont.)	DB-10 (upper) fault	7q	8			0.8	Due S./25° to 45°W.	Reverse, dip-slip, ~55-m displacement 2 m wide in drillhole	<10.5 m.y.	Myers, Price et al. (1979), PSPL (1982)
	Southeast anticline fault	7r	14			Un-known	N.39°W./ 30°SW.	Reverse fault based on borehole data	>730,000 yr B.P.	PSPL (1982)
Yakima Ridge anticline	Cairn Hope Peak anticline and related folds	10a-10k	2	≤75	Asymmetric, SE. plunge, W.-NW.-E.-SE. trend, E. end buried by sediments, eastern exposed part is series of an echelon, doubly plunging, asymmetric folds					Bond et al. (1978), Goff (1981), Myers, Price et al. (1979), Cochran (1982)
	Silver Dollar fault	11	11			~7	W.-NW./ unknown	Interpreted to be high-angle-reverse fault (or normal), zone width 50 to 70 m, displaces Frenchman Springs Member against Umatilla and Pomona Members	<14 m.y.	Goff (1981), Myers, Price et al. (1979)
	Other Yakima Ridge faults	12a-12f	3			≤1	Variable	Reverse and tear faults; small faults associated with larger folds	<10.5 m.y.	Myers, Price et al. (1979)
Rattlesnake Hills-Rattlesnake Mountain uplift	Rattlesnake anticline, western segment	13, 13a-13j	11 8	56	Asymmetric, E.-W. trend, tight, rounded hinge, numerous second-order folds on hinge and crest					Bond et al. (1978), Myers, Price et al. (1979)
	Rattlesnake anticline, eastern segment	14a-14l	14	70	Asymmetric, NW.-trending series of doubly plunging, slightly en echelon, locally faulted folds. #14a is asymmetric, amplitude 350 m NW. trend, and faulted on north side					Bond et al. (1978), Jones and Landon (1978), Myers, Price et al. (1979)

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Table 3-5. Characteristics of folds and faults within or near the Pasco Basin (sheet 5 of 9)

Primary structure	Secondary structure	Map number (Fig. 3-19)	Minimum distance from RRL (km)	Fold characteristics		Fault characteristics				References
				Length (km)	Geometry	Length (km)	Strike/dip	Type of displacement	Age of latest displacement	
Rattlesnake Hills-Rattlesnake Mountain uplift (cont.)	Rattlesnake anticline, second-order folds on south limb	15a-15i	24	5 to 16	Variable plunge and trend					Bond et al. (1978), Myers, Price et al. (1979)
	Faults of western Rattlesnake Hills		18			<2	N.-S. and NW.-SE./ unknown	Minor dip-slip cross faults associated with larger anticlines. Displacements in tens of meters	<10.5 m.y.	Myers, Price et al. (1979)
	Maiden Springs fault	16c	29			~2.5	Unknown	Inferred, high-angle-reverse fault with 45 to 60 m displacement	<10.5 m.y.	Bond et al. (1978)
	Twenty-Nine-Thirty-Six fault	16g	13			4	N.-S./vertical	Scissor fault, west side up, 90 m displacement	<10.5 m.y.	Bond et al. (1978)
	Fault of central Rattlesnake Hills	16h	10			1.5	NW./ unknown	Vertically juxtaposes Priest Rapids and Pomona basalts	<10.5 m.y.	Bond et al. (1978)
	Thrust faults of Snively Basin area	16i-16k	7			>1	NW.-SE./ moderate	Not exposed, but Saddle Mountains Basalt section is repeated three times vertically with angular discordance at lower fault	<10.5 m.y.	Myers, Price et al. (1979)
	Rattlesnake Mountain fault	18	11			16 km	N.50°W./ steep	Probably reverse, 400 m vertical displacement, zone 100 m wide, includes upper local fault, dies out into Rattlesnake Mountain anticline to SE. Appears to merge with faults of Snively Basin	<10.5 m.y.	Bond et al. (1978), Myers (1981)

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Table 3-5. Characteristics of folds and faults within or near the Pasco Basin (sheet 6 of 9)

Primary structure	Secondary structure	Map number (Fig. 3-19)	Minimum distance from RRL (km)	Fold characteristics		Fault characteristics				References
				Length (km)	Geometry	Length (km)	Strike/dip	Type of displacement	Age of latest displacement	
Rattlesnake Hills-Rattlesnake Mountain uplift (cont.)	Rattlesnake Springs fault	12d	3			~1.5	N.-NE./ unknown	Inferred fault to account for geometry change of Yakima Ridge strike-slip	<10.5 m.y.	Myers, Price et al. (1979), Fecht et al. (1984)
	South Yakima Ridge normal fault	12e	3			1.5	E.-W./N.	Inferred reverse fault under south limb of Yakima Ridge	<10.5 m.y.	Myers, Price et al. (1979)
"The Rattles" brachyanticlines		14c, 14e-14l	24	3-10	Aligned asymmetric doubly plunging anticlines (brachyanticlines); NW.-SE. trend; represent the SE. part of the Rattlesnake-Wallula alignment					Myers, Price et al. (1979), WPPSS (1977, 1981)
	Related folds	14d, 14m-14o	32		Second-order asymmetric anticlines and synclines paralleling "The Rattles"					Myers, Price et al. (1979)
	Wallula Gap fault	15d	66			50	NW./steep	Maximum vertical offset 330 m, scissor-type displacement, last movement horizontal. Fault zone ~330 m wide	>13,000 yr	Gardner (1977), Gardner et al. (1981), Farooqui (1979)
	Wallula fault	15b	67			~5	NW./steep	Splay extension of Wallula Gap fault (#15d) west of Columbia River		
	Other faults	15a,15c	40			variable up to 8	Generally NW. to W.-NW./ unknown	Related to brachyanticlines; dip-slip movements up to 50 m; includes faulting at Finley Quarry (#16d)	At least 7,000 yr at Finley Quarry	Jones and Landon (1978), Bond et al. (1978a), Farooqui and Thoms (1980)

Table 3-5. Characteristics of folds and faults within or near the Pasco Basin (sheet 7 of 9)

Primary structure	Secondary structure	Map number (Fig. 3-19)	Minimum distance from RRL (km)	Fold characteristics		Fault characteristics				References
				Length (km)	Geometry	Length (km)	Strike/dip	Type of displacement	Age of latest displacement	
Horse Heaven Hills uplift (western segment)		17	32	>80	Asymmetric, ~200-m amplitude, NE.-SW. trend, open, monoclinal northern hinge. Complex with many segments					Bond et al. (1978), Myers, Price et al. (1979). See Hagood (1985) for most recent interpretation
	Prosser anticline	17d	34	24	Asymmetric, double hinged, N.70 to 80°E. trend, northeast plunge					Hagood (1985)
	Drake anticline	17c	37	11	Asymmetric, low-relief, double hinged, parallels Prosser anticline					Hagood (1985)
	Gibbon anticline	17f	33	12	Asymmetric, locally double hinged, N.70°E. trend, broad, may be en echelon with Prosser anticline					Hagood (1985)
	Chandler anticline	17g	32	7	Asymmetric, double hinged, N.70°E. to N.85°W. trend					Hagood (1985)
	Kiona anticline/ Badger Canyon anticline/ monocline	17h	31	29	Asymmetric, double hinged, W. to NW. trend					Hagood (1985)
	Phelps anticline/ monocline	17j	58	10	Asymmetric, NE. trend, monocline at northeast end					Hagood (1985)
	Gibbon fault	1B	32			5	NE./vertical	Reverse, juxtaposes Selah interbed against Levey interbed, 70-m vertical displacement	<10.5 m.y.	Hagood (1985)

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Table 3-5. Characteristics of folds and faults within or near the Pasco Basin (sheet 8 of 9)

Primary structure	Secondary structure	Map number (Fig. 3-19)	Minimum distance from RRL (km)	Fold characteristics		Fault characteristics				References
				Length (km)	Geometry	Length (km)	Strike/dip	Type of displacement	Age of latest displacement	
Horse Heaven Hills uplift (western segment) (cont.)	Prosser fault	19	37			13	NE./ unknown	Interpreted fault to account for topographic relief along Horse Heaven Hills	<10.5 m.y.	Hagood (1985)
	Phelps fault	20c	31			10	NE./ moderate	Thrust or reverse, juxtaposes Pomona against Elephant Mountain	<10.5 m.y.	Hagood (1985)
	Other faults of western Horse Heaven Hills	20a-20k	28			Variable	Variable	Small faults on north slope of Horse Heaven Hills, partly owing to landsliding	<8.5 m.y.	Hagood (1985)
Horse Heaven Hills uplift (eastern segment)		17h, 17j	32	70	Asymmetric, doubly plunging, NW.-SE. to W.-NW.-E.-SE. trend, gentle to open					Bond et al. (1978), Jones and Landon (1978), Myers, Price et al. (1979). See Hagood (1985) for most recent interpretation
	Webber Canyon anticline	17k	40	5	Western extension of Webber Canyon monocline					Hagood (1985)
	Webber Canyon anticline/ monocline	17i	34	5	Subtle, low-relief, NW. trend					Hagood (1985)
	Badger Coulee fault, Webber Canyon fault	16a,16b	40, 55			5, 9	NW./vertical	Faults of the Badger Canyon monocline. Maximum vertical displacement 80 m down to NE.	Unknown	Hagood (1985), Bond et al. (1978)

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Table 3-5. Characteristics of folds and faults within or near the Pasco Basin (sheet 9 of 9)

Primary structure	Secondary structure	Map number (Fig. 3-19)	Minimum distance from RRL (km)	Fold characteristics		Fault characteristics				References
				Length (km)	Geometry	Length (km)	Strike/dip	Type of displacement	Age of latest displacement	
Pasco syncline		21	~25	>40	Symmetric, SE. curvilinear trend, not exposed					Myers, Price et al. (1979)
Wahluke syncline		22	~8	~40	Asymmetric, plunges SE. from the NW. and to the NW. from the SE. end of structure, not exposed					Myers, Price et al. (1979)
Benson Ranch syncline		23	~5	~25	Asymmetric, low amplitude, SE. plunge, E.-W. to NW.-SE. trend, not exposed					Myers, Price et al. (1979); Myers and Price (1981)
Cold Creek syncline		24	0	60	Asymmetric, low amplitude, 3° to 5° SE. plunge, W.-NW.-E.-SE. trend, gentle, two depressions along trough					Myers, Price et al. (1979); Myers and Price (1981)
Related anticlines		25	13	5	W.-NW. trending					Myers (1981)
Folds of the Eastern Pasco Basin (Palouse subprovince), including Jackass Mountain		26a, 26c, 27, 28a-28c	42	3 to 6.5	Low-amplitude folds on the Palouse slope, W.-NW.-E.-SE. and N.-NW.-S.-SE. trends, parallel to Pasco syncline					Myers, Price et al. (1979)

NOTE: 1 meter = 3.28 feet.
1 kilometer = 1.62 miles.
RRL = reference repository location.
B.P. = before present.
m.y. = million years.

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Structural relief on the basaltic ridges is up to approximately 1,200 meters (3,937 feet); the wavelengths are typically 5 to 10 kilometers (3 to 6 miles). These anticlinal folds typically are concentric, gentle to tight, and upright to inclined. The gentle, upright folds are generally symmetric; whereas the tighter inclined folds are asymmetric, with the steeper limb sometimes vertical to overturned (Price, 1982, p. 12). Asymmetric folds are generally vergent to the north.

The Pasco Basin is elongate northwest-southeast, somewhat arcuate in form, and encompasses approximately 4,900 square kilometers (1,900 square miles) of the central Columbia Plateau (see Fig. 3-1). Main structural trends in the basin are easterly in the northwestern part and southerly in the southeastern part (see Fig. 3-19). The Saddle Mountains structure is convex to the north and forms the northern boundary of the basin. The southern boundary is formed by the Rattlesnake Hills structure, which is convex to the south. The geometry of the central portion of the basin reflects these two structures. In the northwestern part of the basin, the Wahluke syncline, Umtanum Ridge-Gable Mountain structure, Cold Creek syncline, Yakima Ridge anticline, and Benson Ranch syncline trend subparallel to the Saddle Mountains structure. The north Pasco structure and portions of the Pasco syncline reflect the Rattlesnake Hills structures. Structural relief decreases eastward from the western basin margin and many folds terminate within the central portion of the basin. The southeastern part is structurally less deformed by first-order folds than the southwestern part of the basin.

3.2.3.1 Wahluke syncline

The Wahluke syncline is a westerly trending trough that lies between the Saddle Mountains structure and the Umtanum Ridge-Gable Mountain structure. The syncline is relatively broad, as much as 13 kilometers (8 miles) in width. The trough line of the Wahluke syncline is much nearer the Umtanum Ridge-Gable Mountain structure than the Saddle Mountains structure; therefore, its cross section is asymmetric with a steep southern limb. The top of basalt is approximately 60 meters (200 feet) below mean sea level in the lowest part of the Wahluke syncline.

3.2.3.2 Umtanum Ridge-Gable Mountain structure

The Umtanum Ridge-Gable Mountain structure (see Fig. 2-8 and 3-19) extends from the east end of Gable Mountain on the Hanford Site westward and west-northwestward to southwest of Ellensburg, Washington, a distance of 110 kilometers (70 miles). The maximum structural relief approaches 880 meters (2,900 feet) and the wavelength of the ridge is approximately 8 kilometers (5 miles). The structure is divided into discrete segments. This discussion is confined to two segments within the Pasco Basin: Umtanum Ridge segment and Gable Butte and Gable Mountain segment.

The eastern Umtanum Ridge segment is an asymmetrical, overturned, plunging anticline whose crestal surface bifurcates into several subsidiary en echelon folds along the major fold trend (Goff and Myers, 1978; Goff, 1981). The fold is flanked by the Wahluke and Cold Creek synclines to the north and south, respectively. In the Priest Rapids Dam area (see Fig. 3-4), the fold is interpreted by Bentley (1980) to consist of three imbricate thrust slices in which the basalt is folded, overturned, and thrust over relatively undeformed Mabton-equivalent sediments of the Ellensburg Formation. Structural relief and complexity appear to decrease toward the central Pasco Basin. Here, the structure is interpreted by Goff (1981) as a simple, asymmetrical, eastward-plunging anticline with a steeply dipping north limb. Although the Umtanum fault is covered east of the Priest Rapids Dam area, fault displacement is expected to decrease as structural relief decreases. Current judgment is that the Umtanum fault probably dies out approximately 11 kilometers (7 miles) east of Priest Rapids Dam (Myers, 1981).

The Gable Mountain and Gable Butte are topographically isolated, second-order, anticlinal ridges of basalt and interbedded sediments that are the only extensive bedrock outcrops in the central Pasco Basin (see Fig. 3-19). Portions of this segment of the Umtanum Ridge-Gable Mountain structure have been mapped by Newcomb et al. (1972), Bingham et al. (1970), Washington Public Power Supply System (WPPSS, 1974, Fig. 2B-1a and 2B-1b), Brooks (1974), Fecht (1978), and Puget Sound Power & Light Company (PSPL, 1982, Section 20). The surface expression of Gable Mountain and Gable Butte is a series of westerly trending, doubly plunging, en echelon anticlines and synclines. These structures are interpreted as second-order folds within the closure of an asymmetrical first-order fold, consistent with the interpretation of Fecht (1978). These folds are flanked by the Wahluke syncline and Cold Creek syncline to the north and south, respectively. Although the geometry of the first-order fold is somewhat obscured by the second-order folds, it has been estimated from surface exposures, geophysical surveys, and borehole data. The southern flank of the first-order fold has a gentle southerly dip (approximately 2 degrees); the northern flank has a steeper northerly dip (approximately 11 degrees). The structural relief on this segment of the Umtanum Ridge-Gable Mountain structure is approximately 400 meters (1,300 feet).

The second-order folds on Gable Mountain and Gable Butte trend west to northwest, with the exception of a northeasterly trending syncline on Gable Butte. These folds range from 2 to 3 kilometers (1 to 2 miles) in length. Generally, second-order fold axes are parallel and form a westerly trending, en echelon pattern across Gable Mountain and Gable Butte. The axial trends of individual second-order folds are generally curvilinear. The termini of the hinge lines in both anticlinal and synclinal folds are either doubly plunging or are subdued by surrounding folds having higher amplitudes and greater wavelengths. The second-order folds tend to be asymmetrical in profile, with the two larger, second-order folds on Gable Mountain having opposite directions of asymmetry.

Angles subtended by the two flanks and the fold closure of the second-order folds range from open to gentle and angular to rounded, depending on the amplitude and wavelength of a given fold.

The faults on Gable Mountain have recently been investigated by Golder Associates (PSPL, 1982, Section 20) and the U.S. Nuclear Regulatory Commission (NRC, 1982b, Appendixes G and H). These studies examined three previously mapped faults: The south and central faults, located in the central Gable Mountain area, and the west fault, on the west end of Gable Mountain (Bingham et al., 1970, pp. 48 through 62; Fecht, 1978, pp. 43 through 47). During these investigations a fourth, buried fault was discovered in the central Gable Mountain area. All faults on Gable Mountain, except for the west fault, are reverse faults that dip toward the north or south with displacements of approximately 12, 50, and 100 meters (40, 160, and 300 feet) for the south, central, and buried reverse faults, respectively. The west fault is interpreted as a north-trending normal fault with small displacement, perhaps as much as 10 meters (30 feet). The faults on Gable Mountain are tear faults, interpreted to be in response to folding. The length of the faults are controlled by second-order folds and, therefore, the fault lengths have limited extents less than approximately 1.6 kilometers (1 mile).

The trenches in the central Gable Mountain area exposed offsets of up to approximately 6 centimeters (0.2 foot) along narrow fractures in glaciofluvial sediments that are continuous with a reverse fault in the basalt (PSPL, 1982, Section 20). These offset sediments are correlated with other glaciofluvial sediments that contain the 13,000-years-before-present Mount St. Helens "set S" ash. Borehole data show that the fault has much greater displacement in the basalt at depth (the top of the Esquatzel Member is offset approximately 50 meters (160 feet)). The displacement in the glaciofluvial sediments is interpreted (PSPL, 1982, Section 20) to be either the latest movement on an older fault of greater displacement at depth or caused by rapid loading and unloading during catastrophic flooding. The U.S. Nuclear Regulatory Commission and U.S. Geological Survey consider the faults in the central Gable Mountain area capable, but of relatively low seismic potential (NRC, 1982b, Supplement 1, p. 2-3). Long-term, average displacement rates on the fault were calculated to be very low (approximately 6×10^{-4} centimeter (2×10^{-4} inch) per year) (NRC, 1982b, Supplement 1, p. 2-9).

3.2.3.3 Cold Creek syncline

The Cold Creek syncline, in which the reference repository location is situated, occupies the partially sediment-filled structural low between the Umtanum Ridge-Gable Mountain structure and the Yakima Ridge anticline. The Cold Creek syncline is approximately 50 kilometers (30 miles) in length and is an asymmetric, open, broad, and relatively flat-bottomed fold. The steeper limb is the south limb. Two depressions lie along the

trough line of the Cold Creek syncline: Cold Creek Valley and Wye Barricade depressions located on the western and eastern parts of the Pasco Basin, respectively (see Fig. 3-19). The top of basalt in the center of the Cold Creek Valley depression is nearly flat, except, perhaps, for small, monoclinal flexures (Myers, 1981). The Wye Barricade depression is a large, irregular-shaped area. The depression appears to be divided into northern and southern subdepressions separated by a buried, asymmetric, low-amplitude anticline. The axis of the Cold Creek syncline plunges and dies out to the east in the vicinity of the Wye Barricade depression.

A key aspect of site-identification work has been the delineation of relatively intact volumes of Saddle Mountains, Wanapum, and upper Grande Ronde Basalt flows in the Cold Creek syncline area. These relatively intact volumes of basalt are bounded by known or inferred geologic structures, excluding intraflow structures (Myers, 1981) and geophysical features (Subsection 3.2.3.3.4). Based on the results of geophysical surveys, remote sensing, and surface and subsurface mapping, the western Cold Creek syncline area is interpreted to consist of large, relatively intact volumes of basalt whose boundaries are defined by geologic structures and geophysical features. Overall, the reference repository location appears to be relatively free of potentially adverse structures. The strata comprising the top of basalt and the structure at deeper horizons within this area are interpreted as being nearly flat lying with very gentle dips toward the trough of the Cold Creek syncline and with a slight westward component of dip toward the deepest point of the Yakima Barricade depression.

3.2.3.3.1 Top-of-basalt structures using borehole data

Using borehole data, secondary folds on the buried top-of-basalt surface in the reference repository location have been interpreted by Myers (1981). The data set used by Myers (1981) included non-Basalt Waste Isolation Project borehole information of questionable quality and with high expected variation in borehole elevation, borehole deviation, and determining the basalt-sediment contact. In the Myers (1981) top-of-basalt map, geologic features that have less than approximately 15 meters (50 feet) of topographic relief fall within errors associated with normal variation on the top of a flow as well as borehole variations. All secondary structures on the limb of the Cold Creek syncline mapped by Myers (1981) fall within this uncertainty. The quality of borehole data and the variability in the data set must be considered in interpreting subtle structures in the reference repository location. In most cases, a precisely measured and logged borehole in the reference repository location can reduce the uncertainty (i.e., maximum expected variation) at the top-of-basalt surface to approximately 8 meters (26 feet). Since features with greater than 8 meters (26 feet) are not known to occur on the north limb of the Cold Creek syncline in the reference repository location, on the basis of bedrock topography, no faults or secondary folds are interpreted on the bedrock surface.

3.2.3.3.2 Northwest-trending strike-slip faults

Strike-slip faults have not been observed cross cutting the Pasco Basin (Myers, Price et al., 1979, plate III-1). Anticlinal ridges that bound the Pasco Basin have been mapped in detail, and except for some component of dextral movement on the Rattlesnake-Wallula alignment, no strike-slip faults have been observed similar to those in the western Yakima Fold Belt. Tear faults have been observed along the ridges at boundaries between geometrically coherent segments of the structures, as in the Saddle Mountains (Reidel, 1984); but these faults are confined to the individual structure and formed as different geometries developed in the fold. Similar-type faults have been mapped on Gable Mountain and studied in detail (Fecht, 1978; PSPL, 1982); these features are also interpreted as tear faults that are a response to folding. One potential strike-slip fault is along the eastern edge of the Pasco Basin, east of the reference repository location, where the Ice Harbor dikes intruded along a northwest-trending inferred fracture zone (Reidel, 1984, p. 955). This potential fault has not been verified.

In the Cold Creek syncline and the reference repository location there is sufficient structural control on the basalt surface to identify anticlinal domes with structural relief commonly associated with strike-slip faults in the western Yakima Fold Belt. No such features have been detected in the reference repository location, indicating that strike-slip faults of this type probably are not present. One potential fault west of the reference repository location may be the Cold Creek barrier (see Fig. 3-1), and tests are under way to determine the nature of this feature. Should the reference repository location be recommended for site characterization, additional studies will be conducted to reduce the uncertainty in strike-slip faulting in the Cold Creek syncline.

3.2.3.3.3 Small-scale strain features

Two types of features have been identified in the Cold Creek syncline and reference repository location that indicate the north-south compressional stress has produced some strain features. These strain features, tectonic breccia and disking, are discussed below.

Price (1981) observed that synclinal troughs exhibit the least strain of any parts of Yakima folds. They do not show pervasive tectonic joints or small-scale faults as do the anticlinal ridges. Moak (1981) summarized the physical characteristics of the tectonic breccia zones in drill core from the Pasco Basin. Similar tectonic breccia zones have been identified in core holes drilled since 1981. Breccia zones were found to be relatively infrequent in all the thousands of meters (feet) of core drilled and that most zones are from the Wanapum and Grande Ronde Basalts. Breccia zones are generally intact and less than 10 centimeters (4 inches) thick, although some are up to 30 centimeters (1 foot) thick.

For example, core hole DB-10 on the south flank of Gable Mountain has breccia associated with two faults that repeat a section of Saddle Mountains Basalt (Myers, Price et al., 1979). No other breccia zones in the Cold Creek syncline have been identified as having displacements that repeat stratigraphic section. Two zones of tectonic breccia have been encountered in the upper Frenchman Springs flow in borehole RRL-6, which is located in the southwestern portion of the reference repository location (see Fig. 3-7). The zones are between the depth of 647 and 655 meters (2,123 and 2,149 feet) and are each about 1 meter (3 feet) in apparent thickness.

Core disking, which has been detected in core holes on the Hanford Site and within the reference repository location, is an indicator of rock stress. Core disking was described by Moak (1981) and Long and Woodward-Clyde Consultants (Long and WCC, 1984, p. I-230). Kim et al. (1984) concluded the following:

- Saddle-shaped disking is the result of nonaxisymmetrical horizontal stresses.
- Oriented core from holes producing saddle-shaped disks indicate that the maximum horizontal stress is generally north-south.

Kim et al. (1984) concluded that stress ratios calculated from the results of hydraulic fracturing tests are in general agreement with an analysis of core disking at the Hanford Site as presented in Myers and Price (1981). In situ stress is discussed in Subsection 3.2.3.8.

3.2.3.3.4 Geophysical features in and around the reference repository location

Geophysical data from ground-magnetic, aeromagnetic, gravity, and seismic reflection surveys were used to help select the boundaries of the reference repository location. Structural and topographic features such as the Gable Mountain-Gable Butte structure, the buried extension of Yakima Ridge, and the eastward terminus of Yakima Ridge (Fig. 3-20) are clearly depicted in the geophysical data sets. Also delineated is the north-south-trending I(KA)82 (Yakima Barricade) feature, which is associated with the Cold Creek barrier (see Fig. 3-20). This feature is thought to represent a monoclinal fold or a fault. The preferred interpretation of this feature is a fault; however, this interpretation needs to be verified through additional borehole data.

The geophysical character in and around the reference repository location is much more subdued than the surrounding area; therefore, geophysical features cannot be reliably delineated and their origin cannot be clearly resolved. Additional studies and analyses of these geophysical features are planned if the reference repository location is selected for site characterization (Subsection 4.1.1.2).

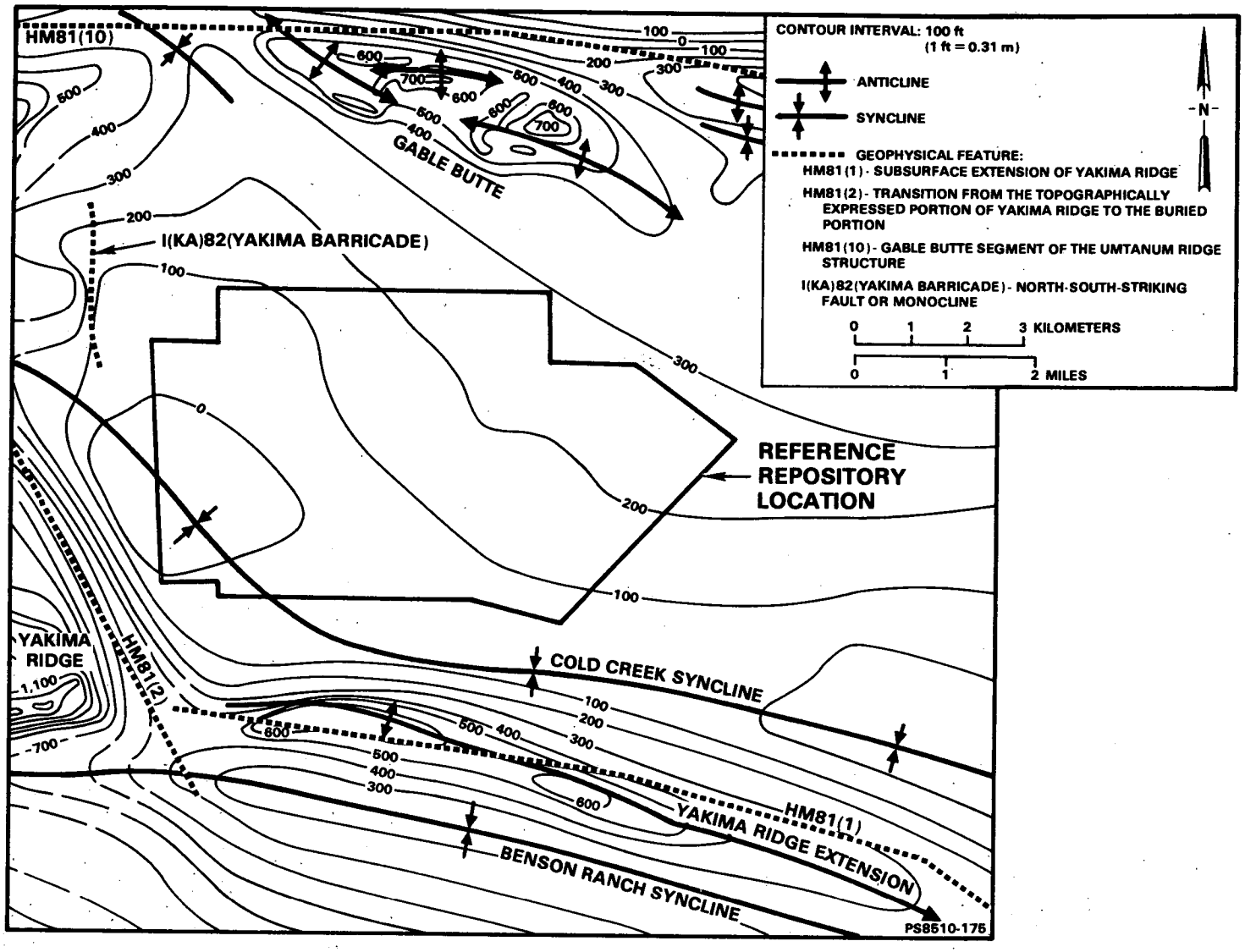

Figure 3-20. Top-of-basalt structure contour map with geophysical features.

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3.2.3.4 Yakima Ridge anticline

The Yakima Ridge anticline is a group of topographic ridges representing the surficial expressions of plunging anticlines, monoclines, and related faults. These ridges extend west-northwest from the western margin of the Pasco Basin to near Yakima, Washington, a distance of approximately 60 kilometers (37 miles). This discussion is confined to the easternmost one-third of the structure within the Pasco Basin.

The Yakima Ridge anticline within the Pasco Basin has been studied by Goff and Gardner (Myers, Price et al., 1979), Bond et al. (1978), Kienle (WPPSS, 1977), and Cochran (1982). The dominant fold within the Yakima Ridge anticline is the Cairn Hope Peak anticline. The shorter and steeper north limb of this anticline dips 30 to 40 degrees north and its wider southern limb dips 10 to 15 degrees south. The Cairn Hope Peak anticline trends north 70 to 75 degrees west and plunges gently southeastward. The southern limb of the Cairn Hope Peak anticline contains two monoclines. The northernmost of the two monoclines, the Cairn Hope Peak monocline, trends north 60 degrees west and is interpreted by Bond et al. (1978) to merge into the Silver Dollar fault of Goff and Myers (1978). The southern unnamed monocline trends north 70 degrees east.

The Silver Dollar fault offsets the Frenchman Springs Member against the Umatilla and Pomona Members across a fault breccia zone 50 to 70 meters (165 to 230 feet) wide (Goff and Myers, 1978). The mapped length of the fault is approximately 5 kilometers (3 miles). Because exposures of the fault zone are poor, the inclination of the fault surface is not readily determinable. The Silver Dollar fault was interpreted by Goff and Myers (1978) and Goff (Myers, Price et al., 1979) as a high-angle, reverse fault, but by Bond et al. (1978) as possibly a normal fault.

Several small, en echelon anticlines and synclines have been mapped that form the eastern part of Yakima Ridge. These folds have lengths of 1 to 2 kilometers (2 to 3 miles) and amplitudes of 200 to 300 meters (650 to 1,000 feet). These are open, doubly plunging, slightly asymmetrical, second-order folds; collectively, they form the first-order Yakima Ridge anticline in that area. The easternmost surface exposure of the Yakima Ridge anticline, which plunges eastward into the Pasco Basin, is represented by two anticlines and a syncline (Bond et al., 1978). Two faults are known to occur in this portion of the ridge. The first is located on the south flank of Yakima Ridge. The fault is westerly trending with an inferred reverse displacement. The second fault is nearly vertical and truncates the west end of the southernmost second-order anticline (Bond et al., 1978). A third fault was proposed by Bond et al. (1978) to account for a linear escarpment and apparent structural displacement on the extreme eastern and southern ends of Yakima Ridge. The existence and nature of such a fault have not been confirmed because of the limited exposure in that area.

Yakima Ridge plunges east-southeast into the central Pasco Basin. The buried structural high is interpreted as an eastward extension of the Yakima Ridge anticline. Current interpretations are that the buried

structure is a westerly plunging anticline with approximately 16 kilometers (10 miles) of length, 180 meters (600 feet) of structural relief, and a width of approximately 2.5 kilometers (1.5 miles) (Cochran, 1982; Myers, Price et al., 1979). The relationship between Yakima Ridge and the eastern extension has not been clearly defined, but a saddle or syncline with some possible faulting appears to be separating the two structures.

3.2.3.5 Benson Ranch syncline

The Benson Ranch syncline (Myers, Price et al., 1979, Plate III-4a) is a low-amplitude, long-wavelength syncline situated between the Yakima Ridge and the Rattlesnake Hills anticline (see Fig. 3-19 and Table 3-5). From borehole data, the axis of the Benson Ranch syncline appears midway between the two bounding anticlines. The syncline that is approximately 32 kilometers (20 miles) in length gently plunges from Dry Creek Valley toward the central Pasco Basin on the east. The Benson Ranch syncline is probably down-dropped to the east along the same northwest-trending fault that is postulated to offset the Yakima Ridge structure (Myers, Price et al., 1979, p. III-140). The Benson Ranch aeromagnetic anomalies and linears indicate that the Benson Ranch syncline and Yakima Ridge anticline continue southwest into the central portion of the basin and die out toward the Wye Barricade depression.

3.2.3.6 Pasco syncline

The Pasco syncline is a broad, low-amplitude depression in the southeastern part of the Pasco Basin. It lies between the Jackass Mountain structure (see Fig. 3-19 and Table 3-5) and the Rattlesnake Hills structure and has a sinuous trend. The syncline is approximately 50 kilometers (30 miles) long and generally plunges north into the Wye Barricade depression. Northeast of the Pasco syncline lies a series of small domes aligned parallel to the syncline (Myers, Price et al., 1979, Plate III-4a). These domes are low relief, areally small features with short arcuate trends.

3.2.3.7 Rattlesnake-Wallula alignment

The Cle Elum-Wallula deformed belt is a 40-kilometer- (25-mile-) wide zone that can be traced from Cle Elum, Washington, southeast to the Blue Mountains, a distance of approximately 200 kilometers (125 miles) (Kienle et al., 1977, p. 2RH.7-1; see Fig. 2-8). This zone is referred to as the Cle Elum-Wallula lineament and is part of Raisz's (1945) Olympic-Wallowa lineament (see Subsection 2.1.1.2). The Cle Elum-Wallula lineament parallels the western and southern boundaries of the Pasco Basin from Wallula Gap northwest to the Saddle Mountains. The segment of the lineament between the north end of Rattlesnake Mountain and the Hite fault

along the front of the Blue Mountains is designated the Rattlesnake-Wallula alignment (see Fig. 3-19). It has been interpreted as a continuous, 120-kilometer- (75-mile-) long, right-lateral strike-slip or right-lateral oblique-slip fault, which was modeled during the development of seismic design for the WNP-2 nuclear powerplant of the Washington Public Power Supply System on the Hanford Site (WPPSS, 1981, pp. 2.5-131 through 2.5-143; NRC, 1982b, pp. 2-12, 29, and 30). The Rattlesnake Mountain-Wallula Gap structural trend that forms the southern margin of the Pasco Basin has been argued to have dextral strike-slip movement (Laubscher, 1977; Davis, 1981). The Rattlesnake-Wallula alignment is approximately 6.4 kilometers (4 miles) from the reference repository location at its nearest point. A series of anticlinal domes occurs along the trend in the southeast part of the basin; these domes are referred to as "The Rattles" (see Fig. 3-19) and resemble the domes along the northwest-trending faults in the southwestern Columbia Plateau. Strike-slip movement has been mapped on the Wallula Gap fault along this trend (Gardner et al., 1981) and supports at least some dextral movement. Continuous exposure of basalt (12 million years old) along the Yakima River where it crosses the Rattlesnake-Wallula alignment near the Hanford Site has shown no strike-slip displacement. Studies of the growth of Rattlesnake Mountain (Reidel et al., 1983) show that this structure along the Rattlesnake-Wallula alignment developed under north-south compression in a manner similar to other Yakima folds. Paleomagnetic data (Reidel et al., 1984) independently support this. Because the Rattlesnake-Wallula alignment trend is northwest, some amount of dextral movement is compatible with fold growth under north-south compression and, therefore, some component of strike-slip faulting is expected along the alignment. However, field data limit the amount and, as along the Yakima River, the age of movement.

Along the central portion of the Rattlesnake-Wallula alignment near Wallula Gap, exposures in trenches along the Wallula fault system indicate movement along the fault in the Quaternary Period. The geomorphic continuity along the Rattlesnake-Wallula alignment has led to the interpretation that this feature may be a capable fault (NRC, 1982b, pp. H-4 and H-20), largely in the absence of distinct geologic evidence to the contrary. While there is considerable uncertainty in this interpretation, the continuity of the structure as a possible expression of deep structure has been assumed (NRC, 1982b).

3.2.3.8 Structural analysis

Price (1981, 1982) and Reidel (1984) observed that the greatest deformation occurs in the hinge of the anticlinal ridges and decreases with distance from that area. Studies of south-dipping limbs of north-vergent anticlines support these observations. To quantify these relationships, Price (1981, 1982) completed a detailed study of strain features on Umtanum Ridge and similar areas on limbs of other folds. These studies were the first to examine strain features; no other study as detailed and complete has been made of the Yakima folds, although

U.S. Department of Energy contractor scientists currently are conducting similar research. Price (1982, pp. 119 through 159) found that the degree of brecciation within the fold is related spatially to the dip of the basalt flows. The greatest amount of tectonic jointing and faulting occurs in the hinge zone and in steeply dipping beds. On the flanks of the folds, Price observed low dips to the faults and often saw conjugate shear zones. The greatest amount of faulting and tectonic jointing occurs in the hinge zone and decreases toward the gently dipping limbs. For example, on the well-exposed south limb of the Frenchman Hills along the Columbia River (see Fig. 2-8), Price (1982, pp. 151 and 152) observed numerous faults and shear zones that are only locally developed, but widely disseminated. Almost all the faults have low dips and occur in conjugate sets. These features typically have small displacements; an apparent maximum displacement of 1 to 2 centimeters (0.4 to 0.8 inch) dissipates to no recognizable displacement at a lateral distance of 1 meter (3 feet) on small shear zones. Faulting is primarily confined to the individual basalt layer in which it occurs.

Price (1981, 1982) also observed that there is relatively little deformation, other than steeply dipping tectonic joints, immediately adjacent to the hinge zone in the anticlinal crest. The synclinal trough south of the Umtanum Ridge along the Yakima River and in the syncline north of Umtanum Ridge near Priest Rapids Dam exhibits the least strain of any parts of the fold (see Fig. 2-8). This trough does not show pervasive tectonic jointing or small-scale faulting related to folding. A study by Reidel et al. (1984) using paleomagnetic techniques also examined strain features in folds. Their study showed the same results as Price's studies; the paleomagnetism recorded the greatest strain features (rotation of rock) in the anticlinal ridges, with decreasing strain down the flanks of the fold and no strain effects (no rotation) in the synclines. The Reidel et al. (1984) study independently supports the strain interpretation of Price (1981, 1982). It further supports Price's interpretation that the syncline shows the least strain effects.

Price (1982) examined the breccia zones described by Moak (1981) in the core drilled from the Pasco Basin to determine if the limited strain effects observed in the field were present in core from the Cold Creek syncline. Price noted that the largest breccia zone (taken from core hole DB-10) came from the flank of a fold, and that breccia zones in the synclines are fewer and thinner than those on the anticlinal flanks. Price interpreted these breccia zones to represent localized minor faults in the syncline, and did not observe any breccia zone that suggested major through-going faults.

Available structural and tectonic data permit a preliminary interpretation of the pattern and chronology of deformation in the Pasco Basin and reference repository location. Deformation of basalt was in progress during late-Grande Ronde time (approximately 14.5 million years before present) as evidenced by the thickness and distribution of flows (Reidel et al., 1983; Reidel, 1984). Uplift on Miocene topography that is presumably of structural origin proceeded at average low rates of between 40 to 80 meters per million years (0.04 and 0.08 millimeter per year)

(130 to 260 feet per million years (2×10^{-3} to 4×10^{-3} inch per year)) during the period 14.5 to 10.5 million years ago, and this can be interpeted as the vertical component of strain. If these average low rates of uplift are projected to the present, they account for the currently observed structural relief and the elevation of flows on the Rattlesnake Hills and the Saddle Mountains. Subsidence in the Cold Creek syncline in the central Pasco Basin relative to the projected Palouse slope of southeastern Washington proceeded at similar rates (Reidel et al., 1983). The decreasing dip of progressively younger strata of the Miocene-Pliocene Ringold Formation on the flanks of anticlines similarly suggests that deformation at relatively low rates of vertical strain was continuous during Neogene and Quaternary time and resulted in greater deformation of older units. Contemporary deformation appears to be continuing at these long-term, average low rates as evidenced by the level and distribution of earthquakes and the measured shortening of lines of a trilateration survey over the period of 1972 to 1981 (Rohay and Davis, 1983). Horizontal strain indicated by eight geodetic surveys is on the order of 0.02 to 0.04 millimeter per kilometer per year (2×10^{-3} to 4×10^{-3} inch per mile per year) compression (Prescott and Savage, 1984). However, these measured values for shortening of lines are within the range of instrumental error, are within the range of daily earthtides, and have suggested different strain axes with different surveys.

Geologic and seismologic data indicate that the axes of crustal shortening are oriented generally north-south and are nearly horizontal. The east-west strike of most anticlinal and synclinal axes and accompanying subparallel thrust and reverse faults suggest north-south, horizontal compression, as do the steeply dipping northwest- (and some northeast-) trending faults and northwest-trending anticlinal axes. Focal mechanism solutions (for individual events and composites of several presumably related events) suggest that the axis of maximum compression is almost horizontal and oriented slightly west of north. The axis of minimum compression from fault plane solutions is almost vertical. Focal planes trend generally east-west, dip steeply, and result from essentially reverse faulting, with little, if any, strike-slip component (see Subsection 2.1.1.3). This pattern holds for shallow as well as deeper events (greater than 6 kilometers (4 miles)). Measurement of in situ stress by hydraulic fracturing in the reference repository location resulted in a mean principal compression of approximately north-south and a near-vertical axis of least compression (Kim and Haimson, 1982; Kim et al., 1984).

Deformation along zones of tectonic weakness (i.e., first-order folds and faults) in the central Columbia Plateau was established no later than middle Miocene. Subsequent deformation appears to have occurred along these established first-order structures with subsequent development of lower order structures in relation to first-order structures, but with no obvious development of geologically youthful structures. Deformation appears to have been in progress at least 14.5 million years ago and appears to have continued, at least in some structures, to the late Pleistocene or Holocene (Caggiano, 1983).

3.2.4 SEISMICITY OF THE REFERENCE REPOSITORY LOCATION AND VICINITY

No earthquakes were instrumentally located near the reference repository location prior to the installation of a network of seismographs in the central Columbia Plateau in 1969. Since installation of the initial regional network, all earthquakes greater than magnitude 1.8 have been consistently located with a 1- to 2-kilometer (0.6- to 1.2-mile) epicentral accuracy; depths are accurate to plus or minus 2 kilometers (1.2 miles), with somewhat greater error for shallow events.

Prior to installation of the Hanford Site area network, earthquake detection and location capability was significantly lower. Between the mid-1800's and 1954, earthquake locations were determined with felt reports and intensity data. Between 1954 and 1969, events of approximately magnitude 4 or larger were located in eastern Washington using records from a three-station network established in western Washington and a station in Spokane, Washington. The record of seismicity for eastern Washington, including the reference repository location, is rather complete for events of approximately magnitude 5 or larger dating back to approximately 1850 (Fig. 3-21). In all of the Columbia Plateau, including the reference repository location, only one event above magnitude 5 (a magnitude 5.75 near Milton-Freewater, Oregon, on July 15, 1936) has occurred in the approximately 135 years of record. Focal mechanisms of a magnitude 4.1 earthquake in 1979 and a magnitude 3.8 in 1983 that occurred near the epicenter of the 1936 event suggest that the stress regime along the front of the Blue Mountains may be different than that in the central Columbia Plateau.

The seismicity of the reference repository location is relatively low in comparison to the moderate seismicity of the central Columbia Plateau (see Fig. 2-9). No instrumentally recorded earthquakes of shallow depth (less than 4 kilometers (2 miles)) have occurred within the boundaries of the reference repository location, although two earthquake sequences have occurred nearby (Fig. 3-22) and a few events have occurred at a depth greater than 4 kilometers (2 miles) beneath the reference repository location.

There have been three areas of swarm-type activity within 10 kilometers (6.2 miles) of the reference repository location. The first area is in and adjacent to the reference repository location and occurred between November 10 and November 24, 1969 (see Fig. 3-22 and 3-23). The swarm included four events that occurred between a 3- and 10-kilometer (2- and 6.2-mile) depth. The maximum event had a magnitude of 2.2.

The second area is approximately 10 to 15 kilometers (6.2 to 9 miles) north of the reference repository location site. This area appears to have an east-northeast trend of activity. Sixty-seven events have been located in this area between 1969 and the present. The two most significant earthquakes were a magnitude 3.8, occurring on October 25, 1971, and a magnitude 3.4, occurring on October 20, 1983. Most of the activity is less than 2 kilometers (1.2 miles) deep.

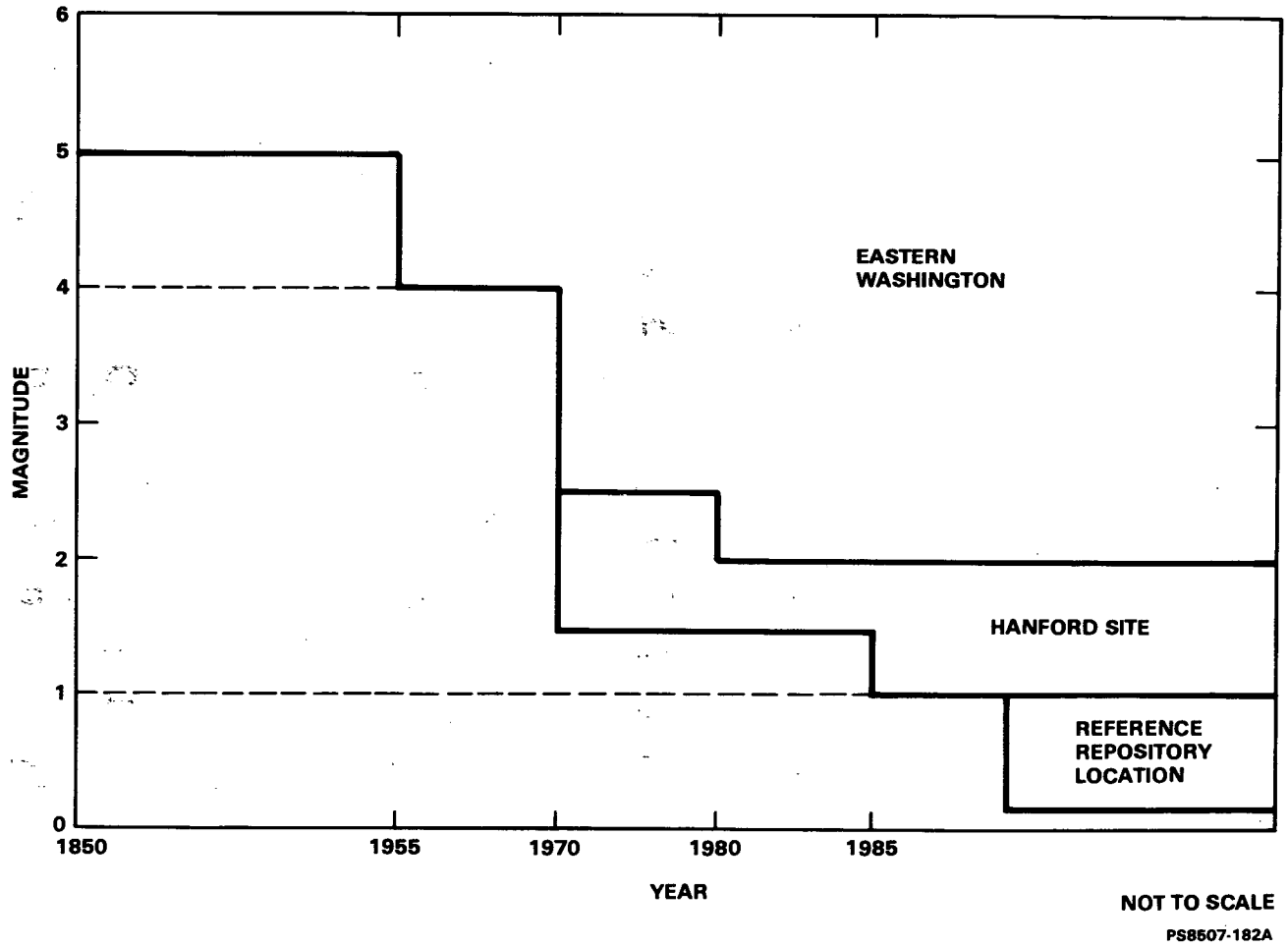

Figure 3-21. Magnitude of smallest earthquake detectable by area.

7 0 1 6 8 0 7 0 7

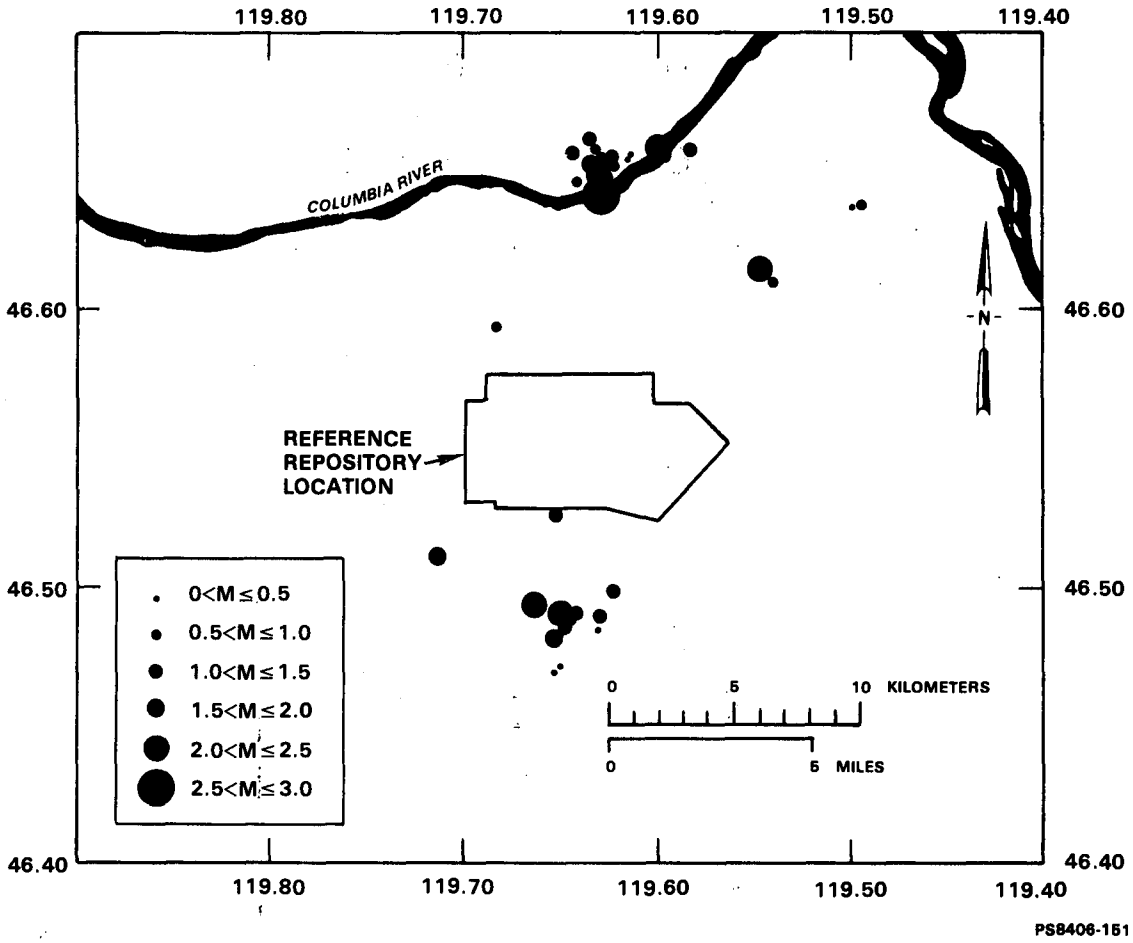

Figure 3-22. Earthquakes less than 4 kilometers (2.5 miles) deep within 10 kilometers (6.2 miles) of the reference repository location from 1969 through March 1983.

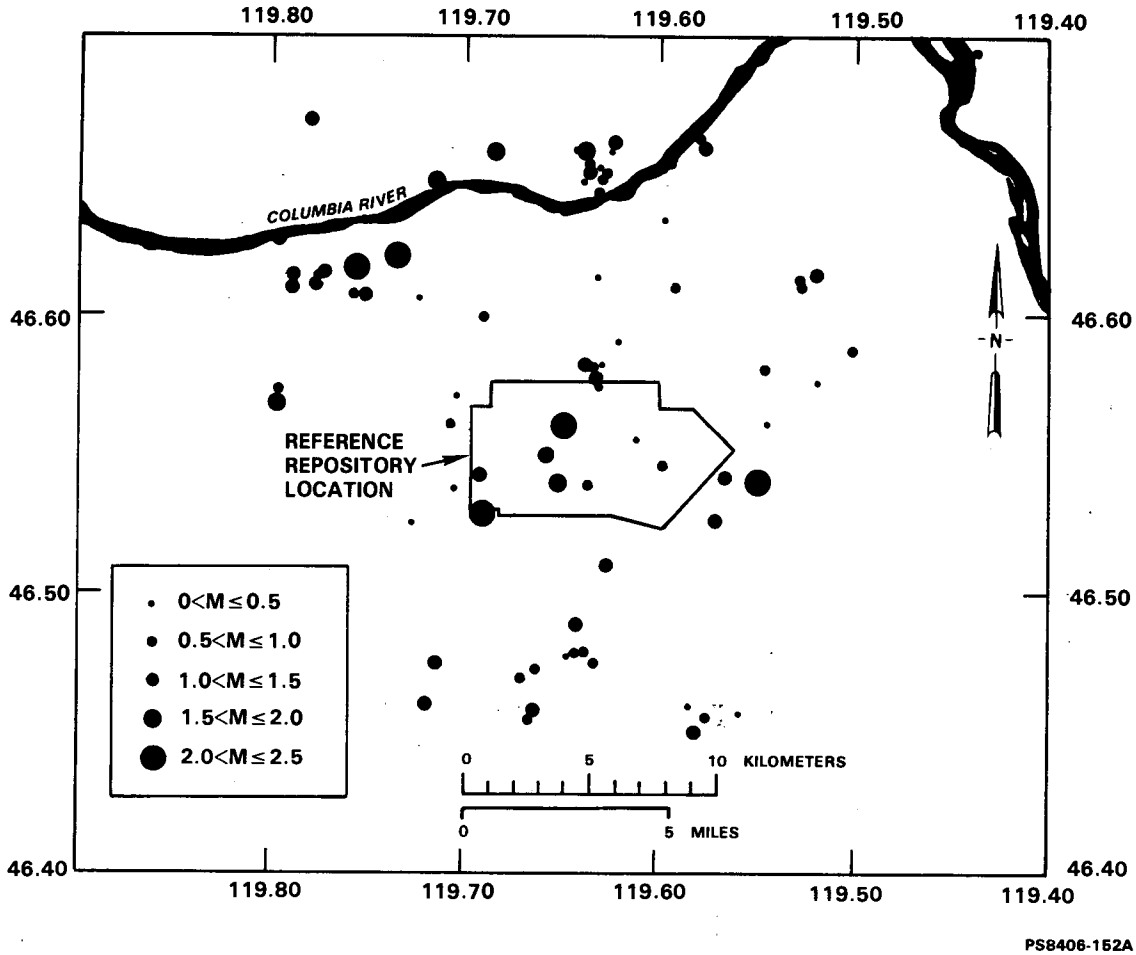

Figure 3-23. Earthquakes greater than 4 kilometers (2.5 miles) deep within 10 kilometers (6.2 miles) of the reference repository location from 1969 through March 1983.

The third swarm area is located approximately 5 to 8 kilometers (3 to 5 miles) south of the Hanford Site. There have been two activity periods: July 8 through November 4, 1979, and August 24 and 25, 1981. Between 1979 and 1981, 15 events occurred, all less than 5 kilometers (3 miles) deep. The largest event was a magnitude 2.4.

A few deeper earthquakes (greater than 4 kilometers (2 miles) in depth) have been recorded within the boundaries of the reference repository location (see Fig. 3-22), including the events of November 1969 mentioned above. These earthquakes occur near the base or beneath the Columbia River Basalt Group and are all small, less than magnitude 2.5. Table 3-6 lists earthquakes that have occurred within and in the near vicinity of the reference repository location.

Earthquake location data and occurrence rates indicate that the reference repository location is sited in an area of relatively low seismicity (see Fig. 2-10, 3-22, and 3-23). Microearthquake activity in the area around the reference repository location is largely shallow, confined to a crust of 28-kilometer (17-mile) thickness, and is characterized by swarms of low-magnitude earthquakes that occur predominantly in the basalts.

3.3 HYDROLOGIC CONDITIONS

The following sections address the basic surface and subsurface hydrologic systems within and in the vicinity of the Hanford Site. Specific emphasis is given to the reference repository location. Section 3.3.1 addresses the topic of surface drainage and potential flooding and Section 3.3.2 deals with ground-water hydrology.

3.3.1 SURFACE WATER

This section examines the surface hydrology of the Pasco Basin and the Hanford Site. Surface flooding potentials are also addressed. The regional surface hydrologic setting is described in Section 2.1.3.

3.3.1.1 Pasco Basin

The Pasco Basin occupies approximately 4,900 square kilometers (1,900 square miles) and is located within the central portion of the Columbia Plateau (see Fig. 2-14). Because of its topographically low position within the plateau, surface drainage enters the Pasco Basin from several other basins.

The Columbia River is joined in the Pasco Basin by major tributaries, including the Yakima, Snake, and Walla Walla Rivers. No natural, perennial streams are supported by hydrologic systems operating solely

Table 3-6. Seismic events in and near the reference repository location (between 46.51 to 46.60°N and 119.53 to 119.75°W)

Designation YYMMDDHHMM[a]	Second	Latitude	Longitude	Depth km	Depth mi	Magnitude[b]
6911100056	15.34	46°33.61' N.	119°39.11' W.	10.28	6.39	2.2[c]
6911181817	37.36	46°32.36' N.	119°39.24' W.	7.48	4.65	1.6[c]
6911210423	57.87	46°30.62' N.	119°37.75' W.	6.57	4.08	1.4
6911261216	25.82	46°31.56' N.	119°39.18' W.	3.00	1.86	1.3
7003161548	21.31	46°32.36' N.	119°33.04' W.	13.80	8.58	2.4
7103062103	48.18	46°34.47' N.	119°38.00' W.	7.08	4.40	0.8[c]
7103062104	07.25	46°34.58' N.	119°38.08' W.	7.15	4.44	0.6[c]
7103062113	16.14	46°34.88' N.	119°37.86' N.	7.41	4.61	0.4
7106100938	04.58	46°34.90' N.	119°38.36' W.	7.98	4.96	1.1
7106101053	10.62	46°34.84' N.	119°38.13' W.	6.53	4.06	1.0
7108170730	06.69	46°34.59' N.	119°38.02' W.	7.29	4.53	0.8[c]
7109260041	04.19	46°35.38' N.	119°37.36' W.	14.29	8.88	0.1
7209220728	30.49	46°34.25' N.	119°42.40' W.	17.33	10.77	0.4
7302051329	02.14	46°32.75' N.	119°36.00' W.	20.26	12.59	0.7[c]
7302101902	58.70	46°32.49' N.	119°34.06' W.	14.92	9.27	1.2
7302111101	40.56	46°33.29' N.	119°36.79' W.	11.14	6.92	0.4[c]
7404220049	23.37	46°32.34' N.	119°38.29' W.	17.56	10.91	0.8[c]
7407100045	58.61	46°35.93' N.	119°41.52' W.	14.10	8.76	0.9
7510282012	04.56	46°34.79' N.	119°32.83' W.	18.91	11.75	1.0
7804041118	20.39	46°31.56' N.	119°41.65' W.	20.00	12.43	1.5[c]
7906220044	42.09	46°30.70' N.	119°42.84' W.	3.00	1.86	1.8
8010221136	24.33	46°33.64' N.	119°32.77' W.	21.80	13.55	0.3
8107130856	29.32	46°33.06' N.	119°39.39' W.	16.93	10.52	0.0[c]
8108072202	38.49	46°32.56' N.	119°34.35' W.	17.04	10.59	1.5
8109231628	39.37	46°31.67' N.	119°41.62' W.	17.44	10.84	2.3
8109241825	12.34	46°32.26' N.	119°42.43' W.	14.29	8.88	0.3
8109272341	15.35	46°31.83' N.	119°41.88' W.	15.62	9.71	0.3[c]
8209051712	68.19	46°35.58' N.	119°41.00' W.	0.10	0.06	0.9
8209131401	15.05	46°33.65' N.	119°42.53' W.	18.28	11.36	0.9

[a]Y = year, M = month, D = day, H = hour, M = minute.
[b]Coda length magnitude.
[c]Denotes earthquake in the reference repository location.

within the Pasco Basin. The location of manmade waterways in the Columbia Basin Irrigation District, north and east of the Hanford Site, is addressed in Bell and Leonhart (1980).

Mean annual precipitation within the Pasco Basin ranges from less than 18 centimeters (7 inches) within the Hanford Site to a maximum of just over 38 centimeters (15 inches) atop Rattlesnake Mountain. Total precipitation over the entire basin is estimated at 9.9×10^8 cubic meters (800,000 acre-feet) annually, averaging less than 20 centimeters (8 inches). Mean annual runoff is low, generally less than 1.3 centimeters (0.5 inch) for most of the basin. Total annual runoff is less than 3.1×10^7 cubic meters (25,000 acre-feet) per year, and the basin-wide runoff coefficient, for all practical purposes, is zero (Leonhart, 1979).

Average annual pan evaporation can exceed 152 centimeters (60 inches). Average annual lake evaporation ranges from approximately 100 to over 105 centimeters (39 to over 41 inches). Actual evapotranspiration is essentially equivalent to annual precipitation. Based on this estimate, total actual evapotranspiration for the Pasco Basin would be approximately 9.9×10^8 cubic meters (800,000 acre-feet) annually (Leonhart, 1979, p. 67).

Streamflow within the Pasco Basin is recorded as inflow at the U.S. Geological Survey gauge below Priest Rapids Dam and outflow at the gauge below McNary Dam (see Fig. 2-16). Average annual flow at these stations is 1.1×10^{11} and 1.7×10^{11} cubic meters (87 million and 140 million acre-feet), respectively. A total gauged flow of approximately 5.5×10^{10} cubic meters (45 million acre-feet) per year enters from tributaries, and an additional 2.8×10^8 cubic meters (230,000 acre-feet) enter as irrigation returns (Leonhart, 1979). The error band associated with the surface-water volumes measured prevents a quantitative evaluation of ground-water inflow into the Columbia River from being made. Studies are planned to quantify a total water balance for the Pasco Basin, including surface to subsurface and interbasin water exchanges.

3.3.1.2 Hanford Site

The Hanford Site occupies approximately one-third of the land area within the Pasco Basin. Primary surface-water features associated with the Hanford Site include the Columbia and Yakima Rivers. Several surface ponds and ditches are present and are associated with nuclear waste-processing activities (Fig. 3-24).

Flow from approximately two-thirds of the Hanford Site is considered to drain directly into the Columbia River, although runoff is extremely low, if not zero. The reference repository location straddles a divide between the Columbia and Yakima River watersheds. The section of the

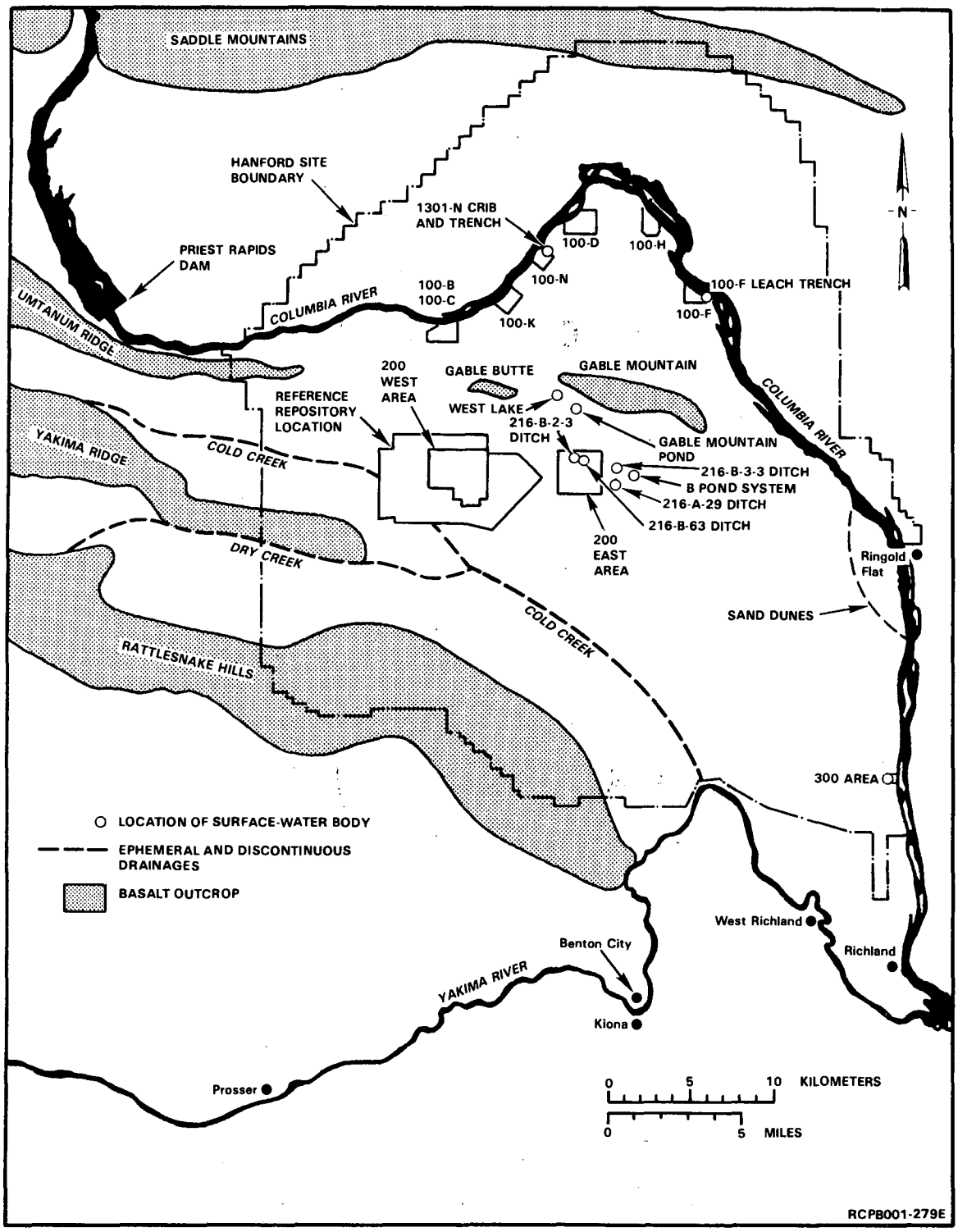

Figure 3-24. Surface-water bodies, including ephemeral creeks, on the Hanford Site.

Columbia River along the Hanford Site reach, which extends from the headwaters of Lake Wallula to the Priest Rapids Dam, has been inventoried and is described in detail in a report by the U.S. Army Corps of Engineers (COE, 1977). Flow along this reach is controlled by the Priest Rapids Dam. Several drains and intakes are also present along this reach; most notably, these include irrigation outfalls from the Columbia Basin Irrigation Project (see Fig. 2-14) and Hanford Site intakes for the onsite water export system.

The Yakima River bordering the southern portion of the Hanford Site has a low annual flow compared to the Columbia River. Average annual discharge of the Yakima River, measured at Kiona, Washington, is on the order of 3.2×10^9 cubic meters (2.6 million acre-feet). Runoff to the Yakima River is also very low, if not zero.

Cold Creek and its tributary, Dry Creek, are ephemeral streams within the Yakima River drainage system along the southern boundary of the Hanford Site (see Fig. 3-24). Approximately one-third of the Hanford Site is drained by the Yakima River system. The southwestern two-thirds of the reference repository location is considered to be situated within the Cold Creek watershed.

West Lake, a shallow pond (less than 1 meter (3 feet)), is the only natural pond within the Hanford Site. Its presence is probably attributable to a combination of factors, such as its location within a topographic depression (which places it closer to the water table) and vertical ground-water leakage from shallow confined aquifers (due to the location of the pond along the Gable Mountain anticlinal axis) (Gephart et al., 1976). The pond generally averages 4 hectares (10 acres) in size. Additionally, several manmade ditches and ponds (see Fig. 3-24) are used for the routine disposal of chemical processing cooling waters, certain industrial wastes, and laboratory and sanitary wastes and for the discharge of water used for plant cooling (ERDA, 1975; Gephart et al., 1976).

The Hanford Site also appears to incorporate the hydrometeorological extremes found within the Pasco Basin with respect to precipitation and evapotranspiration. The lowest precipitation and highest evapotranspiration values within the basin tend to occur within the lower elevations of the Hanford Site; whereas, the opposite extremes are found atop the Rattlesnake Hills.

3.3.1.3 Surface flooding potential

Several documents contribute to our understanding and evaluation of flooding potentials within the reference repository location and the Pasco Basin. The primary report is by the U.S. Army Corps of Engineers (COE, 1951) on artificial flooding along the Columbia River, based on failure scenarios of Grand Coulee Dam. Other key reports include those by the U.S. Energy Research and Development Administration (ERDA, 1976),

the U.S. Federal Emergency Management Agency (FEMA, 1980), and the Washington Public Power Supply System (WPPSS, 1981, pp. 2.4-1 through 2.4-12). Cummans et al. (1975) summarized a methodology for determining flooding characteristics of small watersheds, such as the Cold Creek drainage area in eastern Washington. Reports dealing specifically with the probable impacts of flooding on Basalt Waste Isolation Project activities and the reference repository location include Leonhart (1980) and Skaggs and Walters (1981). Discussions of the nature of catastrophic flooding associated with Pleistocene glaciation are provided in a report by the U.S. Department of Energy (DOE, 1982b) and are summarized in Subsections 2.1.1.1 and 3.2.2.7.

3.3.1.3.1 Flood history of the Columbia River

Major floods on the Columbia River are typically the result of rapid melting of the winter snowpack over a wide area augmented by above-normal precipitation. The maximum historical flood on record occurred June 7, 1894. The peak discharge at the Hanford Site was 21,000 cubic meters per second (740,000 cubic feet per second). The largest recent flood took place in 1948 with an observed peak discharge of 20,000 cubic meters per second (690,000 cubic feet per second) at the Hanford Site. The probability of flooding at the magnitude of the 1894 and 1948 floods has been greatly lowered due to upstream regulation by dams (see Fig. 2-16).

Just below Priest Rapids Dam, the Columbia River has varying flow volume, resulting from seasonal discharge changes and flow regulation by upstream dams. Daily flow rates during the late summer, fall, and winter may vary from 1,020 to 4,500 cubic meters (36,000 to 160,000 cubic feet) per second. During the spring runoff, peak flow rates have been measured from approximately 4,500 to 18,000 cubic meters (160,000 to 650,000 cubic feet) per second (ERDA, 1975, p. II.3-D-4).

The flood plain associated with the 1894 flood is shown in Figure 3-25. A flood of this magnitude would inundate sections of Richland, Washington, but would not reach the reference repository location, which has land surface elevations of 190 to 245 meters (625 to 800 feet) above mean sea level.

3.3.1.3.2 Flood history of the Yakima River

Since 1862, there have been fewer than 20 major floods on the Yakima River. The most severe occurred in November 1906, December 1933, and May 1948. Discharge magnitudes at Kiona, Washington, were 1,870, 1,900, and 1,050 cubic meters per second (66,000, 67,000, and 37,000 cubic feet per second), respectively (WPPSS, 1981). The recurrence intervals for the 1933 and 1948 floods are estimated at 170 and 33 years, respectively.

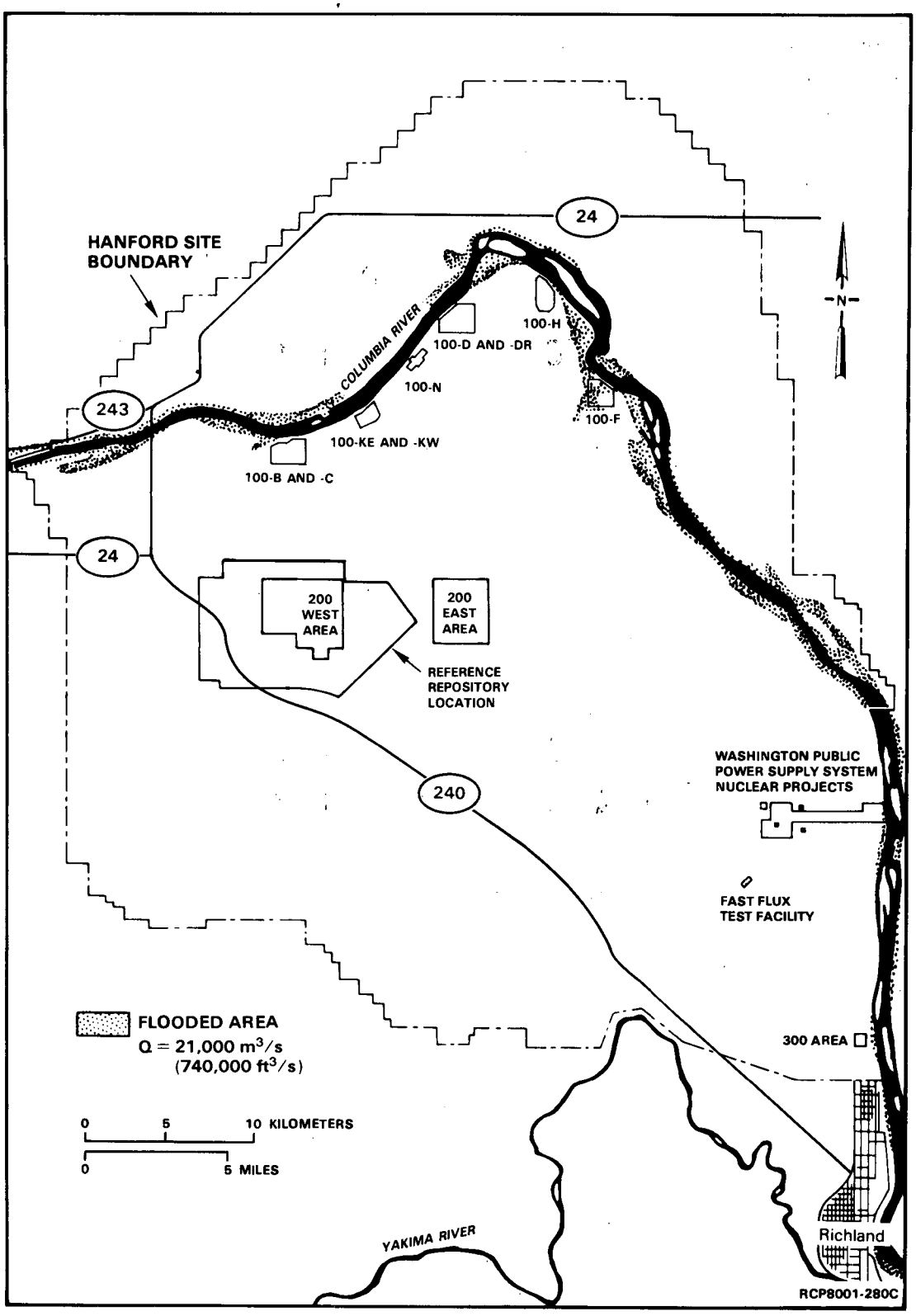

Figure 3-25. Flooded area during the 1894 flood (after ERDA, 1976).

The development of irrigation reservoirs within the Yakima River Basin (see Fig. 2-14 and 2-15) has considerably reduced the flood potential of the river. For example, the December 1933 flood was reduced from 2,400 to 1,500 cubic meters per second (83,000 to 54,000 cubic feet per second) at Yakima, Washington, by management of upstream reservoir storage facilities. A December 1959 flood, which, if uncontrolled, could have reached a magnitude of 1,600 cubic meters per second (55,000 cubic feet per second) at Yakima, was held at 780 cubic meters per second (27,400 cubic feet per second) by the reservoir system.

Lands susceptible to a 100-year flood on the Yakima River are shown in Figure 3-26. Flooded areas near Horn Rapids could extend into the southern section of the Hanford Site; however, these waters would not reach the reference repository location. The Yakima River upstream from Horn Rapids is physically separated from the Hanford Site by Rattlesnake Mountain. This topographic barrier prevents potential flooding of the Yakima River from reaching the reference repository location.

3.3.1.3.3 Flood potential

Associated with the evaluation of flood potential is the concept of the probable maximum flood, which is determined from the upper limit of precipitation falling on a drainage area and other hydrologic factors (e.g., antecedent moisture conditions, snowmelt, and tributary conditions) that result in maximum runoff. The probable maximum flood for the Columbia River below Priest Rapids Dam has been calculated to be 40,000 cubic meters per second (1.4 million cubic feet per second) (COE, 1951, 1969). The flood plain associated with the probable maximum flood is shown in Figure 3-27. This flood would inundate the 100 Areas located adjacent to the Columbia River, but the central portion of the Hanford Site, including the reference repository location, would remain unaffected.

Potential dam failures on the Columbia River also have been evaluated. Upstream dam failures may arise from a number of causes; however, the magnitude of the resulting flood depends on the degree of breach. The U.S. Army Corps of Engineers (COE, 1951) evaluated a number of scenarios on the effects of failures of Grand Coulee Dam (see Fig. 2-16), assuming flow conditions on the order of 11,000 cubic meters per second (400,000 cubic feet per second). The discharge resulting from a 50-percent breach at the outfall of Grand Coulee Dam was determined to be 600,000 cubic meters per second (21 million cubic feet per second). Near 100-N Area on the Hanford Site, this flow would diminish to 230,000 cubic meters per second (8 million cubic feet per second). The resulting land inundation from the 50-percent breach scenario is depicted in Figure 3-28. In addition to areas inundated by the probable maximum flood, the remainder of the 100 Areas, the 300 Area, and nearly all Richland, Washington, would be flooded. To add additional perspective, major flooding also would occur in Portland, Oregon (see Fig. 3-1). The reference repository location would remain above the resultant flood waters. No determinations were made with respect to breaches greater than

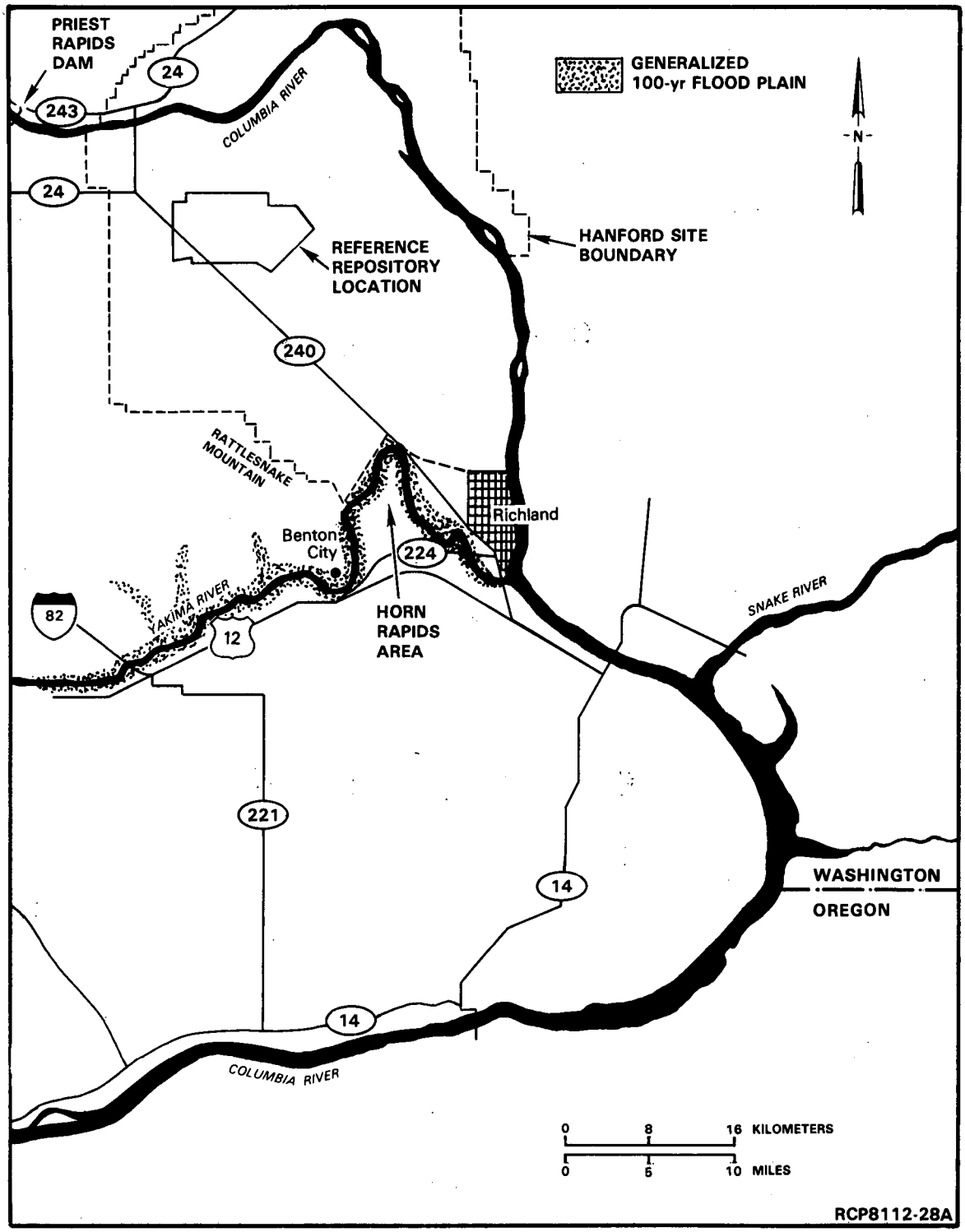

Figure 3-26. Flooded area from a 100-year flood of the Yakima River in the vicinity of the Hanford Site (FEMA, 1980).

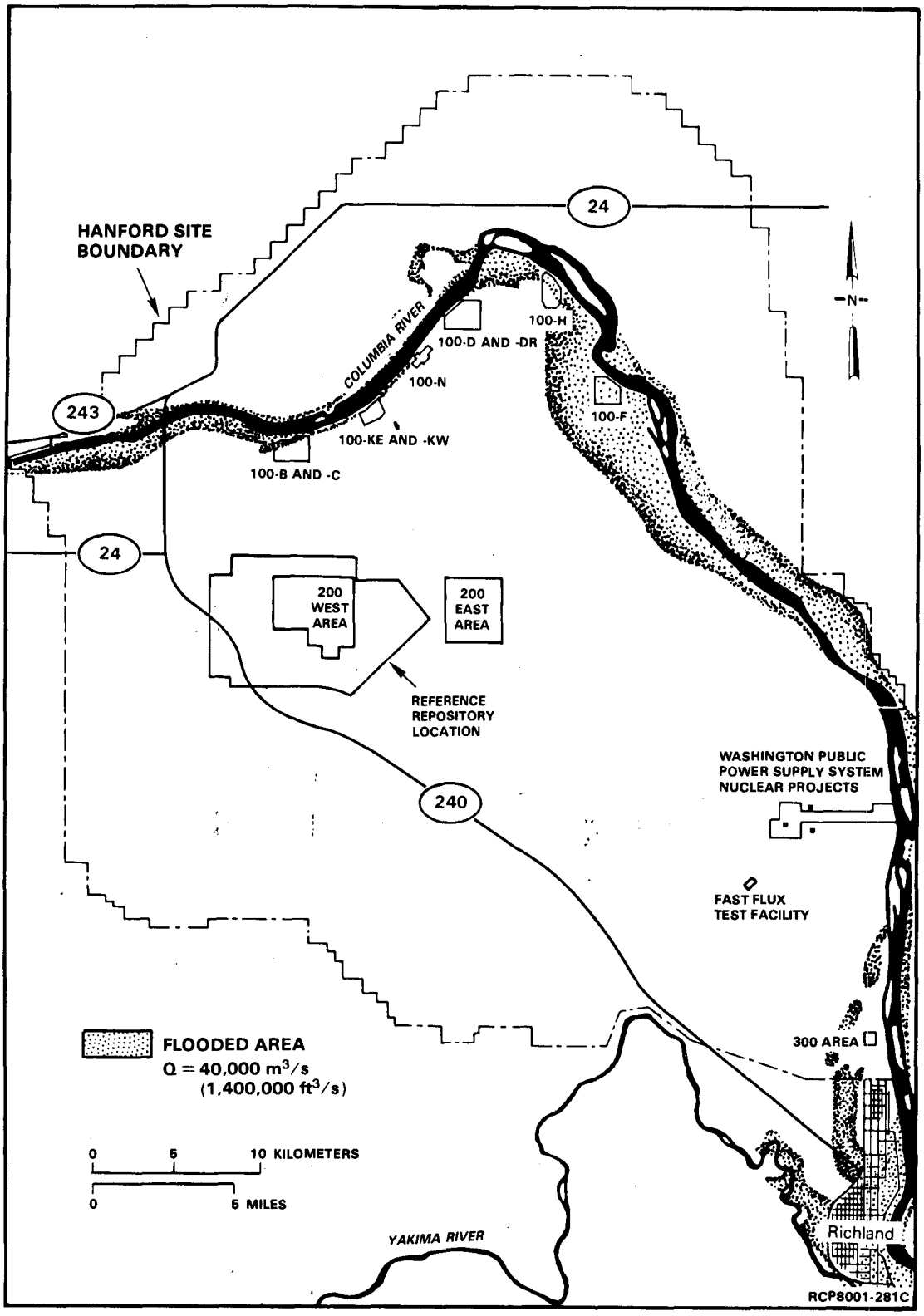

Figure 3-27. Flooded area for the probable maximum flood (after ERDA, 1976).

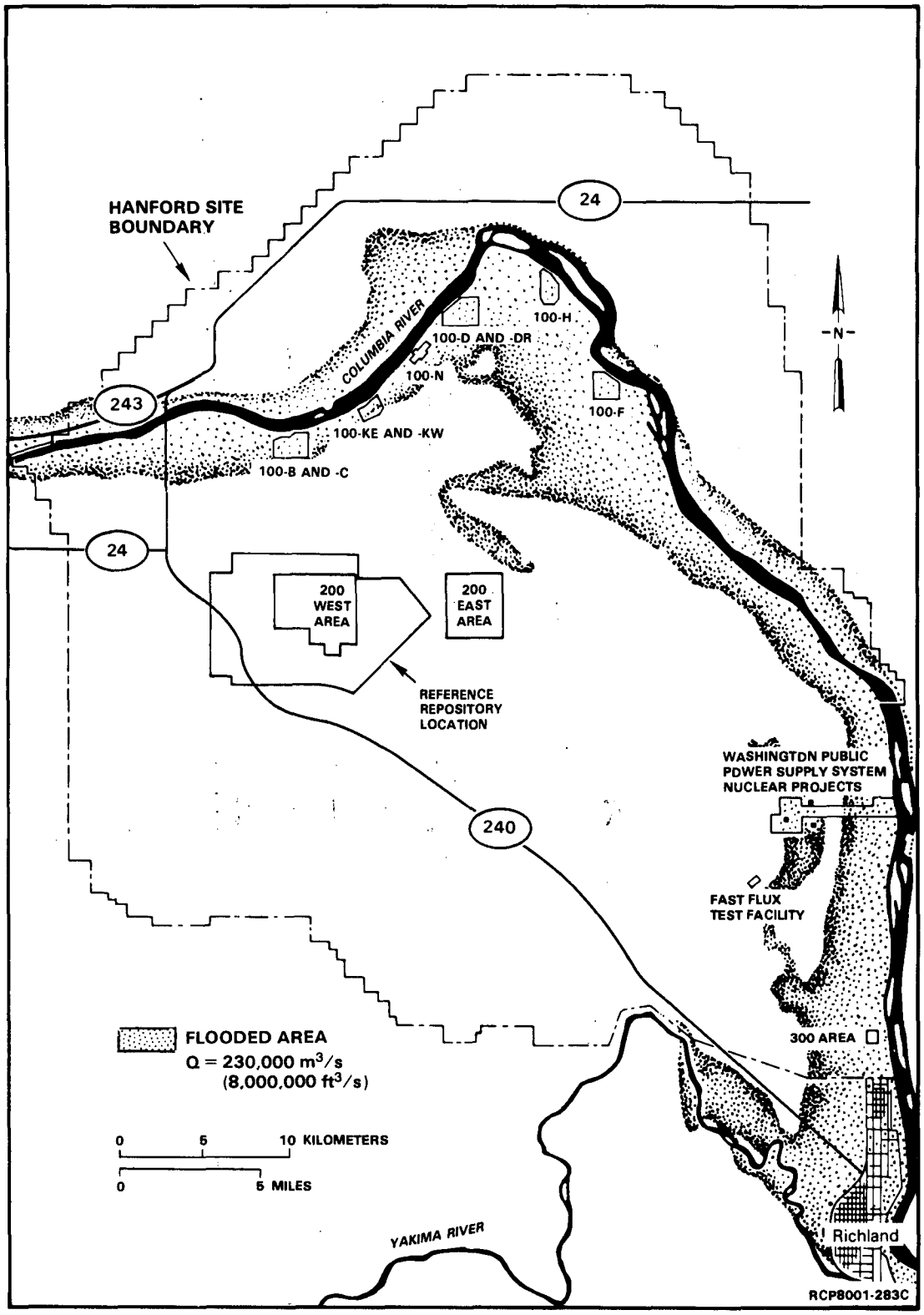

Figure 3-28. Flooded area resulting from a 50-percent breach of Grand Coulee Dam (after ERDA, 1976).

50 percent of Grand Coulee Dam or to failures of dams upstream of Grand Coulee Dam and associated resonant failures of dams downstream (COE, 1951). The 50-percent scenario is believed to represent the largest, realistically conceivable flow resulting from a dam breach from natural or man-induced events (COE, 1951; ERDA, 1976; PSPL, 1981).

A third catastrophic event that could result in flooding portions of the Hanford Site is river blockage and flooding due to landslides along the Columbia River. One potential slide area extends along a 75-meter-(250-foot-) high bluff bordering the east side of the Columbia River upstream from Richland, Washington. This area is commonly referred to as White Bluffs. Calculations indicate that an 8 x 10^5-cubic-meter (1 x 10^6-cubic-yard) landslide concurrent with a flood flow of 17,000 cubic meters per second (600,000 cubic feet per second) (200-year flood) would result in a flood wave crest elevation of 122 meters (400 feet) above mean sea level (Harty, 1979). The reference repository location would be unaffected by such an event. Areas inundated by such a landslide event are similar to those shown in Figure 3-27. Catastrophic flooding of the Hanford Site and vicinity during the recent geologic past is discussed in Subsection 3.2.2.9.

3.3.1.3.4 Cold Creek watershed

The Cold Creek watershed (area draining into Cold Creek) is located along the western boundary of the Pasco Basin. As shown in Figure 3-24, this watershed is bordered on the west by the Rattlesnake Hills and Yakima Ridge, on the north by Umtanum Ridge, and on the east by the central portion of the Hanford Site. This rectangular-shaped, 870-square-kilometer (336-square-mile) basin is ephemeral and a part of the Yakima River drainage system. Elevations in the Cold Creek watershed range from approximately 130 meters (420 feet) above mean sea level at its outlet to over 1,100 meters (3,500 feet) above mean sea level at its headwaters along Yakima Ridge.

The reference repository location lies primarily within the Cold Creek watershed. Cold Creek, trending northwest-southeast within the wash, is the only defined channel within the southeastern portion of the watershed (see Fig. 3-24).

The drainage system within the Cold Creek watershed may be described as ephemeral and discontinuous. This means that the stream flows only in direct response to precipitation events (i.e., it receives no contribution from discharging ground water or sustained snowmelt runoff). Further, for most runoff events, the water within the channel infiltrates within a given distance of flow. Skaggs and Walters (1981) suggest that the Cold Creek watershed behaves essentially as two distinct drainage systems for most runoff events. The source of the upper drainage system is the area bounded by the Umtanum and Yakima Ridges, whereas the lower drainage system occurs near the confluence of Cold Creek and Dry Creek (see Fig. 3-24).

3.3.1.3.5 Flash flood potential within the reference repository location

Skaggs and Walters (1981) examined the potential for flash flooding in the reference repository location from the ephemeral stream called Cold Creek. Results indicate a potential for limited flooding along the southwestern portion of the reference repository location (Fig. 3-29). Analyses suggest that approximately 9 square kilometers (3.5 square miles) of the reference repository location could be inundated by a probable maximum flood. The probable maximum flood is the hypothetical flood considered the most severe reasonably possible based on application of probable maximum precipitation and other hydrologic factors favorable to maximum water runoff (ANS, 1981). Portions of this flood might extend into the area considered for repository surface support facilities. Using conservative factors on precipitation events and magnitudes, infiltration, surface roughness, and topography, a maximum flood depth of 2.3 meters (7.7 feet) was calculated along the southwestern border of the reference repository location. (The elevation of the valley floor is approximately 195 meters (640 feet) along the southwestern corner of the reference repository location.) This area is the topographically lowest point within the reference repository location. Theoretically, the recurrence interval of a probable maximum flood cannot be defined. This flood would be of short duration and is thought to reach the area considered for repository support facilities.

3.3.1.3.6 Proposed dam site

An additional dam site (Ben Franklin Dam) had been proposed for construction on the Columbia River along the Hanford reach approximately 16 kilometers (10 miles) upstream from Richland, Washington (see Fig. 2-16 for identification of existing dam sites along the Columbia and Snake Rivers). No construction schedules or dates are published, since the U.S. Army Corps of Engineers is not actively considering the dam site. The Ben Franklin Dam was conceived as a low-head dam, having a 15-bay spillway and a navigation lock, all on a straight axis across the river. An assessment of the possible effects of such a facility on Hanford Site activities was made by Harty (1979); however, the study did not attempt to evaluate the possible effects of the facility on a deep repository. The inundation of the Columbia River along the Hanford reach, resulting from maintenance of the reservoir at the 122-meter (400-foot) level, is shown in Figure 3-30. Surface inundation would be restricted to the immediate vicinity of the Columbia River. Figure 3-31 shows Harty's (1979) predicted water table elevation and rise within the sediments overlying the Columbia River Basalt Group resulting from this impoundment. Beneath the reference repository location, the expected water-table rise averages approximately 3 meters (10 feet). This is approximately 10 percent of the existing water-table rise resulting from present and past Hanford Site waste-water disposal (Section 3.3.2).

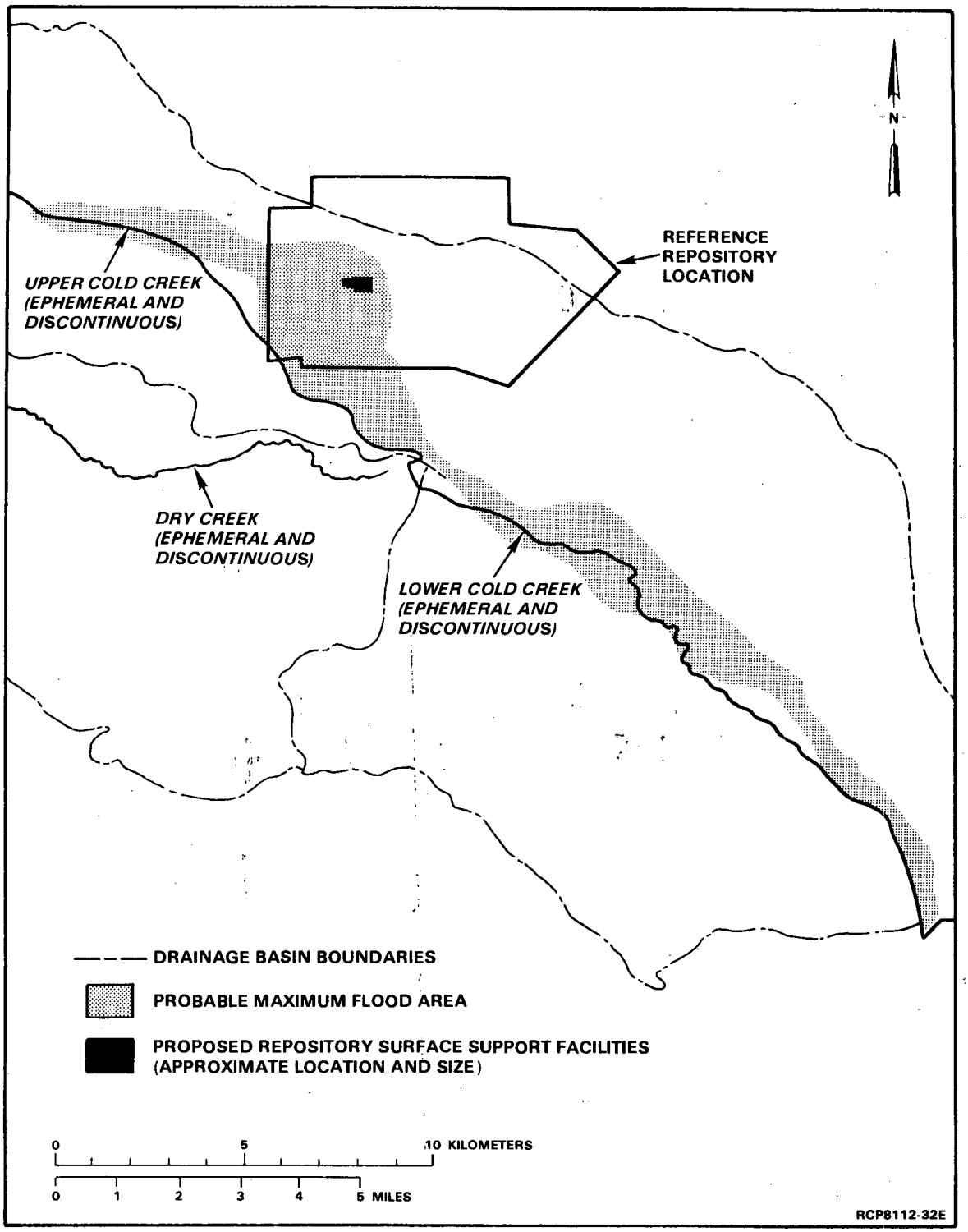

Figure 3-29. Extent of probable maximum flood in Cold Creek area.

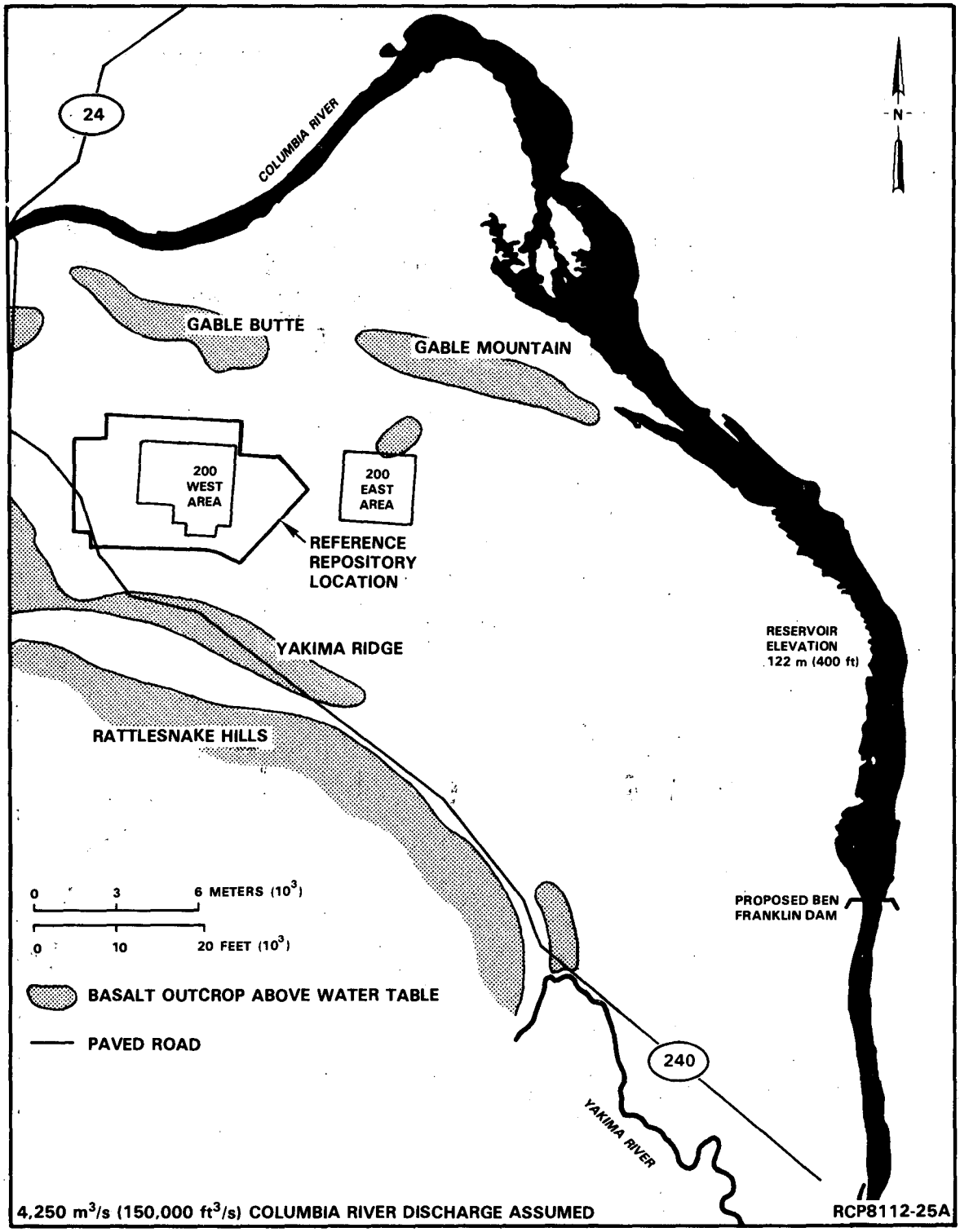

Figure 3-30. Inundation of the Columbia River along the Hanford reach resulting from operation of the proposed Ben Franklin Dam (after PNL, 1967).

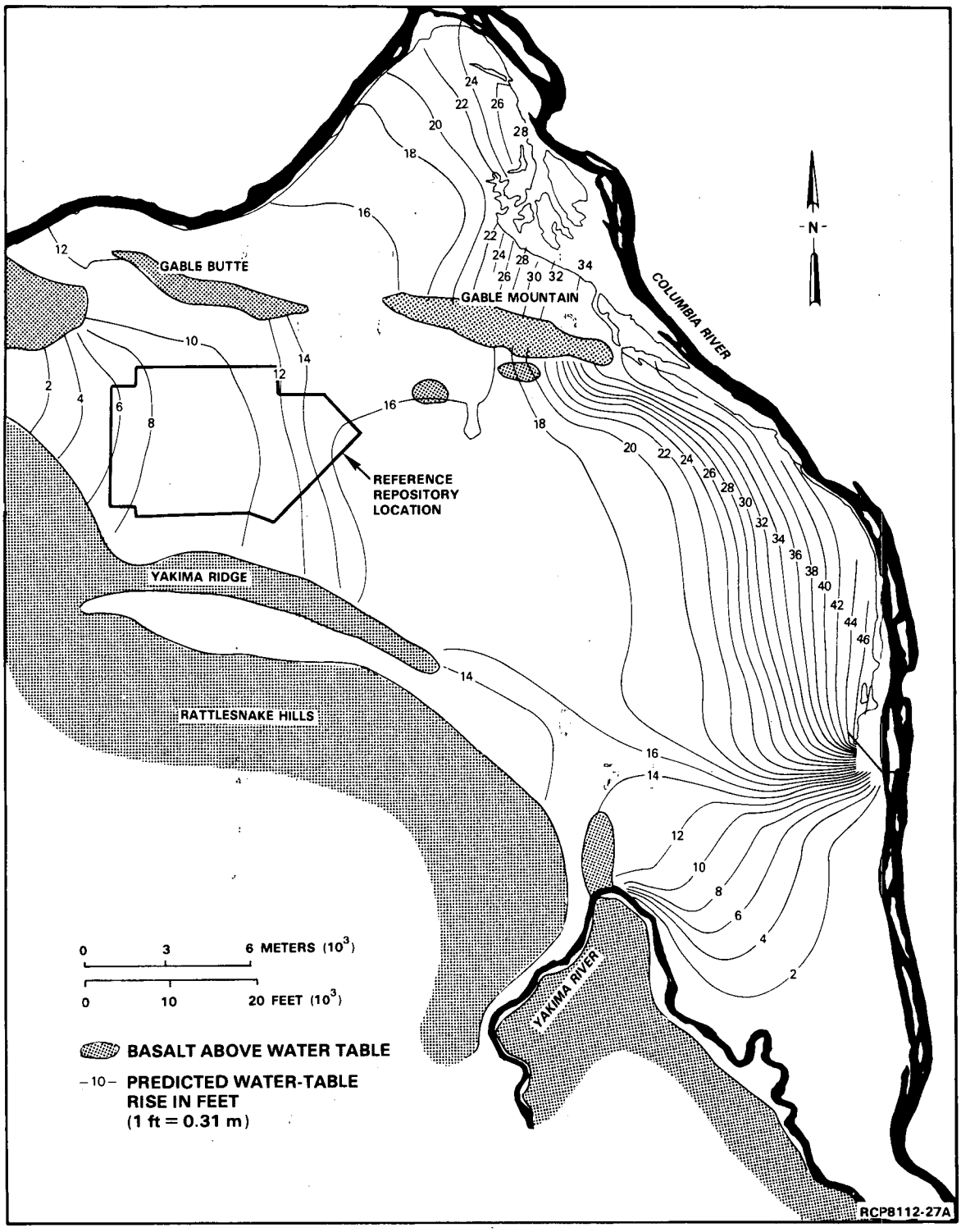

Figure 3-31. Predicted water-table rise, in sediments overlying the basalts, for the proposed Ben Franklin Dam (after Harty, 1979).

3.3.1.4 Surface-water use within the Pasco Basin

Water use within Benton and Franklin Counties may be considered to approximate the total user composition and demand within the Pasco Basin. The one notable exception may be irrigation water use within the Wahluke Slope area, north of the Columbia River and northwest of the Hanford Site along the southern slope of the Saddle Mountains. According to estimates from LANDSAT (Wukelic et al., 1981) and U-2 data, as well as survey statistics, approximately 13,000 hectares (30,000 acres) within this area are receiving irrigation. Water use may be approximated by assuming annual irrigation application on the order of 12,800 cubic meters per hectare (4.2 acre-feet per acre). Thus, the resulting annual estimate of water use would be approximately 1.5×10^8 cubic meters (40,000 million gallons). Annual water use within Benton and Franklin Counties (see Fig. 3-7) totals nearly one-fourth of the total demand within the State of Washington, according to 1975 water-use statistics (Dion and Lum, 1977). This equals a volume of over 2.3×10^9 cubic meters (600,000 million gallons or approximately 1.9 million acre-feet). The more significant portions of water demand occur within the industrial and agricultural sectors, which represent 22 and 76 percent, respectively, of the basin water demand. Municipal water use within Benton and Franklin Counties represents less than 2 percent of the total water use within the Pasco Basin.

Primarily, water is supplied from surface-water sources. Ground-water withdrawals (see Subsection 2.1.4.2) comprise less than 10 percent of the total demand for Benton and Franklin Counties. Table 3-7 presents the distribution of water demands as a percentage of the State total for Benton and Franklin Counties.

Table 3-7. The 1975 water-use totals and composition for Benton and Franklin Counties as a percentage of the State of Washington totals

Type of use	Ground water (%)	Surface water (%)	Total from both sources (%)
Municipal	3	9	6
Industrial	9	35	31
Irrigation	10	25	25
Total	4	26	24

NOTE: After Dion and Lum (1977).

3.3.1.5 Surface-water demand

A preliminary report was prepared on surface-water resource development and potential within the Pasco Basin (Bell and Leonhart, 1980). Later, an economic evaluation of the present and projected Pasco Basin water resource projections to the year 2080 was issued (Leaming, 1981). The projections were based largely on the reported 1975 water-use statistics by Dion and Lum (1977). The combined results of the above studies were addressed in a U.S. Department of Energy report (DOE, 1982b).

The total surface-water demand of the individual projections for municipally supplied, industrial, and agricultural needs are shown graphically in Figure 3-32. The figure shows that by the year 2080 total annual demand for consumptive water uses at 1980 real costs (i.e., 1980 worth of future value) might increase between 36 and 265 percent over 1980 demand. The most likely demand scenario shows that the increase will be on the order of approximately 83 percent. Leaming (1981) concluded that surface-water availability exceeds by orders of magnitude this increased demand, assuming no extra-basin constraints are imposed.

3.3.1.6 Surface-water intakes within the Pasco Basin

Known diversions of Columbia River water for various municipal, industrial, and agricultural purposes within the Pasco Basin and vicinity are shown in Figure 3-33. Table 3-8 provides a listing of the locations and types of these withdrawals.

3.3.2 GROUND WATER

This section describes the general hydraulic characteristics and ground-water flow pathways believed to exist beneath the reference repository location and vicinity based on available data and technical judgments.

Ground water beneath the Hanford Site occurs in a shallow, unconfined aquifer, consisting of fluvial and lacustrine sediments lying atop the basalts, and in deeper confined aquifers, consisting of basalt flow tops and sedimentary interbeds.

The unconfined aquifer thickness varies between 0 and 75 meters (0 and 250 feet). It is thickest along the eastern edge of the reference repository location, where 40 years of local water disposal to surface ponds have raised the water table approximately 25 meters (80 feet) (ERDA, 1975). The hydraulic conductivity of the unconfined aquifer is generally 10^{-2} to 10^{-3} meter per second (10^{3} to 10^{2} feet per day) for coarse sand and gravels and as low as 10^{-7} meter per second (10^{-2} foot per day) for finer grained, indurated sediments (Gephart et al., 1979). Storativity values are typically 10^{-1} to 10^{-2}. The ground-water composition is that

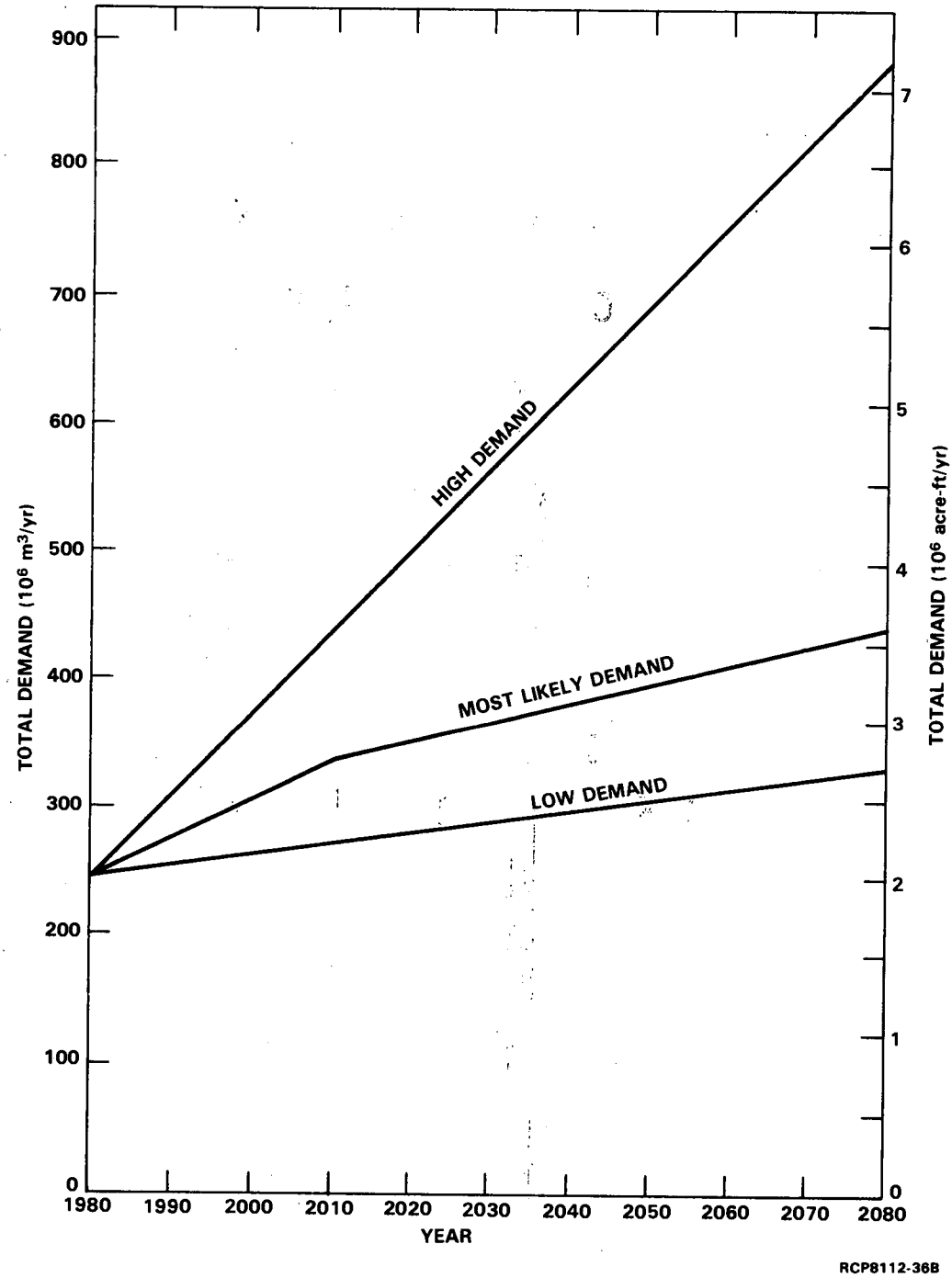

Figure 3-32. Projected demand for water in the Pasco Basin (DOE, 1982b, p. 7.3-9).

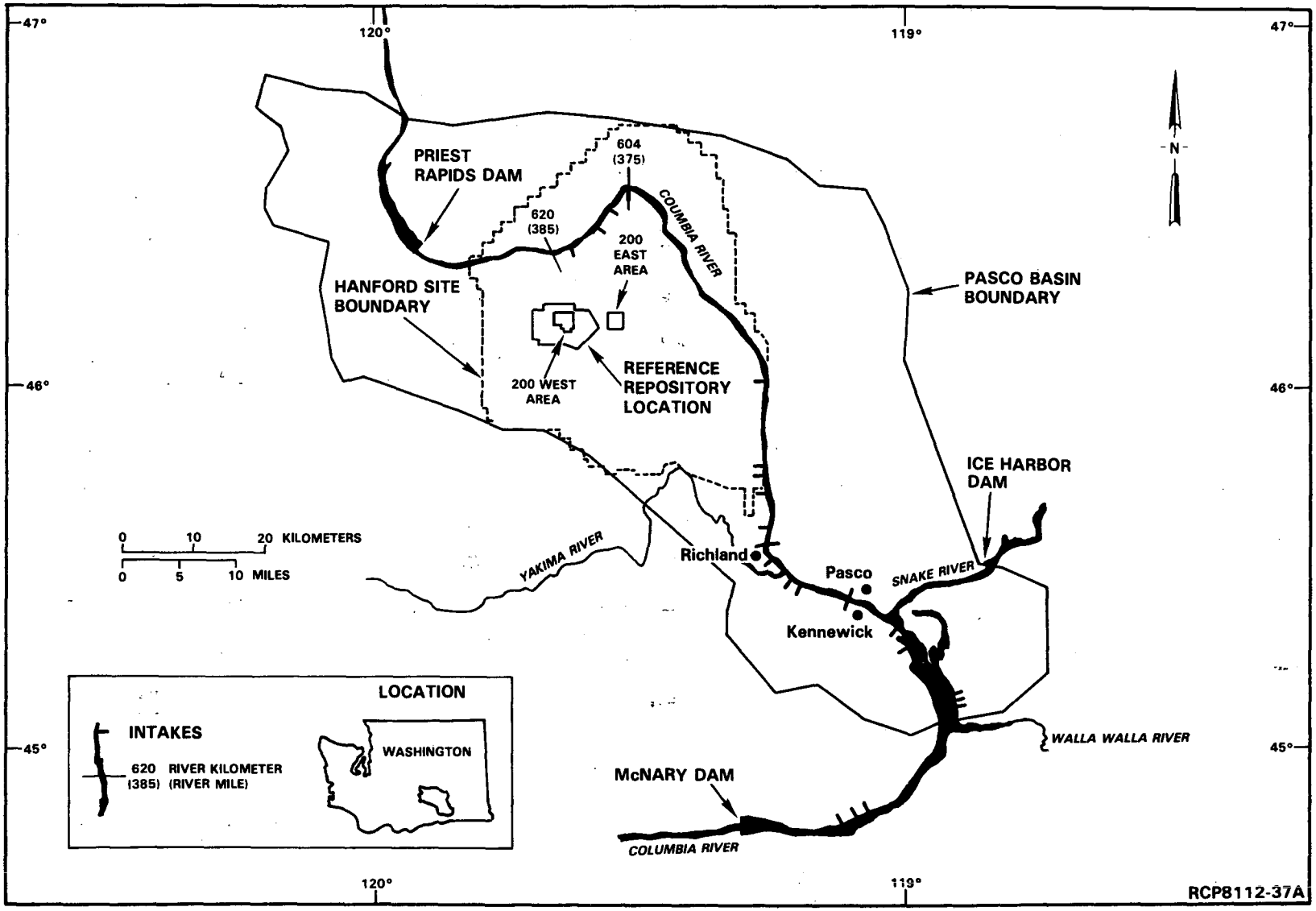

Figure 3-33. Surface-water intakes from the Columbia River in the Pasco Basin and vicinity.

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Table 3-8. Summary of downstream surface-water uses for the Columbia River (sheet 1 of 2)

User	Location of intake		Bank	Annual quantity withdrawn		Type of use[a]	Population served (if municipal)
	River km	River mi		m^3 (millions)	acre-ft		
Hanford Site (200 Areas)	620	385	Right	(b)	(b)	N	--
Hanford Site (100 K Area)	615	382	Right	2.54	2,056	N	--
Hanford Site (100 N Area)	610	379	Right	568	460,405	N	--
Hanford Site (200 Areas)	607	377	Right	(b)	(b)	N	--
Washington Public Power Supply System	565	351	Right	80.4	65,160	N	--
Peter Kiewit Sons Co.	565	351	Right	0.89	724	N	--
L. L. Bailey	558	347	Left	1.84	1,448	I	--
H. D. Loyd	558	347	Left	0.88	717	I	--
Central Premix Cement	558	347	Left	1.79	1,448	N	--
Hanford Site (300 Area)	554	344	Right	2.33	1,888	N	--
Battelle Memorial Inst.	552	343	Right	3.93	3,186	I	--
Univ. of Washington	550	342	Right	1.56	1,267	I	--
City of Richland	550	342	Right	0.60	485	M	(c)
City of Richland	546	339	Right	27.7	22,444	M	(c)
City of Richland	546	339	Right	20.8	16,833	M	(c)
City of Richland	546	339	Right	27.7	22,444	M	(c)
City of Richland	546	339	Right	83.1	67,332	M	c)
E. C. Watts	544	338	Right	0.28	224	I	--
H. S. Petty	544	338	Right	0.43	348	I	--
N. H. & M. E. Ketchersid	544	388	Left	1.48	1,202	I	--
G. C. Walkley	544	388	Left	2.07	1,680	I	--
R. T. Justesen	541	336	Right	2.27	1,839	I	--
Central Premix Concrete	541	336	Right	0.98	796	N	--
City of Richland	538	334	Right	1.79	1,448	I	--
Benton County	534	332	Right	0.89	724	I	--
City of Kennewick	528	328	Right	49.7	40,327	M	(c)
City of Pasco	528	328	Left	31.3	25,340	M	(c)
F. J. Henokel	521	324	Right	0.001	11	I	--
Allied Chemical	521	324	Right	3.17	2,570	N	--

7 0 1 6 8 0 0 7 3 0

Table 3-8. Summary of downstream surface-water uses for the Columbia River (sheet 2 of 2)

User	Location of intake		Bank	Annual quantity withdrawn		Type of use[a]	Population served (if municipal)
	River km	River mi		m^3 (millions)	acre-ft		
Chevron Chemical	520	323	Right	3.37	2,729	N	--
Chevron Chemical	520	323	Right	35.7	28,960	N	--
Philips Pac. Chemical	520	323	Right	73.2	59,368	N	--
Philips Pac. Chemical	520	323	Right	17.9	14,480	N	--
Boise Cascade Corp.	512	318	Left	21.9	17,738	N	--
L. D. Hoyte	510	317	Left	161	130,175	I	--
D. Howe	509	316	Left	5.72	4,634	I	--
Crawford & Sons	489	304	Right	29.3	23,747	I	--
Barborosa Farms	489	304	Right	17.9	14,480	I	--
Crawford & Sons	489	304	Right	6.79	5,502	I	--
Rainier National Bank	489	304	Right	8.40	6,806	I	--
Anderson & Coffin	486	302	Right	216	175,208	I	--
Horse Heaven Farms	484	301	Right	73.2	59,368	I	--
Horse Heaven Farms	484	301	Right	491	398,200	I	--
Horse Heaven Farms	484	301	Right	259	209,960	I	--
Anderson & Coffin	484	301	Right	216	175,208	I	--
Total				2,554.8			

NOTE: Taken from Washington Public Power Supply System (WPPSS, 1977) and U.S. Energy Research and Development Administration (ERDA, 1975).

[a]I = irrigation, M = municipal use, N = industrial use.

[b]Annual water use for the Hanford Site 200 Areas operations withdrawn at river kilometers 620 and 607 (river miles 385 and 377) reported as a total figure of 22.4 million cubic meters (18,166 acre-feet).

[c]Municipal populations served by Richland, Kennewick, and Pasco water-supply systems are approximately 34,250, 33,200, and 17,300, respectively.

7 0 1 6 8 0 7 3 1

of a dilute (less than or approximately 350 milligrams per liter total dissolved solids) calcium-bicarbonate chemical type. Other principal chemical constituents include sulfate, silica, magnesium, and nitrate (the latter contributed through the disposal of chemical reprocessing waters). Ground-water recharge is from precipitation and runoff in nearby hills and artificial recharge from water disposal to ponds. Discharge is to the Columbia River along a hydraulic head gradient of approximately 10^{-3} meter per meter (10^{-3} foot per foot) (Schatz, 1984). Beneath the central portion of the reference repository location, the water-table elevation is approximately 143 meters (470 feet) above mean sea level. This elevation corresponds to a depth of approximately 50 meters (165 feet) below land surface. A summary of the major unconfined aquifer test programs and findings for the Hanford Site is contained in a report by the U.S. Energy Research and Development Administration (ERDA, 1975) and Gephart et al. (1979). A routine onsite ground-water monitoring program reports on constituents in the unconfined aquifer resulting from waste-water disposal on the Hanford Site (Eddy et al., 1983; Prater et al., 1984).

Existing hydrologic data do not lead to a single interpretation of the ground-water-flow system (Subsection 3.3.2.2). However, a number of basic concepts addressing the overall three-dimensional ground-water-flow dynamics in and around the Hanford Site have been proposed by investigators based on available data and judgment; these are discussed below. Section 4.1 identifies the field activities planned for resolving questions regarding the geohydrologic characteristics and setting of the reference repository location.

Within basalt formations, principal ground-water occurrence is within flow tops and interbeds, which possess the largest hydraulic conductivity values found in basalt. The basalt flow interiors separating individual flow tops appear to act as semiconfining aquitards (perhaps aquicludes) through which some degree of vertical leakage occurs along cooling fractures (see Subsection 3.3.2.2 for discussion of alternative conceptual models). This concept of ground-water occurrence principally within flow contacts-interbeds separated by flow interiors of low hydraulic conductivity has been reported by many field investigations:

- LaSala et al. (1973, pp. 17 and 22) state: "Basaltic rocks consistently show that basalt flows yield little water but that thin zones of rubbly or fractured rock along the contacts of basalt flows yield large quantities of water." and "The most permeable water bearing zones in the basaltic rocks occur along the contacts of some of the flows . . . Such zones generally are only a few feet thick and make up a small percentage of the total basaltic-rock section."

- Newcomb (1965) notes that permeable zones comprise about one-tenth of the vertical section of the total basalt sequence. In Newcomb (1982, p. 8) basalt flow interiors are generally considered "impermeable." Newcomb (1982, p. 17) also conceptualizes that outside of permeable flow tops of some individual lava flows

"there is only a small vertical, cross-flow movement of the groundwater and this occurs at aquifer overlaps, steam breccia pipes, and within some of the steeply dipping fault zones."

- Luzier and Burt (1974, pp. 2 and 8) studied the basalt hydrology in east-central Washington; they addressed the inherent "low vertical permeability of individual basalt flows." This concept of flow interiors having low hydraulic conductivities and aquifer occurrence in flow tops-interbeds appears in State of Washington water-resource publications regarding basalt.

- MacNish and Barker (1976, p. 5) state: "The ability of a unit area of an aquifer to transmit water may be measured and described as its hydraulic conductivity. The hydraulic conductivity of horizontal permeability zones may be as large as 5 ft/s, while the vertical hydraulic conductivity may be as small as 0.00000005 ft/s."

- The U.S. Department of Energy (DOE, 1982b) documents preliminary data and conceptual discussions regarding the apparent large differences in hydraulic conductivities between flow tops-interbeds and basalt flow interiors. It is also noted that only a small percentage (approximately 5 percent) of the total basalt thickness appears to constitute permeable ground-water flow paths.

In the western Columbia Plateau, the Vantage interbed (see Fig. 3-6) is typically an aquifer. There, it consists of coarse-grained fluvial volcaniclastic sediments of sand and gravel size deposited by the ancestral Columbia River (Fecht et al., 1985). Eastward across the plateau, the Vantage interbed grades into fine silts and clays. These sediments have a lower hydraulic conductivity than those farther west. In the eastern Columbia Plateau, the Vantage interbed is absent from the stratigraphic section.

Beneath the reference repository location, the Vantage interbed thickness varies from approximately 6 meters (20 feet) to less than 0.1 meter (0.4 foot) (Landon, 1985). Eastward across the Hanford Site, the fine silts and clays of the interbed rapidly thin and disappear. Where missing, a thin, weathered flow top or saprolite caps the uppermost Grande Ronde Basalt flow. When present beneath the Hanford Site, the hydraulic conductivity of the interbed and adjoining flow top or bottom is reported to range between 10^{-6} and 10^{-13} meter per second (10^{-1} and 10^{-8} foot per day) with a geometric mean on the order of 10^{-7} to 10^{-8} meter per second (10^{-2} to 10^{-3} foot per day) (DOE, 1982b; Strait and Mercer, 1984).

Local ground-water recharge to shallow basalts beneath the Hanford Site is believed to result from infiltration of precipitation and runoff along the margins of the Pasco Basin (LaSala and Doty, 1971; Gephart et al., 1979). This concept is based on a variety of data sources, including basalt outcrop maps, precipitation distribution, plus

decreasing hydraulic heads, increasing total dissolved solids, and cationic-exchange processes taking place in ground waters sampled progressively distant from major basalt outcrops. Regional recharge of deep basalts is thought to result from interbasin ground-water movement originating northeast and northwest of the Pasco Basin in areas where the Wanapum and Grande Ronde Basalts crop out extensively (Tanaka et al., 1979; Gephart et al., 1979). For example, Tanaka et al. (1979, p. 28) state "all surface- and ground-water flow from the other subbasins directly or indirectly, with the exception of the Horse Heaven Hills subbasin, enters or flows through the Pasco subbasin" (see Fig. 2-15). Such a flow conceptualization is consistent with depicting regional ground-water movement from areas of high hydraulic head and rock elevation within the Columbia Plateau. Although a quantitative framework describing regional three-dimensional ground-water movement is currently unavailable, studies are directed toward finding answers and resolving differences in ground-water flow-model conceptualizations (Section 4.1).

Ground water probably discharges from the shallow basalt to the overlying unconfined aquifer and the Columbia River. The discharge area(s) for deep ground waters remains uncertain. Investigators have speculated that discharge is south of the Hanford Site (LaSala and Doty, 1971; LaSala et al., 1973; DOE, 1982b). Hydraulic head data collected since 1984 within and near the reference repository location suggest the Wanapum Basalt receives ground water moving downward from the Saddle Mountains Basalt and upward from the Grande Ronde Basalt. If this general flow pattern holds true across the Cold Creek syncline, the discharge point(s) for Wanapum Basalt ground waters might also identify Grande Ronde Basalt ground-water discharge areas.

Along flow paths, water is under artesian pressures. Areas of natural flowing artesian wells exist within the Cold Creek Valley west of the reference repository location and along the Columbia River where lowland elevations exist.

Artificial recharge, induced by losses of irrigation water from the Columbia Basin Irrigation Project, also has a pronounced impact on the hydraulic head and hydrochemistry for zones of the Saddle Mountains and upper Wanapum Basalts within the east-northeast part of the Pasco Basin (DOE, 1982b). The primary mechanism for transference of this recharge water is not completely understood, but may include a combination of leakage to and through underlying basalt formations, conveyance losses along surface canals in areas of surficial basalt exposures, and direct recharge to underlying basalts through poor well construction completions and long open holes across multiple basalt flows. Available studies in the Pasco Basin indicate it is not possible to identify the primary recharge mechanism. It is reasonable to assume, based on results of ground-water studies performed in surrounding areas (e.g., Luzier and Burt, 1974) that all three mechanisms are operative, to varying degrees, in the Pasco Basin.

Ground-water exchange between the unconfined and shallow confined aquifers beneath the Hanford Site also has been reported (Gephart et al., 1976; Graham et al., 1984). This exchange occurs near Gable Mountain Pond and West Lake located along the southwestern side of Gable Mountain (see Fig. 3-24). Here, the shallow basalts are folded and eroded.

Although specifics are currently unavailable, it has been proposed that the shallow basalt ground waters beneath the Hanford Site are locally recharged and discharged, while deeper flow systems are part of a more regional ground-water system. This would be consistent with the concepts of local, intermediate, and regional ground-water flow systems as proposed by Toth (1963) in his generic studies of ground-water flow patterns. The specific hydraulic effect of major geologic structures on ground-water flow patterns, such as anticlines crossing portions of the Columbia Plateau, is currently unanswered but is being addressed (Section 4.1).

At present, regional recharge to deep basalts is thought to result from a combination of factors, including (1) interbasin ground-water movement, (2) leakage along structural and stratigraphic discontinuities, and (3) leakage across nondeformed basalt flow interiors. The significance of each factor would vary depending on location. For example, in the eastern portion of the Columbia Plateau and Hanford Site, no major anticlines exist that could significantly impede or redirect interbasin ground-water movement from the Palouse subprovince (see Subsection 2.1.1.2). Here, the basalts (and overall ground-water flow directions) conform to the southwestern dip of the regional paleoslope. On the other hand, several anticlines exist in the western Columbia Plateau and Hanford Site areas that can influence vertical and lateral ground-water movement. These ridges belong to the Yakima Fold Belt subprovince. In such areas where major topographic relief exists, more complex local and regional flow system development probably occurs.

With the above ideas in mind, the geohydrology of the reference repository location appears to be most influenced by the following:

- A gently dipping (less than or equal to 5 degrees) and structurally uncomplicated bedrock of the Cold Creek syncline (east of the Cold Creek barrier and south of the Umtanum Ridge-Gable Mountain structure). This is believed to promote development of a ground-water flow system in which broad areal flow patterns are roughly in the direction of bedrock dip (i.e, toward the lowest elevations in the basin). (Tanaka et al. (1979) present structure-contour and water-level maps illustrating the general correspondence between structural dip and hydraulic gradient directions across the Columbia Plateau. In the plateau, the combination of pressure head and elevation of head-monitoring points describe a three-dimensional flow system in which ground water moves from high to low head and from high to low rock elevations.)

- The existence of the Cold Creek barrier and Umtanum Ridge-Gable Mountain structure. These nearby structures may tend to isolate the reference repository location from hydraulic influences to the west and north by forming hydraulic boundaries of low lateral hydraulic conductivity. Such a situation exists across the Cold Creek barrier in which the reference repository location appears isolated from the major influences of ground-water pumpage in the Cold Creek Valley. These structural boundaries might also identify areas of increased vertical ground-water leakage between deep and shallow ground-water systems compared to areas of structurally less-deformed basalt. However, ground-water movement near geologic structures is not well understood at this time. The eastern extension of the Yakima Ridge anticline may also influence the geohydrologic setting of the reference repository location.

- A large contrast in hydraulic conductivity between flow tops and flow interiors. This feature promotes lateral ground-water movement in flow tops (aquifers) and vertical flow across basalt flow interiors (aquitards or, possibly, aquicludes). Actual flow directions depend on hydraulic head distributions.

- Local flow-top heterogeneities. This will contribute to hydrodynamic dispersion (mixing) and tortuous ground-water flow paths.

Hydraulic heads are monitored in 35 wells across the Hanford Site in support of basalt studies (Swanson and Wilcox, 1985). Through the use of multiple piezometers, some wells monitor more than one stratigraphic horizon. Overall, there are 11 monitoring points in the unconfined aquifer, 25 in the Saddle Mountains and upper Wanapum Basalts, and 25 in the lower Wanapum and Grande Ronde Basalts. Seven wells monitor composite water levels across the Wanapum or Grande Ronde Basalts. Hydraulic head data are summarized in Swanson and Leventhal (1984), Swanson and Wilcox (1985), and in monthly and quarterly issued reports. The following paragraphs outline available head information from several of these wells. The preliminary nature of these data is recognized and additional monitoring facilities are planned (Subsection 4.1.1.4).

In general, data indicate hydraulic head changes of approximately plus or minus 1 meter (3 feet) in the Mabton interbed of the lower Saddle Mountains Basalt at boreholes DB-1 and DB-2 (Fig. 3-34). These holes are located near the Columbia River in the eastern portion of the Cold Creek syncline. The monitored record extended from 1978 to 1981. Both boreholes later were deepened to monitor the Priest Rapids Member of the upper Wanapum Basalt. Following equilibration in the Priest Rapids Member, water levels stabilized at an elevation of approximately 120 meters (394 feet) in both holes. North of the Umtanum Ridge-Gable Mountain structure, hydraulic heads in the Priest Rapids Member, as measured in borehole DB-12, showed seasonal fluctuations of approximately plus or minus 2.5 meters (8 feet). The monitored period extended from 1980 to 1985. Mean head elevations are approximately 122 meters (400 feet).

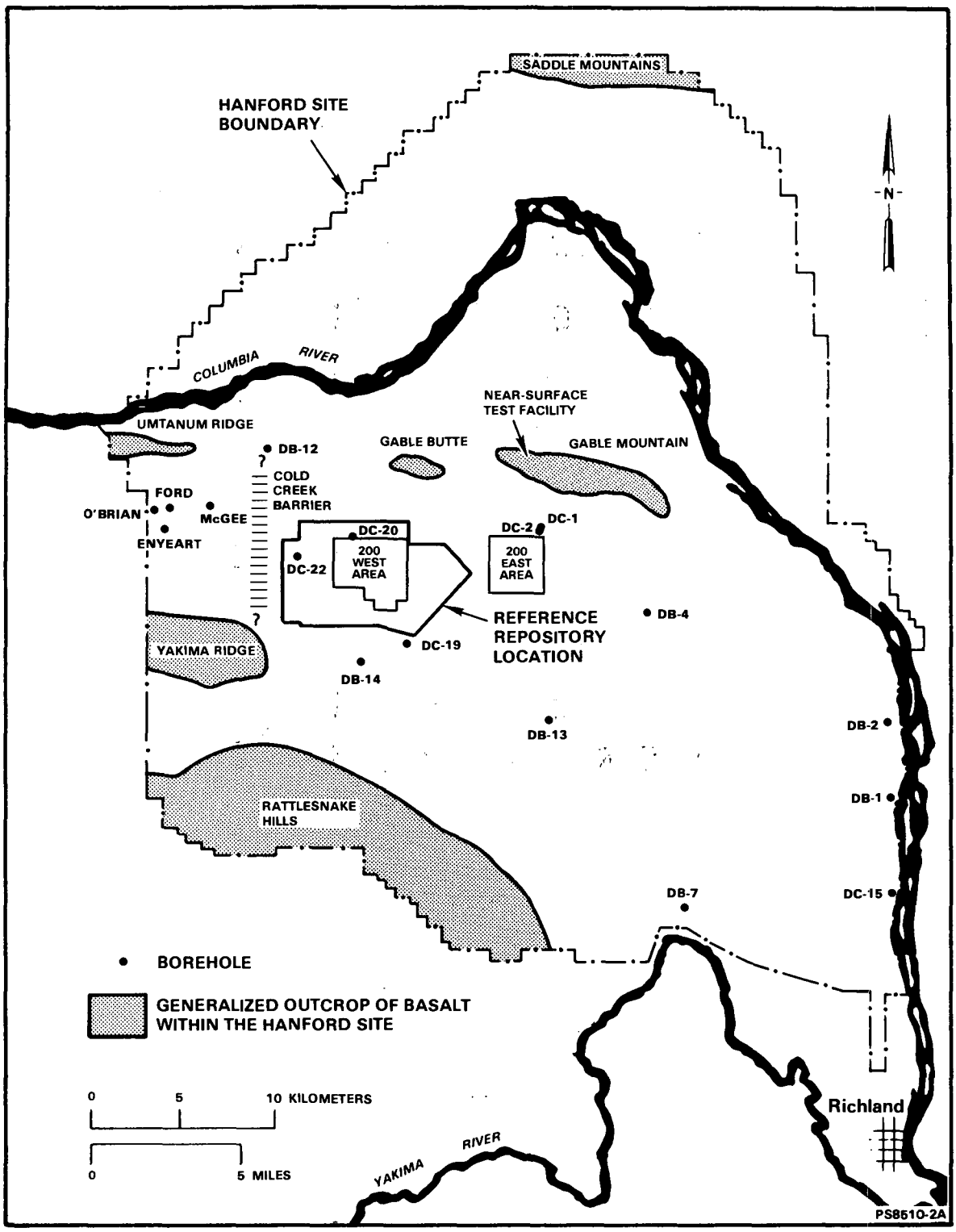

Figure 3-34. Location map for selected boreholes.

Centrally in the Cold Creek syncline, water levels in the Saddle Mountains and upper Wanapum Basalts appear to change little. For example, 3 to 7 years of monitoring are available from boreholes DB-4, DB-13, and DB-14. With the exception of periodic interferences from nearby borehole drilling, hydraulic heads in these holes have been generally uniform (less than or approximately 0.3-meter (1-foot) change). Elevations have centered on approximately 127 meters (418 feet) in DB-4, 128 meters (420 feet) in DB-13, and 122 meters (400 feet) in DB-14. In monitoring holes DC-19, DC-20, and DC-22, completed in early 1984 and located within and adjacent to the reference repository location, water-level changes have also been slight. The largest changes have been less than approximately 0.3 meter (1 foot), and have resulted mostly from barometric and earth-tide effects. Any cyclic changes attributable to irrigation or river-level changes are not evident. Hydraulic head elevations for selected stratigraphic intervals in the Saddle Mountains and Wanapum Basalts at boreholes DC-19, DC-20, and DC-22 are shown in Tables 3-9, 3-10, and 3-11.

South of the Cold Creek syncline, near the horn of the Yakima River, water levels in the lower Saddle Mountains Basalt have had an average elevation of approximately 122 meters (400 feet). Monitoring takes place in borehole DB-7. Since 1981, seasonal water-level changes have been approximately 0.3 meter (1 foot).

West of the Cold Creek barrier, water levels in the Priest Rapids Member of the upper Wanapum Basalt have undergone major changes due to local ground-water withdrawal. Closest to irrigated land, the O'Brian well (see Fig. 3-34) shows a water-level decline of approximately 9 to 11 meters (30 to 35 feet) from 1978 to 1984. Seasonal water-level fluctuations of 10 meters (30 feet) appear typical. Farther east from the area of maximum water withdrawal, yet still west of the Cold Creek barrier, water-level declines in the Enyeart and Ford wells have been as much as 7.5 and 3.0 meters (25 and 10 feet), respectively, since the late 1970's. Average peak hydraulic head elevations in the upper Wanapum Basalt of the Cold Creek Valley vary on location but are generally 277 to 282 meters (910 to 925 feet). This can be compared to head elevations of approximately 122 meters (400 feet) in the same stratigraphic horizon within the reference repository location, east of the Cold Creek barrier. The apparent lack of seasonal water-level changes in the upper Wanapum Basalt in the reference repository location tends to support the conceptualization of a no-flow or low-flow lateral boundary associated with the Cold Creek barrier.

Based on available data, water-level changes in the lower Wanapum and Grande Ronde Basalts of the western Cold Creek syncline appear to be slow and small (Swanson and Wilcox, 1985; Bryce and Yeatman, 1985). These changes are summarized in Table 3-12 for the May 1984 and March 1985 time periods. Generally, hydraulic head elevations in the Sentinel Gap and Ginkgo flows of the Wanapum Basalt have remained steady at approximately 122 meters (400 feet). Most head elevations in the Grande Ronde Basalt are slowly recovering from well installation. Recovery has been

Table 3-9. Vertical hydraulic head gradients calculated from observed water levels in piezometer cluster DC-19 for March 1985

Stratigraphic interval monitored	Observed hydraulic head (m above mean sea level)[a]	Vertical interval separating designated monitored zones (m)[b]	Apparent vertical head gradient across basalt formations
Saddle Mountains Basalt			3×10^{-2} (down)
Rattlesnake Ridge interbed	134.4	220	
Mabton interbed	128.5		
Wanapum Basalt		70	4×10^{-4} (up)
Priest Rapids Member	122.0		
Sentinel Gap flow	122.1	240	
Ginkgo flows	122.1		
Grande Ronde Basalt		115	4×10^{-4} (up)
Rocky Coulee flow	122.4		
Cohassett flow	122.3	250	
Umtanum flow	122.5		
Wanapum and Grande Ronde Basalts			8×10^{-4} (up)[c]

NOTE: 1 meter = 3.28 feet

[a]Data taken from Bryce and Yeatman (1985).

[b]Data taken from Jackson et al. (1984).

[c]Value calculated by subtracting hydraulic heads in Umtanum and Priest Rapids flows. At the time of these comparative head measurements, a slightly lower head elevation existed in the Cohassett flow compared to the Rocky Coulee and Umtanum flows.

7 0 1 6 8 0 7 3 9

Table 3-10. Vertical hydraulic head gradients calculated from observed water levels in piezometer cluster DC-20 for March 1985

Stratigraphic interval monitored	Observed hydraulic head (m above mean sea level)[a]	Vertical interval separating designated monitored zones (m)[b]	Apparent vertical head gradient across basalt formations
Saddle Mountains Basalt			4×10^{-2} (down)
Rattlesnake Ridge interbed	135.5	218	
Mabton interbed	126.3		
Wanapum Basalt		68	0 (no gradient)
Priest Rapids Member	122.4		
Sentinel Gap flow	122.4	243	
Ginkgo flows	122.4		
Grande Ronde Basalt		109	1×10^{-3} (up)
Rocky Coulee flow	123.3		
Cohassett flow	123.3	249	
Umtanum flow	123.6		
Wanapum and Grande Ronde Basalts			2×10^{-3} (up)

NOTE: 1 meter = 3.28 feet

[a]Data taken from Bryce and Yeatman (1985).

[b]Data taken from Jackson et al. (1984).

7 0 1 6 8 0 0 7 4 9

Table 3-11. Vertical hydraulic head gradients calculated from observed water levels in piezometer cluster DC-22 for March 1985

Stratigraphic interval monitored	Observed hydraulic head (m above mean sea level)[a]	Vertical interval separating designated monitored zones (m)[b]	Apparent vertical head gradient across basalt formations
Saddle Mountains Basalt			4×10^{-2} (down)
Rattlesnake Ridge interbed	134.8	231	
Mabton interbed	125.1		
		61	8×10^{-4} (up)
Wanapum Basalt			
Priest Rapids Member	122.1		
Sentinel Gap flow	122.2	257	
Ginkgo flows	122.3		
		91	1×10^{-3} (up)
Grande Ronde Basalt			
Rocky Coulee flow	122.9		
Cohassett flow	123.1	261	
Umtanum flow	123.2		
Wanapum and Grande Ronde Basalts			2×10^{-3} (up)

NOTE: 1 meter = 3.28 feet

[a]Data taken from Bryce and Yeatman (1985).

[b]Data taken from Jackson et al. (1984).

7 0 1 6 8 0 7 4 1

Table 3-12. Hydraulic head changes in basalt flow tops and sedimentary interbeds monitored in boreholes DC-19, -20, and -22*

Stratigraphic interbed	Observed hydraulic head (m above mean sea level)					
	Borehole DC-19		Borehole DC-20		Borehole DC-22	
	May 1984	March 1985	May 1984	March 1985	May 1984	March 1985
Saddle Mountains Basalt						
Rattlesnake Ridge interbed	133.0	134.4	135.4	135.5	134.7	134.8
Mabton interbed	128.3	128.5	126.2	126.3	125.1	125.1
Wanapum Basalt						
Priest Rapids Member	122.0	122.0	122.2	122.4	122.1	122.1
Sentinel Gap flow	122.1	122.1	122.3	122.4	122.1	122.2
Ginkgo flows	122.1	122.1	122.4	122.4	122.0	122.3
Grande Ronde Basalt						
Rocky Coulee flow	120.7	122.4	123.0	123.3	121.0	122.9
Cohassett flow	122.1	122.3	122.7	123.3	122.2	123.1
Umtanum flow	121.9	122.5	122.8	123.6	122.5	123.2

NOTE: 1 meter = 3.28 feet.

*Data taken from Bryce and Yeatman (1985).

asymptotic and over a range of approximately 0.6 to 1.8 meters (2 to 6 feet). This recovery has been steady without evidence of other imposed cyclic changes. Such a slow recovery for most Grande Ronde Basalt hydraulic heads, compared to the rapid recovery of water levels in shallower basalts, lends support to the concept that deeper basalt flows appear to be hydraulically tighter than shallower basalts (Subsection 3.3.2.1.2). Depending on location, hydraulic head elevations in the Grande Ronde Basalt in and around the reference repository location are approximately 122 to 124 meters (401 to 406 feet) (see Table 3-12).

Borehole DC-1 (see Fig. 3-34) is located approximately 4 kilometers (2.5 miles) northeast of the reference repository location. In 1972, five piezometers were installed in this borehole: Four within Grande Ronde Basalt and one across a composite section of Wanapum Basalt. Except for one piezometer that responded erratically (LaSala, 1973; Gephart et al., 1979), maximum head variations from 1972 to 1979 were less than approximately 1 meter (3 feet). Since the 1978 completion of nearby borehole DC-2, water levels in several of the DC-1 piezometers have slowly declined approximately 1.5 meters (5 feet). This decline is attributed to the construction and open-hole completion of borehole DC-2 across the Grande Ronde Basalt. The present monitoring integrity of borehole DC-1 is questioned.

The only Grande Ronde Basalt head monitoring west of the Cold Creek barrier is in the McGee well (see Fig. 3-34). There, head elevations in the McCoy Canyon flow have remained essentially unchanged at 183.5 to 183.8 meters (602 to 603 feet) over the initial monitoring period of October 1984 to August 1985. The reason why these heads are approximately 90 meters (300 feet) lower than heads in the overlying upper Wanapum Basalt is unknown. The difference could be related to a depth change in the hydraulic characteristics of the Cold Creek barrier.

Table 3-13 gives a comparison of areal head gradients between boreholes DC-22 and DC-15 located inside and far outside the reference repository location. These boreholes are along the general trend of the Cold Creek synclinal axis, and are believed to be located along the approximate direction of deep ground-water movement. Rock intervals selected for head comparisons are within the Wanapum and Grande Ronde Basalts. A lateral head gradient of 1×10^{-4} meter per meter (1×10^{-4} foot per foot) appears typical. As noted in Table 3-13, hydraulic heads in borehole DC-15 were measured during reconnaissance hydrologic studies, when water levels were recorded during a progressive drill-and-test basis as the borehole was deepened. Head measurements from this technique are considered preliminary because of possible local head changes resulting from hole emplacement, hydrologic tests, and natural variations over time. Hydraulic heads now monitored in and around the reference repository location (e.g., those in borehole DC-22 as listed in Table 3-13) are measured by permanent piezometers.

Table 3-13. Comparison of observed hydraulic head gradients for selected basalt flows in the Wanapum and Grande Ronde Basalts

Stratigraphic interval	Observed hydraulic heads (m above mean sea level)[a]		Average areal head gradient between boreholes (m/m)[b]
	Head in DC-22	Head in DC-15	
Wanapum Basalt			
Priest Rapids Member	122.1	117.5	1×10^{-4}
Sentinel Gap flow	122.2		
Ginkgo flows	122.3	118.0	1×10^{-4}
Grande Ronde Basalt			
Rocky Coulee flow	122.9	119.0	1×10^{-4}
Cohassett flow	123.1	119.0	1×10^{-4}
Umtanum flow	123.2	121.5	4×10^{-5}

NOTE: 1 meter = 3.28 feet.

[a]Observed hydraulic heads in borehole cluster DC-22 are monitored values recorded during March 1985. Values are reported to nearest 0.1 meter (Bryce and Yeatman, 1985). Observed hydraulic heads in borehole DC-15 were collected in 1980 on a drill-and-test basis. Values are reported to nearest 0.5 meter (Swanson and Wilcox, 1985).

[b]Boreholes DC-22 and DC-15 are separated by 37 kilometers (approximately 23 miles).

Within the reference repository location, lateral hydraulic head gradients can be calculated using monitored water levels from piezometers at boreholes DC-19, DC-20, and DC-22. Results for the eight basalt or sedimentary interbed intervals monitored are reported in Sorooshian et al. (1985) and shown in Table 3-14. Gradients range from 4×10^{-4} to 8×10^{-5} meter per meter (4×10^{-4} to 8×10^{-5} foot per foot). The median value appears to be 1×10^{-4} to 2×10^{-4} meter per meter (1×10^{-4} to 2×10^{-4} foot per foot). The flow direction is generally south to southwest.

Table 3-14. Observed hydraulic head gradients and azimuths as determined from three points in the reference repository location[a]

Stratigraphic interval	Lateral gradient[b] (m/m)	Azimuth[c]
Rattlesnake Ridge interbed	3×10^{-4}	205°
Mabton interbed	4×10^{-4}	295°
Priest Rapids Member (Rosalia flow)	1×10^{-4}	205°
Sentinel Gap flow	1×10^{-4}	205°
Ginkgo flows	8×10^{-5}	190°
Rocky Coulee flow	2×10^{-4}	195°
Cohassett flow	2×10^{-4}	180°
Umtanum flow	2×10^{-4}	195°

NOTE: 1 meter = 3.28 feet

[a]Analyses after Sorooshian et al. (1985).

[b]Calculated to nearest significant figure for observed heads monitored between February 1984 and May 1985 at borehole sites DC-19, DC-20, and DC-22.

[c]Given to nearest 5-degree interval.

As noted earlier, the overall deep ground-water-flow direction for the Cold Creek syncline is believed to be southeast along the synclinal axis. This is also the general direction of bedrock dip. New boreholes are planned north and south of the reference repository location to assess the structural influence of the Umtanum Ridge-Gable Mountain structure and Yakima Ridge anticline on local ground-water flow patterns (Gephart, 1985). These new data are essential in developing an overall conceptualization of flow patterns and directions across the Cold Creek syncline, of which the reference repository location is only a part. New boreholes are also planned east of the reference repository location along the structural trend of the Cold Creek synclinal axis.

Vertical head gradients within the reference repository location and vicinity are shown in Tables 3-9, 3-10, and 3-11. Data used are from the eight basalt flow tops and sedimentary interbeds monitored in boreholes DC-19, DC-20, and DC-22 (see Fig. 3-34). Overall, the hydraulic head potential is downward across the Saddle Mountains Basalt along a gradient of 3×10^{-2} to 4×10^{-2} meter per meter (3×10^{-2} to 4×10^{-2} foot per foot). This gradient is indicative of an area of ground-water recharge. Gradients across the Wanapum and Grande Ronde Basalts are directed upward, with values ranging from 2×10^{-3} to 8×10^{-4} meter per meter (2×10^{-3} to 8×10^{-4} foot per foot). These gradients suggest ground-water discharge. The rate and quantity of such discharge are dependent on head gradient and the vertical permeability of the basalt. As addressed later in this section, hydrochemical data also suggest vertical ground-water movement, although the rate and extent are unknown. Based on this preliminary knowledge of vertical head distributions, it appears that the more permeable flow tops of the upper Wanapum Basalt might act as conduits or drains for deeper ground-water discharge.

The hydraulic head values and gradients given above and throughout this environmental assessment are based on observed water levels and fluid pressures. Research is under way to account for fluid-column density effects, which commonly occur in deep hydrologic systems such as those tested beneath the Hanford Site (Spane and Mercer, 1985). These corrected heads are called environmental water heads and are used to examine vertical head gradients. Corrections applied include those due to temperature, pressure, and salinity differences. In addition, external stresses resulting from barometric and earth-tide fluctuations and gravitational acceleration variation are taken into consideration. Observed and environmental head values appear to agree closely. Such corrected values, to be documented in future reports, will not affect the basic head gradients given in this environmental assessment. Studies are also under way in reducing hydraulic heads to a standard temperature, pressure, and salinity. These values are called fresh-water heads and are another way to examine horizontal gradients.

When the above data are combined with existing preliminary hydraulic head information collected on a progressive drill-and-test basis, a preliminary understanding emerges of the broad head patterns that might exist across the Hanford Site. The western Hanford Site, that region closest to the Rattlesnake Hills and the Yakima and Umtanum Ridges, appears to be a recharge area for the shallow basalts (see Fig. 3-24). Here, hydraulic heads decrease with depth. (This head gradient also may have been influenced by water discharges from previous Hanford Site operations.) Eastward across the Hanford Site, heads become more uniform with depth in the central Cold Creek syncline, suggesting lateral ground-water movement. Close to the Columbia River, heads in the shallow basalts either increase with depth or have a variable pattern, suggesting potential discharge. In deep basalt flows (principally Wanapum and Grande Ronde Basalts), available hydraulic head data indicate an upward gradient. Overall, ground water appears to flow southeast, although local flow patterns in other directions may exist due to structural influences.

These generalized head patterns have been reported or suggested by several investigators; e.g., LaSala and Doty (1971, p. 60) state: ". . . water in the basaltic rock possibly moves from where it enters the rocks on the ridges and plateaus fringing the Pasco Basin to the Columbia River or the low ground south of the Reservation near Wallula Gap" (see Fig. 3-1). In like manner, LaSala et al. (1973, p. 4) state: "The ground water beneath the main part of the Hanford Reservation, south and west of the Columbia River, moves southeastward from the recharge areas in the uplands, including Cold Creek and Dry Creek Valleys, and ultimately discharges to the Columbia River south of the reservation." The above broad concepts appear to be generally supported by data collected and reported in Gephart et al. (1979), U.S. Department of Energy (DOE, 1982b), and U.S. Department of Energy/U.S. Nuclear Regulatory Commission (DOE/NRC, 1983). A lateral hydraulic gradient of approximately 10^{-4} meter per meter (10^{-4} foot per foot) is reported based on available data (Long and WCC, 1984; DOE, 1982b; Bryce and Yeatman, 1985; Swanson and Wilcox, 1985). The exact location(s) of ground-water discharge from the Wanapum and Grande Ronde Basalts, after it moves beneath the Hanford Site, is not presently known. Ultimately, these ground waters likely discharge into the Columbia River. Additional hydraulic head data are needed from these formations to infer reliably ground-water-flow paths and areas of recharge and discharge.

In addition, the U.S. Department of Energy (DOE, 1982b, p. 5.1-203) states: "Because of a hydraulic low near the Umtanum Ridge-Gable Mountain anticline, shallow ground waters from the northern portion of the reference repository location may flow north rather than east to southeast; whether the hydraulic low extends to the Wanapum and Grande Ronde Basalts is an unanswered question." An examination of hydraulic head distributions near this anticlinal structure and between the northern border of the reference repository location and the Columbia River is planned (Section 4.1.1).

The above statements on hydraulic head patterns are not given as conclusions, but rather conceptualizations based on information available by researchers at the time of their studies. Some controversy exists concerning the representativeness of heads acquired over a period of time on a progressive drill-and-test basis and the possible hydraulic effects of past waste-water disposal on the Hanford Site. Therefore, because of the apparent low hydraulic gradient in the deep basalts beneath the Hanford Site and the fact that time-variant heads are an essential ingredient of site characterization, additional monitoring wells were installed in and around the reference repository location. Three piezometric suites were completed in which 11 boreholes were drilled and 27 ground-water-monitoring points established. Water levels are now being monitored from within the unconfined aquifer to the flow top of the Umtanum flow. Preliminary data from these piezometers were discussed previously in this section. These data appear to support earlier concepts of generally low hydraulic gradients existing in the deep basalts in and near the reference repository location (Yeatman and Bryce, 1984a, 1984b; Bryce and Yeatman, 1985).

Areal and stratigraphic changes in ground-water chemistry characterize basalt ground waters beneath the Hanford Site (Graham et al., 1982; Early et al., 1985). The stratigraphic position of these changes is believed to delineate flow-system boundaries and to identify chemical evolution taking place along ground-water flow paths. Some locations of potential mixing of ground waters have also been identified. However, the rate of any mixing is unknown. If the presently detected low hydraulic gradients of the Wanapum and Grande Ronde Basalts beneath the western Cold Creek syncline were maintained in the geologic past, any ground-water mixing may have been slow, perhaps approaching near-stagnation conditions. This concept suggests that an active, local ground-water flow system might exist at shallow depths (e.g., in the unconfined aquifer sediments, Saddle Mountains Basalt, and possible upper Wanapum Basalt), and a slower moving ground-water circulation system lies in the deeper Wanapum and Grande Ronde Basalts beneath the reference repository location. However, knowledge of the actual flow patterns existing in the basalts and possible mixing rates must await completion of further studies (Section 4.1.1).

The Cold Creek barrier and Umtanum Ridge-Gable Mountain structure also may play a role in any vertical ground-water exchange taking place within the basalt mass itself or between the basalts and underlying rocks. The possible significance of these structures in influencing vertical ground-water movement is unknown at this time.

The proposed hydrochemical model interprets the Cold Creek barrier as an impediment to eastward ground-water flow. The barrier creates a relatively stagnant lateral flow regime within the reference repository location. Consequently, the local vertical hydraulic gradient transports more mineralized, deep ground water into shallower stratigraphic horizons than would occur if the barrier did not exist.

Deep profiles of hydrochemical changes from other boreholes located on the Hanford Site also show increasing concentrations of conservative, naturally occurring tracers. However, these profile details differ from those observed in the reference repository location. They suggest that the vertical ground-water flow component is less pronounced than in the reference repository location. This observation appears compatible with a conceptual model having constant vertical ground-water flux of deep waters across the Hanford Site with more active lateral mixing of shallower waters by recent recharge. Dilution from these younger waters may mask evidence for upward migration of deep, mineralized water except in the possible stagnant zone east of the Cold Creek barrier. The rate and extent of such mixing are presently unknown.

An alternative conceptualization explaining ground-water chemical evolution in the reference repository location and vicinity involves preferential upward vertical flow (e.g., resulting from larger local vertical hydraulic conductivity), compared to other areas on the Hanford Site where vertical flow appears less evident. Such flow might represent a point source for introduction of deep, mineralized ground water into the Wanapum Basalt. Lateral variation within the Cold Creek syncline of

conservative, natural tracers (e.g., chloride) may identify a southeast-directed path of solute transport from the reference repository location.

Preliminary interpretation of hydrochemical data from Columbia River basalts for the entire plateau suggests that the vertical component of ground-water flow hypothesized for the Hanford Site might be related to a deep regional flow system. Additional studies need to address this interpretation (Subsection 4.1.1.5).

Overall, shallow basalts are of a sodium-bicarbonate chemical type; deep basalts are of a sodium-chloride chemical type (Early et al., 1985). Table 3-15 summarizes the range of concentration and mean compositions of major inorganic constituents in ground waters sampled beneath the entire Hanford Site. On a location-by-location basis, chemical and isotopic shifts can be pronounced (DOE, 1982b). The stratigraphic boundaries separating chemical types vary depending on location. When hydrochemical data from the reference repository location boreholes (RRL-2, RRL-6, RRL-14, and DC-16 (see Fig. 3-7 for locations)) are taken as a composite, it is observed that ground-water composition changes systematically as a function of depth. For example, chloride (a conservative tracer) concentration is uniformly low (less than 10 milligrams per liter) within the Saddle Mountains Basalt (Early et al., 1985). Within the Wanapum Basalt, ground-water chloride content increases systematically from approximately 100 milligrams per liter at the top of the Wanapum Basalt to approximately 450 milligrams per liter at its base. At greater depth (within the Grande Ronde Basalt), chloride concentrations remain essentially constant at approximately 450 milligrams per liter to the total sampled depth of approximately 1,100 meters (3,600 feet). Analogous hydrochemical gradients for other key parameters (sodium, fluoride, and ratios of stable hydrogen and oxygen isotopes) over the same stratigraphic interval also are observed. Studies are under way to understand the basalt and ground-water interactions controlling these chemical types and to interpret the role of geochemistry in developing a ground-water conceptual model.

The concept of minimal vertical ground-water leakage between flow systems was suggested by LaSala and Doty (1971, p. 59). Based on their test results at borehole DC-1, they state: "The chemical and isotopic characteristics of the groundwater show a strong horizontal zonation of the deeper water in the well. . .This zonation indicates that little, if any, vertical movement of water has occurred at the site of the well." Whether or not this conceptualization is correct must be determined through further study. However, it is recognized that over broad regions, ground-water movement (even across basalt flow interiors of apparent low hydraulic conductivity) can be an important consideration in understanding flow dynamics and geochemical evolution. Future geochemical modeling is directed toward evaluating hydrochemical zonations.

Springs are common on basalt ridges surrounding the Pasco Basin. Rattlesnake Mountain, located southwest of the reference repository location, is an area where spring-related studies have been completed

Table 3-15. Range of concentration and mean compositions of major inorganic constituents of basalt ground waters

Constituent	Saddle Mountains Basalt		Wanapum Basalt		Grande Ronde Basalt	
	Range	Mean	Range	Mean	Range	Mean
Anions (mg/L)						
Total alkalinity as HCO_3	104-303	194	110-211	174	64-251	157
Cl^-	3.4-63	12	4.1-452	98	71-507	221
SO_4^{-2}	0.5-107	43	<0.5-38	7.3	1.7-199	92
NO_3^-	<0.5-7.6	<0.5	<0.5	<0.5	<0.5	<0.5
F^-	<0.3-7.6	1.2	0.4-27	8.6	11-44	27
Cations (mg/L)						
Na^+	16-122	60	27-346	120	161-373	269
K^+	6.2-14	10	7.1-35	16	0.4-25	9.7
Ca^{+2}	0.5-55	13	0.5-18	6.1	1.0-10	2.7
Mg^{+2}	0.08-16	4.1	0.1-10.3	2.5	0.01-0.17	0.04
SiO_2 (mg/L)	21-91	61	56-120	75	82-162	103
Total dissolved solids (mg/L)	227-518	369	298-1,009	486	527-1,129	830
pH (field)	7.0-9.4	8.2	7.5-9.5	8.9	9.1-10.6	9.6

NOTE: Values are based on approximately 150 unique ground-water samples. Some 400 to 500 values are available when sample duplicates and triplicates are considered.

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(Schwab et al., 1979; Gephart et al., 1979; Fecht et al., 1984) and hydrochemical analyses conducted (Early et al., 1985). A total of 125 springs or suspected spring locations were identified in Schwab et al. (1979) over the 470-square-kilometer (182-square-mile) area studied. Springs occur where natural recharge from precipitation infiltrates along rock having higher hydraulic conductivity until a zone of lower conductivity is encountered. Such a zone may be a basalt flow interior or clays in a sedimentary interbed. Some water then moves in the direction of bedrock dip or along a geologic feature of higher hydraulic conductivity until it reaches land surface. Most springs in the Rattlesnake Mountain area appear to discharge from basalt flow tops and interbeds and along structural features. Springs inventoried occur across elevations of 320 to 1,000 meters (1,050 to 3,300 feet). Total spring discharges increase with decreasing elevations, reaching a peak discharge of approximately 380 liters (100 gallons) per minute between the elevations of 490 and 610 meters (1,600 and 2,000 feet) for the area studied. Alluvial sediment covers any spring discharges below the approximate 320-meter (1,000-foot) elevation along Rattlesnake Mountain.

Geochemically, spring waters are of a calcium-sodium-bicarbonate type with low total dissolved solids (approximately 200 to 400 milligrams per liter) (Early et al., 1985). Compositionally, these waters are similar to shallow local ground waters (unconfined aquifer and upper Saddle Mountains Basalt). However, they are readily distinguishable from waters of the lower Saddle Mountains (Mabton interbed) and the Wanapum and Grande Ronde Basalts, which are of sodium-bicarbonate to sodium-chloride-bicarbonate (or sodium-chloride-sulfate) type. Currently, there is no evidence suggesting these spring waters contain any significant component of deeper ground water, an occurrence that would be recognized, for example, by elevated concentrations of fluoride and chloride in spring samples.

The observed abundance of naturally occurring, cosmogenically produced, radioactive isotopes such as tritium (half-life = 12.3 years) and carbon-14 (half-life = 5,570 years) tend to support the hypothesis that these spring waters have recharged recently. For example, tritium concentrations range from 0 to 7 tritium units. Furthermore, carbon-14 content ranges from approximately 20 to over 100 percent modern. Both observations are indicative of relatively young waters with evidence of some recent meteoric inputs (post-mid-1950's). The possibility of contamination of these waters with modern carbon and hydrogen through exposure in the spring pools cannot be dismissed. However, most springs sampled had flow rates on the order of 20 to 55 liters (5 to 15 gallons) per minute, and samples were collected as close to the source of the spring as practical. Therefore, it is unlikely that observed concentrations of carbon-14 and tritium resulted from atmospheric contamination.

Iodine-129 and tritium have been detected in confined ground-water zones in the Saddle Mountains Basalt beneath the Hanford Site. Two areas have above-background concentrations of iodine-129. These are in the vicinity of West Lake and Gable Mountain Pond and at one borehole DB-7, located approximately 20 kilometers (12 miles) to the southeast near the Yakima River (see Fig. 3-24 and 3-34).

In the West Lake-Gable Mountain Pond area, the basalts were uplifted along the eastern extension of the Umtanum Ridge-Gable Mountain structure and then eroded by postglacial floodwaters and the ancestral Columbia River. Hydraulic intercommunication now exists between the upper confined and unconfined aquifers in this area. Because cooling waters from chemical processing plants are discharged into ponds near the 200 East Area on the Hanford Site, hydraulic heads in the unconfined aquifer near these discharge areas have at times exceeded those in the shallow basalts. This created a hydraulic driving force for transporting low-level contaminated water from the unconfined aquifer into the uppermost basalt aquifer(s) (Gephart et al., 1976; Graham et al., 1984). The presence of iodine-129 and tritium in the Saddle Mountains Basalt is thought to result from past water exchange. Reported concentrations of iodine-129 in the Rattlesnake Ridge interbed (see Fig. 3-6) range from near the detection limit of 4×10^{-6} picocurie per liter to a maximum of 4×10^{-2} picocurie per liter near liquid waste-disposal sites (Graham et al., 1984; Strait and Moore, 1982; Gephart et al., 1976).

At borehole DB-7 near the horn of the Yakima River, iodine-129 in the Mabton interbed was detected at concentrations of approximately 3×10^{-4} picocurie per liter. This concentration appears higher than at other ground-water sampling points away from waste-disposal areas. However, data given in Early et al. (1985) show the absence of tritium (less than 0.1 tritium unit) in any wells monitoring the Mabton interbed outside the 200 Areas, including borehole DB-7. This implies that the source of slightly elevated iodine-129 concentrations in borehole DB-7 could not be the result of aquifer transport originating from either precipitation or subsurface movement from radioactive liquid waste-disposal sites farther north. The source of iodine-129 in borehole DB-7 is unknown and will be addressed by the U.S. Department of Energy. Studies are under way to examine the sampling integrity of borehole DB-7, which may influence the quality of water samples taken. (The analytical and ground-water sampling techniques used for iodine-129 detection are described in Brauer and Rieck (1973).)

Iodine-129 concentrations of 6×10^{-5} picocurie per liter and 2×10^{-2} to 8×10^{-3} picocurie per liter have been detected in the Columbia River and Hanford 300 Area rain water, respectively. Price et al. (1985) reported that iodine-129 concentrations in the Columbia River in 1984 ranged from 1.2×10^{-5} picocurie per liter upstream from the Hanford Site to 7.4×10^{-5} picocurie per liter downstream from the Hanford Site. The U.S. Department of Energy concentration guideline for iodine-129 is 60 picocuries per liter (DOE, 1981). The U.S. Environmental Protection Agency drinking water standard is 1.0 picocurie per liter (EPA, 1976).

The U.S. Department of Energy has solicited extensive outside critiques of the hydrochemistry program (e.g., Bentley, 1982; LBL, 1982; PNL, 1983). The purpose of these reviews is to enhance data interpretation, as well as analytical and sampling procedures, through consultation. Aspects of the reviews are being considered for incorporation into future hydrochemistry plans.

3.3.2.1 Potential ground-water pathways

Ground-water movement in basalt most likely occurs along pathways found in three groups of features: (1) Discontinuities within flow interiors, (2) flow contacts and sedimentary interbeds, and (3) bedrock structures (Gephart et al., 1983). These features are illustrated in Figure 3-35, as is the hypothetical location of a repository within the central part of a generic flow interior; as noted in Figure 3-35, no horizontal or vertical scale is intended. This figure simply illustrates the range of possible interbasalt and intrabasalt flow features that might exist and influence ground-water movement. The figure does not imply that all or any specific combination of features are expected to occur in a given area, or that a geohydrologic significance is assigned to these features. The existence of any one or combination of features may or may not be important to site characterization or waste isolation. Each of the above three categories is discussed below in regard to possible ground-water and solute pathways near a repository.

3.3.2.1.1 Flow interiors

Ground water moving from a repository would travel through fractures in the flow interior before reaching flow contacts or bedrock structures. The most ubiquitous discontinuities within the flow interior are cooling fractures found in the entablature and colonnade portions of a flow (see Fig. 3-35, features A and B).

Seventeen hydrologic tests (using a variety of test methods as described in Strait et al., 1982) have been conducted across the dense entablature and colonnade portions of the individual flow interiors. These tests were done at depths from approximately 360 to 1,200 meters (1,200 to 3,900 feet) beneath the Hanford Site. The horizontal hydraulic conductivities measured ranged from 10^{-10} to 10^{-16} meter per second (10^{-5} to 10^{-11} foot per day) with a median of 10^{-13} meter per second (10^{-8} foot per day). (The lower limit of detection is considered to be approximately 10^{-13} to 10^{-14} meter per second (10^{-8} to 10^{-9} foot per day).) These tests straddled flow interiors not containing vesicular zones. Low hydraulic conductivities for flow interiors have also been reported or suggested by other investigators (e.g., LaSala and Doty, 1971; Luzier and Burt, 1974; Newcomb, 1982). Such values in a fractured medium are attributed to a high degree of secondary mineral infilling and dead-end space in cooling fractures, in addition to lithostatic loading (DOE, 1982b). Field tests quantifying vertical conductivities and evaluating test methodologies within flow interiors are in progress. An initial ratio test conducted in boreholes DC-4 and DC-5 (see Fig. 3-7) by Spane et al. (1983) suggests a vertical conductivity of less than approximately 10^{-10} meter per second (10^{-5} foot per day) for a test zone in the Rocky Coulee flow interior. Since this is the first test of its kind in basalt, an uncertainty cannot yet be assigned to the measured value. Other test methods are under investigation (Section 4.1.1).

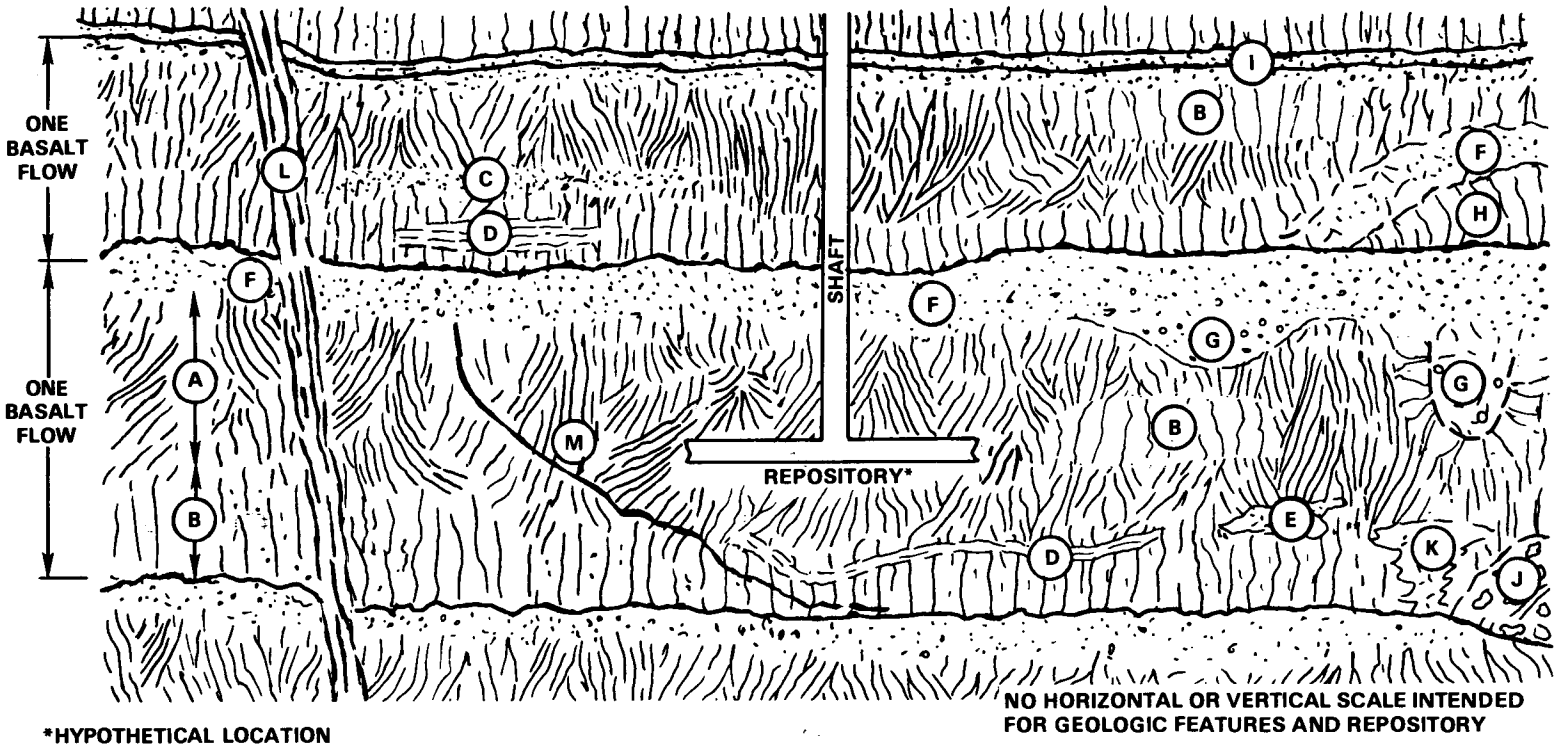

Figure 3-35. Hypothetical composite cross section of possible geologic features in a layered basalt sequence (after Gephart et al., 1983).

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Tanaka et al. (1974) performed a digital model study of the ground-water hydrology in the Columbia Basin Irrigation Project area. This was a cooperative study between the State of Washington Department of Ecology and the U.S. Geological Survey. One data set need was for vertical hydraulic conductivity. On pages 23 and 24 of Tanaka et al. (1974) it is stated: "In the absence of reliable field data on the vertical hydraulic conductivity of basalt in the project area, several hydraulic conductivity values were estimated indirectly by analysis of the head response in basalt to application of known amounts of irrigation water, and these values were tested as model parameters. After repeated trials on the model, comparing different values of hydraulic conductivities to head response in the upper and lower aquifers, an average value of 0.00002 foot per day (within a range of 0.000001 foot/day to 0.000037 foot/day) gave computed heads that were similar in response to measured heads in both aquifers." In metric units, the above range equates to 3×10^{-12} to 1×10^{-10} meter per second. In MacNish and Barker (1976, p. 5), vertical hydraulic conductivity was said to be "as small as 0.00000005 ft/s." This is equivalent to 1×10^{-8} meter per second. (These computer-model-generated values for hydraulic conductivity are approximately two orders of magnitude larger than that suggested by available field test data for basalt flow interiors.) The representativeness of the above estimates for vertical hydraulic conductivity will be examined during large-scale stress tests and research conducted from within the exploratory shaft facility.

Field-derived values of the anisotropy ratio of vertical-to-horizontal hydraulic conductivity within basalt flow interiors are not available. Estimates based on ground-water model simulations and statistical analysis of fracture data are reported in U.S. Department of Energy (1982b) to range between 3.5 to 1 and 10 to 1. Thus, once several field measurements become available, it is believed vertical hydraulic conductivity of undeformed flow interiors will likely be within a factor of 10 of horizontal conductivity values currently reported. This concept is based on the representativeness of the previously noted ratios. The present uncertainty of these ratios is recognized; planned research (Subsection 4.1.1.3) will address this uncertainty.

Uncertainty in hydrologic test results, such as those outlined in this and the following section, is related to the extent that analytical assumptions are satisfied, as well as related to the relative hydraulic conductivity of the rock tested. For example, an uncertainty of approximately 2 or 3 times might apply to a rock of higher hydraulic conductivity (greater than approximately 10^{-6} meter per second (10^{-1} foot per day)) when data interpretations from several accepted analytical solutions are compared. On the other hand, when a single solution (e.g., Theis, 1935; Cooper and Jacob, 1946; Papadopulos and Cooper, 1967) is used, results of multiple tests in the same rock zone can be nearly identical. Equipment compliance and test system unknowns increase uncertainties in test results for rocks of low hydraulic conductivity. Such test uncertainties are common to all rock types. Overall, an uncertainty of approximately two to three times the hydraulic conductivity value measured is assigned for the flow top and interbed. For flow interiors, the upper range of values reported is considered high because equipment compliance results in an

overestimation of the true hydraulic conductivity (i.e., if a flow interior test results in a 10^{-10} meter per second (10^{-5} foot per day) horizontal conductivity, the actual in situ value of the zone stressed is probably lower).

Preliminary single hole tests have been conducted on the possible effects of drilling fluid (mud) invasion on hydraulic conductivity estimates within a basalt flow interior. Results suggest that no discernible impact occurred from the use of drilling fluids under the test conditions examined (Spane and Thorne, 1984).

Few examples are formally available for comparing test interpretations conducted by different organizations. One brief comparison is given in Table 3-16. These calculations by Jackson (1982) and Wilson (1983) are essentially identical.

Besides entablature and colonnade joints, other discontinuities potentially present within flow interiors include vesicular zones, platy zones, and localized fracture zones. These features are illustrated as features C, D, and E in Figure 3-35.

Within the Cold Creek syncline, a vesicular zone in the entablature of the Cohassett flow (see Fig. 3-12) was hydrologically tested at four borehole sites. The hydraulic conductivity values calculated were 10^{-8} to 10^{-9}, 10^{-12} to 10^{-14}, 10^{-13} to 10^{-16}, and 10^{-14} to 10^{-16} meter per second (10^{-3} to 10^{-4}, 10^{-7} to 10^{-9}, 10^{-8} to 10^{-11}, and 10^{-9} to 10^{-11} foot per day). Whether such hydraulic conductivity values are typical of vesicular zones within flow interiors is not known.

The hydraulic conductivity of the Cohassett flow interior typically ranges from 10^{-10} to 10^{-14} meter per second (10^{-5} to 10^{-9} foot per day). These test results included straddling the vesicular zone of the flow. At borehole DC-16, the hydraulic conductivity of the Cohassett flow vesicular zone was tested at 10^{-8} to 10^{-9} meter per second (10^{-3} to 10^{-4} foot per day). The larger than normal conductivity reported at borehole DC-16 is believed to represent a local hydraulic heterogeneity. This is because the hydraulic conductivity of the vesicular zone is much lower at other boreholes in the reference repository location and its geologic characteristics are similar throughout the reference repository location (see Subsection 3.2.2.3).

A fracture zone approximately 2 meters (6 feet) thick was identified in the entablature near the base of the Umtanum flow in one borehole located in the reference repository location. A hydraulic conductivity of 5×10^{-4} meter per second (147 feet per day) was calculated from pump and slug tests (Strait and Spane, 1983). This is the highest hydraulic conductivity measured in a flow interior on the Hanford Site. Hydrologic tests across the Umtanum flow entablature-colonnade contact in other boreholes on the Hanford Site indicate values of approximately 10^{-13} meter per second (10^{-8} foot per day). Although the extent of this fracture zone is unknown, it is presently considered a localized feature (symbolically shown as feature E in Figure 3-35) that may be interconnected to the

Table 3-16. Comparison of hydrologic properties from boreholes DC-7 and DC-8 tests in the McCoy Canyon flow top of the Grande Ronde Basalt

Property	Jackson (1982)	Wilson (1983)
Transmissivity, m^2/s (ft^2/d)		
Range	$3.9 \times 10^{-7} - 8.4 \times 10^{-7}$ (0.39 - 0.84)	$1.7 \times 10^{-7} - 1.25 \times 10^{-6}$ (0.17 - 1.25)
Best estimate	7.8×10^{-7} (0.78)	Not given
Hydraulic conductivity, m/s (ft/d)		
Range	$3.8 \times 10^{-8} - 8.1 \times 10^{-8}$ (0.011 - 0.023)	$3.8 \times 10^{-8} - 1.2 \times 10^{-7}$ (0.011 - 0.034)
Best estimate	7.4×10^{-8} (0.021)	7.0×10^{-8} (0.020)
Storativity best estimate	4×10^{-5}	3×10^{-5}

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basalt flow top or bottom. At other borehole sites tested, this same stratigraphic zone possesses a much lower hydraulic conductivity typical of other basalt flow interiors studied.

3.3.2.1.2 Flow contacts and sedimentary interbeds

After ground water travels through joints or other pathways within a basalt interior, it may enter a flow contact. Commonly, these contacts represent the closest zones of higher hydraulic conductivity near the reference repository location. Flow contacts may contain features F through K as shown in Figure 3-35.

A flow top (see features F and G in Fig. 3-35) may form a more or less continuous layer atop the flow interior. The flow top of an areally extensive basalt flow may cover several thousand square kilometers (square miles) while its thickness, internal characteristics, and hydrologic properties spatially vary. Flow termination (pinch outs), such as feature H in Figure 3-35, represents places where ground water could move from one flow top to another without traversing a basalt interior.

Associated with some flow tops are sedimentary interbeds (see feature I in Fig. 3-35). Most interbeds within the Pasco Basin vicinity are located in the Saddle Mountains Basalt, approximately 500 meters (1,600 feet) above the Cohassett flow (see Fig. 3-6).

In excess of 200 single-hole hydrologic tests have been conducted in flow tops and interbeds in some 35 separate boreholes across the Hanford Site. These data indicate that within both the Saddle Mountains and Wanapum Basalts, the hydraulic conductivities of most individual flow tops and interbeds range between approximately 10^{-4} and 10^{-7} meter per second (10^{1} and 10^{-2} foot per day) with a geometric mean of approximately 10^{-5} meter per second (10^{0} foot per day). Some hydraulic conductivity values as large as 10^{-2} to 10^{-3} meter per second (10^{3} to 10^{2} feet per day) and as small as 10^{-8} to 10^{-10} meter per second (10^{-3} to 10^{-5} foot per day) are also reported for selected flow tops in the Saddle Mountains and Wanapum Basalts (Long and WCC, 1984). Large hydraulic conductivity values are commonly associated with the Priest Rapids Member of the upper Wanapum Basalt. Most hydraulic conductivity values within Grande Ronde Basalt flow tops range between approximately 10^{-5} and 10^{-9} meter per second (10^{0} and 10^{-4} foot per day) with a geometric mean of approximately 10^{-7} meter per second (10^{-2} foot per day) (Long and WCC, 1984). A few hydraulic conductivity values as large as 10^{-3} to 10^{-4} meter per second (10^{2} to 10^{1} feet per day) and as small as 10^{-10} to 10^{-11} meter per second (10^{-5} to 10^{-6} foot per day) are also reported (Long and WCC, 1984). In heterogeneous media (e.g., basalt), the use of geometric mean values generally is considered to provide the best integration of hydraulic conductivity over a large area (Neuman, 1982; Snow, 1965).

Existing hydrologic data, based on single-hole tests stressing localized rock volumes, suggest that flow-top hydraulic conductivities are heterogeneous across the reference repository location. For example, the hydraulic conductivity of the Rocky Coulee flow top changes only slightly, from 10^{-6} to 10^{-7} meter per second (10^{-1} to 10^{-2} foot per day), while that of the Cohassett flow top ranges between 10^{-6} to 10^{-11} meter per second (10^{-1} to 10^{-6} foot per day). Furthermore, borehole fluid-temperature and flow-velocity surveys performed during air-lift pumping tests sometimes indicate the presence of ground-water inflow zones within individual flow tops. Such zones can be thin (i.e., less than 1 to 3 meters (3 to 9 feet)), and may possess higher local hydraulic conductivities than the equivalent hydraulic conductivity assigned to the entire effective test interval (i.e., flow-top thickness). Zones of high permeability within flow tops appear as localized features and are not laterally continuous. For large-scale performance, the entire effective test interval is believed involved in ground-water movement. Additional information on the actual thickness of basalt flow tops involved in ground-water transport will be obtained by planned large-scale interference and tracer tests mentioned in Subsections 4.1.1.3.1 and 4.1.1.3.3.

Two tracer tests have been conducted in the flow top of the McCoy Canyon flow (Bakr et al., 1980; Gelhar, 1982; Leonhart et al., 1982). Dispersivity values reported were 0.45 and 0.85 meter (1.5 to 2.8 feet) with an effective thickness of 2×10^{-3} and 3×10^{-3} meter (6×10^{-3} and 1×10^{-2} foot).

Hydraulic heads measured across flow tops and interbeds by piezometers and also on a progressive drill-and-test basis suggest that the areal hydraulic gradient in the Cold Creek syncline is approximately 10^{-4} meter per meter (10^{-4} foot per foot). Vertical head measurements across the deep basalts reveal upward gradients of 10^{-3} to 10^{-4} meter per meter (10^{-3} to 10^{-4} foot per foot). It has been suggested that in structurally undeformed areas, ground-water movement is predominantly lateral with the general flow direction semiconforming to bedrock dip (Newcomb, 1982).

Because pillow breccia zones (see feature J in Fig. 3-35) have not been penetrated by boreholes in the Hanford Site, none have been hydrologically tested. Their existence, however, as well as spiracles or spiracle-like features (see feature K in Fig. 3-35), should be anticipated based on field observations in the Columbia Plateau. These features represent rock zones of possibly high hydraulic conductivity that may locally influence ground-water movement.

3.3.2.1.3 Bedrock structures

Bedrock structural discontinuities represent zones of potentially significant fracture anisotropy (shown symbolically as features L and M in Fig. 3-35) that may hydraulically connect flow systems above and below a

repository, or may represent low hydraulic conductivity barriers to ground-water movement. All bedrock in the western Pasco Basin is along some portion of a Yakima fold, either on a limb or in a hinge area. The local tectonic setting is described in Section 3.2.3.

Synclinal troughs, where exposed in the Columbia Plateau outside of the Pasco Basin, appear to exhibit less strain than other portions of a Yakima fold structure (Price, 1981). The difficulty of directly extrapolating this regional characteristic to the Cold Creek syncline, however, is that the Cold Creek syncline is filled with sediment, which precludes direct comparison. Because the trough of the Cold Creek syncline is a broad, open structure, it is interpreted to contain fewer bedrock structures relative to anticlinal areas. Nearly flat-lying strata away from anticlinal hinge areas may be crossed by strike-slip faults. These faults, designated by feature L in Figure 3-35, may represent bedrock structural discontinuities having a linear extent of perhaps tens of kilometers (miles). Inferred or known bedrock structures in the Cold Creek syncline have been reported (Myers, 1981) and are under investigation.

Observations of cliff exposures, manmade cuts, and tunnels through the Columbia River Basalt Group indicate that, even where flat lying, the interiors of thick flows are locally crossed by subtle, subhorizontal tectonic fractures that intersect cooling joints (DOE, 1982b). These fractures, shown as feature M in Figure 3-35, may be continuous on scales of tens to hundreds of meters (tens to hundreds of feet). Many are thought to be of tectonic origin related to fold growth (Price, 1980); others are of uncertain origin and might be phenomena related to deposition or cooling of basalt flows.

The gently dipping limbs of anticlines and synclines within the reference repository location contain small zones of tectonic breccia. These zones are typically approximately 1 meter (3 feet) thick in basalt core and are of unknown lateral extent (Moak, 1981). A 5-meter-(16-foot-) thick tectonic breccia in the Frenchman Springs Member of the Wanapum Basalt in one borehole in the reference repository location was hydrologically tested using the pulse technique. A hydraulic conductivity of approximately 10^{-11} meter per second (10^{-6} foot per day) was measured. Future hydrologic testing will determine whether this value is characteristic of other tectonic breccias.

The Cold Creek barrier (see Fig. 3-1) is an example of what is interpreted as a bedrock structural discontinuity that represents an impediment to lateral ground-water flow. From west to east across this possible structure, hydraulic heads abruptly drop as much as 150 meters (500 feet). In addition, hydrochemical data suggest that mineralized deep waters may be mixing vertically with more dilute, shallower ground waters along or near this feature. Whether or not the observed hydrochemical patterns in the reference repository location are directly related to the existence of the Cold Creek barrier is unknown at this time. The lateral extent and rate of possible ground-water mixing are not yet defined;

however, if the existing low-head gradients in the deep basalts of the reference repository location were maintained in the geologic past, vertical ground-water movement may have been slow (see Section 3.3.2).

3.3.2.2 Alternative ground-water flow concepts

When the existing geohydrologic data base is too preliminary to support conclusively a single ground-water flow model, alternative working hypotheses must be developed. Such is the case in Figure 3-36 where four concepts are shown depicting ground-water movement in a layered basalt sequence such as beneath the reference repository location (Gephart et al., 1983). These alternative models help to focus hydrologic test and characterization efforts so as to develop eventually a single or narrow range of models suitable for detailed numerical simulation (Section 6.4.2). In a broad sense, Figure 3-36 incorporates the range of concepts proposed to identify ground-water flow patterns. These concepts are as follows:

- Concept A--This concept illustrates ground water moving principally within heterogeneous, permeable flow tops separating flow interiors of relatively low vertical and horizontal hydraulic conductivity. Upward ground-water movement into shallower systems can occur as a result of (1) the positioning of flows where the front of one basalt flow of limited extent terminates atop a more continuous flow, creating a direct fluid conduit between two flow tops or (2) ground-water leakage across low hydraulic conductivity flow interiors over large areas. In this concept, local features of relatively high hydraulic conductivity (e.g., thickening of flow-top breccia atop a spiracle) are not commonly juxtaposed. This concept depicts an anisotropic, heterogeneous flow system undisturbed by major folds and faults.

- Concept B--This concept is similar to Concept A, except basalt flows are crossed by bedrock structural discontinuities having potentially larger vertical hydraulic conductivities than the confining aquitards. On a local scale, such discontinuities might represent individual tectonic fractures or shear zones. Regionally, these features could depict major fault or fold zones. If rock movement has occurred, such structures could depict zones where the lateral continuity of flow contacts is disrupted, causing a flow contact(s) to terminate against a flow interior(s) of lower hydraulic conductivity. In this concept, structural discontinuities are heterogeneities having the potential for vertically connecting shallow and deep flow systems. Dependent on the extent of fracture mineral infilling and (or) fine gouge materials present, these discontinuities could act as conduits of high hydraulic conductivity or ground-water barriers. Overall, this concept depicts rock volumes of relatively low vertical leakage bounded by structural discontinuities.

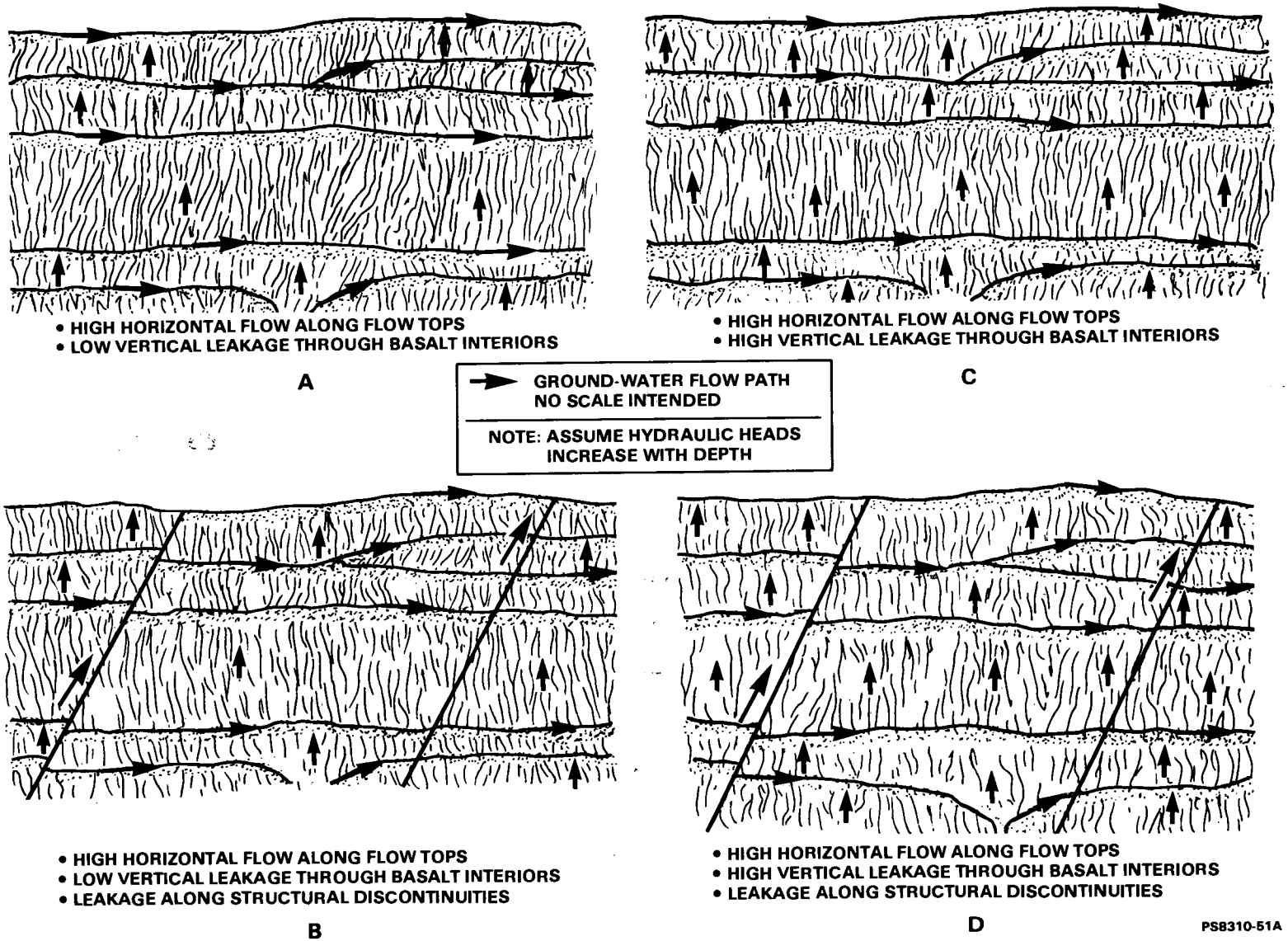

Figure 3-36. Alternative concepts for ground-water movement based on anisotropy contrasts and hypothetical structures (after Gephart et al., 1983).

7 0 1 6 8 0 2 6 7

- Concept C--This concept represents a flow system characterized by lateral ground-water movement in flow tops bounded by basalt interiors of relatively high leakage. The anisotropy of flow-top and interior hydraulic conductivity is considerably less than in Concept A. In this concept, ground-water movement between deep and shallow systems occurs as a result of stratigraphic positioning or intersection of flow contacts, vertical leakage through unfilled or partially filled cooling fractures, and other primary features of relatively high hydraulic conductivity that are juxtaposed.

- Concept D--This concept superimposes bedrock structural discontinuities on Concept C. As described in Concept B, such discontinuities might act as vertical conduits and (or) barriers of low hydraulic conductivity. This concept depicts rock zones of relatively high vertical leakage bounded by structural discontinuities.

As noted, the existing geohydrologic data base is too preliminary to support conclusively a single quantified ground-water flow concept. However, of the overall concepts listed above, Concept B is currently interpreted by the U.S. Department of Energy as most supported by available data for deep basalts (see Fig. 3-36). Bedrock structural discontinuities in this concept are considered to be less frequent and more widely spaced in the gently dipping limbs of the Yakima folds (e.g., within the reference repository location) than in the hinge areas and steeply dipping limbs of these folds. The broad aspects of this conceptual model as it may apply to the Hanford Site and vicinity were discussed in Section 3.3.2.

There has been controversy (NRC, 1983) concerning what constitutes the details of a conceptual model for basalt, as well as points of agreement (Gephart, 1983). However, in a broad sense, the layered geology at the reference repository location consists of alternating basalt flows containing high to low-conductivity intraflow units. Such heterogeneity forces essentially rectilinear, three-dimensional ground-water movement to occur with lateral movement in flow tops and interbeds (potential aquifers) and vertical movement across flow interiors (aquitards). The U.S. Department of Energy believes this to be the overall conceptual model of which details remain to be quantified during site characterization (Section 4.1). Such details would specify a model having little vertical leakage across undeformed flow interiors (see A in Fig. 3-36) or pronounced leakage (see C in Fig. 3-36). The role of leakage along structural discontinuities (see B and D in Fig. 3-36) also would be addressed during site characterization.

A number of geohydrologic characterization activities are currently under way to reduce the present uncertainty regarding conceptual models and ground-water flow paths. These are discussed in Section 4.1 and include such items as (1) further analysis of potential geologic features depicted in Figure 3-36, (2) large-scale, multiwell pump tests,

(3) vertical permeability measurements, (4) installation of piezometers, and (5) plans for exploratory shafts involving breakout and testing within the candidate horizon. Studies are also under way of tectonic processes that may generate new ground-water flow paths or alter the hydrologic properties of existing bedrock structures.

3.4 ENVIRONMENTAL SETTING

The Hanford Site is bounded on the north by the Saddle Mountains, on the east by the Columbia River, and on the south and west by the Yakima River and Rattlesnake Hills, respectively (see Fig. 3-1). The dominant features of the Hanford Site include the Columbia River (and associated aquatic habitats that act as an attraction and migration corridor for those species associated with water), sand dunes located near the Columbia River, and the basaltic ridges, including the Rattlesnake Hills, rising to an elevation of greater than 1,100 meters (3,600 feet).

The Hanford Site is one of the few large areas of land in the Pasco Basin that is currently not developed for agricultural use. The site is also unique, in that use of the area is institutionally controlled and a large portion of the site is restricted to projects directly associated with the nuclear industry. The major nuclear facilities and activities occupy only approximately 6 percent of the total available land area.

3.4.1 LAND USE

The two principal land uses within the Pasco Basin are agricultural and Federal Government activities. Agricultural land lies primarily north and east of the Columbia River and south of the Yakima River. Most of the agricultural land is used for growing irrigated crops. Government activities include the U.S. Department of Energy-controlled Hanford Site, in the north-central portion of the Pasco Basin, and the U.S. Army Yakima Firing Center along the northwestern edge of the basin. Land use in the Columbia Plateau is presented in detail in Wukelic et al. (1981).

Lands adjacent to the Hanford Site are privately owned, with the exception of those areas controlled by the State of Washington and county and city governments. The State exercises control over State and Federal highways and special-use areas (e.g., parks and wildlife reserves). County and city governments have jurisdiction over publicly owned facilities and establish land-use controls within their respective borders.

The closest Indian reservation is that of the Yakima Indian Nation and is located approximately 26 kilometers (16 miles) west of the Hanford Site, 50 kilometers (30 miles) from the reference repository location. The U.S. Army Yakima Firing Center is located approximately 10 kilometers (6 miles) west of the Hanford Site, 16 kilometers (10 miles) from the reference repository location.

3.4.1.1 Agricultural use

Agriculture is the predominant land use in the six-county region near the Hanford Site (Adams, Franklin, Walla Walla, Benton, Yakima, and Grant Counties). Over 75 percent of the land area in the region is in agricultural-related uses, compared to less than 40 percent statewide. In terms of market value of agricultural products sold, the six-county region accounts for over 50 percent of the State total value.

In 1982, over 33 percent of the agricultural land in the State of Washington was irrigated. Of the 2,429,250 irrigated hectares (6,002,592 acres) in the State, nearly one-half were in the six-county region. The number of irrigated hectares (acres) in the region has grown slightly between 1978 and 1982, whereas the total irrigated hectares (acres) of agricultural land in the State has declined. Within the six-county region, the proportion of agricultural land irrigated varies from a low of 33 percent in Yakima County to a high of 73 percent in Grant County (BOC, 1981, 1984).

The U.S. Department of Energy has determined that no prime farmland exists within the reference repository location or the Hanford Site. These lands have, for over 40 years, been set aside and reserved for use by the U.S. Department of Energy in connection with nuclear-related activities.

3.4.1.2 Federal Government activities

The 1,500-square-kilometer (570-square-mile) Hanford Site (Fig. 3-37) was established in 1943 as a national security area for plutonium production. The major activity on the Hanford Site continues to be nuclear materials production and activities related to nuclear energy. Detailed descriptions of nuclear defense activities on the Hanford Site can be found in a number of documents. The following discussion was prepared using reports of the U.S. Energy Research and Development Administration and the U.S. Department of Energy (ERDA, 1975; DOE, 1983c). Both documents are recommended to anyone seeking additional details regarding defense activities at the Hanford Site. A discussion of environmental surveillance activities conducted at the Hanford Site to monitor and assess the current environmental impacts of U.S. Department of Energy operations is provided in Subsection 3.4.2.7.

The long-term impacts of disposal of defense high-level, tank, and transuranic wastes at the Hanford Site is not addressed in this document. However, the U.S. Department of Energy plans to release a draft environmental impact statement in 1986 that will describe alternatives for final disposition of presently stored and future generated high-level, tank, and transuranic wastes on the Hanford Site. Any alternative selected for disposal of stored or future generated high-level, tank, and transuranic wastes would be subject to applicable provisions of 40 CFR 191 (EPA, 1985).

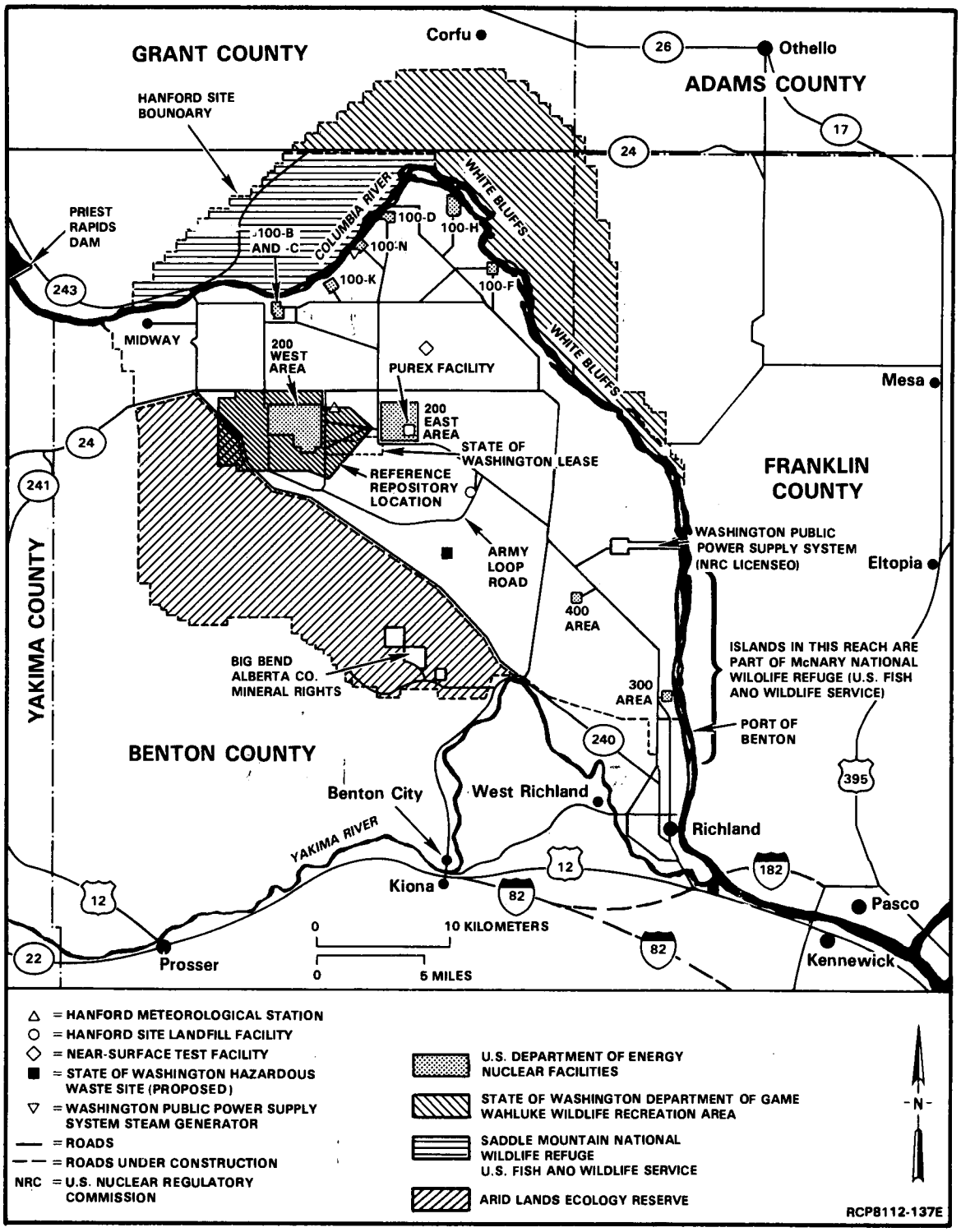

Figure 3-37. Map of the Hanford Site (including land use).

Sections 6.2 and 6.3 of this document contain a preliminary preclosure and postclosure performance assessment related to potential long-term environmental impacts of repository operation and closure. If the reference repository location on the Hanford Site were selected for site characterization, a more comprehensive performance assessment would be conducted. The potential long-term impacts of a repository at the reference repository location, as predicted by a performance assessment, along with consideration of potential long-term impacts for the alternative selected for defense high-level, tank, and transuranic wastes at the Hanford Site would be appropriately addressed in the environmental impact statement that would be written for selection of the first repository site.

The selected alternatives for Hanford Site defense high-level, tank, and transuranic wastes and a repository for commercial waste would be subject to the applicable release limits established by 40 CFR 191 (EPA, 1985). When the release limits specified in Table 1 of 40 CFR 191 are met, the U.S. Environmental Protection Agency indicated in the preamble to the rule that the number of premature cancer deaths over 10,000 years from disposal of the wastes from 100,000 metric tons (110,000 tons) of reactor fuel is not expected to exceed 1,000. Based on this relationship in complying with the U.S. Environmental Protection Agency regulations, a repository with a capacity of 70,000 metric tons (77,000 tons) of commercial spent fuel would not be expected to result in more than 700 premature cancer deaths over 10,000 years. Again, based on this same relationship and on projections of defense fuels processed at the Hanford Site through 1995, compliance with the release limits of 40 CFR 191 (EPA, 1985) and the notes thereto would imply that the total number of premature cancer deaths over 10,000 years for the disposal of defense wastes in a manner meeting U.S. Environmental Protection Agency criteria would not be expected to exceed 180. This latter figure is not a projection of premature cancer deaths that may be associated with any of the specific alternatives being considered for disposal of Hanford Site defense wastes. Such projections, based on alternative specific analyses, will be included in the defense waste environmental impact statement. The above-described premature cancer deaths may be viewed in the context of exposure to natural background radiation over the 10,000-year period for the local Hanford Site population, which would be expected to result in premature cancer deaths several orders of magnitude greater.

In early 1943, approximately a month after the successful Fermi experiment in Chicago demonstrated that nuclear fission could be controlled in a small reactor, the U.S. Army Corps of Engineers selected the Hanford Site as the location for a facility in which a larger version of the Fermi reactor would be built to produce plutonium for possible use in military weapons. Actual construction started on three reactor facilities and three chemical processing facilities in March 1943. The first of the reactors went into operation approximately 18 months after the start of construction, and the first plutonium was available some 4 months later. During the course of early construction efforts, approximately 94,000 men and women were involved at various times in the project, with a peak onsite population of 51,000.

After World War II, a total of five additional reactors similar to those built during the war were constructed, resulting in a total of eight graphite-moderated reactors using Columbia River water for once-through cooling (i.e., water circulated through the reactor only once before being temporarily held for radioactivity monitoring and some heat dissipation prior to release back to the river).

In the early 1950's, construction of the research and development facilities known as the Hanford Laboratories began. This marked the first diversification of the Hanford Site from a purely defense materials production facility to one involved in peacetime uses of the atom. In 1963, the first dual-purpose reactor constructed in the United States, the N Reactor (see Fig. 3-37), was built at the Hanford Site. In addition to plutonium, the N Reactor produces byproduct steam, that since 1966 has been used by the Washington Public Power Supply System to generate electricity.

In early 1964, a Presidential decision was made to begin closing down the older Hanford Site reactors. By the end of 1971, N Reactor was the only production reactor still in operation. Another major change occurred in 1964 with the departure of General Electric Company, which in 1946 had succeeded E. I. du Pont de Nemours and Company as the prime operating contractor. In a unique segmentation and diversification program, (1) the General Electric Company was replaced by a number of contractors, (2) the economic base of the communities was diversified, and (3) the Hanford Site became involved in many U.S. Atomic Energy Commission programs relating to the peaceful use of nuclear materials and radiation.

The current principal operating contractors at the Hanford Site include:

- Rockwell Hanford Operations, responsible for fuel processing, waste management, and all site general support services such as plant security, fire protection, central stores, and electrical power distribution.

- Battelle Memorial Institute, responsible for operation of the Pacific Northwest Laboratory, which conducts research on general areas of life sciences, environmental science, environmental surveillance, advanced methods of nuclear waste management, and a wide variety of other physical and biological sciences.

- UNC Nuclear Industries, responsible for operations of N Reactor, and for N Reactor fuel fabrication. UNC Nuclear Industries also is in charge of decontaminating and decommissioning the eight shutdown reactors.

- Westinghouse Hanford Company, responsible for the operation of the Hanford Engineering Development Laboratory, which oversees advanced reactor developments, principally the Liquid Metal Fast Breeder Program and the Fast Flux Test Facility.

The Hanford Site operating areas are identified by area numbers. Each area is identified below and a description of the principal facilities is provided. Figure 3-37 illustrates the location of these operating areas relative to each other and to the reference repository location.

3.4.1.2.1 100 Areas

The six 100 Areas, bordering directly on the Columbia River in the northernmost portion of the Hanford Site, were chosen as sites for the plutonium production reactors. In the early 1960's, nine production reactors were in operation. Currently, only the dual-purpose N Reactor is operating to provide plutonium for military purposes and U.S. Department of Energy research and development and to provide the byproduct steam used for electrical power production in the Hanford Generating Project steam plant. The status of these reactors is shown in Table 3-17.

Table 3-17. Reactor status summary

Reactors	Construction start	Operation	
		Start	Shutdown
105-B	Aug. 1943	Sep. 1944	Feb. 1968
105-C	June 1951	Nov. 1952	Apr. 1969
105-KW	Nov. 1952	Jan. 1955	Feb. 1970
105-KE	Jan. 1953	Apr. 1955	Jan. 1971
105-N	May 1959	Dec. 1963	Operating
105-D	Nov. 1943	Dec. 1944	June 1967
105-DR	Dec. 1947	Oct. 1950	Dec. 1964
105-H	Mar. 1948	Oct. 1949	Apr. 1965
105-F	Dec. 1943	Feb. 1945	June 1965

With the shutdown of eight production reactors and the elimination of solid waste disposal in the 100 Areas in 1973, waste management activity in the 100 Areas has significantly decreased. With the exception of 100-N, little radioactive waste is generated by the 100 Areas.

The N Reactor, still in operation, differs significantly from all earlier Hanford Site reactors. At N Reactor, the primary coolant circulates through the reactor and absorbs heat from the fuel elements, but is not returned directly to the river. Instead, heat is transferred through heat exchangers to a secondary coolant loop, which produces steam to power the electrical generators of the Hanford Generating Project steam plant. By not having to release cooling water from the reactor core directly to the river to dissipate heat, the amount of radioactivity released to the river is reduced.

Low-level liquid waste from N Reactor is directed into a 38-meter- (125-foot-) wide by 88-meter- (290-foot-) long crib. The total flow to the crib during normal reactor operations is 9,463 liters per day (2,500 gallons per day). Most radioactive species discharged to the crib are retained in the soil by chemical reactions, precipitation, and ion exchange.

Approximately 2,270,000 liters (600,000 gallons) of liquid waste are shipped to the 200 Areas each year. The bulk of the waste is generated once a year when the N Reactor primary cooling piping is internally decontaminated to remove radioactive corrosion products and deposited materials.

3.4.1.2.2 200 Areas

The fuels processing, plutonium separation, and plutonium finishing portions of operations on the Hanford Site are located in the 200 East and 200 West Areas. Additional activities in these areas include plutonium scrap processing, waste fractionization, laboratory work, and management of high-level, low-level, transuranic, and tank radioactive waste resulting from the separation process. Radioactive waste from the 100 and 300 Areas also is sent to the 200 Areas for storage or disposal. Principal facilities in the 200 East and 200 West Areas are described below.

PUREX

The PUREX Plant (plutonium and uranium recovery through extraction) is the most recently constructed of the irradiated fuel processing plants. PUREX was constructed between April 1953 and October 1955. The plant operated until 1972, and then was maintained in standby condition until 1983 when it was restarted.

Irradiated fuel from N Reactor is processed by the PUREX Plant to recover plutonium and uranium. Processing steps include metal dissolution, solvent extraction, and ion exchange. Irradiated uranium fuel elements enter a dissolver where the cladding is chemically removed and the fuel is then dissolved with nitric acid. Chemical additions to the dissolver solution are made to produce suitable feed for the solvent extraction operation, where the major separation of the plutonium, neptunium, and uranium from fission products is accomplished. A partition cycle separates plutonium from neptunium and uranium. The plutonium stream is routed through two additional solvent extraction cycles for further purification. After final concentration, the plutonium nitrate solution is loaded into containers for transfer to the plutonium finishing operations. The stream from the partition cycle, bearing uranium, is routed to the final uranium cycle where purification and concentration of the uranium are accomplished. The product, uranyl nitrate hexahydrate solution, is stored in large tanks and ultimately transferred to the Uranium Oxide Plant by truck-trailer for conversion to uranium trioxide. A portion of the backcycle waste stream is routed to the neptunium recovery and purification process, which consists of a solvent extraction cycle, a concentrator, and an ion exchange column. The neptunium nitrate product solution is loaded into containers for storage and shipment offsite. Supporting process systems include organic decontamination and recovery, nitric acid recovery, and waste concentration and treatment.

Redox Plant

The reduction-oxidation process for fuel separation preceded the PUREX process. The Redox Plant was constructed from May 1950 to August 1951, and operated until July 1967 when it was shut down. Although the Redox Plant is no longer in service, the 222-S analytical laboratory remains in operation, supporting the operations of B Plant, PUREX, and the Plutonium Finishing Plant, performing research, and helping develop waste management and environmental control processes.

U, T, and B Plants

U Plant, T Plant, and B Plant were, the original fuel separation facilities on the Hanford Site, preceding both the PUREX and Redox Plants. All three plants were designed to extract plutonium from irradiated fuel using a bismuth phosphate process. This process produced a waste stream containing uranium from the irradiated fuel mixed with the bulk of the fission products.

U Plant was never used for the design purpose noted above, but was converted to recover uranium from stored radioactive waste. From 1952 to 1958, waste was sluiced from storage tanks, and U Plant was used for uranium recovery. Although this processing is now finished and the building is unused, the adjacent Uranium Oxide Plant is still used to produce powdered uranium trioxide by calcining the uranyl nitrate hexahydrate solution from PUREX. The uranium trioxide is sealed in steel hoppers and shipped offsite.

T Plant was constructed between June 1943 and October 1944 and was last used for fuel separation in 1956. T Plant is presently used for decontamination and repair of equipment from other Hanford facilities.

B Plant was constructed between August 1943 and February 1945 and was operated until 1952. As a result of a program to develop methods for the solidification of high-level waste, B Plant was converted in 1968 to a waste fractionization plant, which removed cesium-137 and strontium-90 from PUREX current acid waste and high-level supernatant liquids and sludges. In addition, an encapsulation and storage facility was constructed on the west end of the B Plant building. Here, the strontium and cesium were converted to solid strontium fluoride and cesium chloride, double encapsulated, and placed in a water basin for storage.

Plutonium Finishing Plant

Constructed in 1949, the Plutonium Finishing Plant is the site of plutonium processing operations, including the processing of plutonium scrap materials as well as providing laboratory support and shipping and receiving of nuclear material. The Plutonium Reclamation Facility processes plutonium scrap in a variety of forms and plutonium content to produce a pure plutonium nitrate solution. A solvent-extraction system is used to remove impurities in the nitrate solution. The remote, mechanical C line subsequently converts the plutonium nitrate solution from the Plutonium Reclamation Facility and PUREX to plutonium metal. Contaminated waste streams consist of high- and low-salt aqueous solutions and degraded organic solutions. The high- and low-salt waste solutions are routed to underground double-wall storage tanks for conversion to salt cake.

Tank Farms and Other Waste-Management Facilities

Liquid waste containing high concentrations of radionuclides from the chemical processing plants has been stored on an interim basis in underground tanks in the 200 East and 200 West Areas of the Hanford Site since startup. Between 1944 and 1972, Hanford Site nuclear defense activities generated 397,000 cubic meters (14,019,923 cubic feet) of liquid radioactive waste. This volume was reduced to approximately 185,000 cubic meters (6,533,000 cubic feet) of salt cake, sludge, liquids, and slurries stored in 149 single-shell tanks and 20 double-shell tanks. Wastes generated since 1979 are being stored in double-shell tanks.

A significant quantity of the cesium and strontium was separated from the stored waste and has been converted to dry cesium chloride and strontium fluoride salts, sealed in double-wall metal capsules, and stored in water basins (pending use). Removal of these high-activity radionuclides has significantly reduced the potential hazard of stored waste. The cesium capsules are in the process of being shipped to offsite commercial facilities for use in sterilizing medical equipment and irradiating food. These capsules will be returned to the U.S. Department of Energy at the end of their useful life for final disposal.

Essentially, all free liquids have been pumped from single-shell tanks to reduce the possibility of leakage to surrounding soil. When such leaks did occur in the past, the long-lived radioactive material of concern was fixed in place by the sorptive properties of the soil.

The largest waste storage tank leak on the Hanford Site was the 241-T-106 leak in the 200 West Area, confirmed June 8, 1973. Subsequent investigation revealed that 435,275 liters (115,000 gallons) of radioactive liquid waste had leaked into adjacent sediments. A study was conducted to define the boundary of the contaminated zone and the depth to which the liquid had percolated. The deepest penetration of contamination observed was 33 meters (108 feet) below ground surface (29 meters (95 feet) above the water table) (Brown et al., 1979; Routson et al., 1979).

Other waste-management facilities in the 200 East and West Areas include low-level waste-burial grounds, retrievably stored transuranic waste trenches, cribs, and ponds. Low-level, solid, radioactive waste resulting from U.S. Department of Energy defense nuclear materials production and research programs is buried in shallow land burial trenches. Since May 1970, solid waste classed as, or suspected of being, transuranic waste has been packaged, labeled, and stored so as to be retrievable for at least 20 years. Retrievably stored transuranic waste from U.S. Department of Energy defense programs is planned for permanent disposal in the Waste Isolation Pilot Plant located in New Mexico. Process steam condensates and low-level liquid waste are released to the ground via structures called cribs. Process cooling water potentially contaminated with low levels of radioactivity and nonradioactive liquid effluents are released to manmade ponds on the Hanford Site. Details on these waste-management and disposal facilities are provided in a report by the U.S. Energy Research and Development Administration (ERDA, 1975, Chapter II and Appendixes).

3.4.1.2.3 300 Area

Facilities in the 300 Area, completed in 1943 and the years immediately following, were related to the fabrication of reactor fuel. Facilities included technical and service support functions, as well as fuel manufacturing. As the Hanford Site production reactors were shut down, fuel manufacturing activities decreased. For the last 20 years, research and development programs have constituted a major part of the activities in the 300 Area. The newer facilities house mostly laboratories and large test facilities in support of peaceful utilization of plutonium, reactor fuels development, liquid metal technology, Fast Flux Test Facility support, gas-cooled reactor programs, and life sciences programs.

3.4.1.2.4 400 Area

The 400 Area is the site of the Fast Flux Test Facility, a sophisticated reactor for testing breeder reactor fuels, materials, and components.

3.4.1.2.5 600 Area

Included in the 600 Area (see Fig. 3-37) (all of the Hanford Site that is not included as 100, 200, 300, or 400 Areas) are

1. Arid Lands Ecology Reserve, a 310-square kilometer (120-square mile) tract set aside by the U.S. Atomic Energy Commission in 1968 for ecological studies.

2. Land (4 square kilometers (1.5 square miles)) leased to the State of Washington, part of which is subleased to U.S. Ecology, Inc., and used for disposal of low-level radioactive waste.

3. Land (4.4 square kilometers (1.7 square miles)) leased to the Washington Public Power Supply System, the site for three nuclear power reactors; one reactor is currently in operation, construction has been deferred on another, and terminated on a third.

4. Land (2.6 square kilometers (1.0 square mile)) transferred to the State of Washington as a potential site for the disposal of nonradioactive hazardous wastes.

5. Land (approximately 130 square kilometers (50 square miles)) north of the Columbia River made available for the Saddle Mountain Wildlife Refuge under a revocable permit to the U.S. Fish and Wildlife Service. This area is not considered by the U.S. Department of Energy to be a Federal- or State-protected resource and is available for U.S. Department of Energy activities.

6. Land (220 square kilometers (85 square miles)) northeast of the Columbia River made available for the Wahluke Wildlife Recreation Area (to be used for public outdoor recreation) under revocable permit to the State of Washington Department of Game. This area is not considered by the U.S. Department of Energy to be a Federal- or State-protected resource and is available for U.S. Department of Energy activities.

7. Support facilities for the controlled access areas.

8. The Near-Surface Test Facility in Gable Mountain. This facility is part of the Basalt Waste Isolation Project to assess the feasibility of radioactive waste storage in basalt formations.

9. Reference repository location for the Basalt Waste Isolation Project (46 square kilometers (18 square miles)). This site includes all of the 200 West Area (DOE, 1982b). The site for the principal borehole and exploratory shafts for the Basalt Waste Isolation Project covers approximately 1 square kilometer (0.4 square mile) and is located just west of the 200 West Area within the reference repository location.

As noted above, two parcels of land within the Hanford Site are leased to the State of Washington and the Washington Public Power Supply System. The State subleases a portion of its leased land to U.S. Ecology, Inc., for disposal of low-level radioactive wastes. The Washington Public Power Supply System-leased land is the site for three nuclear power reactors. The State also retains fee title to a section of land for use as a proposed hazardous waste-disposal site. A portion of the State-leased land is included within the reference repository location. However, the area that the State subleases to U.S. Ecology, Inc., is not contained within the reference repository location. No other activities are carried out on the State-leased land. All activities conducted on the leased land must be compatible with U.S. Department of Energy activities, must be nuclear related, and must be approved by the U.S. Department of Energy. The U.S. Department of Energy retains the right to remove from the leased area any portion that is not currently being utilized or developed by the State. In addition, the Big Bend Alberta Company owns the mineral rights for several parcels of land within the Arid Lands Ecology Reserve. The lands designated for the reference repository location consist of acquired land plus sections that have been withdrawn from all forms of appropriation under the public land laws, including the mining and mineral leasing laws. Future plans for the Hanford Site call for the continuation of its present use as an area dedicated primarily to nuclear energy activities (ERDA, 1975). Designation of the Hanford Site as a national environmental research park was made by the U.S. Energy and Research Development Administration, the predecessor agency to the U.S. Department of Energy. This designation provides a mechanism whereby the U.S. Department of Energy can authorize environmental research activities compatible with U.S. Department of Energy nuclear defense and research and development activities.

3.4.1.3 Other land uses

The U.S. Army Yakima Firing Center is located approximately 30 kilometers (19 miles) west of the reference repository location. This facility is under the command of Fort Lewis (DOA, 1979, pp. 67-109).

The Yakima Firing Center is used primarily as a training area for large-scale maneuvers, particularly those involving tracked vehicles (tanks and armored personnel carriers) and for training in use of large, long-range weapons. The use of the Yakima Firing Center is necessary to enhance the ability and readiness of the primary headquarters, 9th Infantry Division, Fort Lewis, and Reserve Components (U.S. Army Reserve, National Guard) in accomplishment of their military mission.

Much of the training activity at the Yakima Firing Center is designed to take advantage of the large, relatively trafficable areas and the large impact area. Training activity is greatest from March to November. Mechanized units (tanks, armored personnel carriers) conduct extensive maneuvers throughout all accessible areas of the Yakima Firing Center, and use specially designed ranges to practice use of their weapons. Infantry and engineer units also train here; much of their activity supports the mechanized units.

Training of armored and mechanized units at the Yakima Firing Center emphasizes large-scale, cross-country maneuvers and practice on tank gunnery ranges. Use of the ranges near the cantonment is particularly heavy. During maneuvers, mechanized and armored units typically have infantry units attached for support. During defensive operations, tanks and armored personnel carriers are dug in using heavy equipment operated by engineer units. Engineer units also construct large antitank ditches during occasional training exercises; these ditches, intended to stop the advance of tanks or armored personnel carriers, are 3 meters (10 feet) wide, 1.2 to 2 meters (4 to 6 feet) deep and may be many meters (yards) long. Demolition of obstacles of this type (i.e., refilling the trench) is also part of engineer training, as are bridge construction, firebreak and road construction and maintenance, firefighting, and airfield construction.

In an environmental impact statement issued by the U.S. Department of the Army in 1977 (DOA, 1979, pp. 67-109), no current or proposed activity on the Yakima Firing Center was identified that would significantly affect nuclear-related operations on the Hanford Site. These included assessments of land use and environmental or socioeconomic impacts resulting from any current or proposed activity on the Yakima Firing Center.

The reference repository location is not located within the boundaries of a significant nationally protected natural resource (see Fig. 3-37), nor would activities at the reference repository location irreconcilably conflict with designated uses of any protected resources. Within 80 kilometers (50 miles) of the reference repository location lie several national wildlife refuges, including:

- Toppenish National Wildlife Refuge--60 kilometers (37 miles) southwest of the reference repository location.
- Columbia National Wildlife Refuge--20 kilometers (12.5 miles) north of the reference repository location.
- Seven islands within the Hanford reach of the Columbia River, which are part of the McNary National Wildlife Refuge--35 kilometers (22 miles) east of the reference repository location.
- Cold Springs National Wildlife Refuge--80 kilometers (50 miles) south of the reference repository location.

The nearest national historic site is the Whitman Mission, located 105 kilometers (65 miles) southeast of the reference repository location. The closest national forest is the Snoqualmie National Forest, located 100 kilometers (62 miles) west of the reference repository location.

Some areas of the Hanford Site are managed under a multipurpose concept by the U.S. Department of Energy and act as buffer zones for nuclear energy activities, but are also available for other programmatic uses by the U.S. Department of Energy. The closest buffer area is 130 square kilometers (50 square miles) of Hanford Site lands north of the Columbia River (7 kilometers (4 miles)) north of the reference repository location, designated as the Saddle Mountain National Wildlife Refuge and managed under revocable permit from the U.S. Department of Energy by the U.S. Fish and Wildlife Service. A second multipurpose area is the 220 square kilometers (85 square miles) of Hanford Site lands northeast of the Columbia River (15 kilometers (8 miles)) northeast of the reference repository location, designated as the Wahluke Wildlife Recreation Area and managed under revocable permit from the U.S. Department of Energy by the State of Washington Department of Game. These areas are not considered Federal- or State-protected areas and remain available for U.S. Department of Energy programmatic uses.

3.4.2 TERRESTRIAL AND AQUATIC ECOSYSTEMS

The Hanford Site has been characterized as a shrub-steppe grassland (Daubenmire, 1970, pp. 83 and 84) made up of a variety of plant communities. The sagebrush-cheatgrass community currently dominates the majority of the reference repository location, providing food, cover, and shelter to many species of wildlife. The reference repository location occupies 3 percent of the Hanford Site area.

Terrestrial habitats on the Hanford Site are (1) the Rattlesnake Hills, which provide the only mountainous environment on the Hanford Site, (2) sand dunes near the Columbia River, which rise 3 to 5 meters (10 to 16 feet) above ground level and create sandy habitats ranging from less than 1.0 to several hundred hectares (2.5 to several hundred acres) in size, (3) basaltic ridges (e.g., Gable Butte and Gable Mountain), (4) streamside habitats along the Columbia River, as well as the ponds and ditches of the Hanford Site area, and (5) trees introduced by man at historic farmsteads, townsites, and artillery emplacements.

Aquatic habitats on the Hanford Site are limited to the Columbia River system (Rickard et al., 1982), several natural springs (e.g., Snively, Bobcat, and Rattlesnake) on the side slope of Rattlesnake Mountain, one natural pond (West Lake), several manmade ditches, and two manmade ponds (see Subsection 3.3.1.2). These manmade systems attract some animal species that would not otherwise be found in these normally arid locations. There are no naturally occurring surface-water systems or wetlands (DOE, 1982b) on the reference repository location.

Rickard et al. (1981) characterized the 29-hectare (71-acre) Gable Mountain Pond (see Fig. 3-24), which was created in 1957 by releasing water from a chemical processing facility. Since that time, the pond has received a more or less constant flow of effluent water. The dominant riparian plants are bulrush (Scirpus acutus) and cattail (Typha latifolia). Reed canary-grass (Phalaris arundinacea), goldenrod (Solidago), barnyard grass (Echinochloa crusgalli), Conyza (Conyza canadensis), and Russian knapweed (Centaurea repens) are some of the common herbaceous species around the pond. The important aquatic plants include Myriophyllum heterophyllum, Potamogeton richardsonii, P. filiformis, and Chara. Russian olive (Elaeagnus angustifolia) and peach-leafed willow (Salix amygdaloides) are the dominant tree species that have become established around the shoreline.

B Pond (see Fig. 3-24) is similar in many respects to Gable Mountain Pond; however, B Pond is less successionally advanced. Many aquatic and riparian-associated organisms (e.g., birds, mammals, fish, insects) occur at the waste ponds. The ponds contain low, but detectable, levels of radioactive materials that resulted from releases of process water. A formerly utilized waste water pond, U Pond, has been taken out of service and the site stabilized.

3.4.2.1 Vegetation

The Hanford Site ecosystem is termed a shrub-steppe ecosystem to distinguish it from the true steppe lands of Asia. The shrub-steppe ecosystem, a relatively fragile environment, contains several distinct ecological communities, each having common distinguishing features. The vegetation is adapted to tolerate semiarid conditions. The community structure is short, consisting of grasses, forbes, and shrubs with few trees, except along waterways. The Hanford Site comprises nine plant communities (ERDA, 1975; Cline et al., 1977): Sagebrush and bluebunch wheatgrass; sagebrush, bitterbrush, wheatgrass, Sandberg's bluegrass; sagebrush, cheatgrass, Sandberg's bluegrass; cheatgrass; riparian (streamside) habitats; greasewood; spiny hopsage; winterfat; and thyme buckwheat (Fig. 3-38). Some of these plant communities are extremely limited in distribution. The sagebrush-cheatgrass community currently dominates the proposed reference repository location, with other small tracts of vegetation types interspersed throughout (Fig. 3-39). Some of these other vegetation types are found at World War II army bunker sites dominated by locust trees and Siberian wheatgrass, an undisturbed area consisting of spiny hopsage, and several disturbed areas dominated by tumbleweeds and cheatgrass. These plant communities not only stabilize the soil, but provide food, cover, and shelter for many terrestrial animals. The sagebrush-cheatgrass community is particularly susceptible to brush fires during the hot, dry summer months. The most recent major fire occurred in 1985.

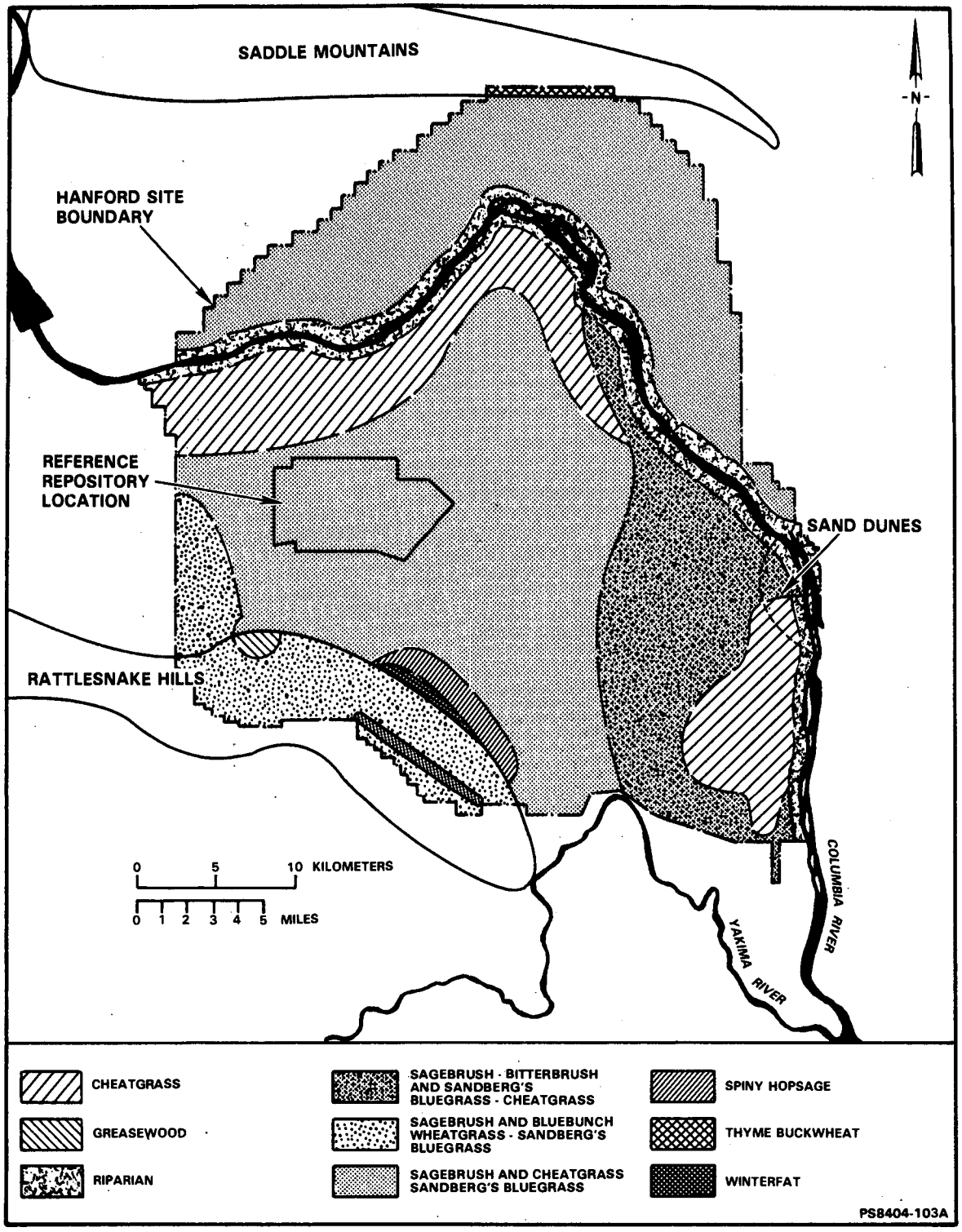

Figure 3-38. Major vegetation types on the Hanford Site (after ERDA, 1975, p. II.3-46).

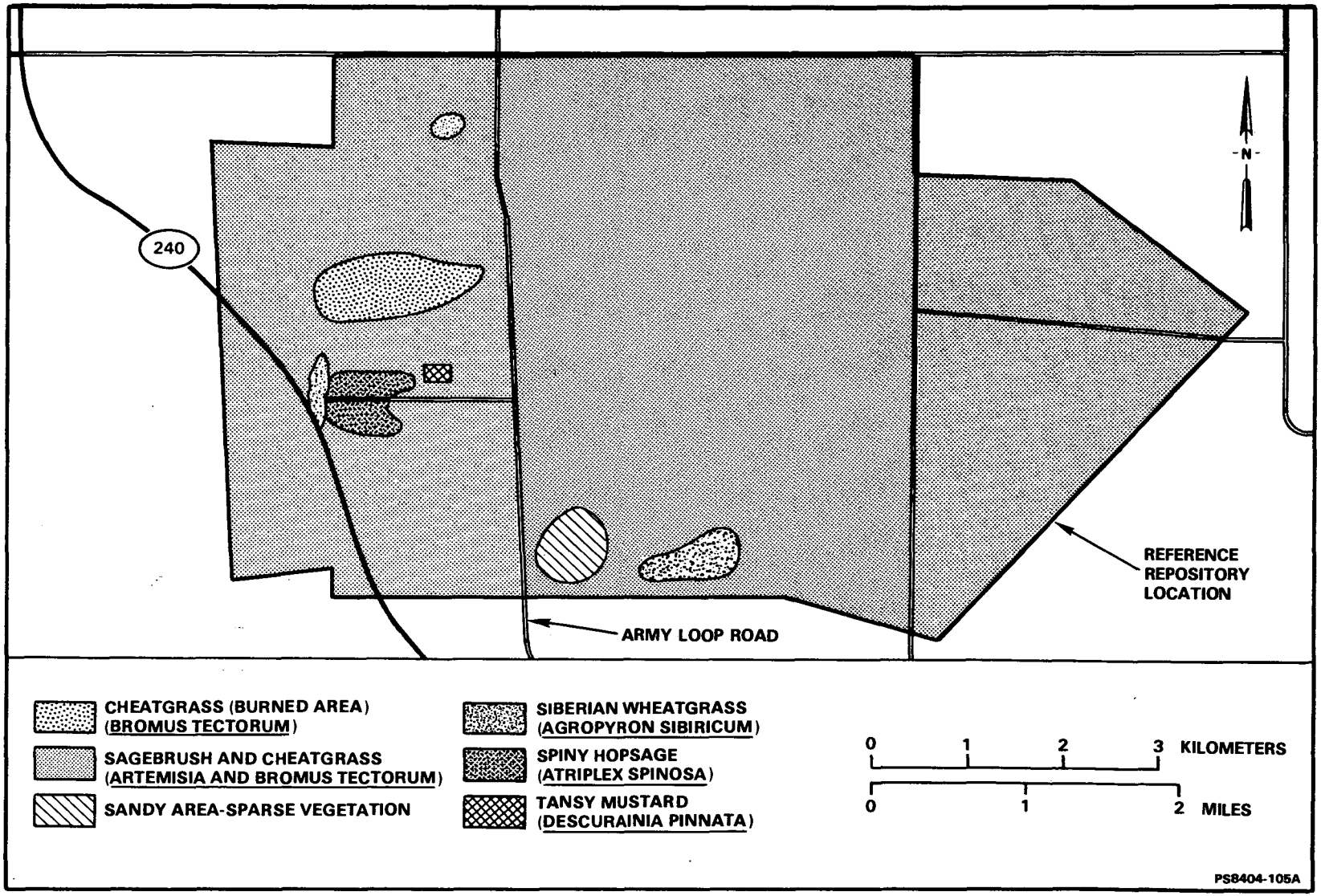

Figure 3-39. Locations of major plant communities within the reference repository location.

0 3 7 0 0 9 1 6 8 7

3.4.2.2 Mammals

A total of 27 mammal species (excluding bats) are known to occupy the Hanford Site (Table 3-18) (Rogers and Rickard, 1977; Honacki et al., 1982). Big-game species include elk and mule deer. Currently, only mule deer are found with any regularity on the reference repository location; although in the future, the local elk herd may increase in number and expand its range to areas near the proposed repository site. Other mammals that inhabit the Hanford Site include porcupine, coyote, striped skunk, badger, racoon, black-tailed hare, and Nuttal's cottontail rabbit. The coyote and badger are the most common mammalian predators, preying on rodents and other vertebrate organisms. Coyotes are also known to feed on insects, fish, and plant matter. The Great Basin pocket mouse, deer mouse, Townsend's ground squirrel, and pocket gopher are the common small mammal species that inhabit the reference repository location. Pocket mice, pocket gophers, and Townsend's ground squirrel are excellent burrowers and serve as prey for carnivores.

3.4.2.3 Birds

A list of the principal bird species observed on the reference repository location is given in Table 3-19. A complete list of birds of the Hanford Site is given in a report by the U.S. Department of Energy (DOE, 1982b).

The most common upland game birds found within the Hanford Site are the chukar partridge, ring-necked pheasant, and California quail. The mourning dove, a migratory game bird, is a common summer resident of the Hanford Site. A variety of raptor species is known to inhabit the Hanford Site. Swainson's hawks, red-tailed hawks, and the American kestrel often nest in trees at the retired army bunker sites and along the Columbia River. The marsh hawk nests on the Hanford Site, as does the burrowing owl. Great horned owls, prairie falcons, red-tailed hawks, and the ferruginous hawk nest along the cliffs at Gable Mountain and Gable Butte.

Some of the Hanford Site aquatic areas attract numerous species of waterfowl and shorebirds. These areas are an important stopover point for migrating species and a year-round home to several resident bird species (e.g., magpies, pheasants, song sparrows, and long-billed marsh wrens). Long-billed curlews nest throughout the Hanford Site from March through July and can be expected to nest on the reference repository location (Allen, 1980). Common song and perching birds known to nest within the Hanford Site include sage sparrows, western kingbirds, Brewer's blackbirds, Say's phoebes, black-billed magpies, common crows, ravens, loggerhead shrikes, horned larks, and western meadowlarks. Many of these species migrate south during the winter, returning to the Hanford Site to nest in the spring.

Table 3-18. Mammal species, excluding bats, observed on the Hanford Site

Common name	Scientific name*
Badger	Taxidea taxus
Beaver	Castor canadensis
Black-tailed hare	Lepus californicus
Bobcat	Lynx rufus
Bushy-tailed woodrat	Neotoma cinerea
Coyote	Canis latrans
Deer mouse	Peromyscus maniculatus
Elk	Cervus canadensis
Great Basin pocket mouse	Perognathus parvus
House mouse	Mus musculus
Longtail weasel	Mustela frenata
Merriam's shrew	Sorex merriami
Mink	Mustela vison
Motane vole	Microtus montanus
Mule deer	Odocoileus hemionus
Muskrat	Ondatra zibethicus
Northern grasshopper mouse	Onychomys leucogaster
Northern pocket gopher	Thomomys talpoides
Norway rat	Rattus norvegicus
Nuttall's cottontail rabbit	Sylvilagus nuttallii
Porcupine	Erethizon dorsatum
Racoon	Procyon lotor
Sagebrush vole	Lagurus curtatus
Striped skunk	Mephitis mephitis
Townsend's ground squirrel	Spermophilus townsendii
Vagrant shrew	Sorex vagrans
Western harvest mouse	Reithrodontomys megalotis
White-tailed hare	Lepus townsendii

*Honacki et al. (1982, pp. 97, 244, 254, 261, 262, 263, 264, 282, 320, 324, 371, 382, 389, 390, 430, 435, 451, 461, 488, 495, 499, 533, 551, 572, 599, 601, 603).

Table 3-19. Principal bird species observed on the reference repository location

Common name	Scientific name*
American kestrel	Falco sparverius
American robin	Turdus migratorius
Bald eagle	Haliaeetus leucocephalus
Black-billed magpies	Pica pica
Brewer's blackbird	Euphagus cyanocephalus
Burrowing owl	Athene cunicularia
California quail	Callipepla californica
Chukar	Alectoris chukar
Common crow	Corvus brachyrhynchos
Common nighthawk	Chordeiles minor
Common raven	Corvus corax
Ferruginous hawk	Buteo regalis
Golden eagle	Aquila chrysaetos
Great horned owl	Bubo virginianus
Horned larks	Eremophila alpestris
Killdeer	Charadrius vociferus
Loggerhead shrikes	Lanius ludovicianus
Long-billed curlew	Numenius americanus
Marsh hawk	Circus cyaneus
Mourning dove	Zenaida macroura
Northern flicker	Colaptes auratus
Prairie falcon	Falco mexicanus
Red-tailed hawk	Buteo jamaicensis
Ring-necked pheasant	Phasianus colchicus
Rock dove	Columba livia
Sage sparrow	Amphispiza belli
Say's phoebe	Sayornis saya
Starling	Sturnus vulgaris
Swainson's hawk	Buteo swainsoni
Western kingbird	Tyrannus verticalis
Western meadowlarks	Sturnella neglecta

*The American Ornithologists' Union (AOU, 1983, pp. 106, 108, 117, 118, 120, 125, 129, 134, 135, 147, 171, 186, 250, 257, 297, 301, 308, 395, 458, 473, 489, 507, 509, 511, 562, 585, 704, 725, 727).

3.4.2.4 Reptiles and amphibians

Reptile and amphibian species are relatively scarce at the Hanford Site. Since amphibians require moisture and standing water in which to propagate, they play only a minor role in the ecosystem of the Hanford Site. Reptiles, on the other hand, are more abundant than amphibians because of their physiological adaptions to the semiarid desert environment. Snakes most common to the Hanford Site include the gopher snake (Pituophis melanoleucus), northern Pacific rattlesnake (Crotalus irridus), and western yellow-bellied racer (Coluber constrictor). The most common lizard is the side-blotched lizard (Uta stansburiana). Lizards depend primarily on insects as food items, and snakes prey on a variety of small mammals. Lizards and snakes are common prey items of mammalian and avian carnivores.

3.4.2.5 Threatened and endangered species

At this time, no federally recognized threatened or endangered animal species are known to nest within or use the reference repository location as critical habitat. However, within the reference repository location, one threatened bird species, the bald eagle (Haliaeetus leucocephalus), and one endangered bird species, the peregrine falcon (Falco peregrinus) (FWS, 1984), have been sighted infrequently. The bald eagle and the peregrine falcon also are classified by the State of Washington as threatened and endangered, respectively, and are protected by State law (State of Washington, 1983c). Three additional bird species found within the reference repository location are now being considered as potential candidates for inclusion on the Federal threatened and endangered species list. These are the ferruginous hawk (Buteo regalis), the Swainson's hawk (Buteo swainsoni), and the long-billed curlew (Numenius americanus), all of which nest within or near the reference repository location. The State of Washington Department of Game classifies the ferruginous hawk as threatened. The State of Washington also lists over 20 animal species that may be found on the repository area on a sensitive list (State of Washington, 1983c). Swainson's hawk is included on this list. These species are receiving particular attention in ongoing biological surveys and investigations.

At this time there are no federally recognized threatened or endangered plant species or critical habitat within the reference repository location (FWS, 1984). However, the U.S. Fish and Wildlife Service (FWS, 1985a) is reviewing the status of several vascular plant species that do occur on the Hanford Site for consideration as proposed threatened species. Included in this category are the Columbia milk-vetch (Astragalus columbianus) and the persistentsepal yellowcress (Rorippa calycina Variety columbiae). One State-threatened species, a sandwort (Arenaria franklinii Variety thompsonii), and one State-sensitive species, gray cryptantha (Cryptantha leucophaea), have been located at the Hanford Site and might occur within the reference repository location (State of Washington, 1984f, 1985). However, the presence of these or other

potentially sensitive species within the reference repository location has not been established, although investigations are continuing.

The U.S. Department of Energy, in accordance with Sections 7(a) and 7(c) of the Endangered Species Act of 1973, has initiated informal consultation with the U.S. Fish and Wildlife Service regarding wildlife impacts from potential site-characterization activities.

Section 7(a) requires the following:

- Federal agencies to utilize their authorities to carry out programs to conserve endangered and threatened species.

- Consultation with the U.S. Fish and Wildlife Service when a Federal action may affect a listed, endangered, or threatened species to ensure that any action authorized, funded, or carried out by a Federal agency is not likely to jeopardize the continued existence of listed species or result in the destruction or adverse modification of critical habitat. The process is initiated by the Federal agency after they have determined if their action may affect (adversely or beneficially) a listed species.

- Conference with the U.S. Fish and Wildlife Service when a Federal action is likely to jeopardize the continued existence of a proposed species or result in destruction or adverse modification of proposed critical habitat.

Section 7(c) requires Federal agencies or their designees to prepare a biological assessment for projects that may significantly affect the quality of the human environment. The purpose of the biological assessment is to identify any proposed and (or) listed species that is likely to be affected by such an activity.

The U.S. Department of Energy also has consulted with the State of Washington Department of Natural Resources through the Washington Natural Heritage Program. This consultation has included several visits by State personnel to selected localities within the Hanford Site for the purpose of conducting rare plant surveys. A summary of these visits is found in Sheehan (1984). Such visits will continue if the reference repository location is selected for site characterization.

3.4.2.6 Columbia River habitat

The reference repository location is approximately 7 kilometers (4 miles) south of the closest point of the Columbia River (see Fig. 3-37). The Columbia River adjacent to the Hanford Site is the only undammed segment of that river in the United States. In 1970, the Hanford

reach was being considered for designation under the Wild and Scenic Rivers Act (USDA, 1970). It has since been withdrawn from consideration. The principal biological elements of the Columbia River habitat may be roughly divided into nonfisheries and fisheries resources.

3.4.2.6.1 Nonfisheries resources

The Hanford reach of the Columbia River is uncharacteristic of other river and stream environs due to the "paucity of tree corridors, willows and cottonwoods, that characteristically border most rivers and streams" (Rickard et al., 1982, p. 64). Instead of these "tree corridors," one finds plant species capable of rooting in the cobble and gravel substrate, such as shrub willows, rushes, grasses, and forbes (Rickard et al., 1982).

The Hanford reach of the Columbia River also is home to numerous bird species all or part of the year, including the bald eagle (Haliaeetus leucocephalus), various species of geese and ducks, upland game birds, and fish-eating birds (Rickard et al., 1982). Bald eagles winter in the Hanford reach, attracted by the supply of salmon carcasses washed ashore during the fall and winter spawning season (Rickard et al., 1982). The Hanford reach is part of the Pacific Flyway, and therefore hosts waterfowl during their migration from northern breeding grounds (WPPSS, 1983, p. 2.2-5).

3.4.2.6.2 Fisheries resources

The fisheries resource of the Columbia River is diverse; 44 species of fish have been identified in the Hanford reach (PSPL, 1981). The chinook (Oncorhynchus tshawytscha), coho (Oncorhynchus kisutch), and sockeye salmon (Oncorhynchus nerka), steelhead trout (Salmo gairdneri), and American shad (Alosa sapidissima) comprise the important anadromous fish species of commercial and recreational value (PSPL, 1981; WPPSS, 1983, p. 2.2-9).

The Hanford reach of the Columbia River serves as a major spawning ground for chinook salmon and steelhead trout; other anadromous fish use the reach as a migration route to spawning areas farther upstream (PSPL, 1981). Other recreationally important fish species include the mountain whitefish (Prosopium williamsoni), white sturgeon (Acipenser transmontanus), smallmouth bass (Micropterus salmoides), yellow perch (Perca falvescens), and bluegill (Lepomis macrochirus) (PSPL, 1981; WPPSS, 1983, p. 2.2-10). No Federal threatened or endangered fish species have been identified (WPPSS, 1983, p. 2.2-11).

More complete descriptions of the fisheries resource in the Hanford reach of the Columbia River can be found in reports by the Puget Sound Power and Light Company (PSPL, 1981) and the Washington Public Power Supply System for units one and four (WPPSS, 1983, pp. 2.2-9 through 2.2-11).

3.4.2.6.3 Water quality

The State of Washington Department of Ecology classifies the Columbia River as Class A (excellent) between Grand Coulee Dam and the mouth of the river near Astoria, Oregon (WPPSS, 1983, p. 2.4-3; Price et al., 1984). The Class A designation requires that industrial uses of this water be compatible with other uses including drinking water, wildlife, and recreation (Price et al., 1984).

The U.S. Department of Energy conducts routine monitoring of Columbia River water quality for both radiological and nonradiological water-quality parameters (Price et al., 1984). A yearly publication of results has been printed since 1973 (Price et al., 1984). Numerous other water-quality studies have been conducted on the Columbia River relative to the impact of the Hanford Site over the past 37 years (WPPSS, 1982). The U.S. Department of Energy currently holds a national pollutant discharge elimination system permit for eight effluent discharges into the Columbia River.

Radiological monitoring showed low levels of radionuclides in samples of Columbia River water (Price et al., 1984). Hydrogen-3 (tritium), strontium-90, iodine-129, iodine-131, cobalt-60, and natural uranium were found in slightly higher concentrations downstream from the Hanford Site, but were well below concentration guidelines established by the U.S. Department of Energy and the U.S. Environmental Protection Agency drinking water standards (Price et al., 1984; Tables 3-20 and 3-21).

Temperature is one of the water-quality parameters that most affects fish in the Columbia River (WPPSS, 1983, p. 5.1-6). The salmonids are the most sensitive to thermal changes (WPPSS, 1983, p. 5.1-6). The months of July through September are most critical as temperatures peak and reach the upper limits of salmonid tolerance (WPPSS, 1983, p. 5.1-6). The U.S. Department of Energy found no significant temperature differences between points above and below the Hanford reach of the Columbia River. Therefore, solar radiation appears to be the major cause for temperature fluctuations within the Hanford reach (Price et al., 1984).

Table 3-22 presents 1984 Columbia River nonradiological water-quality data from sampling upstream and downstream from the Hanford Site. With one exception (pH 9.1 at downstream location), all constituents measured by the U.S. Department of Energy were within State standards. None of the analytical results indicated a significant deterioration in water quality at the downstream-sampling locations (Price et al., 1985). Concentrations of water-quality variables during 1984 were consistent with measurements of previous years.

Table 3-20. Average annual radionuclide concentrations[a] in Columbia River water upstream from the Hanford Site

Radionuclide, pCi/L	Year					
	1979	1980	1981	1982	1983	1984
Tritium	2.9×10^{2}	2.3×10^{2}	1.7×10^{2}	1.6×10^{2}	1.0×10^{2}	1.3×10^{2}
Strontium-89	$<1.3\times10^{-1}$[b]	$<1.2\times10^{-1}$[b]	8.3×10^{-2}[b]	$<1.5\times10^{-1}$	6.3×10^{-2}	1.4×10^{-1}
Strontium-90	7.2×10^{-1}	2.4×10^{-1}	1.4×10^{-1}	1.8×10^{-1}	1.8×10^{-1}	1.4×10^{-1}
Uranium	4.5×10^{-1}	4.0×10^{-1}	4.1×10^{-1}	3.6×10^{-1}	2.7×10^{-1}	3.3×10^{-1}
Cobalt-60						
Particulate	7.9×10^{-1}[c]	1.0×10^{-1}[c]	3.6×10^{-3}[b]	5.0×10^{-3}	2.1×10^{-3}	$<1.2\times10^{-3}$
Dissolved			1.1×10^{-2}[b]	1.0×10^{-2}	4.2×10^{-3}	3.3×10^{-3}
Iodine-129						
Dissolved	1.0×10^{-4}	5.9×10^{-6}	6.9×10^{-6}	6.2×10^{-6}	2.4×10^{-5}	1.2×10^{-5}
Iodine-131						
Particulate	1.1×10^{-1}[c]	2.0×10^{-2}[c]	3.4×10^{-3}[b]	$<1.0\times10^{-2}$	-2.4×10^{-4}	$<2.7\times10^{-4}$
Dissolved			$<9.6\times10^{-3}$[b]	$<2.0\times10^{-2}$	1.3×10^{-3}	$<5.6\times10^{-4}$
Cesium-137						
Particulate	1.0×10^{-1}[c]	1.0×10^{-2}[c]	$<1.2\times10^{-2}$	3.3×10^{-2}	1.8×10^{-2}	1.4×10^{-2}
Dissolved			$<2.4\times10^{-2}$	6.9×10^{-2}	3.9×10^{-2}	2.9×10^{-2}
Plutonium-239, 240						
Particulate	2.0×10^{-4}[c]	3.3×10^{-4}[c]	3.5×10^{-5}	3.0×10^{-5}	2.3×10^{-5}	2.7×10^{-5}
Dissolved			1.8×10^{-4}	9.0×10^{-6}	-6.0×10^{-6}	3.0×10^{-4}

[a]Values are those reported in annual Pacific Northwest Laboratory reports for each of the listed years (Houston and Blumer, 1980, 1981; Sula et al., 1982, 1983b; Price et al., 1984, 1985). Refer to these reports for additional detail.

[b]Not reported in annual report.

[c]Reported in annual report as sum of particulate and dissolved fractions.

Table 3-21. Average annual radionuclide concentrations[a] in Columbia River water downstream from the Hanford Site

Radionuclide, pCi/L	Year					
	1979	1980	1981	1982	1983	1984
Tritium	3.6×10^{2}	2.7×10^{2}	2.0×10^{2}	2.2×10^{2}	1.3×10^{2}	1.7×10^{2}
Strontium-89	$<1.1\times10^{-1}$[b]	$<1.1\times10^{-1}$[b]	9.0×10^{-2}	$<1.8\times10^{-1}$	2.3×10^{-1}	1.5×10^{-1}
Strontium-90	3.4×10^{-1}	2.0×10^{-1}	2.3×10^{-1}	1.7×10^{-1}	2.2×10^{-1}	1.7×10^{-1}
Uranium	5.0×10^{-1}	5.4×10^{-1}	4.2×10^{-1}	3.8×10^{-1}	5.0×10^{-1}	4.5×10^{-1}
Cobalt-60						
Particulate	9.0×10^{-2}[b]	3.0×10^{-2}[b]	$<8.0\times10^{-3}$	4.0×10^{-3}	7.8×10^{-3}	7.6×10^{-3}
Dissolved			$<1.8\times10^{-2}$	1.5×10^{-2}	8.5×10^{-3}	1.2×10^{-2}
Iodine-129						
Dissolved	1.1×10^{-4}	5.4×10^{-6}	4.5×10^{-6}	6.5×10^{-6}	7.5×10^{-5}	7.4×10^{-5}
Iodine-131						
Particulate	7.0×10^{-2}[c]	5.0×10^{-2}[c]	3.4×10^{-3}[b]	$<5.0\times10^{-2}$	1.7×10^{-3}	2.0×10^{-3}
Dissolved			$<2.3\times10^{-2}$	1.3×10^{-2}	1.2×10^{-2}	1.7×10^{-2}
Cesium-137						
Particulate	3.0×10^{-2}[c]	2.0×10^{-2}[c]	$<1.1\times10^{-2}$	2.8×10^{-2}	1.7×10^{-2}	1.1×10^{-2}
Dissolved			$<2.7\times10^{-2}$	5.5×10^{-2}	3.6×10^{-2}	2.3×10^{-2}
Plutonium-239, 240						
Particulate	3.1×10^{-4}[c]	3.2×10^{-4}[c]	5.4×10^{-5}	3.0×10^{-5}	2.3×10^{-5}	1.8×10^{-5}
Dissolved			1.1×10^{-4}	1.0×10^{-5}	6.2×10^{-5}	$<1.5\times10^{-4}$

[a]Values are those reported in annual Pacific Northwest Laboratory reports for each of the listed years (Houston and Blumer, 1980, 1981; Sula et al., 1982, 1983b; Price et al., 1984, 1985). Refer to these reports for additional detail.

[b]Not reported in annual report.

[c]Reported in annual report as sum of particulate and dissolved fractions.

Table 3-22. Columbia River water-quality data for 1984 (Price et al., 1985)

Analysis	Units	Vernita Bridge (upstream)				Richland (downstream)				State standard
		Number of samples	Maximum	Minimum	Annual average[a]	Number of samples	Maximum	Minimum	Annual average[a]	
U.S. Department of Energy sampling program										
pH	pH units	13	8.5	7.7	NA[b]	13	9.1	7.2	NA[b]	6.5 to 8.5
Fecal coliform	#/100 mL	13	25	2	2[b]	13	95	2	11[b]	100
Total coliform	#/100 mL	13	540	2	49[b]	13	920	2	49[b]	
Biological oxygen demand	mg/L	13	8.7	1.5	2.9 ± 1.1	13	6.2	1.2	2.4 ± 0.77	
Nitrate	mg/L	13	0.80	0.040	0.17 ± 0.11	13	0.38	0.050	0.17 ± 0.064	
U.S. Geological Survey sampling program[c]										
Temperature[d]	°C (°F)	351	19.3 (66.7)	2.5 (36.5)	10.7 ± 5.8 (51.3 ± 10.4)	286	(e)	2.6 (36.7)	--	20 (68) (maximum)
Dissolved oxygen	mg/L	5	12.4	9.5	11 ± 0.54	4	12.3	9.4	11 ± 0.64	8 (minimum)
Turbidity	NTU[f]	6	2.5	1.8	2.2 ± 0.10	4	3.7	2.6	3.0 ± 0.25	5 + background
pH	pH units	6	7.9	7.4	NA	4	8.2	7.3	NA	6.5 to 8.5
Fecal coliform	#/100 mL	5	3,000	<1	<1[b]	4	4,000	<1	2,500[b]	100
Suspended solids, 105°C (221°F)	mg/L	6	15	1	6.8 ± 2.1	4	16	6	9.5 ± 2.4	
Dissolved solids, 180°C (356°F)	mg/L	6	98	73	85 ± 4.0	4	91	74	83 ± 4.0	
Specific conductance	µmhos	6	160	122	146 ± 6.0	4	158	122	144 ± 8.5	
Hardness, as $CaCO_3$	mg/L	6	78	58	69 ± 2.8	4	76	61	70 ± 3.2	
Phosphorus, total	mg/L	6	0.040	0.020	0.037 ± 0.0042	4	0.030	0.010	0.20 ± 0.0058	
Chloride, dissolved	mg/L	6	3.3	1.0	1.6 ± 0.35	4	2.3	1.2	1.7 ± 0.26	
Chromium, dissolved	mg/L	4	<1	<1	<1	4	20	<10		
Nitrogen, Kjeldahl	mg/L	6	0.06	0.20	0.28 ± 0.065	4	0.30	<0.20		
Total organic carbon	mg/L	4	6.9	3.2	5.1 ± 0.76	4	6.6	1.5	3.2 ± 1.2	
Iron, dissolved	mg/L	4	31	11	19 ± 4	4	37	11	19 ± 6	
Ammonia, dissolved (as N)	mg/L	6	0.180	0.010	0.06 ± 0.03	4	0.050	0.010	0.03 ± 0.009	

NOTE: NA = not applicable.
[a]Average values plus or minus two-standard error of the calculated mean (95-percent confidence interval).
[b]Annual median.
[c]Provisonal data subject to revision.
[d]Each value represents a daily average.
[e]Missing data.
[f]Nephelometric Turbidity Units.

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3.4.2.7 Radiological conditions

Radiological surveillance of the Hanford Site and surrounding environs is part of an ongoing program designed to evaluate existing and potential pathways of exposure to radiation releases from Hanford Site operations. Measurement of the natural background radiation at the Hanford Site began in 1944 with the startup of the first plutonium production reactors. Details of the early surveillance activities have been published in the open literature as topical, periodic reports (Rogers and Rickard, 1977, App. D, pp. D.1 through D.8). Beginning in 1958, the historical record has been maintained through a series of annual reports that evaluate the air, water, soil, flora, and fauna of the Hanford Site environs in terms of existing and potentially significant radioactive release pathways. Special emphasis is given to pathways of likely environmental reconcentration and those potentially resulting in direct exposure to the work force or the public. These annual reports are of three basic types: Environmental surveillance, environmental status, and ground-water surveillance.

3.4.2.7.1 Environmental surveillance reports

The environmental surveillance reports summarize sampling data from off the Hanford Site and other pertinent data that relate to calculation of potential offsite radiation doses. Also included are discussions of the relationship between observed results and background levels, and an assessment of the impact of Hanford Site operations on the environment in terms of radiation dose. Typical of these environmental surveillance reports is Price et al. (1985).

3.4.2.7.2 Environmental status reports

The environmental status reports address surface and atmospheric measurements made on the Hanford Site, including radioactive and nonradioactive environmental discharges. Typical of these status reports are Sula et al. (1983a), Conklin et al. (1984), and Greagor (1983).

3.4.2.7.3 Ground-water surveillance reports

Ground-water surveillance reports document the movement of process cooling and waste water discharged from Hanford Site facilities that have reached the unconfined ground water and that contain low levels of radioactive and chemical substances. Eddy et al. (1983) and Wilbur et al. (1983) typify the ground-water surveillance reports.

3.4.2.7.4 Radiation sources

The sources of radiation in the Hanford Site and vicinity are as follows (after Jamison, 1982):

- Naturally occurring long-lived radionuclides, primarily potassium-40, uranium, thorium, and their decay products.
- Cosmic radiation and naturally occurring radionuclides formed by the interaction of that radiation with stable nuclides present in the atmosphere.
- Fallout from above-ground testing of nuclear weapons.
- Radionuclides released to the environment from activities at the Hanford Site.

3.4.2.7.5 Radiation exposures

The concentrations of natural and manmade radionuclides on and around the Hanford Site have resulted in a calculated annual background dose of 100 millirems per year (for calendar year 1984) that was received by the average-exposed person living in the Hanford Site vicinity (80 kilometers (50 miles)) (Price et al., 1985, pp. 57 through 63). The amount of dose to this average individual that is attributable to the operations on the Hanford Site has been estimated to be 0.01 millirem per year (Price et al., 1985, pp. 57 through 63), the major component of which originates from the remaining plutonium production facility, N Reactor (see Fig. 3-37).

The 50-year whole-body cumulative maximum dose from Hanford Site effluents to an individual residing off the Hanford Site has been calculated to be 2.0 millirems. This dose equates to 5 manrems to the population living within 80 kilometers (50 miles) of the Hanford Site (Price et al., 1985). In comparison, natural background radiation exposes the individual and the 80-kilometer (50-mile) population to an annual dose equivalent of 100 millirems and 34,000 manrems, respectively (Price et al., 1985, p. 61).

The manmade ponds and the one natural pond located on the Hanford Site (see Fig. 3-24), outside operating area exclusion fences, have been routinely sampled for radioactivity. The manmade ponds (Gable Mountain Pond and B Pond), north and east of the 200 East Area, respectively, were built for disposal of process cooling water and wastes occasionally containing low levels of radioactive materials (Price et al., 1985). The natural pond, West Lake, does not directly receive any discharges from Hanford Site facilities.

Of these ponds, West Lake exhibits the highest concentrations of gross alpha and beta emitters. A special study in 1975 indicated naturally occurring uranium as the principal source of the radioactivity (Sula et al., 1983a, p. 22). Natural recharge to the pond appears to come from shallow confined aquifers with less exchange occurring between the pond and the shallow unconfined aquifer (Gephart et al., 1976). Thus, the naturally occurring radionuclides have been concentrated by evaporation through time (Sula et al., 1983a, p. 22).

The primary human exposure pathways for radioactive liquid effluents are associated with the Columbia River. During the early years of Hanford Site operations (1944 to 1971), thousands of curies per day of short-lived radionuclies were discharged to the river from production reactors located along the shoreline. With the noted exception of the N Reactor, all the production reactors were closed down by 1972. The shutdown of these production reactors resulted in a major reduction in radionuclides released to the Columbia River. Unlike the earlier production reactors, the dual-purpose N Reactor was constructed to a newer design that does not utilize the once-through cooling process and its primary coolant is not discharged to the Columbia River. Since that time, the N Reactor has been outfitted with additional liquid effluent control systems, further reducing the discharge of radioactive materials to the river. The increase in concentration downstream results in a radiation dose to the thyroid of an assumed maximum individual from iodine-129 calculated to be 0.002 millirem (Sula et al., 1983b, p. 52).

Tritium is found in the unconfined ground-water aquifers as a result of waste discharges in the 200 Areas. The estimated amount of tritium entering the river from the unconfined ground water was 450 curies in 1984. This estimated tritium contribution to the river from the ground water was too small to be accurately measured in the presence of relatively high background concentrations found in the river (130 plus or minus 15 picocuries per liter) (Price et al., 1985, p. A.12). The tritium plume continues to show increasing concentrations near the Columbia River (Eddy et al., 1983, p. 25), although, as previously stated, the overall contribution to the river was so small that it could not be accurately measured.

Drinking water obtained from the unconfined aquifer was consumed by employees at the Fast Flux Test Facility during 1983. The annual whole-body dose attributable to the tritium in the drinking water (average 25 picocuries per milliliter) was calculated to be 0.38 millirem, based on an ingestion rate of 250 liters (66 gallons) per year. Because of the short half-life (10 days) of tritium in the body, the entire dose commitment is received in the year of exposure. The calculated dose was less than 10 percent of the 4-millirem dose equivalent limit (Prater et al., 1984, p. 21) for calendar year 1982. The U.S. Department of Energy is drilling a new drinking-water well beyond the tritium plume for Fast Flux Test Facility employees.

Samples of agricultural foodstuffs grown in the vicinity of the Hanford Site have been examined annually for radiological contamination. Recent levels have been consistently low and are probably attributable to global weapons testing. No associations with radioactivity from the Hanford Site have been made since the shutdown of eight original reactors (Price et al., 1985, p. A.12).

Low concentrations of radionuclides attributable to Hanford Site operations have been measured in ducks and game birds collected near operating facilities. Concentrations were low enough that doses resulting from ingestion of any of these wildlife forms that might migrate off the Hanford Site would be well below applicable Federal radiation protection standards. Fish from the Hanford reach of the Columbia River have been found to exhibit cobalt-60 and strontium-90 more frequently than those collected upstream. However, levels are generally too low and too variable to permit quantification of any differences. Cesium-137 levels measured in Hanford Site deer over a recent 2-year interval have been consistently low, potentially resulting in a maximum dose to a consumer of less than 1 percent of the applicable radiation protection standard.

Soil and vegetation assays taken from the Hanford Site environs show that some locations near operating areas have slightly elevated levels of radionuclides. For more details see Price et al. (1985, pp. 31 and 33).

3.4.3 METEOROLOGICAL CONDITIONS AND AIR QUALITY

Meteorological data are collected at a number of locations on the Hanford Site. Complete climatological data are available for the Hanford Meteorological Station, located between the 200 Areas in the northeast section of the reference repository location. Data have been collected at the Hanford Meteorological Station since 1945, and temperature and precipitation data from a nearby location are available for the period 1912 through 1943. A summary of these data for the period through 1980 has been published by Stone et al. (1983). The summary also contains wind data for several locations on and near the Hanford Site. Data from the Hanford Meteorological Station are representative of the general climatic conditions that exist at the reference repository location. Hanford Site climatological conditions discussed in this section are based on the data summaries given in Stone et al. (1983).

3.4.3.1 Wind

Wind data are collected routinely at the Hanford Site by the Hanford Meteorological Station and a series of wind telemetry stations are distributed on and around the Hanford Site. Figure 3-40 indicates the wind direction frequency distributions at the Hanford Meteorological Station and 12 of the telemetry stations. Some differences in dominant wind directions as a function of location can be noted in Figure 3-40. These differences are attributed to terrain influences.

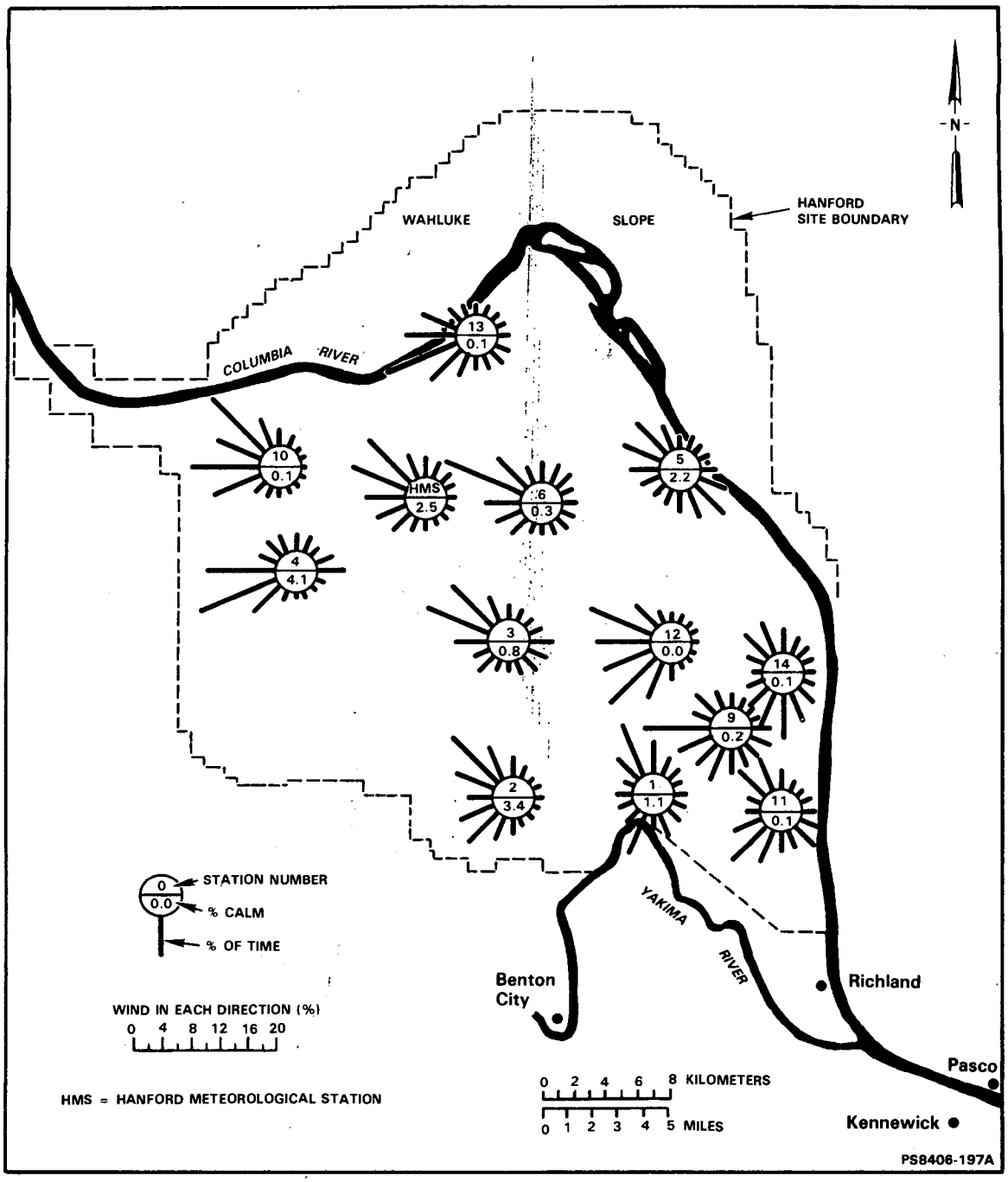

Figure 3-40. Wind roses for the Hanford Telemetry Network (after Stone et al., 1983). (The points of the rose represent the directions from which the wind blows toward the center of the rose. The lengths of the points represent the percent of time the wind blows from that direction.)

Frequencies of wind direction by month at the Hanford Meteorological Station are given in Figure 3-41 for the 26-year period of 1955 through 1980. Prevailing wind directions are from the northwest in all months. Secondary maximums are indicated for southwesterly winds. The wind direction summaries indicate that winds from the northwest quadrant (i.e., west-northwest, northwest, north-northwest) occur most often during the winter (i.e., December, January, February) and summer (i.e., June, July, August). During the spring and fall, the frequency of southwesterly winds increases with a corresponding decrease in northwest flow. Winds blowing from other directions (e.g., northeast) display minimal variation from month to month.

Monthly and annual joint frequency distributions of wind direction versus wind speed at a height of 15.2 meters (50 feet) above the surface near the Hanford Meteorological Station are given in Stone et al. (1983, Table 41, pp. X-13 through X-19). According to these summaries, monthly average wind speeds are lowest during the winter months, averaging 10 to 11 kilometers per hour (6 to 7 miles per hour), and are highest during the summer months, averaging 14 to 16 kilometers per hour (9 to 10 miles per hour). In over 40 years of continuous wind measurement at the Hanford Meteorological Station, the peak wind gust recorded at 15.2 meters (50 feet) above the surface had a speed of 130 kilometers (80 miles) per hour in January 1982. Like most gusts at the station that exceed 48 kilometers (30 miles) per hour, this wind came from the southwest. Dust storms, which occur periodically in the region during the summer months, are usually associated with these gusty winds from the southwest.

Other conditions associated with winds are thunderstorms and summertime afternoon drainage winds. An average of ten thunderstorms occur each year. Although they have been recorded in every month, they are most frequent during the summer months. The winds during thunderstorms show no directional preference. The summertime strong drainage winds are generally northwesterly.

The Hanford Meteorological Station climatological summary (Stone et al., 1983) and National Severe Storms Forecast Center data base list 22 tornado events in the vicinity of the Hanford Site (160-kilometer (100-mile) radius) between 1916 and August 1982. At least two tornadoes have occurred since August 1982, and several funnel clouds have been reported. One of the two confirmed tornadoes since August 1982 occurred between Touchet and Lowden, Washington. The other was reported between Connell and Eltopia, Washington. The tornado recurrence interval within a 160-kilometer (100-mile) radius of the Hanford Site is reported in Stone et al. (1983) as one per 146,000 years. The average dimensions for tornadoes within this area for which dimensions are reported are path length, 14.2 kilometers (8.8 miles), path width, 40 meters (130 feet).

The maximum wind speed estimated for the design basis tornado at the reference repository location is 78 meters per second (175 miles per hour). The rotational component of the speed is estimated to be 67 meters per second (150 miles per hour), and the translation component is

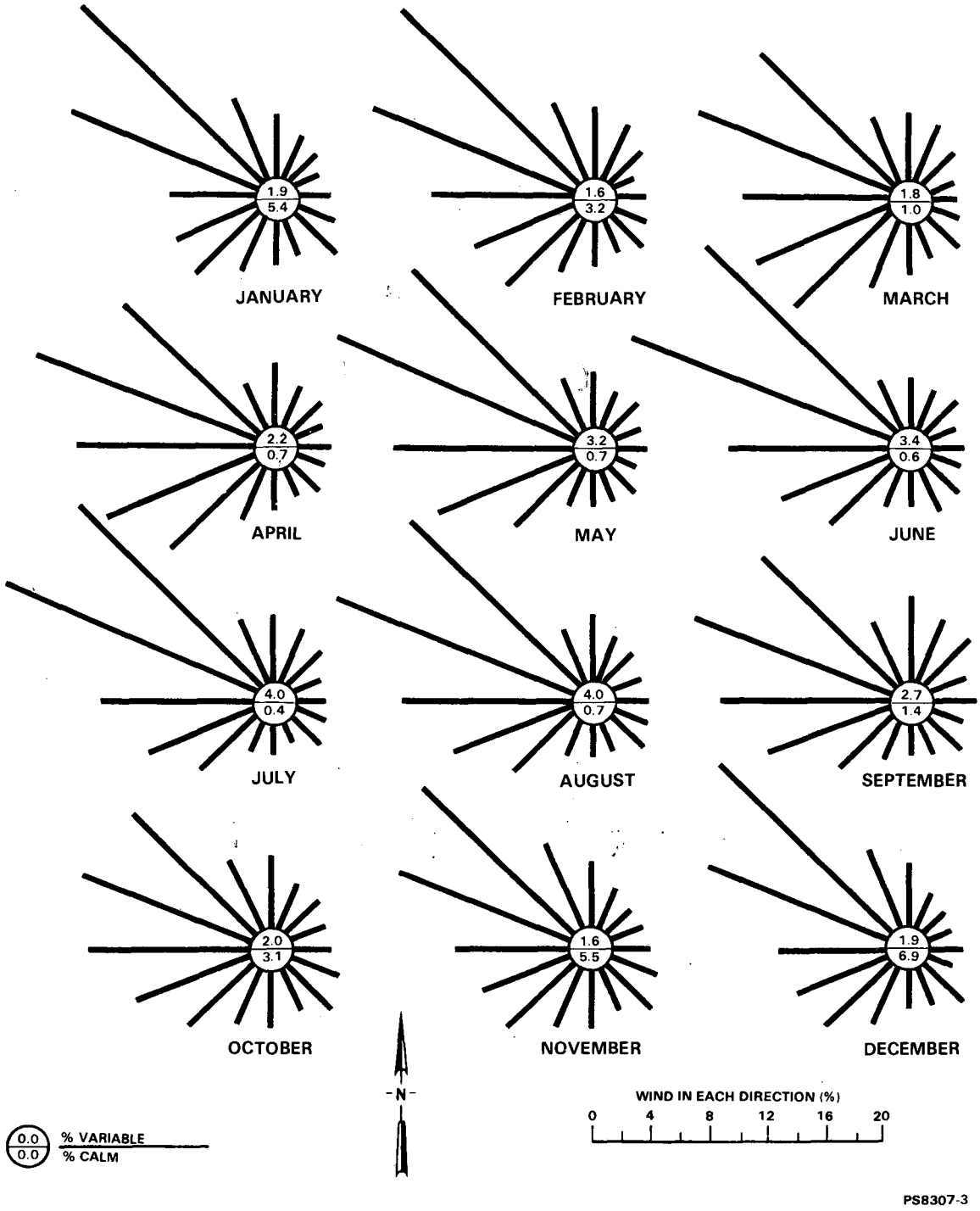

Figure 3-41. Monthly wind roses for the Hanford Meteorological Station based on 15.2-meter (40-foot) wind data, 1955 through 1980 (after Stone et al., 1983). (The numbers in the center are the percentages of variables (top numbers) and calm (bottom numbers) winds. The points of the rose represent the directions from which the wind blows toward the center of the rose. The lengths of the points represent the percent of time the wind blows from that direction.)

estimated at 11 meters per second (25 miles per hour). The differential pressure loading results from a 5.2-kilopascal (0.75-pound-force per square inch) ambient pressure decrease in 3 seconds, held for 1 second, and return to ambient at the same rate.

3.4.3.2 Temperature and humidity

Diurnal and monthly averages and extremes of temperature, dewpoint, and humidity are contained in Stone et al. (1983). Temperature records are summarized for the period 1912 through 1980. Average monthly temperatures range from a low of minus 1.5°C (29.3°F) in January to a high of 24.7°C (76.4°F) in July. The maximum monthly average temperature at the Hanford Meteorological Station during the winter was 6.9°C (44.5°F), and the lowest was minus 5.9°C (21.4°F), both occurring during February. The maximum monthly average temperature during the summer was 27.7°C (81.8°F) in July, and the lowest was 17.2°C (63.0°F) in June. The annual average relative humidity at the Hanford Meteorological Station is 54 percent, with maximums during the winter months (averaging approximately 75 percent) and minimums during the summer (on a monthly basis, approximately 35 percent).

3.4.3.3 Precipitation

Average annual precipitation at the Hanford Meteorological Station is 16 centimeters (6.3 inches). Most of the precipitation takes place during the winter. On the average, the months of November through February account for half of the annual precipitation. Fewer than 1 percent of the days have rainfall greater than 1.3 centimeters (0.5 inch). Rainfall intensities of 1.3 centimeters (0.5 inch) per hour persisting for 1 hour (i.e., 1-hour duration) are expected once every 10 years. Rainfall intensities of 2.5 centimeters (1.0 inch) per hour for 1 hour are expected only once every 500 years. The average annual snowfall at the Hanford Site is 34 centimeters (13.4 inches). The depth of snow on the ground exceeds 15 centimeters (5.9 inches) approximately one winter out of eight. The record amount of snow measured on the ground was 62 centimeters (24.5 inches) in February 1916. The recorded maximum depth of snow has not exceeded 31 centimeters (12.2 inches) in any other year.

3.4.3.4 Dispersion conditions

The atmospheric transport of airborne particles, gases, water vapor, and kinetic energy are a function of the horizontal and vertical distribution of wind speed, wind direction, atmospheric stability, and mixing depth, among other parameters. Generally speaking, poor dispersion conditions will exist when an effluent is released into a stable layer with a low capping inversion and light winds. Conversely, good dispersion conditions will prevail when wind speeds are moderate to strong in a

neutrally or unstably stratified atmosphere with very deep vertical mixing. Both sets of conditions are found in the Hanford Meteorological Station data summaries.

Good dispersion conditions prevail at the Hanford Site during most of the year. In the summer, unstable or neutral stratifications occur 57 percent of the time. Wind speeds of under 1.8 meters per second (4 miles per hour) are accompanied by a stable stratification only 2.9 percent of the time (Stone et al., 1983, p. X-79). Below-average to poor dispersion conditions occur most frequently during the winter. Wind speeds of under 1.8 meters per second (4 miles per hour) are accompanied by stable stratifications approximately 15.6 percent of the time (Stone et al., 1983, p. X-77).

Extended periods of poor dispersion are typically associated with low-level temperature inversions. The probabilities of extended periods with temperature inversions at the Hanford Site are discussed by Stone et al. (1972) and shown in Figure 3-42. Given an initial observation of inversion conditions between 1 and 61 meters (3 and 200 feet), the probability of inversion persistence for more than 24 hours reaches a maximum of slightly more than 2 percent in January and February.

These low probabilities of inversion persistence indicate relative good atmospheric diffusion transport characteristics for the Hanford Site. This equates well with the favorable results of radiological exposure measurements and modeling (see Subsection 3.4.2.7.5) and nonradiological air-quality calculations (Subsection 3.4.3.5). The results of dispersion computations for ground-level and elevated releases for the Hanford Site 200 Areas using data from the Hanford Meteorological Station and Telemetry Stations are presented in McCormack et al. (1984).

3.4.3.5 Air quality

Air quality in the vicinity of the Hanford Site is generally quite good. National Ambient Air Quality Standards (Federal) and State of Washington Air Quality Standards, which may be used as a benchmark in evaluating the impacts of the proposed repository activities, are given in Table 3-23. The Benton-Franklin-Walla Walla Counties Air Pollution Control Authority routinely monitors total suspended particulate concentrations at the Hanford Meteorological Station. No other criteria pollutants are routinely monitored by this agency in the region. The discussion of air quality in the Skagit/Hanford draft environmental impact statement (NRC, 1982a, Subsection 4.2.10.2) reflects the current conditions in the Columbia Basin, but does not cover the release of nitrogen oxides.

Releases of nitrogen oxides associated with the chemical processing of reactor fuel at the PUREX Plant on the Hanford Site were resumed in November 1983 for the first time since 1972. These releases are controlled under a prevention of significant deterioration permit.

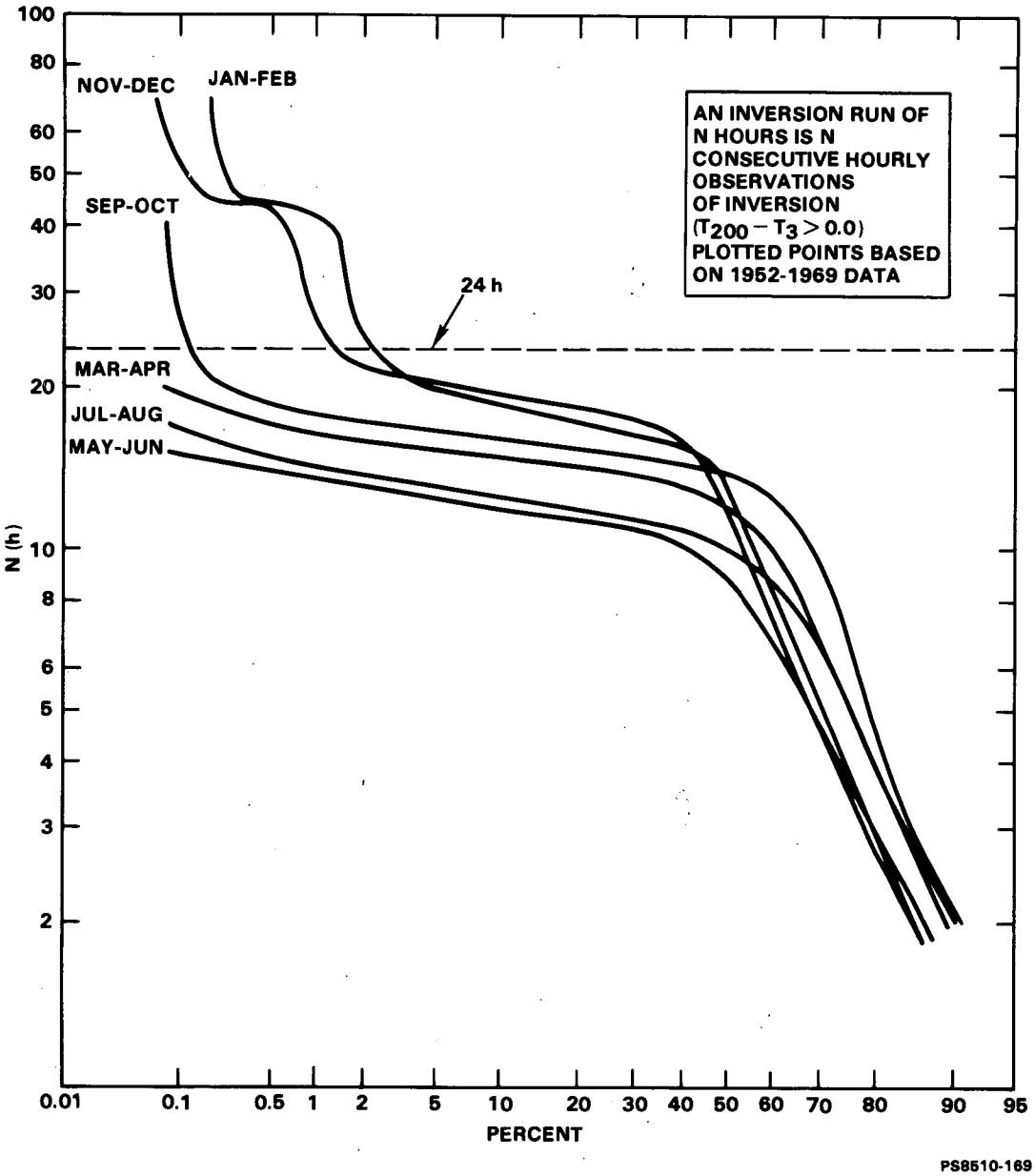

Figure 3-42. Probability (percent) that the first hourly observation of an inversion will mark the beginning of an inversion run of N hours (Stone et al., 1972).

Table 3-23. National and State ambient air-quality standards and local background concentrations

Pollutant	Type of standard[a]	Averaging time	Concentration standard		Maximum background concentrations[b]
			Federal, μg/m³	State, μg/m³	μg/m³
Carbon monoxide	Primary	1 hr[c]	40,000	40,000	11,795.0
		8 hr[c]	10,000	10,000	6,525.0
Nitrogen dioxide	Primary and secondary	1 yr	100	100	20.0
Total suspended particulate	Primary	24 hr[c]	260	120+bkg[d]	<150[e]
		1 yr[f]	75	40+bkg[d]	37[e]
	Secondary	24 hr[c]	150	150	--
		1 yr[f]	60	60	--
Sulfur dioxide	Primary	24 hr[c]	365	260	5.7
		1 yr	80	52	0.5
	--	1 hr[c]	--	1,018	49
	--	1 hr[g]	--	655	49
	Secondary	3 hr[c]	1,300	--	19.6

[a]Federal standards only, does not apply to State standards.

[b]Background concentrations for the region surrounding the Hanford Site are taken from a report by the U.S. Nuclear Regulatory Commission (NRC, 1982a, Table 4.33) and unpublished air-quality monitoring data collected by the Benton-Franklin-Walla Walla Counties Air Pollution Control Authority.

[c]Not to be exceeded more than once per year.

[d]bkg = background; applies east of the Cascade Mountain crest.

[e]This maximum value reflects the impact of exceptional natural events (e.g., dust storms, sand storms, range fires). In the absence of exceptional events, the maximum annual background concentration would not exceed 20 μg/m³ and the maximum 24-hour concentration would not exceed 30 μg/m³. The U.S. Environmental Protection Agency uses these lower values for evaluating new sources in eastern Washington State, thereby neglecting the impact of natural events.

[f]Annual geometric mean.

[g]Not to be exceeded more than two times in any consecutive 7 days.

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Ramsdell (1981) reports on the observed nitrogen oxide levels in the vicinity of the processing facility during the last period of operation (1968 to 1969). Annual average concentrations estimated from these measurements were near or below 12 parts per billion (detection threshold of the instrumentation), which in turn are below the 50 parts per billion (100 micrograms per cubic meter) annual average nitrogen dioxide air-quality standard. Nitrogen oxide measurements made before the facility restart indicate a background concentration of less than 0.007 part per million (Sula et al., 1983a). During renovation of the facilities before fuel processing was resumed, nitrogen oxide emission control equipment was upgraded. As a result, even with fuel processing, the ambient nitrogen oxide concentrations are expected to remain within permissible Federal and State of Washington limits (DOE, 1982a, 1983b).

Wind-eroded dust is a problem in the area, but is likely to occur under conditions that are otherwise favorable to pollutant transport and diffusion. The dust storms that occur in the region can produce high total suspended particulate concentrations. However, on an annual average basis, the region is in compliance with the National Ambient Air Quality Standards for particulates. All other pollutant levels also satisfy Federal and State of Washington standards (Jenne, 1981).

3.4.4 NOISE

Background noise at the reference repository location was not measured for this study. However, background noise measurements were conducted by Puget Sound Power & Light Company for the Skagit/Hanford Nuclear Project approximately 13 kilometers (8 miles) east of the reference repository location (PSPL, 1981, Table 2.7-1 and Fig. 2.7-1). Ambient noise levels on the Hanford Site do not exceed Federal and State of Washington noise guidelines. The noise-measurement site nearest the proposed reference repository location recorded ambient noise levels of 32 decibels using the A-scale.

3.4.5 AESTHETIC RESOURCES

The National Registry of Natural Landmarks lists the following four natural sites, which are within approximately 80 kilometers (50 miles) of the Hanford Site (NPS, 1983):

- Ginkgo Petrified Forest, located in Kittitas County, 47 kilometers (29 miles) east of Ellensburg, Washington, 58 kilometers (36 miles) north-northwest of the reference repository location.

- Grand Coulee, located in Grant County between the towns of Grand Coulee and Soap Lake, Washington, 88 kilometers (55 miles) north of the reference repository location.

- Wallula Gap, located in Benton and Walla Walla Counties, approximately 26 kilometers (16 miles) south of Pasco, Washington, 80 kilometers (50 miles) south-southeast of the reference repository location.

- Umtanum Ridge Water Gap, located in Kittitas County, approximately 23 kilometers (14 miles) north of Yakima, Washington, 69 kilometers (43 miles) west-northwest of the reference repository location.

One of the most notable natural features of this area is the Hanford reach of the Columbia River. The White Bluffs, rising 100 to 165 meters (340 to 540 feet) above the eastern shoreline of the river, provide another natural feature. The southwestern edge of the Hanford Site is marked by Rattlesnake Mountain, the highest peak in the vicinity of the Hanford Site. Other natural features in the area include Sentinel Gap and the Saddle Mountains to the north of the Hanford Site, the Yakima River to the south, and the Snake River to the southeast.

3.4.6 ARCHAEOLOGICAL, CULTURAL, AND HISTORICAL RESOURCES

In prehistoric times, the Columbia Basin was densely occupied by numerous camps and villages of various Plateau Indian groups. Today, the Hanford reach of the Columbia River contains the only intact remaining evidence of these aboriginal cultures. Controlled access to the Hanford Site and the U.S. Department of Energy policy of not publicizing the location of sites have protected these remaining sites from destruction by relic collectors. At present, nine archaeological properties on the Hanford Site are listed in the National Register of Historic Places (State of Washington, 1981b). None of these properties is located within the reference repository location.

Some of the Rattlesnake Springs sites, which are within 2.5 kilometers (1.6 miles) of the reference repository location boundary, are the closest known archaeological sites. A number of other archaeological sites, many of them not of national significance, have been identified on the Hanford Site (Rice, 1968a, 1968b). In 1981 and 1982, archaeological field surveys were conducted to identify potential important archaeological and historical sites. These studies suggested that none of the repository activities will have an effect upon significant cultural resources (Rice, 1984a, 1984b). A Programatic Memorandum of Agreement between the U.S. Department of Energy, the Advisory Council on Historic Preservation, and the Washington State Historic Preservation Office is being negotiated to outline procedures that will be followed in the event that unexpected cultural resources are encountered during site-characterization activities. The Programatic Memoradum of Agreement would be consistent with the archaeology program for the Hanford Site.

3.5 TRANSPORTATION

An excellent transportation network facilitates travel and the marketing of goods and commodities within the Tri-Cities (Richland, Pasco, and Kennewick, Washington) region, which is approximately 35 kilometers (22 miles) southeast of the reference repository location. Commercial air transportation is available at the Tri-Cities Airport, which offers direct service to major regional cities with connections to cities nationwide via several airlines. Transportation of bulk commodities along the Columbia and Snake Rivers is available through barge lines. A network of freight rail transportation is provided by Burlington Northern and Union Pacific. Interstate highways and State routes connect the region to major metropolitan areas throughout the Pacific Northwest. Several highway projects are under construction or are planned that include (1) a new Columbia River bridge connecting Interstates 82 and 84 in Oregon, (2) new Columbia and Yakima River bridges (Interstate 182) in Richland, Washington, providing a third link between Benton and Franklin Counties, and (3) completion of Interstates 82 and 182, which will connect the Tri-Cities to Seattle, Washington, to the west and the Tri-Cities to Interstate 84 to the south. The major improvements planned for U.S. Highway 395 to the north and east include widening to four lanes and increasing the Snake River bridge to four lanes.

3.5.1 RAILROAD SERVICE

The Tri-Cities area is served by the Burlington Northern and Union Pacific Railroads, making the area one of the few between the Cascade Range and Rocky Mountains to be linked to both systems. Passenger services are provided by Amtrak. In addition, a short line operated by the U.S. Department of Energy runs in the Richland-Hanford Site area.

Agricultural products, fuel, and fertilizer, plus construction materials and equipment, are the principal commodities shipped by rail in this area. Manufactured fertilizer products, grain, and frozen food make up the greatest share of outgoing commodities. Large quantities of other food products also leave the Tri-Cities by rail. The inbound freight includes fertilizer, raw materials, chemicals, fuel, farm equipment, and construction supplies and equipment.

The State of Washington experienced 50 train accidents in 1984, Oregon 58, Idaho 22, and Montana 52. Total damages for these four states exceeded 16.5 million dollars. Nationally, in 1984 there was a total of 3,900 train accidents with damages in excess of 240 million dollars (DOT, 1985). During 1984 there were no train accidents on the Hanford Site railroad system (excluding two minor derailments that did not involve collision, personnel injury, or significant damage). There has not been a train accident on the Hanford Site resulting in a lost-time injury, death, or release of radioactive material since 1947.

Figure 3-43 shows the major rail lines in the northwestern United States.

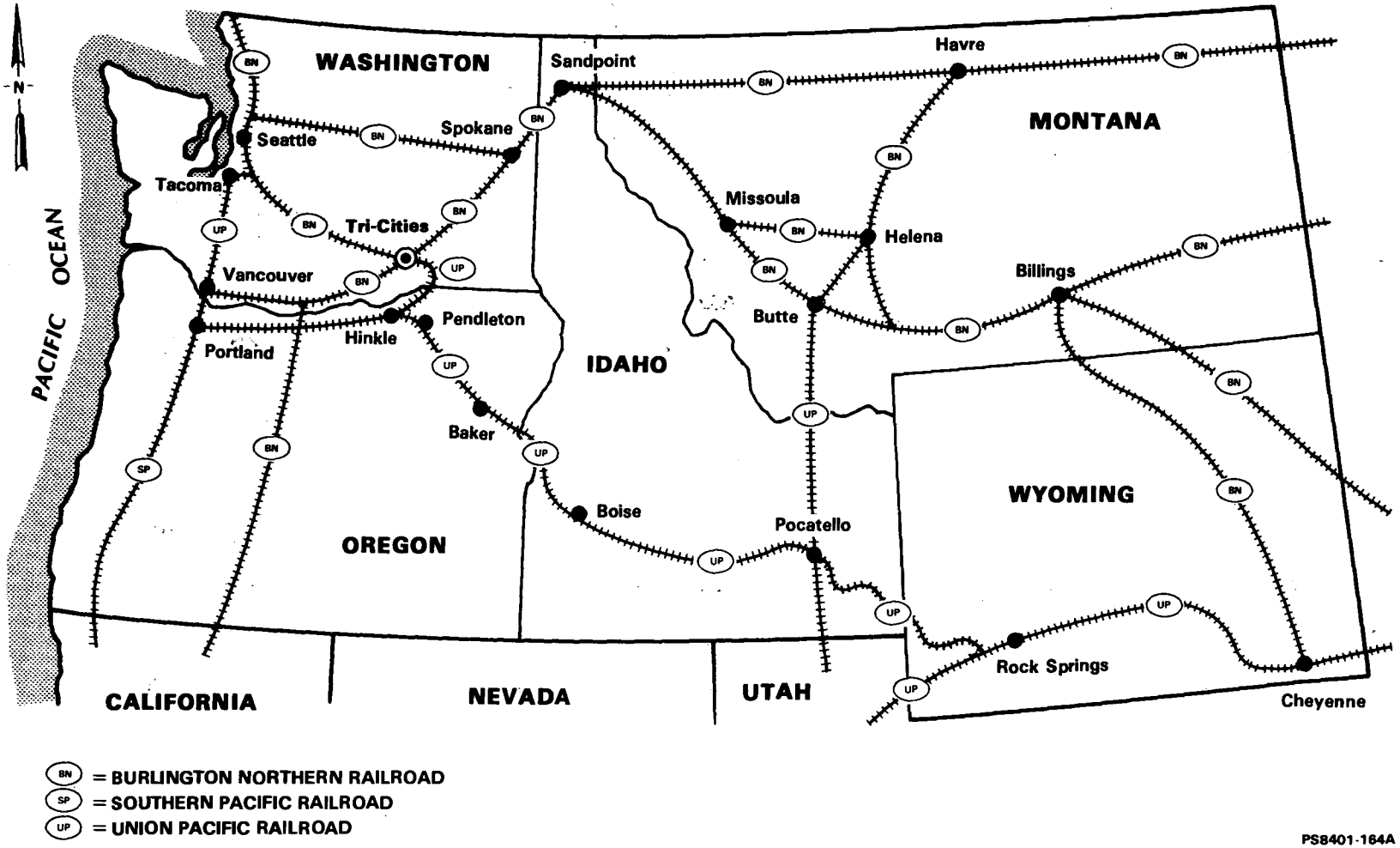

Figure 3-43. Major rail lines providing access to the Tri-Cities, Washington.

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3.5.1.1 Burlington Northern Railroad

The Burlington Northern is the longest railroad in the United States. Its tracks stretch from Canada to the Florida Panhandle, from the Gulf of Mexico to the Great Lakes, and into the Pacific Northwest. The Tri-Cities is at the hub of the Burlington Northern lines in the Pacific Northwest, which extends 373 kilometers (232 miles) southwest to Portland, Oregon, 404 kilometers (251 miles) northwest to Seattle, Washington, and 233 kilometers (145 miles) northeast to Spokane, Washington. A computerized classification yard is located in Pasco, Washington. Trains move into the yard and are broken up and blocked to move east, west, north, or south. The Burlington Northern Railroad experiences 3.76 accidents per million train kilometers (6.09 accidents per million train miles) traveled, as compared to a national average of 4.04 accidents per million train kilometers (6.54 accidents per million train miles) traveled by all Class I rail carriers (DOT, 1985).

3.5.1.2 Union Pacific Railroad

The recent merger of the Union Pacific Railroad with the Missouri Pacific and Western Pacific Railroads makes the Union Pacific the second longest railroad in the United States. The Union Pacific now connects the Pacific Northwest, San Francisco and Los Angeles, California, on the west coast to the Great Lakes region and the Gulf of Mexico to the east and southeast, respectively. All service to the Pacific Northwest over the Union Pacific system goes through the modern, computerized regional classification yard at Hinkle, Oregon, some 80 kilometers (50 miles) south of the Tri-Cities. The Tri-Cities is served by the Yakima, Washington, branch line, which connects directly to the regional classification yard at Hinkle, Oregon. The Union Pacific experiences 3.14 accidents per million train kilometers (5.09 accidents per million train miles) traveled, as compared to the national average of 4.04 accidents per million train kilometers (6.54 accidents per million train miles) traveled by all Class I rail carriers (DOT, 1985).

3.5.1.3 U.S. Department of Energy railroad

The U.S. Department of Energy controls the rail access into the Hanford Site; the agency trackage ties in with the Union Pacific Railroad tracks southeast of the Richland "Y" area near the U.S. Highway 12 and Route 240 interchange. The Burlington Northern and Union Pacific have trackage rights over the U.S. Department of Energy trackage between the Richland "Y" area and the U.S. Department of Energy 1100 Area in north Richland, Washington. The U.S. Department of Energy tracks serving the Hanford Site are installed parallel to the Route 240 bypass around the Richland, Washington, urban area.

3.5.2 HIGHWAY SERVICE

The east-west interstate highways providing ready access to the Tri-Cities area are Interstates 90 and 84, which pass north and south of the Tri-Cities, respectively (Fig. 3-44). These two highways provide the major links to Seattle, Washington, and Portland, Oregon. The primary north-south highway is Interstate 5, which connects Seattle, Washington, and Portland, Oregon, and runs the entire length of the West Coast. In California, this highway connects to several east-west interstate highways.

The Tri-Cities region is served by four important highway routes separate from, but providing access to, the major interstate highways. The local and regional highway network in the Tri-Cities region is shown in Figure 3-45. United States Highway 12 comes from the Puget Sound area and continues through to the Midwest via Walla Walla, Washington, and Lewiston, Idaho; U.S. Highway 395 begins north of Spokane, Washington, at the Canadian border and extends south to southern California; State Route 14 provides intrastate traffic between the Tri-Cities and Vancouver, Washington; and Route 240 provides access to Interstate 90 at Vantage, Washington. Interstate 90 extends from Seattle, Washington, through the Midwest to Chicago, Illinois, Cleveland, Ohio, Buffalo, New York, and Boston, Massachusetts. Interstate 84 provides access from Portland, Oregon, to Salt Lake City, Utah, Omaha, Nebraska, Chicago, Illinois, Cleveland, Ohio, and New York, New York.

Regional segments of new interstate highways (Interstates 82 and 182) are currently under construction. These new segments will further improve access to the Tri-Cities area. These new interstate highways will connect Interstate 84 in Oregon to a point just south of Richland, Washington, thereby replacing existing two-lane highways and bypassing the existing four-lane highway between Kennewick and Richland, Washington.

Major highways within the Tri-Cities area are predominantly four lanes over which between 30,000 and 50,000 vehicles travel per day. With the new interstate highways planned and under construction, highway capacities will be adequate to meet highway transportation needs through the turn of the century.

3.5.2.1 Highway traffic and accident data

This subsection presents data on traffic volumes and traffic accidents in the region surrounding the Hanford Site. The additional data are included to provide some basic information regarding the local and regional highway network. Chapters 4 and 5 present a discussion of the expected transportation impacts during potential site characterization (Section 4.2.3) and repository operation activities (Section 5.2.2).

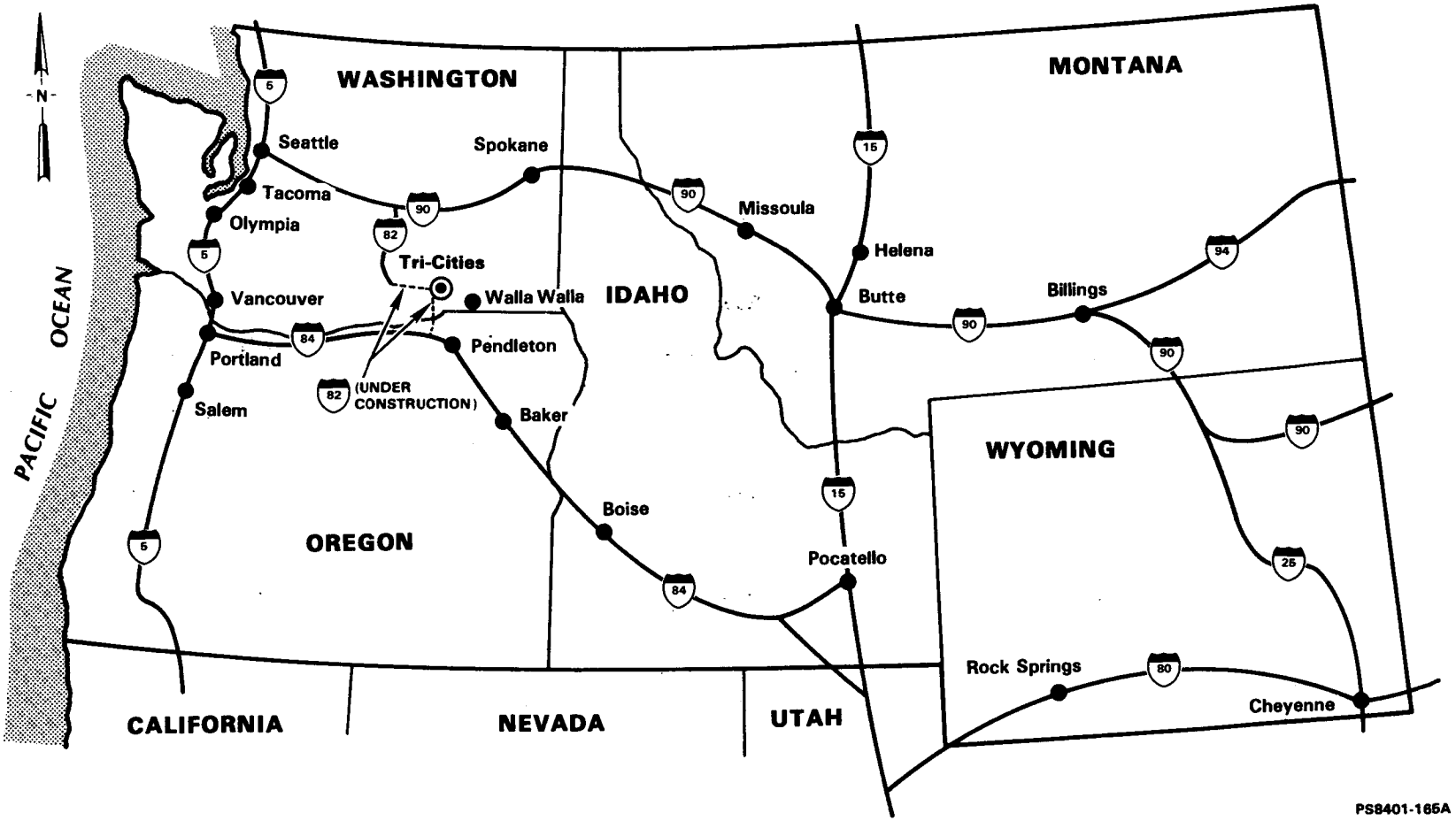

Figure 3-44. Major interstate highways providing access to the Tri-Cities, Washington.

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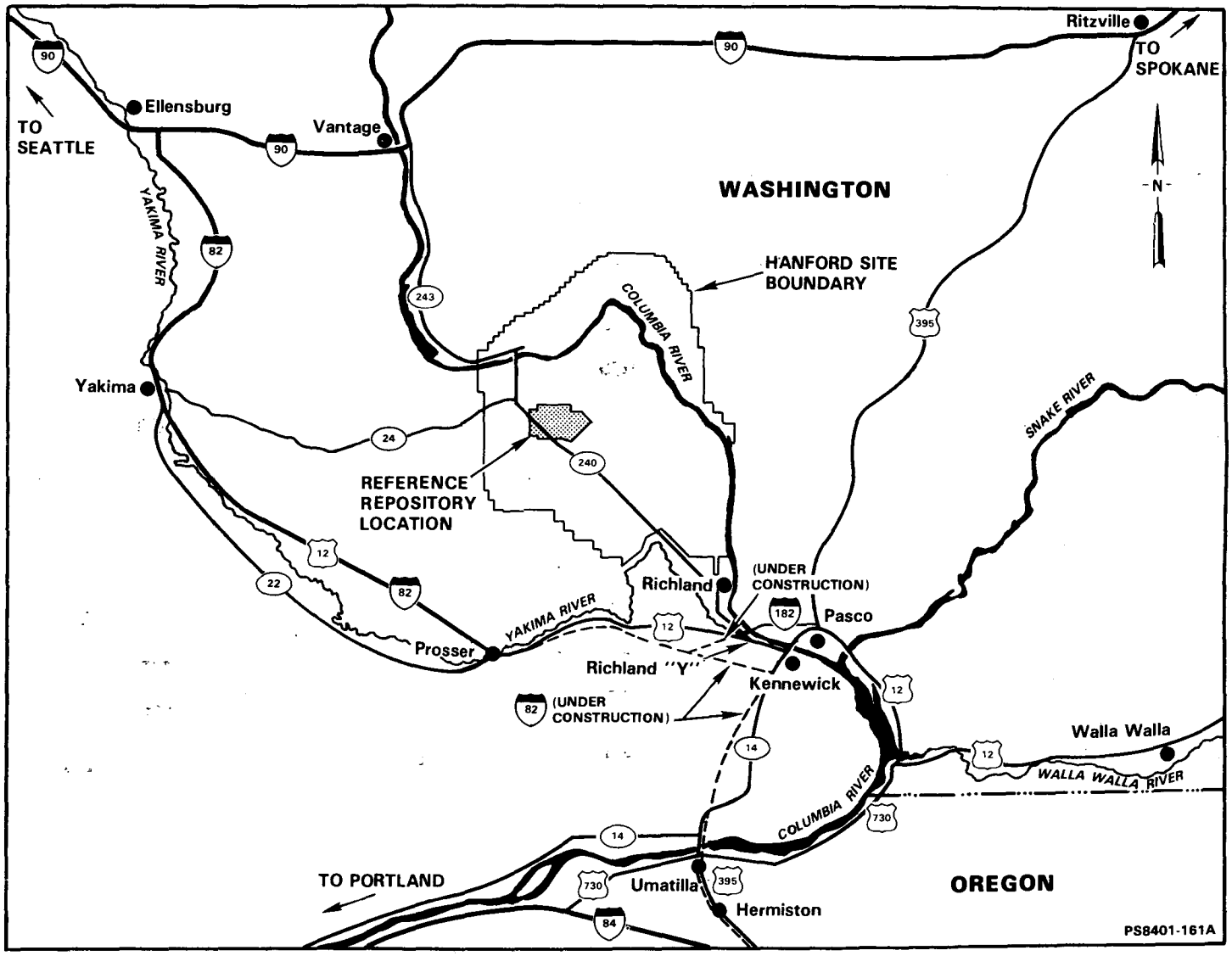

Figure 3-45. Local and regional highway network linking the Tri-Cities with major interstate highways.

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Table 3-24 shows annual average daily traffic volumes for highways in Washington, Oregon, and Idaho for the year 1983. Traffic volumes are used by the state highway departments to predict trends. Here, they serve only as an indication of total traffic volume at a given point. Because not all data points could be included in the table, individual data points were selected that are of particular interest (e.g., large population centers) or are representative of the overall route. For example, the junction between Route 240 and U.S. Highway 12 sees a total of about 41,000 vehicles per day and can be a point of congestion at peak traffic hours in the Tri-Cities. Congestion at this point and other points will be reduced on completion of new highways currently under construction that will redistribute traffic flows. The data point chosen on Interstate 84 at the Oregon-Idaho state line (8,400 vehicles per day), on the other hand, is more representative of traffic volumes along Interstate 84 between Pendleton, Oregon, and Boise, Idaho.

Table 3-25 provides accident rates for Washington and Oregon highways leading to the Hanford Site from the northeast and southeast, the directions from which the majority of spent fuel shipments would travel. The reader should be cautioned that these data are presented as an indication of accident rates for the highways of interest, but in actuality represent only the accident rate of the segment described. Additional data on accidents in Oregon and Washington are available in State of Washington (1984d) and Oregon Department of Transportation (ODT, 1984b).

Vehicles on highways in the State of Washington traveled 29.877 billion kilometers (18.673 billion miles) during 1983 and had an accident rate of 1 per million vehicle kilometers (1.6 per million vehicle miles). There were 635 fatal accidents in the State of Washington during 1983, of which 44 involved heavy trucks (State of Washington, 1984c, p. 9). The accident rate has declined since 1980, when it was 1.4 per million vehicle kilometers (2.2 per million vehicle miles). Total number of fatalities and injuries have also declined, while total economic losses have increased (State of Washington, 1984d).

A majority of all accidents (59.1 percent) in Washington occur on a dry roadway, 31.6 percent on a wet roadway, with ice- and snow-covered roadways accounting for 5.9 and 3.4 percent, respectively. Speed is noted as the number one factor contributing to accidents on State highways (19 percent), followed by failure to yield (10 percent), and inattention (10 percent). For accidents resulting in fatalities, driving while intoxicated surpasses speed as the number one contributing factor (State of Washington, 1984d).

3.5.2.2 Highway transportation disruptions due to weather conditions

The states of Washington, Oregon, Idaho, and Montana all report that road closures due to weather on State or interstate highways are infrequent occurrences. Localized road closures of short duration do occur, however, and are discussed below. This information was obtained

Table 3-24. Annual average daily traffic volumes for 1983[a]

Route	Description of data point	Average daily traffic volume (number of vehicles)[b]
	Local	
Route 240	Junction with U.S. Highway 12, Richland, Washington	41,316
U.S. Highway 12	Junction with State Route 14, Kennewick, Washington	48,500
U.S. Highway 12	Junction with U.S. Highway 395, Pasco, Washington	17,800
	Southern route	
State Route 14	Junction with Route 143, Washington (just north of the Washington and Oregon border)	3,850
U.S. Highway 395	North city limits, Stanfield, Oregon	7,200
Interstate 84	Pendleton, Oregon	8,300
Interstate 84	Baker and Malheur County line, Oregon (approximately 32 km (20 mi) north of Ontario)	4,100
Interstate 84	Oregon and Idaho State line	8,400
Interstate 84	Boise, Idaho	31,070
	Northern route	
U.S. Highway 395	Junction with State Route 26, Washington (approximately 48 km (30 mi) north of Pasco)	4,400
Interstate 90	Adams and Lincoln County line, Washington (approximately 27 km (17 mi) north of Ritzville)	11,000
Interstate 90	Lincoln and Spokane County line, Washington (approximately 40 km (25 mi) south of Spokane	8,565
Interstate 90	Spokane, Washington (offramp to Sprague Avenue)	49,600

[a]Taken from State of Washington (1984g), Oregon Department of Transportation (ODT, 1984a), and Idaho Transportation Department (ITD, 1985a).

[b]Average daily traffic volumes are for traffic in both directions at the given data point.

Table 3-25. Washington and Oregon highway accident statistics[a]

Route	Description	Length of segment analyzed, km (mi)	Average daily traffic volume (number of vehicles)[b]	Accident rate (per million vehicle km (mi))[c]
	Local			
Route 240	Richland southeast to junction with State Route 12, Richland, Washington	3.03 (1.87)	46,050	0.80 (1.3)
U.S. Highway 12	Colorado Street east to junction with State Route 14, Kennewick, Washington	6.97 (4.30)	36,400	0.68 (1.1)
U.S. Highway 12	Franklin County line (Columbia River) northeast to junction with U.S. Highway 395, Pasco, Washington	5.86 (3.62)	29,800	1.7 (2.7)
	Southern route			
State Route 14	Union Loop Road south to junction with Route 143, Washington	29.89 (18.45)	9,450	0.74 (1.2)
U.S. Highway 395	Hermiston south to Stanfield, Oregon	1.31 (0.81)	7,300	0.777 (1.26)
Interstate 84	Pendleton, Oregon	6.98 (4.31)	7,139	0.14 (0.23)
Interstate 84	Baker County line south to Baker Valley rest area, south of Baker, Oregon	14.73 (9.09)	4,649	0.18 (0.30)
Interstate 84	Ontario east to Idaho State line	0.81 (0.50)	8,400	0.40 (0.65)
	Northern route			
U.S. Highway 395	Junction with State Route 26, north to Cunningham Road, Washington	6.64 (4.10)	4,300	0.5 (0.8)
Interstate 90	Adams and Lincoln County line, north to junction with State Route 23, Washington	9.96 (6.15)	11,000	0.2 (0.3)
Interstate 90	Lincoln and Spokane County line, north to junction with Route 904, Washington	3.89 (2.40)	8,600	0.3 (0.5)
Interstate 90	Route 195 east to junction with State Route 2, Spokane, Washington	3.22 (1.99)	46,700	0.92 (1.5)

[a]Taken from State of Washington (1984d) and Oregon Department of Transportation (ODT, 1984b).

[b]Average daily traffic represents volume at beginning of segment and is for traffic in both directions.

[c]Data are averaged over two or more years.

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for as far east as Pocatello, Idaho, and Butte, Montana, since this area represents the last opportunity for a vehicle to change major highways enroute to the Tri-Cities from the east if weather should become inclement. Routes discussed below are illustrated in Figure 3-44.

The State of Washington Department of Transportation does not maintain road-closure logs except for the Cascade Range passes where winter weather causes conditional closures of short duration. Conditional closure refers to closure to vehicles without proper equipment (e.g., chains or studded tires) or closure of a road segment for several hours to clear a vehicle wreck or snow slide. In most instances, traffic is rerouted and even conditional closures are not necessary. No problem areas were identified in eastern Washington (Erlandson, 1985).

The State of Oregon reported routine winter conditional closures on Interstate 84 in two primary areas: (1) Between Pendleton and LaGrande, Oregon, (Emigrant Hill) and (2) between LaGrande and Baker, Oregon (Ladd Canyon). Only two other complete closures were noted since the winter of 1980-1981. Interstate 84 was closed for slightly more than 26 hours due to drifting and blowing snow, and traffic was stopped in LaGrande, North Powder, and Baker, Oregon. Some traffic was rerouted as conditions permitted. A second closure of Interstate 84 for approximately 3 days was due to the roadway being washed out by the Snake River near Ontario, Oregon. A detour was established to reroute traffic (ODT, 1985).

During the winter of 1984-1985, the Idaho Transportation Department documented three closures of Interstate 15 at different locations north of Idaho Falls, Idaho, due to blizzard conditions. One closure due to blizzard conditions was reported west of Pocatello, Idaho, on Interstate 86. Most closures were of several-hour durations. No closures were reported on Interstate 90 or Interstate 84 (ITD, 1985b).

The State of Montana Department of Highways has kept a road-closure log since the fall of 1982; in that time, no closures have occurred on either Interstate 90 or Interstate 15 from Butte, Montana, to the Idaho border. It was suggested, however, that in years preceding record keeping, heavy winter snows had caused closures of up to 4 hours on Interstate 90 and up to 24 hours on Interstate 15 (SMDH, 1985).

3.5.3 REPOSITORY ACCESS ROUTES

The State of Washington is empowered by U.S. Department of Transportation regulations to designate acceptable State highway routes to the repository. The Basalt Waste Isolation Project currently is considering two alternate truck access routes to the reference repository location. One alternate truck access route would utilize Route 240, which runs through the Hanford Site; a new access road less than 1.7 kilometers (1.1 miles) long would have to be constructed from Route 240 to the

proposed repository surface facilities (Fig. 3-46). The other alternate would exit from State Route 240 onto the existing Hanford Site highway system at the southern end of the Hanford Site. Trucks would then proceed north past the 300 Area, then northwest past the Fast Flux Test Facility and the Washington Public Power Supply System operating plant 2. At the Wye Barricade, trucks would be stopped briefly for a security inspection. Trucks would then continue in a northwest direction and pass alongside the perimeter fences of the 200 Areas. A new road, less than 5 kilometers (3 miles) long, would be constructed to allow access to the proposed repository surface facilities from the vicinity of the 200 West Area (see Fig. 3-46).

The Hanford Site railroad system extends from the west side of Richland, Washington, throughout the Hanford Site, as shown in Figure 3-46. Railroad tracks serve the 200 Areas. A new railroad spur of less than 5 kilometers (3 miles) is needed to run to the proposed surface facilities site within the reference repository location from the vicinity of the 200 West Area.

3.6 SOCIOECONOMIC CONDITIONS

Socioeconomic conditions over the period of 1965 to 1984 and projected to 2010 are presented as the appropriate baseline against which project-related effects can be judged. The study region for this analysis is defined as Benton and Franklin Counties with special attention to the municipalities of Richland, Kennewick, West Richland, and Benton City, Washington, in Benton County, and Pasco, Washington, in Franklin County. This definition conforms to that used in other recent studies of the repository in basalt and incorporates those areas expected to be most affected by the employment and demographic changes associated with projects on the Hanford Site based on analysis of previous projects (e.g., the Washington Public Power Supply System construction activities) (DOE, 1982b, 1983a; Cluett et al., 1984). Possible significant socioeconomic impacts likely to be caused by the construction and operation of a repository will be evaluated in Section 5.2.3 in terms of the baseline conditions described here.

During the decade of the 1970's, the study region was one of the most rapidly growing metropolitan areas in the nation (Rand McNally, 1985). The study region experienced a reversal of a well-established pattern of rapid economic and demographic growth in mid-1981 as a result of the termination and mothballing of Washington Public Power Supply System Nuclear Projects WNP-1 and WNP-4, respectively. Therefore, it is inappropriate to assess the potential socioeconomic impacts of the proposed repository development in terms of boomtown effects that typify rural sites. This analysis will address the socioeconomic effects of that decline and the prognosis for future recovery. The discussion of socioeconomic conditions in this section is based on data from approximately 1965 to 1984. Based on available information, conditions are forecast through the year 2010 (Section 5.2.3).

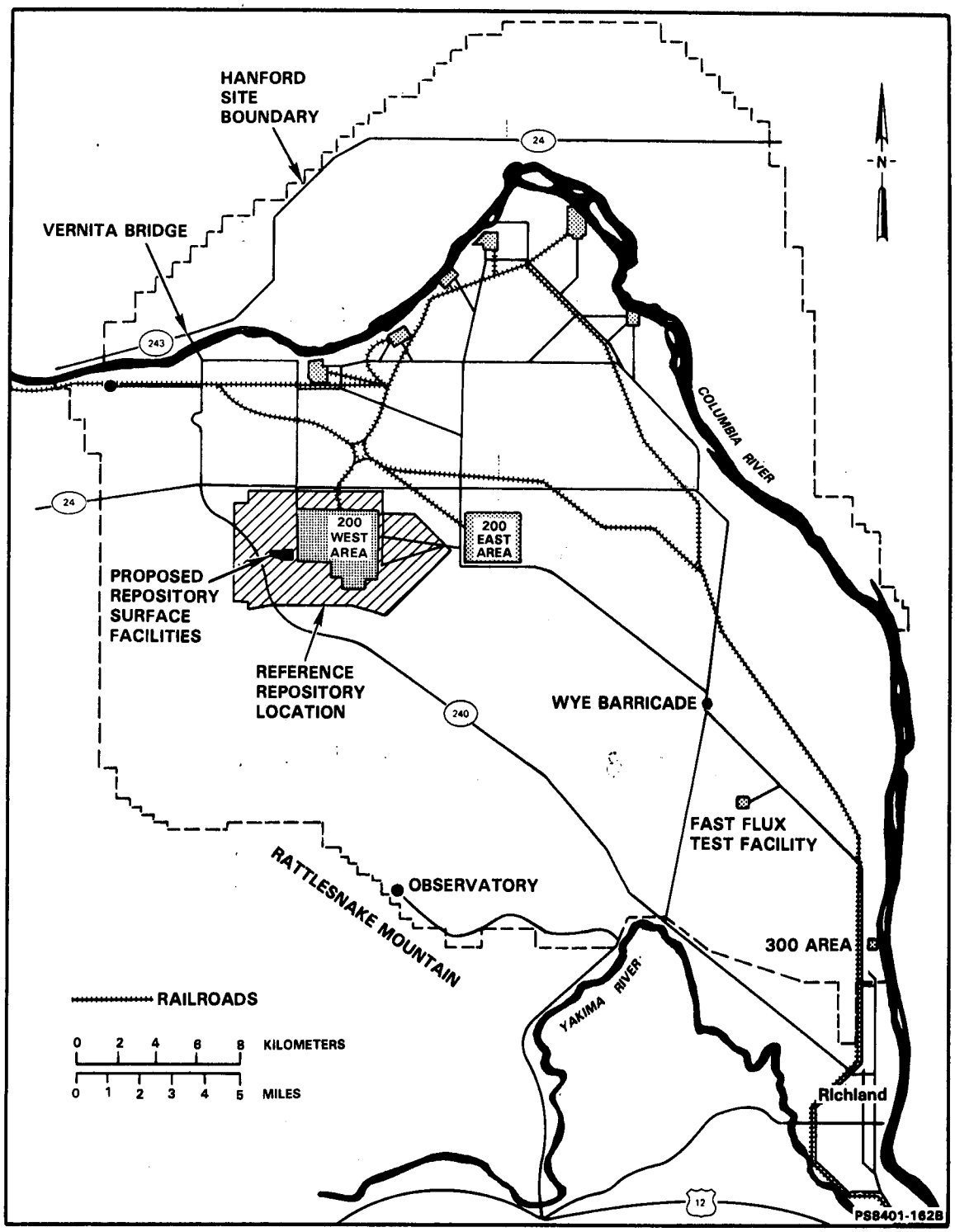

Figure 3-46. Transportation network within the Hanford Site.

3.6.1 POPULATION DENSITY AND DISTRIBUTION

Approximately 60 percent of the population of this study region is concentrated in the Tri-Cities; namely, Richland, Kennewick, and Pasco, Washington (see Fig. 3-37 for a map of the study region). The ratio between the population of the Tri-Cities and the bicounty study region has remained relatively constant since the mid-1960's, in spite of the exceptionally rapid growth in population between 1973 and 1981. Data on population size for Benton and Franklin Counties are provided in Table 3-26. The population density for Benton County is 25 persons per square kilometer (64 persons per square mile); for Franklin County, it is 11 persons per square kilometer (28 persons per square mile). Only 73 persons actually reside on the Hanford Site (total area of 1,500 square kilometers (570 square miles)) at Midway (see Fig. 3-37), for a population density substantially less than one person per square kilometer (per square mile). Data for each of five cities, including the Tri-Cities, located near the Hanford Site are provided in Table 3-27. Figure 3-47 shows the population distribution for a 16-sector compass grid with annular concentric circles every 16 kilometers (10 miles), extending out to 80 kilometers (50 miles) (Sommer et al., 1981). In terms of Nuclear Waste Policy Act of 1982 requirements, none of these cities is in close proximity to the proposed repository site. The nearest metropolitan area is 35 kilometers (22 miles) or more from the Hanford Site. Trends in population size in the study region are illustrated in Figures 3-48 and 3-49.

The rapid growth of construction activity on the Washington Public Power Supply System Nuclear Projects, which began in 1973, caused most of the population growth observed between 1973 and 1981. Much of this population growth occurred in Benton County. During the Washington Public Power Supply System construction period, Benton County grew at an average annual rate of 6.1 percent, compared to the 4.0-percent growth rate in Franklin County. In contrast, during the pre-Washington Public Power Supply System period, Benton County grew at the same rate as Franklin County. Nevertheless, the population of Benton County increased by many more people in both periods compared with Franklin County. Net in-migration during the period 1970 to 1980 accounted for 80 percent of the growth in Benton County and almost 55 percent of the growth in Franklin County (State of Washington, 1981a). The balance of total growth is due to natural increase, the excess of births over deaths.

Table 3-27 illustrates that the largest increase in population size of the Tri-Cities near the Hanford Site was experienced in Kennewick, Washington, (in Benton County) during the Washington Public Power Supply System construction period. From 1973 to 1981, the population of Kennewick, Washington, grew at a rate approaching 10 percent per year, nearly a twelvefold increase compared to the pre-Washington Public Power Supply System period growth rate. But the growth in Benton County spread beyond the Tri-Cities, especially to West Richland and Benton City, Washington. Before Washington Public Power Supply System construction activities began in 1973, the population of Benton City, Washington,

Table 3-26. Population of Benton and Franklin Counties: 1965 to 1984

Year	Benton County	Average annual rate of change (%)	Franklin County	Average annual rate of change (%)	Total Benton-Franklin Counties	Average annual rate of change (%)
			Pre-Supply System[a] period			
1965	63,301		24,158		87,459	
1966	64,019		24,504		88,523	
1967	64,433		24,865		89,298	
1968	65,276		25,061		90,337	
1969	65,418	1.1	24,891	1.1	90,309	1.1
1970[b]	67,540		25,816		93,356	
1971	67,069		26,430		93,499	
1972	67,214		26,508		93,722	
1973	68,988		26,301		95,289	
			Supply System[a] construction period			
1973	68,988		26,301		95,289	
1974	72,202		27,101		99,303	
1975	76,880		28,004		104,884	
1976	84,453		29,510		113,963	
1977	89,472	6.1	30,592	4.0	120,064	5.5
1978	97,825		32,824		130,649	
1979	104,838		34,228		139,066	
1980[b]	109,444		35,025		144,469	
1981	112,090		36,276		148,366	
			Supply System[a] rampdown period			
1981	112,090		36,276		148,366	
1982	108,710	-2.5	35,231	-1.2	143,941	-2.2
1983	106,777		35,363		142,140	
1984	103,841		34,999		138,840	

NOTE: U.S. Bureau of the Census (BOC, 1960, 1970, 1980).

[a]Washington Public Power Supply System.

[b]Reliable data were available only for the census years 1960, 1970, and 1980. To develop more reasonable intercensal estimates, the annual rates of change in the resident civilian work force for the bicounty area (revised, State of Washington, 1984e) were compared with the population from the U.S. Bureau of the Census between 1960 and 1970. Estimates through 1973 were computed this way. Similarly, changes in the labor force between 1973 and 1980 were used to provide population estimates for the 1973 to 1984 period. The bicounty estimates were prorated to each county based on the proportion in the independent estimates provided by the State of Washington (1984b). The average annual rate of change (percent) assumes a continuous compounded rate based on the formulation found in Cluett et al. (1984, app.).

Table 3-27. Population of cities near the Hanford Site: 1965 to 1984

Year	Richland	Average annual rate of change (%)	Kennewick	Average annual rate of change (%)	Pasco	Average annual rate of change (%)	West Richland	Average annual rate of change (%)	Benton City	Average annual rate of change (%)
Pre-Supply System* period										
1965	25,900		15,200		15,800		1,350		1,185	
1966	26,500		15,400		16,350		1,350		1,185	
1967	26,500		15,400		16,400		1,350		1,185	
1968	28,500		16,000		16,600		1,127		1,185	
1969	28,900	0.3	16,500	0.8	17,000	-1.5	1,130	-1.2	1,185	-0.9
1970	26,290		15,212		13,920		1,143		1,070	
1971	26,300		15,400		13,920		1,143		1,093	
1972	26,350		15,580		14,000		1,159		1,090	
1973	26,600		16,200		14,050		1,225		1,100	
Supply System* construction period										
1973	26,600		16,200		14,050		1,225		1,100	
1974	28,000		16,800		14,100		1,247		1,125	
1975	28,600		18,253		14,450		1,477		1,315	
1976	30,009		21,301		14,618		1,561		1,422	
1977	31,050	3.0	23,638	9.5	15,375	3.6	2,024	14.1	1,583	8.4
1978	32,350		26,564		16,000		2,311		1,917	
1979	33,550		29,810		16,370		2,641		1,900	
1980	33,578		34,397		18,425		2,938		2,087	
1981	33,700		34,700		18,700		3,783		2,150	
Supply System* rampdown period										
1981	33,700		34,700		18,700		3,783		2,150	
1982	33,550		35,350		19,050		3,934		1,970	
		-2.1		2.4		0.4		-1.2		-2.8
1983	32,000		35,700		19,100		3,869		1,880	
1984	31,660		37,240		18,930		3,650		1,975	

NOTE: Distances to the reference repository location on the Hanford Site are Richland, 35 kilometers (22 miles), Kennewick, 45 kilometers (28 miles), Pasco, 45 kilometers (28 miles), West Richland, 32 kilometers (20 miles), Benton City, 32 kilometers (20 miles). Figures for 1965 to 1969 are from State of Washington (1969, Table 2), 1970 to 1979 are from State of Washington (1979, Table 1), 1980 to 1984 are from State of Washington (1984e, Table 1). The average annual rate of change assumes a continuous compounded rate based on the formulation found in Cluett et al. (1984, app.).

*Washington Public Power Supply System.

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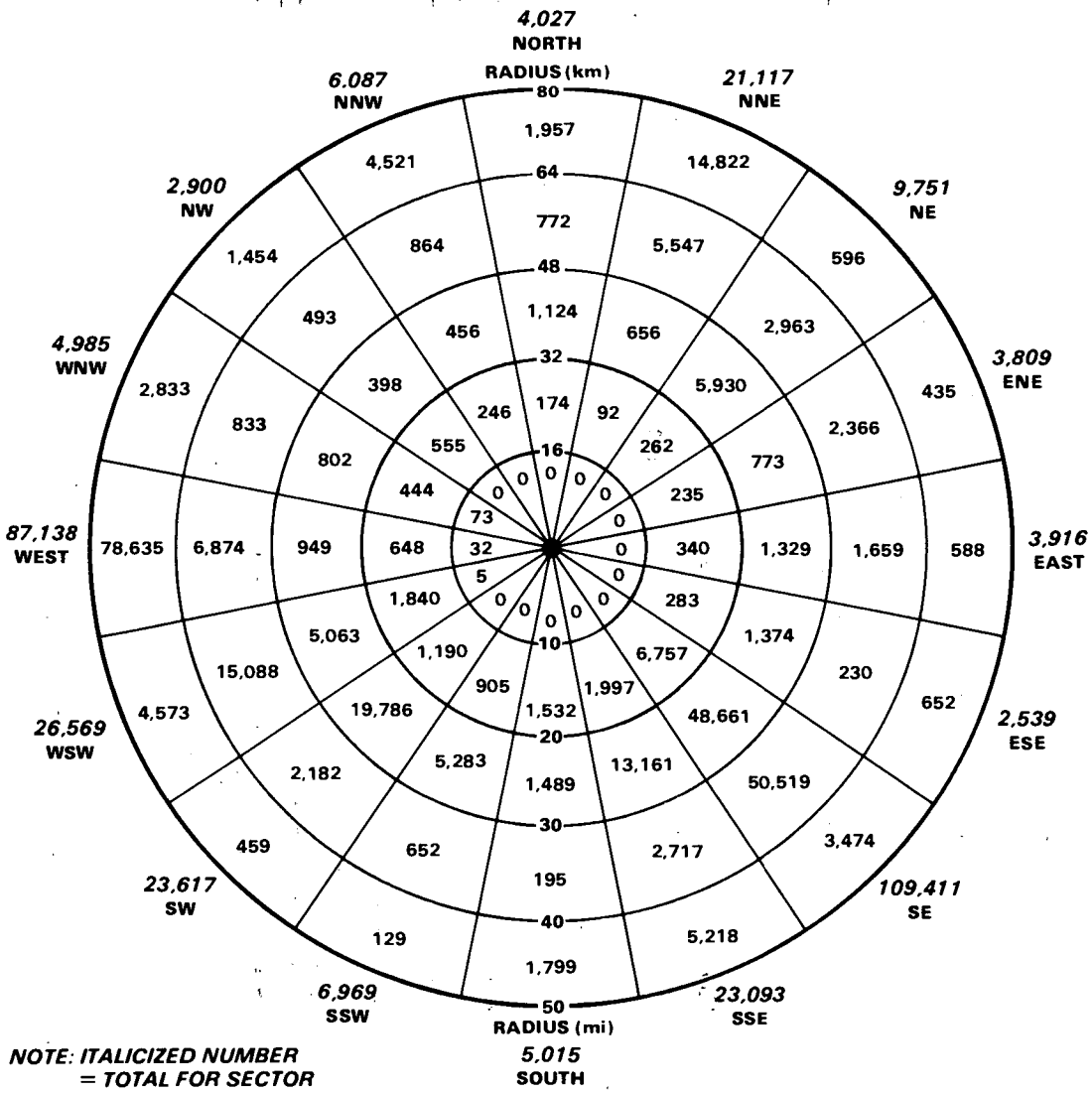

RING km (mi)	0-16 (0-10)	16-32 (10-20)	32-48 (20-30)	48-64 (30-40)	64-80 (40-50)	TOTAL 0-80 (0-50)
POPULATION	110	17,500	107,234	93,954	122,145	340,943

RING km (mi)	0-16 (0-10)	0-32 (0-20)	0-48 (0-30)	0-64 (0-40)	0-80 (0-50)
POPULATION DENSITY PERSONS PER km^2 (mi^2)	0.1 (0.3)	5 (14)	17 (44)	17 (43)	17 (43)

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Figure 3-47. Distribution of residential population in an 80-kilometer (50-mile) radius of the Hanford Meteorological Station by population grid sector for 1980 (after Sommer et al., 1981, p. 11).

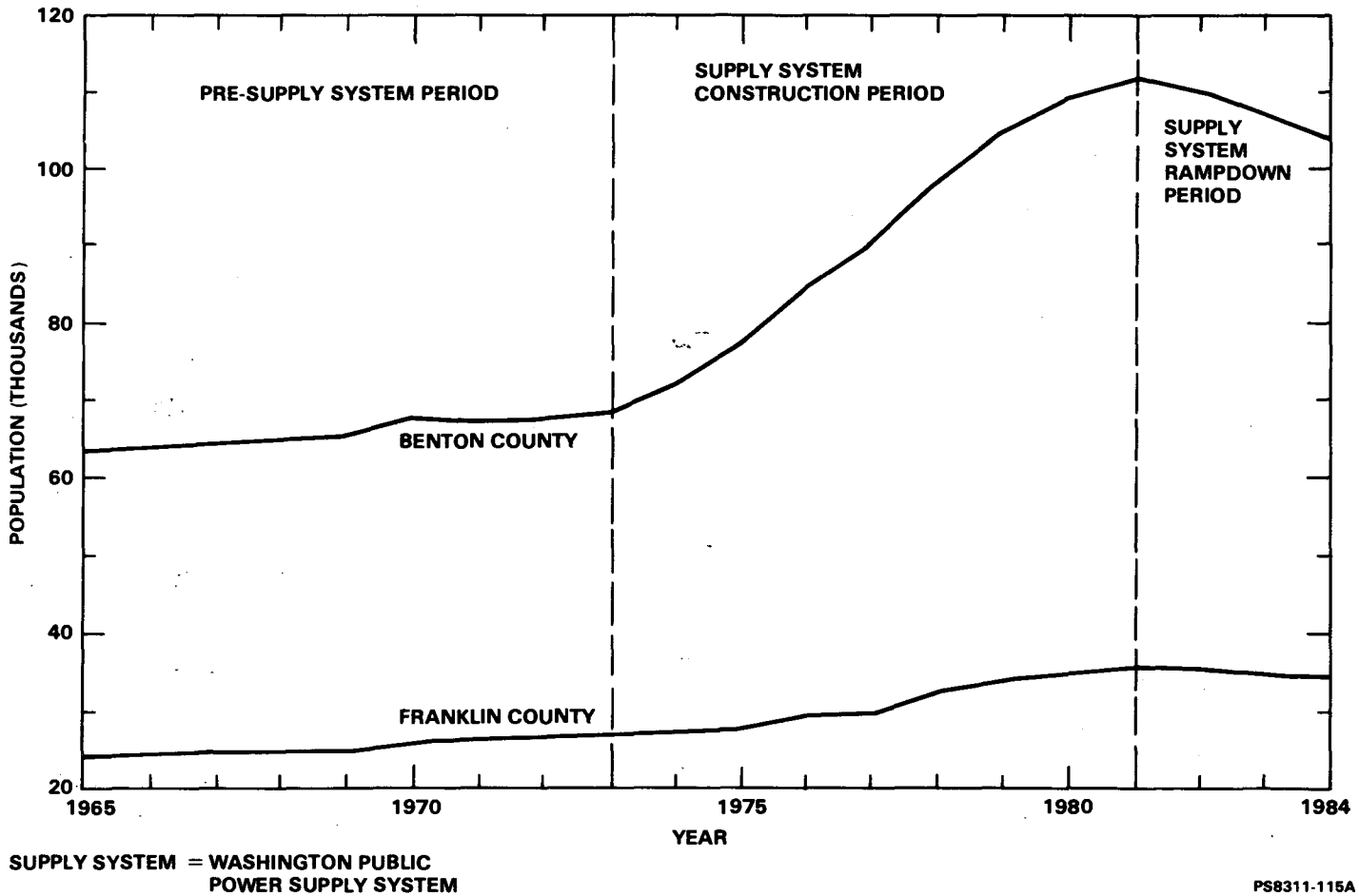

Figure 3-48. Population trends for Benton and Franklin Counties: 1965 to 1984.

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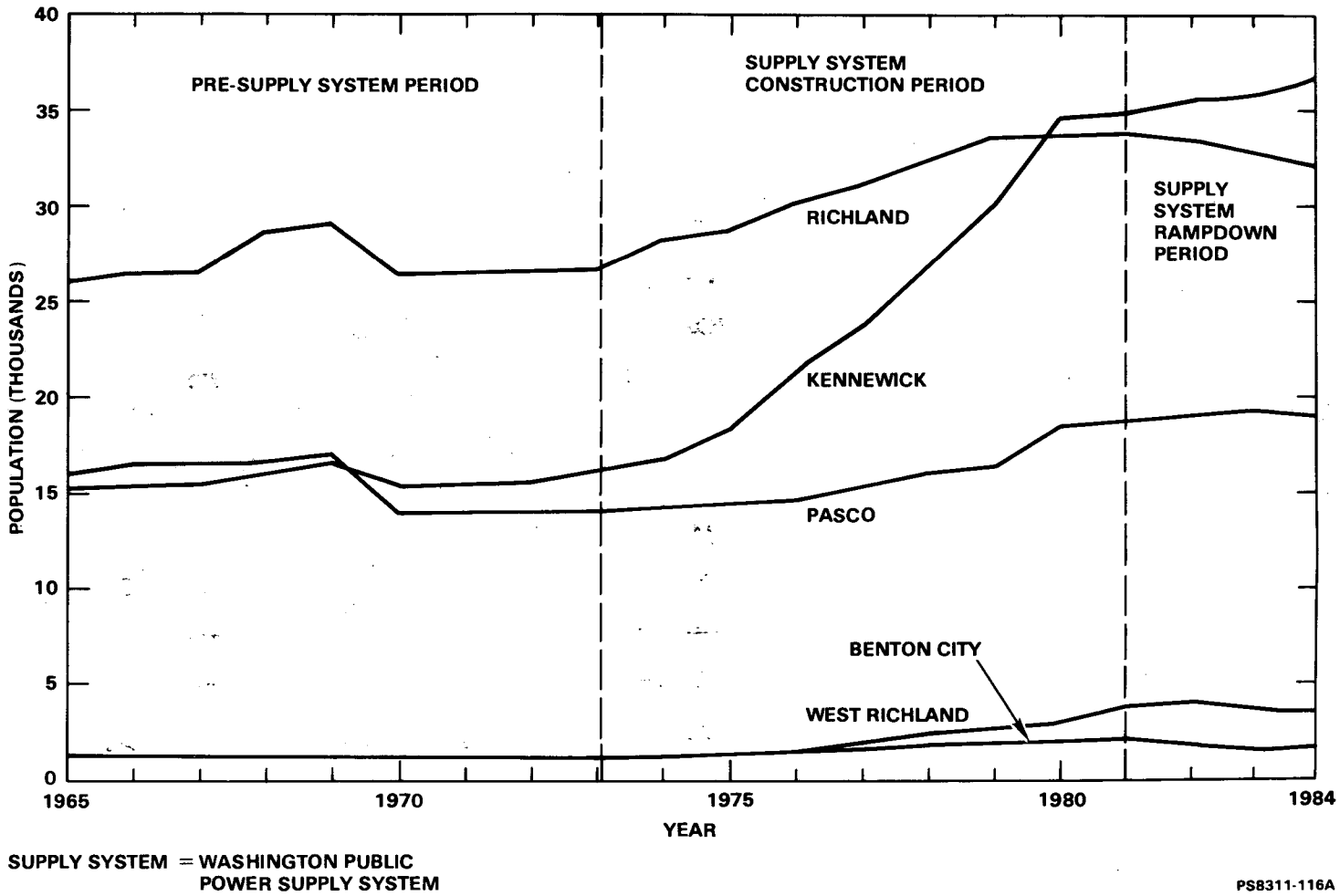

Figure 3-49. Population trends for cities near the Hanford Site: 1965 to 1984.

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remained constant at around 1,100 persons, but almost doubled in size between 1973 and 1981. The most rapid growth during the 1973 to 1981 period, however, took place in West Richland, Washington, where the population grew at an average annual rate of 14.1 percent during this period. In Franklin County the rapid population growth during the Washington Public Power Supply System construction period was concentrated in Pasco, Washington, and the surrounding unincorporated areas.

Pinpointing the exact components of growth in each of the above municipalities is difficult, however, because each has also grown due to annexation of adjacent unincorporated areas. According to an analysis, "From 1970 to 1980, the cities of Richland, Pasco, Kennewick, and West Richland had expanded their municipal boundaries by 51 percent" (State of Washington, 1982a, p. 5). Table 3-28 illustrates the increase in area since 1960 for the Tri-Cities, West Richland, and Benton City, Washington. This table also shows how population density in these five cities has changed in response to population growth and to annexations of adjacent land area. The data suggest that the effect of population growth in the urbanized areas around the Hanford Site has been to maintain a fairly constant urban density over time by concentrating new settlement on the outskirts of existing communities. As these peripheral suburban areas approach the density of the central city, they tend to be annexed into that city. The effect of future population growth, such as might be caused by the proposed repository, probably would be similar. Of course, some new population growth will take place in other outlying areas or in areas of relatively sparce settlement. Available land for residential settlement in the Tri-Cities region is not particularly constrained at this time; therefore, the population densities of the major cities near the Hanford Site are not likely to exceed those observed in recent years within the time frame of this analysis (see Table 3-28).

Tables 3-26 and 3-27 illustrate the dramatic reversal in regional, economic, and demographic activity that began in mid-1981 when Washington Public Power Supply System Nuclear Project WNP-1 was mothballed and WNP-4 construction work was terminated. Preliminary economic and demographic data for Benton and Franklin Counties indicate that the effects of the Washington Public Power Supply System work-force reductions extended through 1984.

3.6.2 ECONOMIC CONDITIONS

Economic conditions in this study region can be characterized in terms of three distinct time periods over the past two decades. Before Washington Public Power Supply System construction activities between 1965 and 1973, employment grew at the steady, moderate rate of 2.4 percent per year (Table 3-29). Then, as construction activities increased rapidly on the three Washington Public Power Supply System Nuclear Projects at the Hanford Site, employment growth averaged 8.3 percent per year between 1973 and 1981.

Table 3-28. Population density for cities in the bi-county area (per square kilometer (square mile)) near the Hanford Site: 1960 to 1983

Year	Richland		Kennewick		Pasco		West Richland		Benton City	
	Area, km² (mi²)	Population density	Area, km² (mi²)	Population density	Area, km² (mi²)	Population density	Area, km² (mi²)	Population density	Area, km² (mi²)	Population density
1960	29.3 (11.3)	790 (2,048)	11.7 (4.5)	1,217 (3,165)	19.9 (7.7)	730 (1,886)	3.6 (1.4)	374 (962)	3.4 (1.3)	356 (931)
1968	65.5 (25.3)	436 (1,128)	16.1 (6.2)	994 (2,581)	29.0 (11.2)	573 (1,485)	3.6 (1.4)	313 (805)	3.4 (1.3)	349 (912)
1970	61.9 (23.9)	425 (1,100)	16.6 (6.4)	916 (2,377)	29.0 (11.2)	480 (1,243)	3.6 (1.4)	315 (811)	3.4 (1.3)	315 (823)
1972	72.0 (27.8)	366 (949)	24.6 (9.5)	636 (1,647)	29.5 (11.4)	475 (1,229)	3.6 (1.4)	320 (822)	3.4 (1.3)	320 (838)
1973	72.0 (27.8)	370 (958)	24.6 (9.5)	657 (1,702)	29.5 (11.4)	477 (1,234)	3.6 (1.4)	338 (869)	3.4 (1.3)	323 (846)
1974	72.8 (28.1)	384 (996)	25.4 (9.8)	661 (1,714)	29.5 (11.4)	478 (1,237)	3.6 (1.4)	344 (884)	3.4 (1.3)	331 (865)
1975	74.9 (28.9)	382 (990)	28.0 (10.8)	654 (1,696)	29.5 (11.4)	490 (1,268)	3.6 (1.4)	408 (1,048)	3.4 (1.3)	387 (1,012)
1976	74.9 (28.9)	401 (1,039)	29.8 (11.5)	716 (1,855)	29.5 (11.4)	495 (1,282)	3.6 (1.4)	430 (1,107)	3.4 (1.3)	418 (1,094)
1977	74.9 (28.9)	415 (1,075)	31.1 (12.0)	759 (1,967)	30.3 (11.7)	508 (1,317)	4.4 (1.7)	455 (1,177)	3.4 (1.3)	466 (1,218)
1978	74.9 (28.9)	432 (1,119)	31.3 (12.1)	847 (2,190)	33.2 (12.8)	484 (1,255)	4.7 (1.8)	486 (1,270)	3.4 (1.3)	564 (1,475)
1979	75.9 (29.3)	442 (1,146)	36.8 (14.2)	811 (2,102)	35.7 (13.8)	459 (1,188)	5.7 (2.2)	470 (1,217)	3.4 (1.3)	559 (1,462)
1980	82.9 (32.0)	405 (1,050)	40.1 (15.5)	857 (2,218)	40.7 (15.7)	453 (1,175)	8.0 (3.1)	363 (938)	35.7 (13.8)	58 (151)
1981	82.9 (32.0)	406 (1,053)	40.7 (15.7)	855 (2,217)	40.7 (15.7)	460 (1,193)	49.5 (19.1)	76 (198)	36.8 (14.2)	59 (152)
1982	82.9 (32.0)	404 (1,048)	40.9 (15.8)	816 (2,112)	40.7 (15.7)	469 (1,215)	50.0 (19.3)	78 (203)	37.6 (14.5)	52 (135)
1983	83.1 (32.1)	385 (997)	42.2 (16.3)	847 (2,194)	60.1 (23.2)	318 (825)	53.6 (20.7)	72 (187)	37.6 (14.5)	50 (129)
1984	83.1 (32.1)	381 (986)	42.7 (16.5)	872 (2,257)	60.1 (23.2)	315 (816)	53.6 (20.7)	68 (176)	38.1 (14.7)	52 (134)

NOTE: Figures for 1960 and 1968 are from Schmid and Schmid (1969; Tables 4:III and 4:V) and for 1970 to 1984 are from State of Washington (1973, 1974, 1975, 1976, 1977, 1978, 1979, 1980, 1981a, 1982b, 1983a, 1984e).

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Table 3-29. Work force, employment, and unemployment in Benton and Franklin Counties: 1965 to 1984

Year	Resident civilian work force	Average annual growth rate (%)	Employ-ment	Average annual growth rate (%)	Unemploy-ment	Annual unemploy-ment rate (%)
Pre-Supply System[a] period						
1965	34,080		32,170		1,910	5.6
1966	35,160		33,060		1,810	5.1
1967	35,960		33,910		2,000	5.6
1968	37,050		34,410		2,480	6.7
1969	37,020	2.8	34,530	2.4	2,460	6.6
1970	40,330		36,570		3,760	9.3
1971	40,490		36,500		3,990	9.9
1972	40,740		36,960		3,780	9.3
1973	42,520		38,960		3,560	8.4
Supply System[a] construction period						
1973	42,520		38,960		3,560	8.4
1974	45,270		42,300		2,970	6.6
1975	49,190		45,550		3,640	7.4
1976	55,800		51,800		4,000	7.2
1977	60,400	8.4	55,500	8.3	4,900	8.1
1978	68,670		64,340		4,330	6.3
1979	75,500		70,500		5,000	6.6
1980	80,000		72,100		7,700	9.9
1981	83,300		75,900		7,400	8.9
Supply System[a] rampdown period						
1981	83,300		75,900		7,400	8.9
1982	81,600	-3.7	70,000	-5.7	11,600	14.2
1983	78,500		67,600		10,900	13.9
1984b	74,600		63,900		10,700	14.3

NOTE: Figures for 1965 to 1969 are from Benton-Franklin Governmental Conference (1983), 1970 to 1978 are from State of Washington (1983b), and 1979 to 1984 are from State of Washington (1984b).

[a]Washington Public Power Supply System.

[b]First quarter preliminary (from State of Washington, 1984b).

The primary sectors of employment growth in the study region include not only the Washington Public Power Supply System and its contractors but also the U.S. Department of Energy and its contractors and the agricultural sector. Out of a total employment level of 75,900 persons in 1981, almost 29,000 persons, or 38.2 percent, were employed in one of these sectors. Table 3-30 shows employment by selected industry groups in Benton and Franklin Counties from 1967 to 1982. Employment for the Washington Public Power Supply System and the U.S. Department of Energy are included in several of the other sectors, particularly construction and government. Therefore, total employment shown in Table 3-29 equals the sum of employment in agriculture, construction, manufacturing, sales, service, and government, as shown in Table 3-30.

During the pre-Washington Public Power Supply System period, the major employment growth occurred in the agricultural and construction sectors. Between 1967 and 1973, the agricultural sector grew at an average annual rate of nearly 11 percent, due to large irrigation projects undertaken in the region, and the construction sector grew at over 5 percent. In comparison, other industries exhibited little growth, except for retail and wholesale industries that grew at an average annual rate of approximately 2.6 percent. The U.S. Department of Energy employment declined between 1967 and 1971 and then began to rise again. In spite of this temporary drop in U.S. Department of Energy employment, total growth in the primary employment sector was 2,314 persons for that period. The primary sector refers to those industries that sell production principally outside the region. Secondary sector industries are local industries that service the needs of firms and workers of the primary sector. Corresponding growth in secondary sector employment was 2,736 jobs.

During the Washington Public Power Supply System construction period (1973 to 1981), economic and demographic growth in the study region was caused primarily by growth in employment offered by the Washington Public Power Supply System and its contractors, which increased at an average rate of approximately 39 percent per year. This growth was supplemented by an annual growth rate of 4.2 percent in the agricultural sector and 5.6 percent in the U.S. Department of Energy sector. The U.S. Department of Energy employment increased mostly during the first half of the period. Increasing employment opportunities in these three primary sectors during this phase, at a combined average annual rate of 11.1 percent, resulted in average annual employment growth rates of 6.6 percent in manufacturing, 8.6 percent in retail and wholesale, 6.6 percent in service-based industries, and 6.0 percent in all the government sectors. During this period of time, primary sector jobs increased by 17,026, compared to 19,614 jobs in the secondary sector (i.e., 1.2 secondary sector jobs for every primary sector job, or a primary sector-based total employment multiplier of 2.2).

This substantial growth in the secondary sector of the regional economy due to Washington Public Power Supply System construction activities at the Hanford Site suggests that the region was perceived as

Table 3-30. Employment by selected industry groups in Benton and Franklin Counties: 1967 to 1982

Year	Primary employment[a]						Nonagricultural employment[b,c]									
	Supply system[c,d]	Average annual rate of change[e] (%)	DOE[f]	Average annual rate of change[e] (%)	Agricultural[b,g]	Average annual rate of change[e] (%)	Construction	Average annual rate of change[e] (%)	Manufacturing	Average annual rate of change[e] (%)	Retail and wholesale	Average annual rate of change[e] (%)	Service-based industry[h]	Average annual rate of change[e] (%)	Government	Average annual rate of change[e] (%)
Pre-Supply System[d] period																
1967	--	--	9,000		1,989		2,432		5,946		5,572		11,413		6,557	
1968	--	--	8,850		2,170		1,900		5,930		5,697		12,272		6,441	
1969	--	--	8,500		2,472		2,094		5,850		5,811		12,068		6,234	
1970	--	--	7,900	-2.9	3,065	10.7	1,908	5.1	6,022	0.2	6,211	2.6	12,726	1.5	6,638	0.8
1971	--	--	6,500		3,233		1,859		5,767		6,368		12,603		6,671	
1972	--	--	7,000		3,249		2,567		5,763		6,430		12,402		6,549	
1973	530	--	7,570		3,773		3,300		6,014		6,506		12,466		6,900	
Supply System[d] construction period																
1973	530		7,570		3,773		3,300		6,014		6,506		12,466		6,900	
1974	1,115		8,700		4,376		4,175		6,339		6,808		13,324		7,278	
1975	1,946		9,800		4,608		5,458		6,859		7,025		13,565		8,035	
1976	2,954		10,680		5,850		5,663		7,614		8,509		15,488		8,676	
1977	3,412	38.7	12,300	5.6	4,315	4.2	7,720	18.8	8,259	6.6	9,354	8.6	17,132	6.6	8,720	6.0
1978	7,097		11,750		4,456		9,936		9,420		11,193		19,716		9,618	
1979	8,926		12,000		5,113		11,910		9,804		12,148		20,673		10,831	
1980	7,935		12,100		5,228		10,847		9,843		12,216		22,151		11,715	
1981	11,728		11,880		5,291		14,900		10,226		12,942		21,090		11,150	
Supply System[d] rampdown period																
1981	11,728	-28.3	11,880	-3.3	5,291	1.0	14,900	-38.5	10,226	2.8	12,942	-1.7	21,090	-2.9	11,150	-2.5
1982	8,841		11,500		5,344		10,135		10,521		12,729		20,490		10,874	

NOTE: Total employment from the U.S. Bureau of Economic Analysis (nonagricultural employment plus agriculture) is slightly less than the total employment provided by the State of Washington Employment Security Department (see Table 3-29). Therefore, the ratio between the two was determined for each year and multiplied times the individual U.S. Bureau of Economic Analysis employment categories.

[a]See the text for definition of primary employment as used in this report.

[b]Figures from 1967 to 1974 were estimated from the U.S. Bureau of Economic Analysis (1983) and from 1975 to 1980 are from the U.S. Bureau of Economic Analysis (1982) baseline forecasts.

[c]Figures from 1981 to 1982 are from McGinnis and Schau (1983).

[d]Washington Public Power Supply System.

[e]Average annual rate of change assumes a continuous compounded rate based on the formulation found in Cluett et al. (1984, app.).

[f]Data from State of Washington (1982a).

[g]Figures from 1981 are estimated from Cluett et al. (1984, Table 5-3) and for 1982 are estimated from Cluett et al. (1984, Table 6-1).

[h]Includes service, transportation, finance, and real estate.

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providing long-term economic stability and future growth potential. Such an atmosphere encouraged families to settle in the region permanently and fostered optimism regarding the future course of the regional economy.

Table 3-30 illustrates the significant decline in regional employment due to lost construction jobs, primarily on the Washington Public Power Supply System Nuclear Projects, that began in mid-1981. Employment losses in the region are expected to continue through 1984 and to be accompanied by losses in population. Employment is estimated to have declined approximately 17 percent from the 1981 peak through the first quarter of 1984 and population is estimated to have declined approximately 6 percent (see Tables 3-27 and 3-29). Figure 3-50 illustrates the changes in work force and employment in the region between 1965 and 1984. The shaded area between these two curves represents trends in unemployment. That gap has widened since 1981, and high unemployment probably will persist for several more years. Persons who have lost their jobs have either left the area, remained in the area as unemployed members of the work force who are looking for jobs, or remained in the area but have left the work force and are not looking for jobs. A good portion of the construction workers have left the area for temporary jobs while leaving their families in the Tri-Cities area. If the perception of long-term economic opportunity is being eroded by recent events and poor near-term employment prospects, significant numbers of additional people could decide to leave the region.

3.6.3 COMMUNITY SERVICES

Population growth, such as that experienced in the study area between 1973 and 1981, resulted in a substantial increase in the demand for publicly and privately supplied community services. In response to this increased demand, the service capacity of many local governmental units and private suppliers was expanded. The subsequent decline in population in the study area following the Washington Public Power Supply System work force reduction in 1981 has left many governmental units with excess capacity. As a result of the experience gained during the rapid growth period of the late 1970's, many governmental units have acquired a greater ability to respond quickly to changing conditions.

Community services are provided to residents of the study area by a variety of public and private agencies. Of particular interest to this analysis are those public services provided by county or municipal governments or special districts that derive their resources from local taxes and might experience increased or changed demand for service as a result of the proposed project. Community services that have been affected by past developments in the study region include public water supply and waste-water disposal, solid waste disposal, fire- and police-protection services, health services, education, and local transportation. Although the provision of housing is not a public service, housing has been included in this discussion because of its importance to public service demand and community well-being.

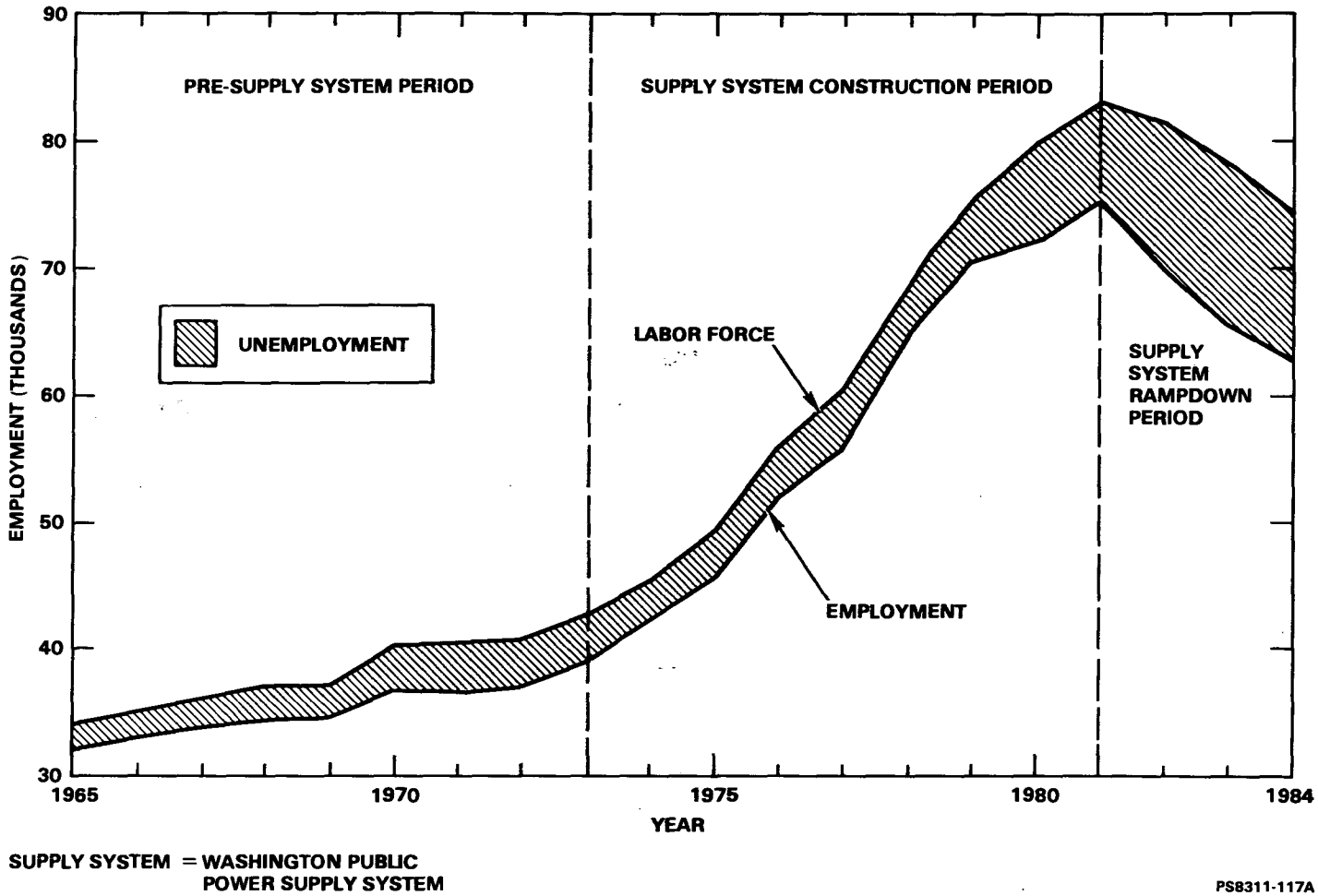

Figure 3-50. Work force and total employment in Benton and Franklin Counties: 1965 to 1984.

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3.6.3.1 Housing

The increase in the growth rates of housing units that is evident between 1973 and 1981 indicates that the total housing units were increased as the population increased. For example, the average annual rate of increase in housing stock in Benton and Franklin Counties was 1.6 percent between 1965 and 1973; 7.8 percent between 1973 and 1981. The population increase was 1.1 percent and 3.7 percent for the respective periods (Table 3-31). During the high-growth period of the 1970's, the largest numbers of people moved into the three largest cities of the area: Kennewick, Richland, and Pasco, Washington. The rate of increase in the housing supply in each of these three communities more than kept pace with the rate of population growth each community experienced (see Table 3-27). More than 30 percent of the housing in Benton and Franklin Counties has been added since 1973 (Table 3-32). One indicator of this is the vacancy rate in these communities during the period of high growth (Table 3-33). Figures available from 1975 to 1983 indicate a very tight housing market in the initial years of the high-growth period. For example, the vacancy rate in Benton and Franklin Counties, and in the Tri-Cities specifically, was less than 1 percent in 1975 and 1976. However, the overall vacancy rate climbed to greater than 1 percent beginning in 1977, indicating that the supply of new housing units was more than keeping pace with the population influx. By 1981 the vacancy rate in the Tri-Cities was 4.3 percent.

As the population of the area declined as a result of the Washington Public Power Supply System rampdown, the vacancy rate for all housing units rose accordingly, particularly for multifamily housing composed primarily of rental units. The 1983 vacancy rate for single-family dwellings remained fairly low, at 3.6 percent for the Tri-Cities, but multifamily units for the same year reached a high 19.1-percent vacancy rate, both due to the overbuilding of these units and to the departure of temporary construction workers. According to the 1980 U.S. Bureau of the Census (BOC, 1980), home-owner units in the State of Washington experienced a vacancy rate of 2.1 percent and rental units had a rate of 7.3 percent. Thus, even during 1980, the study area experienced housing vacancy rates higher than the State average, particularly in rental units.

3.6.3.2 Public water supply

Each of the incorporated communities in the study area operates municipal public water-supply- and waste-water-treatment systems. Residents in the peripheral areas frequently use individual wells and septic tanks.

Table 3-31. Comparison between average annual percentage rates of change in population and housing units: 1965 to 1981

Year	Counties			Tri-Cities			
	Benton	Franklin	Combined	Richland	Kennewick	Pasco	Combined
				Population[a]			
1965-1973	0.9	1.4	1.1	0.3	0.8	-1.5	--
1973-1981	6.2	3.7	3.7	3.0	9.5	3.6	--
				Housing units[b]			
1965-1973	1.4	2.0	1.6	--	--	--	--
1973-1981	8.7	5.4	7.8	6.2[c]	10.6[c]	7.2[c]	8.3[c]

[a]Based on data in Tables 3-26, 3-27, and 3-29.

[b]For county figures, rates of change are calculated on housing unit statistics from the U.S. Bureau of Census (BOC, 1960, 1970, 1980). For Tri-Cities figures, rates of change are calculated from data on housing unit statistics from the Tri-Cities Real Estate Research Committee (1982) (not available prior to 1975).

[c]1975 to 1981.

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Table 3-32. Number of housing units in Benton and Franklin Counties: 1973 to 1984

Year	County	
	Benton	Franklin
1973[a]	21,976	8,946
1974[a]	23,551	9,159
1975[a]	25,906	9,353
1976[a]	29,351	10,263
1977[a]	32,332	10,317
1978[a]	36,415	11,763
1979[a]	40,065	12,693
1980[b]	42,610	13,122
1981[c]	43,649	13,566
1982[c]	43,649	13,566
1983[c]	44,427	14,019
1984[c]	45,029	14,061

[a]Intercensal estimates taken from Cluett et al. (1984).

[b]Census year figures taken from U.S. Bureau of the Census (BOC, 1980).

[c]Intercensal estimates taken from State of Washington (1984e).

Table 3-33. Tri-Cities housing vacancies: 1975 to 1983

Year	Total units		Single-family units		Multifamily units[a]		Mobile homes and trailers	
	No.	%	No.	%	No.	%	No.	%
Supply System[b] construction period								
1975	183	0.6	114	0.5	54	1.6	15	0.7
1976	282	0.8	171	0.6	96	1.8	15	0.6
1977	651	1.7	232	0.9	384	4.1	35	0.9
1978	573	1.3	256	0.9	286	2.7	31	0.6
1979	923	2.0	330	1.2	548	4.4	45	0.9
1980	1,316	2.8	367	1.2	855	7.0	94	1.6
1981	2,138	4.3	459	1.5	1,551	11.3	128	2.1
Supply System[b] rampdown period								
1981	2,138	4.3	459	1.5	1,551	11.3	128	2.1
1982	2,553	5.1	757	2.5	1,604	12.1	192	3.2
1983	4,324	8.6	1,091	3.6	2,215	19.1	518	8.8

NOTE: Tri-Cities Real Estate Research Committee (1983).
[a]Includes condominiums.
[b]Washington Public Power Supply System.

During the period of rapid population growth in the late 1970's and early 1980's, the water-supply-treatment systems of Kennewick, Pasco, and Richland, Washington, were all expanded and (or) upgraded. All three communities obtain water from the Columbia River, which requires filtration and treatment. Kennewick and Richland also obtain water from wells, which requires only chlorination. As shown in Table 3-34, existing water-storage and -filtration facilities in each of these communities are more than adequate to meet current needs. Neither Kennewick nor Richland has current plans for additional major expansions or improvements in their water-supply systems. However, Pasco has plans to upgrade its water-pumping system and filtration plant. Preliminary designs for this renovation were prepared in 1984. In all study area communities, water use peaks during the summer months, when usage runs 2 to 3 times the average yearly rate. Use is lowest during the winter (e.g., dropping to approximately 1 x 10^4 cubic meters (3 million gallons) per day in Pasco). Based on a per capita consumption standard of 1.5 cubic meters (400 gallons) per person per day, the municipal facilities for treating Columbia River water could serve a population of approximately 19,000 people in Kennewick, 40,000 in Pasco, and 75,000 in Richland. Using this same standard, existing wells could provide sufficient water for a population of approximately 50,000 in Kennewick and 45,500 in Richland, although the systems in neither Kennewick nor Richland are designed to operate at full capacity when drawing from the river and wells.

3.6.3.3 Waste-water treatment

Existing waste-water-treatment service for the Tri-Cities is summarized in Table 3-35. None of the peak demands has exceeded capacity. The City of Richland completed the construction of a new waste-water-treatment facility with a design capacity of 4.6 x 10^4 cubic meters (12 million gallons) per day. This new facility came on line in August 1985. The old system served a population of approximately 33,000, while the new system is sized for 68,500 residents.

3.6.3.4 Solid waste disposal

The City of Richland operates a garbage-collection and -disposal system, with a landfill site located near the city limits. Residents of Kennewick and Pasco, Washington, contract with private carriers for solid waste collection and disposal. The carrier servicing Kennewick is currently contracting with the City of Richland to use their landfill on a temporary basis. The existing capacity of the sanitary landfills in the Tri-Cities area is estimated to be adequate to meet existing and future needs through at least the 1990's (DOE, 1982b, p. 9.3-21; PSPL, 1981, p. 4-14).

Table 3-34. Municipal water supply and consumption for the Tri-Cities: 1984

Water system	Kennewick[a]	Pasco	Richland[b]
	Capacity		
Storage, m^3 (Mgal)	9.3×10^{10} (24.5)	4×10^{10} (10.6)	9×10^{10} (23.7)
Treatment			
River, m^3/d (Mgal/d)	2.8×10^4 (7.5)	6.1×10^4 (16)	1.2×10^5 (30)
Wells, m^3/d (Mgal/d)	7.6×10^4 (20)	—	6.9×10^4 (18.2)
	Use		
Peak day, m^3/d (Mgal/d)	6.4×10^4 (17)	5.8×10^4 (15.4)	1.1×10^5 (28.6)
Yearly average, m^3/d (Mgal/d)	3.4×10^4 (9)	2.1×10^4 (5.5)	5.7×10^4 (15)

NOTE: Some figures are estimates. Mgal = million gallons, Mgal/d = million gallons per day, 1 cubic meter = 35.3 cubic feet.

[a]Over the period of a year, the Kennewick, Washington, system utilizes approximately 60 percent well water and 40 percent river water.

[b]The Richland, Washington, system has 18 wells that are used as an auxiliary source because the well water is so hard. Wells can provide approximately 18.2 megagallons per day, but the system is not designed to run river and well systems at full capacity simultaneously.

Table 3-35. Waste-water-treatment facilities for the Tri-Cities: 1984

Facility	Kennewick	Pasco	Richland
Design capacity, m^3/d (Mgal/d)	6.4×10^4 (17)	1.6×10^4 (4.2)	4.6×10^4 (12)
Average demand, m^3/d (Mgal/d)	2.1×10^4 (5.5)	9.5×10^3 (2.5)	1.8×10^4 (4.7)
Peak demand, m^3/d (Mgal/d)	3.0×10^4 (8)	Not available	2.3×10^4 (6)

NOTE: Mgal/d = million gallons per day, 1 cubic meter = 35.3 cubic feet.

3.6.3.5 Public safety

Each of the municipalities, as well as the two counties and the Washington State Patrol, maintain law enforcement agencies. Table 3-36 shows the total staff, number of sworn officers, and department vehicles for the police departments of Kennewick, Pasco, Richland, Benton City, West Richland, Washington, and the sheriff's departments of Benton and Franklin Counties. Jail facilities are located in Benton and Franklin Counties, as well as in the municipalities of Kennewick, Pasco, and Richland. Both county jails have recently expanded. The new Franklin County jail, scheduled to be in operation in early 1986, has 105 cells with capacity for 210 persons. A new Benton County jail was completed in 1984.

Each major municipality and both counties in the study area maintain separate fire departments. West Richland, Benton City, and Prosser, Washington, contract for fire-protection service with Benton County (Districts 4, 2, and 3 and 5, respectively). Mutual aid agreements to reinforce fire-protection services during times of emergency have been established among the departments. For example, in 1980, Pasco, Kennewick, Richland, the rural fire districts 1, 2, and 3 of Benton County, district 3 of Franklin County, district 5 of Walla Walla County, along with the Rockwell Hanford Fire Protection Department, established the Tri-City Mutual Aid Agreement to improve fire-response capabilities. The Cities of Kennewick, Pasco, and Richland, Washington, maintain a paid, full-time professional fire-protection staff (WCC, 1975, p. 5-45; PSPL, 1981).

Table 3-36. Law enforcement personnel and vehicles: 1984

Jurisdiction	Sworn officers	Total staff	Vehicles
Police departments			
Kennewick	41[a]	50	17
Pasco	37[b]	NA	8[b]
Richland	43	55	16[c]
Benton City	5	5	3
West Richland	7[d]	11	4
Sheriff's departments			
Benton County	NA	NA	16[e]
Franklin County	17	40	15

NOTE: NA = not available.

[a]Kennewick Police Department plans to increase the number of sworn officers to 48.

[b]No current information was available from the Pasco Police Department; figures are from 1981 (PSPL, 1981).

[c]In addition, the Richland Police Department has 4 traffic motorcycles, 1 technical team van, 1 offroad motorcycle, and 1 bomb trailer.

[d]The West Richland Police Department also has 7 fully commissioned reserve officers.

[e]No current information was available from the Benton County Sheriff's Department; figures are from 1981 (PSPL, 1981).

3.6.3.6 Health-care and social services

Numerous health facilities, services, and personnel are available to residents of the study area. There is a general hospital in each of the major municipalities—Kennewick General Hospital in Kennewick, Our Lady of Lourdes Hospital in Pasco, and Kadlec Medical Center in Richland--as well as a general hospital in Prosser. In addition, the bicounty medical health facility operated by the Benton-Franklin District Health Department, the medical clinic in Benton City, the Mid-Columbia Mental Health Center in Richland, and the Hanford Environmental Health Foundation in Richland provide health-care services to the area population. In 1984, Kennewick General Hospital had 71 beds, Our Lady of Lourdes Hospital had 95 beds, and Kadlec Medical Center had 136 beds.

In addition to the wide range of health care available in the study area, Federal, State, and local governmental units, as well as private and voluntary organizations, provide a broad range of social services. In many cases, these services were expanded to meet increased demand during the rapid growth period (NRC, 1982a).

3.6.3.7 Public schools

The six municipalities and the unincorporated areas of Benton and Franklin Counties are served by a number of public school districts, as well as a variety of private schools. In addition, vocational schools, a community college, and the Tri-Cities University Center, which offers undergraduate and graduate degrees through several Washington and Oregon universities, serve area residents. Each school district in the Tri-Cities area offers public education through grade 12. Three of these districts enroll over 5,000 students. As shown in Table 3-37, most school districts have excess capacity as of 1984, a result of the declining enrollment that has occurred since about 1981.

3.6.3.8 Local transportation

Local traffic congestion was a major community problem during the high-growth period in the 1970's. The geographic arrangement of the major municipalities in a linear pattern with respect to the Hanford Site created transportation bottlenecks during periods of heavy use. Transportation planning in the region has received special attention in an effort to reduce bottlenecks. Improvements have been made in roads in the area, particularly in some of the formerly congested intersections. The Interstate 182 bridge over the Columbia River has relieved congestion on the routes to Richland, Washington, and the Hanford Site from Kennewick and Pasco, Washington. Increased emphasis has been placed on the development and use of mass public transportation in the region. These changes in the transportation system may alter the traditional patterns of residential growth in the area. Traffic volume in the Tri-Cities grew

Table 3-37. School enrollment and building capacity: September 1984

District	Enrollment[a]	Capacity[b]	Excess capacity[c]
Columbia (#400)	834	1,150[c]	316
Finley (#53)	893	1,162[d]	269
Kennewick (#17)	10,437	11,071	634
Kiona-Benton (#52)	1,263	1,429	166
Pasco (#1)	5,724[e]	7,200[f]	1,476[f]
Richland (#400)	7,058	8,865[g]	1,807
Total	26,209	30,877	4,668[f]

[a]Head counts in September 1984.

[b]Capacity is expressed in terms of student positions.

[c]Excess capacity is in junior and senior high school levels; elementary schools are at capacity.

[d]Includes place for 36 handicapped students and 6 portable classrooms.

[e]Includes 91 students in an alternative high school, but does not include an estimated 800 migrant students who enter the system in February or March of each year.

[f]Estimated capacity.

[g]Includes two buildings not currently in use, but available to the district.

steadily between 1973 and 1981, generally following the pattern of employment and population growth associated with increased activities on the Hanford Site. Traffic volumes in 1981 were at an all-time peak (NRC, 1982a), and often exceeded the capacity of the major arterials connecting the Hanford Site with the major residential areas. Average daily traffic volume in October, 1981, was approximately 52,000 vehicles (counted in both directions). In April, 1984, the average daily traffic volume was approximately 41,800, an overall reduction of almost 20 percent. The peak hourly flow in one direction in April, 1984 was approximately 3,300 vehicles, or about 18 percent below the 4,000-vehicle-per-hour capacity for this two-lane roadway. These measures of traffic volume were taken just south of the Yakima River Bridge on State Route 240, a location that experiences the largest traffic volumes in the study area (Benton-Franklin Governmental Conference, 1984). In 1982, a public transportation service for the Tri-Cities area was initiated. In addition to this public system, the U.S. Department of Energy (through Rockwell Hanford Operations) operates a shuttle bus system from Richland to the Hanford Site (DOE, 1982b, p. 9.3-22). These transportation improvements and planning efforts reduced congestion to levels that should be sustained as long as overall population remains below the 1981 level.

3.6.4 SOCIAL CONDITIONS

The social conditions of a community refer, in general, to the level of satisfaction community residents have with the quality of life they experience. Social conditions also refer to the network of social relationships people experience in their community and their attitude toward and participation in community social life. Social conditions in the study region have been shaped significantly by economic developments since the 1940's, particularly the growth of the Hanford Site activities and the Columbia Basin Irrigation Project. Since the study region now contains a large metropolitan complex, it is unlikely to experience the stereotypical boomtown socioeconomic impacts of rapid development. Yet, the current social conditions of the region are a direct product of rapid economic and population growth experienced in the 1970's. For the next several years, social conditions will be shaped by the effects of the Washington Public Power Supply System rampdown and the community perception of the prospects for the future.

There are several indicators of social condition that can help describe the characteristics of the population of this study area. These indicators show the differences between the study area and the State of Washington, as well as the marked distinctions between the three main cities in the area. Table 3-38 presents the 1980 age composition of the population by gender and a forecast of these data for 1985. The study area has a younger population than the State as a whole, with over 63 percent of the population in the area under 35 years of age compared to the State average of 59 percent. There is a younger population in Franklin County than in Benton County.

Table 3-38. Age composition (in percent) of males and females in Benton and Franklin Counties and the State of Washington

Age	1980 Census			1985 Forecast		
	Male	Female	Total	Male	Female	Total
Benton County						
0-9	17.3	17.0	17.2	18.0	17.7	17.8
10-19	17.6	17.3	17.5	15.0	14.8	14.9
20-34	28.5	28.2	28.3	27.6	27.1	27.4
35-64	30.9	30.0	30.4	33.0	32.1	32.6
65+	5.7	7.6	6.6	6.3	8.2	7.3
Total	100.0	100.0	100.0	100.0	100.0	100.0
Franklin County						
0-9	20.3	20.1	20.2	21.2	21.1	21.2
10-19	17.0	16.4	16.7	14.6	14.2	14.4
20-34	28.1	26.8	27.5	27.2	25.8	26.5
35-64	28.1	27.9	28.0	29.7	29.4	29.5
65+	6.5	8.7	7.6	7.3	9.5	8.4
Total	100.0	100.0	100.0	100.0	100.0	100.0
Bicounty area						
0-9	18.0	17.7	17.9	18.8	18.5	18.6
10-19	17.5	17.1	17.3	14.9	14.7	14.8
20-34	28.4	27.8	28.1	27.5	26.8	27.2
35-64	30.2	29.5	29.9	32.2	31.5	31.8
65+	5.9	7.8	6.8	6.6	8.6	7.5
Total	100.0	100.0	100.0	100.0	100.0	100.0
State of Washington						
0-9	15.0	14.1	14.6	15.6	14.7	15.1
10-19	17.3	16.2	16.7	14.7	13.8	14.3
20-34	28.4	27.1	27.7	27.4	26.0	26.7
35-64	30.5	30.5	30.5	32.5	32.4	32.4
65+	8.8	12.1	10.4	9.8	13.2	11.5
Total	100.0	100.0	100.0	100.0	100.0	100.0

NOTE: Based on the 1980 census and a 1985 forecast (State of Washington, 1982e).

Table 3-39 shows the composition of the population of the study area and the State of Washington by ethnic group and minority status. The study area as a whole has a higher proportion of persons of minority status than the State. This is due to the high proportion of persons of Spanish origin and Blacks in Franklin County relative to Benton County or the State.

Table 3-40 presents 1980 data on a variety of social characteristics of the study area and the State. These also reveal substantial differences between Benton and Franklin Counties. These indicators all reflect distinctions due to the very different economic base between the two counties. Benton County has developed a technically trained, highly educated, young population, largely in conjunction with work at the Hanford Site, while Franklin County has continued to depend primarily on its agricultural base. Table 3-41 highlights these distinctions even further by comparing each of the three Tri-Cities.

The prosperity of the 1960's and 1970's appears to have had a positive effect on social conditions in the study area overall, although most of the benefits of Hanford Site activities have been to Benton County. A highly skilled and educated work force and a construction trades work force that typically is highly mobile settled in the region on a relatively permanent basis, confident of the economic future of the region. The population has shown itself to be quite responsive to the need to manage rapid growth, based on its experiences during their growth in the 1970's.

Social conditions in the study area with regard to potential public acceptance of the proposed reference repository can generally be described as favorable. Study area residents have been found to be more knowledgeable about nuclear waste disposal than the general population of the State of Washington, with study area residents less likely to oppose a repository at the Hanford Site than residents of the State as a whole (Nealey and Rankin, 1978). A survey conducted in 1983 showed that citizens of the State of Washington had concerns about the risk associated with nuclear waste disposal, with the top three concerns being waste leaks (76 percent concerned), transportation of radioactive materials (72 percent concerned), and earthquake damage (59 percent concerned). However, a majority of these respondents (58 percent) indicated a belief that the problem of nuclear waste disposal could be solved in an acceptable way (Communications Design, 1983).

3.6.5 FISCAL CONDITIONS AND GOVERNMENT STRUCTURE

The presence of the Hanford Site has created a governmental structure in the Tri-Cities area that is somewhat more complex than that found in communities with similar population. General, local governmental services are provided to residents of the study area by county and municipal units and special districts. In addition, State and Federal agencies are represented in the study area. Each of the two counties in the study area

Table 3-39. Population by race, ethnic group, and minority status for Benton and Franklin Counties and State of Washington

Population	Benton County		Franklin County		Bicounty		State of Washington	
	No.	%	No.	%	No.	%	No.	%
1980 Census								
Total population	109,444	100.0	35,025	100.0	144,469	100.0	4,132,156	100.0
White	103,107	94.2	30,025	85.7	133,132	92.2	3,779,170	91.5
Black	857	0.8	1,452	4.1	2,309	1.6	105,574	2.6
American Indian, Eskimo, Aluet	779	0.7	234	0.7	1,013	0.7	60,864	1.5
Asian and Pacific Islander[a]	1,693	1.5	439	1.3	2,132	1.5	110,052	2.7
Other races[b]	3,008	2.7	2,875	8.2	5,883	4.1	76,556	1.9
Spanish origin[c]	4,598	4.2	5,412	15.5	10,010	6.9	120,016	2.9
Minority group[d]	8,009	7.3	7,525	21.5	15,534	10.8	406,278	9.8
1983 Estimates[e]								
Total population	108,700	100.0	36,000	100.0	144,700	100.0	4,285,100	100.0
White	101,524	93.4	30,051	83.5	131,575	90.9	3,883,824	90.6
Black	945	0.9	1,586	4.4	2,531	1.7	117,916	2.8
American Indian, Eskimo, Aluet	877	0.8	264	0.7	1,141	0.8	65,109	1.5
Asian and Pacific Islander[a]	2,041	1.9	566	1.6	2,607	1.8	136,399	3.2
Other races[b]	3,313	3.0	3,533	9.8	6,846	4.7	81,852	1.9
Spanish origin[c]	4,842	4.5	6,034	16.8	10,876	7.5	127,094	3.0
Minority group[d]	8,828	8.1	8,483	23.6	17,311	12.0	456,044	10.6

NOTE: Based on the 1980 census and 1983 estimates (State of Washington, 1984a). Because of the small numbers involved for some race categories, the 1980 to 1983 changes should be interpreted with caution. Percentage data may not add up to 100% because figures have been rounded.

[a]Numbers have been revised to include additional Asians and Pacific Islanders that were previously counted in the "other races" category.

[b]The other races category is primarily a count of persons who marked "other race" on the 1980 Census questionnaire and wrote in entries (e.g., Cuban, Puerto Rican, Latino, Mexican, Dominican). In 1980, at the state level, this category represented a tabulation of 67,154 Spanish persons who considered themselves racially Spanish, and 9,402 additional responses that could not be classified elsewhere.

[c]Spanish origin is not a race category. Persons of Spanish origin may be of any race and are counted in the other racial categories shown in footnote b.

[d]Minority group consists of all races other than White, plus those Whites of Spanish origin.

[e]The 1983 estimates of population by race are from the Office of Financial Management (State of Washington, 1983a).

Table 3-40. Selected social characteristics of Benton and Franklin Counties and the State of Washington: 1980

Social characteristic	Benton County	Franklin County	State of Washington
Median age, yr	28.1	26.7	29.8
Crime rate per 100,000 resident population, July 1, 1981	4,472	7,917	6,579
Persons over 25 yr			
With 12+ yr education	81.3%	71.8%	77.6%
With 16+ yr education	22.6%	12.5%	19.0%
Civilian labor force in 1980 employed in professional and related services	15.5%	13.8%	20.3%
Median household income for 1979	$25,472	$20,989	$21,696
Families with income below poverty level	5.6%	10.4%	7.2%

NOTE: Based on data from the U.S. Bureau of the Census (BOC, 1983).

Table 3-41. Selected social characteristics of the Tri-Cities: 1980

Social characteristic	Richland	Pasco	Kennewick
Population 65+ yr	7.9%	10.3%	5.8%
High school graduate	86.7%	65.0%	81.0%
Below poverty level	5.0%	17.1%	9.2%
Median household income for 1979	$25,388	$15,956	$21,145
Black population	1.4%	7.9%	0.5%
Spanish origin	2.1%	20.8%	4.1%

NOTE: Based on data from the U.S. Bureau of the Census (BOC, 1983).

(Benton and Franklin) are governed by a board of three county commissioners. There are nine incorporated cities in these two counties. A substantial, although declining, portion of the land area in the two counties remains unincorporated. The major cities of Richland, Pasco, and Kennewick, Washington, each utilize the council-manager form of government, while the remaining municipalities are governed by a mayor and city council. Population and economic growth on the fringes of the incorporated areas, as well as the proximity of the Tri-Cities, has led to efforts to develop joint programs to coordinate service provision and to provide services to residents of the urbanized unincorporated areas.

Fiscal conditions in this study region can be understood in terms of the various governing bodies and taxing authorities that collect revenues and expend them for community services. The major revenue collecting bodies include the two counties, the three cities of Richland, Kennewick, and Pasco, Washington, and various utilities and other smaller municipalities within the two counties. Because of the large metropolitan base of the Tri-Cities and its associated administrative complexity and experience, the fiscal structure and capability of the region have been well adapted to the socioeconomic conditions that are characterized by rapid change. Thus, in the past growth periods, the fiscal effects of maintaining revenues in balance with expenditures, while ensuring an equitable distribution of fiscal benefits throughout the region, have been adequately handled. It is currently less clear how the fiscal institutions of the region will be able to manage a period of rapid decline in economic activity and population.

Most of the Hanford Site, including the proposed location for a repository, is within the boundaries of Benton County (see Fig. 3-37). The Hanford Site falls under the jurisdiction of the Federal Government. The Federal Government activities on the Hanford Site are tax-exempt, and there is no compensation for property taxes lost due to the tax-exempt status of the site. However, the U.S. Department of Energy contractors on the Hanford Site pay sales and use taxes and business and occupation taxes in accordance with the requirements of laws of the State of Washington.

The Tri-Cities have received the major portion of the population growth and economic prosperity associated with past nuclear development activities at the Hanford Site. They also have experienced the bulk of the fiscal effects from these major projects. In the Tri-Cities, total operating revenues increased more rapidly between 1975 and 1981 than did the population in all three cities (Table 3-42). Richland and Kennewick, Washington, displayed higher rates of growth in revenue than Pasco. In Richland, revenue grew much faster than population during this period. Based on this experience, it appears that the bicounty region is quite adaptable from a fiscal standpoint. Neither per capita revenues nor expenditures were reduced during the growth phase, implying a maintenance of adequate service levels.

Table 3-42. Comparison between average rates of increase in population, revenues, and expenditures: 1975 to 1981

Fiscal condition	Counties		Tri-Cities		
	Benton	Franklin	Richland	Kennewick	Pasco
Population change[a]	43,746[b]	9,225[b]	7,100[c]	18,500[c]	4,650[c]
Average annual rate of population increase[a]	6.2%	3.7%	3.0%	9.5%	3.6%
Average annual rate of revenue change[d]	9.2%	2.4%	7.4%	10.2%	4.3%
Average annual rate of expenditure change[d]	10.9%	3.6%	11.6%	16.2%	3.8%

[a]1973 to 1981.
[b]Based on data from Table 3-26.
[c]Based on data from Table 3-27.
[d]Based on data from Cluett et al. (1984, Tables 5-18, 5-19, 5-20, and 5-21). These supporting data are expressed in constant 1981 dollars.

7 0 1 6 8 0 8 4 5

Between 1975 and 1981, total operating revenues in real terms (1981 dollars) for Benton County grew much more rapidly than the revenues for Franklin County; this reflects the distribution of the new population during the period. Benton County received approximately 80 percent of the total bicounty population increase and approximately 85 percent of the total revenue increase experienced between 1975 and 1981.

A decline in revenues and expenditures was expected in 1981, in keeping with the decline in economic activity and population that began in mid-year. However, expenditures were higher in Richland and in the region as a whole in 1981 than in 1980. This may be due to a lag effect between the beginning of the decline and programs designed and implemented at an earlier date to accommodate an increasing population. It also may be due to increased need for community services during periods of high unemployment. Since Benton County and the cities of Richland and Kennewick, Washington, had the greater growth associated with Hanford Site activities, they are likely to experience the greater decline during the current downswing in the economy.

3.6.6 AFFECTED INDIANS

Section 2(2) of the Nuclear Waste Policy Act of 1982 defines an affected Indian Tribe as any Indian Tribe:

"(A) within whose reservation boundaries a monitored retrievable storage facility, test and evaluation facility, or repository for high-level radioactive waste or spent fuel is proposed to be located;

"(B) whose federally defined possessory or usage rights to other lands outside of the reservation's boundaries arising out of congressionally ratified treaties may be substantially and adversely affected by the locating of such a facility; Provided, that the Secretary of the Interior finds, upon petition of the appropriate governmental officials of the tribe, that such effects are both substantial and adverse to the tribe; . . . "

In a letter dated March 30, 1983, the U.S. Department of the Interior certified that under Section 2(2)B of the Nuclear Waste Policy Act of 1982, the Yakima Indian Nation is an affected Indian Tribe (DOI, 1983b). This finding was based on the potential impact that the proposed repository at the Hanford Site could have on the negotiated off-reservation fishing rights of the Yakima Indian Nation.

The Confederated Tribes of the Umatilla Indian Reservation have also been granted the status of an affected Indian Tribe by the U.S. Department of the Interior. In a letter to the U.S. Department of Energy on July 13, 1983, the U.S. Department of the Interior cited the potential impacts on the off-reservation fishing rights of the Tribe as the basis for granting such status (DOI, 1983a).

On September 17, 1984, the U.S. Department of the Interior issued a letter granting the Nez Perce Indian Tribe the status of an affected Indian Tribe (DOI, 1984). This finding was based on existing treaty rights that specify Indian fishing rights at reserved fishing locations of the Columbia River Basin, and the potential for adverse impacts should a repository be developed on the Hanford Site.

Each of the three reservations discussed in this section is located well beyond the boundaries within which primary work-force-related socioeconomic impacts are forecasted to occur. To date, none of the three affected Indian Tribes has experienced significant economic participation in the activities at the Hanford Site or the Tri-Cities area. However, designation as potentially affected Tribes has resulted in their active participation in review, monitoring, and assessment of the potential consequences of the commercial repository program.

The locations of the three reservations and the Hanford Site are shown in Figure 3-51. The Hanford Site is located on lands ceded to the United States Government by the Yakima and Umatilla Indians and is adjacent to lands ceded by the Nez Perce Indians. The Hanford Site contains or is near reserved fishing locations for the Yakimas, Umatillas, and Nez Perces, and areas sacred to these Tribes.

The ceded lands and reservations of the affected Indian Tribes are shown in Figure 3-52.

Within native North America, the people between the Cascade Mountains and the northern Rocky Mountains made distinctive adaptations to semiarid steppeland environment ringed by mountains and incised by the Columbia River drainage system. The particular subsistence practices emphasized a way of life that followed a seasonal round of fishing, hunting, and gathering of natural foods. Common religious beliefs and social practices resulted from the mutual cross-utilization of subsistence resources. These particular beliefs and practices refer to the aboriginal Plateau culture area.

The three affected Tribes are members of the aboriginal Plateau Indian culture and share a tradition of seasonal fishing, hunting, and gathering over large areas of the Columbia Basin that are now parts of the states of Washington, Oregon, and Idaho. Elements of this traditional Plateau culture have been kept alive to varying degrees among present day members of these Indian groups. As a consequence, it is generally acknowledged that these American Indians are culturally distinct from the White population living near them.

The traditional religious beliefs of the affected Indian Tribes share many common elements. All are integrally tied to the guardian spirit concept and to shamanistic curing. Basic beliefs are contained in an extensive body of mythical oral literature. Important beliefs include the following:

- The Earth and its natural resources are inherently sacred.
- Guardian spirits are essential to health and good fortune.

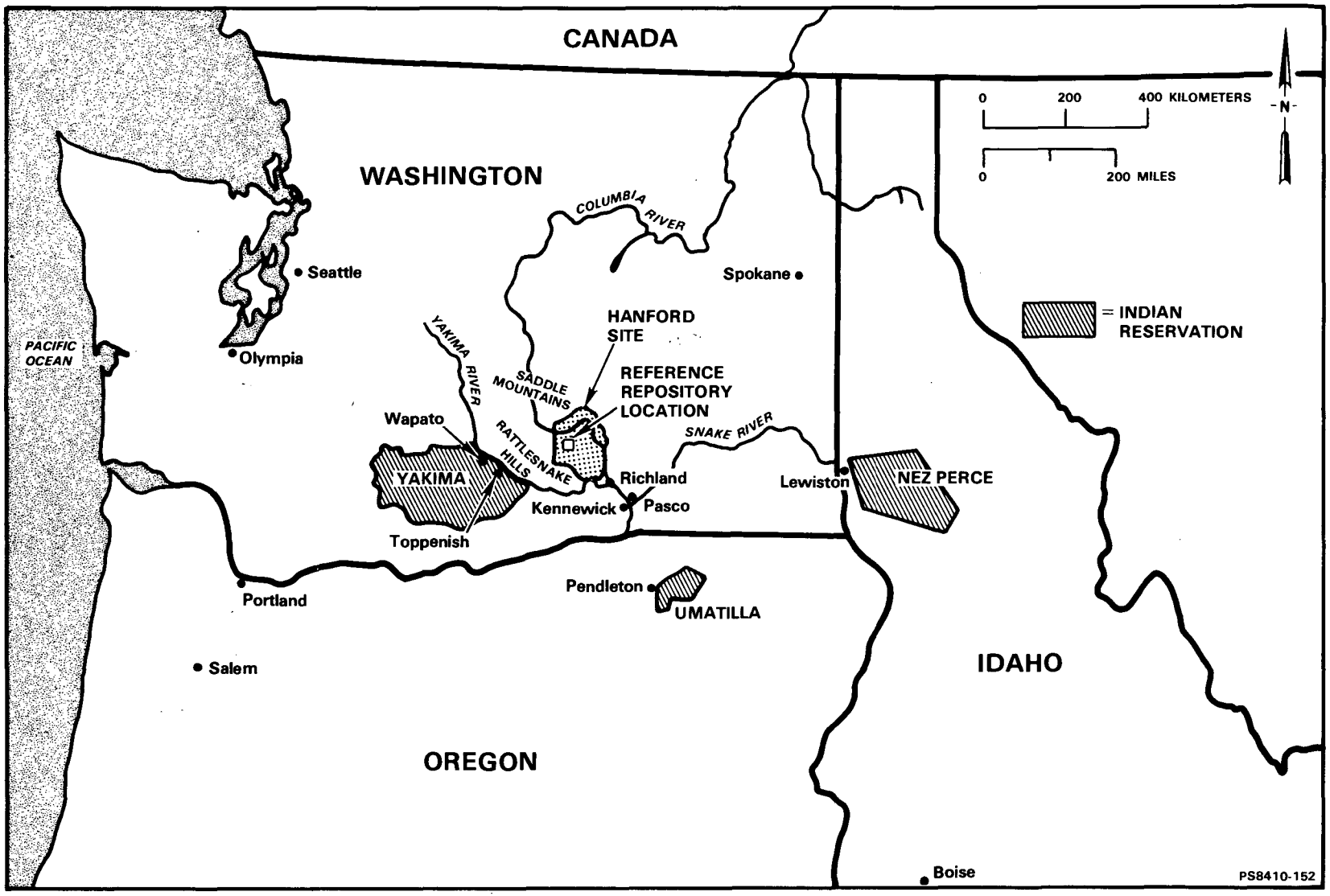

Figure 3-51. Locations of reservations of affected Indian Tribes.

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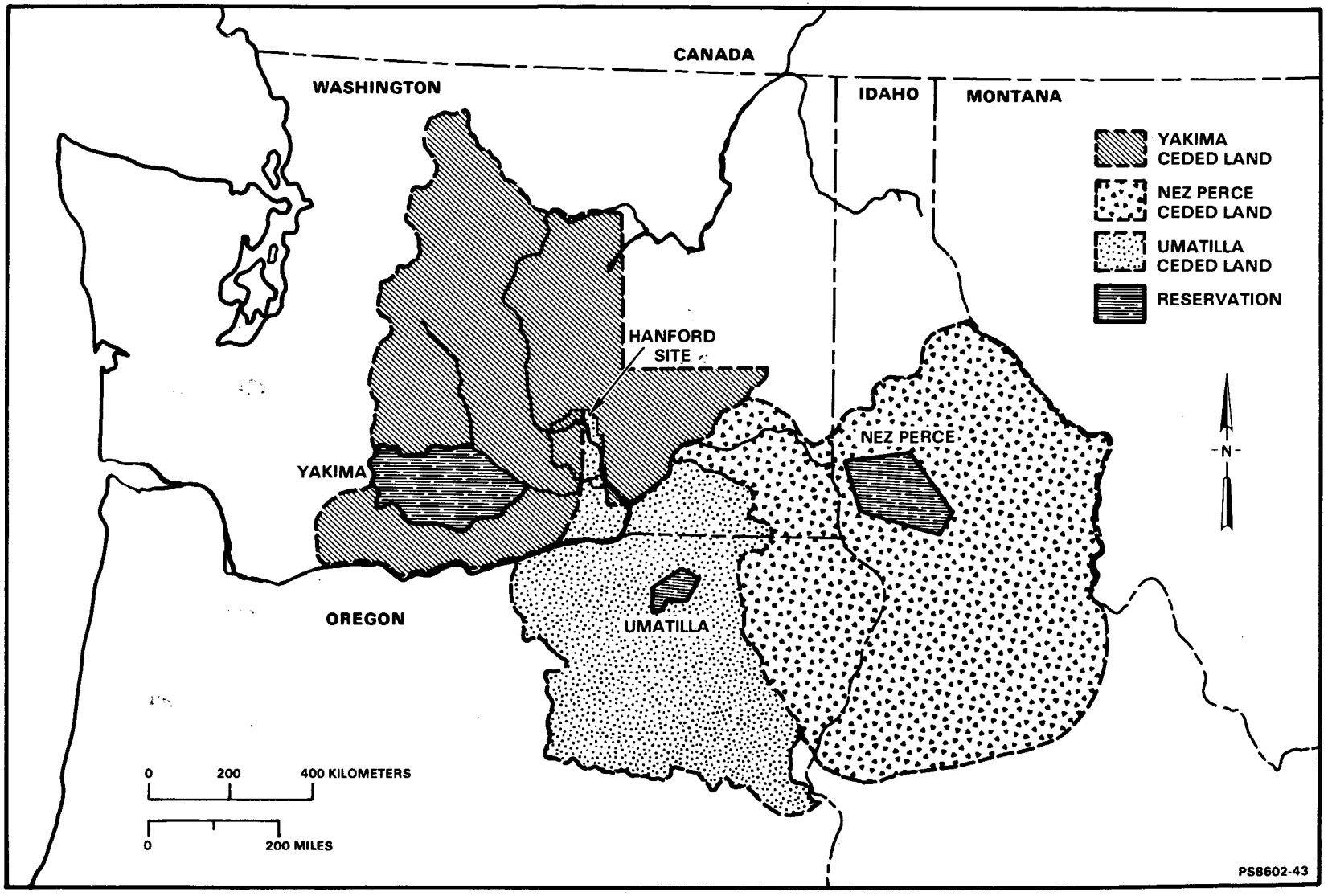

Figure 3-52. Ceded lands and reservations of affected Indian Tribes.

7 0 1 6 8 0 8 4 0

- Illness and misfortune are caused by malevolent spirit powers or soul loss.

- Disturbances to the Earth cause disruption in the spirit world.

The principal calendrical rituals are the Root Feast and the Salmon Feast. Longhouse ceremonialism, incorporating many of these beliefs and involving first foods feasts, marriages, funerals, memorials, and namings, is well established in the reservation communities of the affected Tribes today. The Gable Mountain locality on the Hanford Site was used by Indians as a traditional guardian spirit quest site. While major site-characterization or repository activities are not planned for Gable Mountain, the locality is now being evaluated for archaeological resources. The U.S. Department of Energy plans to consult with Indian leaders on religious and cultural issues during site characterization.

3.6.6.1 Reservation setting for the Confederated Tribes and Bands of the Yakima Nation

The Yakima Indian Reservation occupies about 567,000 hectares (1.4 million acres) in the Yakima Valley of south-central Washington. Tribal headquarters are located in Toppenish, Washington. In 1974, approximately 62 percent of the reservation was Tribally owned, with the balance in individually allotted lands to Tribal members (20 percent) and non-Indian owned lands (18 percent) (DOC, 1974). The Tribe has gradually been adding land to its holdings. Yakima, Washington is located 10 kilometers (6 miles) north, and Richland, Washington, about 64 kilometers (40 miles) east of the reservation. The reference repository location is approximately 50 kilometers (30 miles) east of the Yakima Indian Reservation boundary (see Fig. 3-51).

The Yakima Indian Reservation includes an environmentally diverse area from Mount Adams (3,752 meters (12,307 feet) in elevation) on the Cascade Mountain crest to the Yakima River at Mabton, Washington (218 meters (715 feet) in elevation). The western half of the reservation includes 250,000 hectares (625,000 acres) of forested timberland, with the eastern half divided almost equally between sagebrush/cheatgrass rangeland and partially irrigated agricultural cropland. These habitats and land-use areas include soils classified as Inceptisols (suborder Andepts) for the higher elevations, and Mollisols (suborder Xerolls) and Aridisols (suborder Orthids) for lower elevations. Major water resources include the Yakima and Klickitat Rivers, which are important for crop irrigation and as anadromous fisheries.

Estimates of Tribal population size and employment vary. In 1985, the Indian population of the Yakima Reservation was estimated to be about 8,000, with the principal settlements located more than 50 kilometers (30 miles) from the reference repository location. Indians are numerically a minority on the reservation, however. Unemployment on the reservation has ranged up to 71 percent. Approximately 1,200 Tribal members were estimated to be employed in early 1985.

The reservation economy is based principally in forest products, agriculture, and livestock. The Yakima Tribe receives income from timber sales, land leases for agriculture and grazing, industrial land leases for businesses, and has a major investment in salmon fisheries. Resources on the reservation include 250,000 hectares (625,000 acres) of forest, rangeland for 8,000 head of cattle, and over 57,500 hectares (142,000 acres) of irrigable land. The Yakima River provides salmon fisheries and potential hydroelectric sites. A 32-hectare (80-acre) industrial park with wood products related tenants is located on the reservation, and other small industries and businesses are scattered throughout the reservation. Transportation resources include Interstate 82 and 560 kilometers (350 miles) of paved roads; rail services are available in the major centers (Mabton, Toppenish, and Wapato, Washington), with a branch line to Zillah and White Swan, Washington. Health care and education services are available in Toppenish.

The traditional culture of the Yakima Indian people is varied. The Confederated Tribes and Bands of the Yakima Nation are comprised of 14 aboriginally distinct groups, including speakers of Sahaptian, Salishan, and Chinookan language families. The traditional beliefs of all of these Plateau Indians placed great value on the land and its natural resources. These beliefs were traditionally expressed through renewal rituals like the annual Salmon Feast and Root Feast. These ceremonial practices survive today as evidence for the vitality of the traditional religions.

The major treaty affecting the Yakimas was the Treaty of 1855. Following the Walla Walla Treaty Council of 1855 that established the treaty, but before the treaty could be ratified, the Yakima War broke out. It was not until after the war, in 1859, that the Treaty of 1855 with the Yakimas was ratified by Congress and signed into proclamation by President Buchanan. The treaty contains eleven articles that established the terms of the agreement between Confederated Tribes and the Federal Government concerning land cessions, establishment of the present reservation, compensation, land disposition and usage, and other conditions.

The Hanford Site is located in part on lands ceded to the United States Government by the Yakimas as part of the 1855 treaty agreement (see Fig. 3-52). As part of their treaty agreement, the Yakimas were granted sovereign status, and were generally assured the right to fish at all their usual and accustomed places. The treaty also extended the privilege of hunting, gathering of roots and berries, and pasturing of livestock on open and unclaimed areas of their traditional lands. The Hanford Site is a secured facility operated by the U.S. Department of Energy in the interest of national security and does not fall within the category of open and unclaimed land.

3.6.6.2 Reservation setting for the Confederated Tribes of the Umatilla Indian Reservation

The Umatilla Indian Reservation occupies approximately 70,000 hectares (172,000 acres) west of the Blue Mountains in northeastern Oregon. The Tribal headquarters are in Mission, Oregon, while the Umatilla County seat and trade and service center are located in Pendleton, Oregon, approximately 0.8 kilometer (0.5 mile) west of the reservation boundary. In 1974, approximately 6 percent of the reservation land was Tribally owned, about 29 percent individually allotted to Tribal members, and 65 percent was non-Indian owned lands (DOC, 1974). The boundary of the Umatilla Reservation is approximately 120 kilometers (75 miles) southeast of the Hanford Site (see Fig. 3-51).

The Umatilla Indian Reservation extends from the western flanks of the Blue Mountains (approximately 1,200 meters (4,000 feet) in elevation) to the Umatilla River near Pendleton, Oregon (320 meters (1,068 feet) in elevation). Much of the southeastern portion of the reservation is heavily timbered, whereas the northern and western cropland and pasture areas are rolling plains dissected by the east-west trending Umatilla River valley. Soils on the Umatilla Reservation are mostly Mollisols (suborder Xerolls), supporting steppeland grasses at lower elevations and conifer forest at higher levels. The Umatilla River, a tributary of the Columbia River, is the key water resource. Its tributaries provide extensive steelhead spawning and rearing habitat.

In 1985, Tribal population was estimated to be about 1,500, with settlements at a distance of more than 120 kilometers (75 miles) from the reference repository location. Unemployment has run between 39 percent and 47 percent on the reservation. Approximately 400 Tribal members were estimated to be employed in 1985.

The reservation economy is based substantially on agriculture. The Umatilla Tribe derives income from a Tribal farming enterprise and a Tribal leasing enterprise. Tribal lands provide resources for livestock grazing, timber harvest, and recreation. Tributaries of the Umatilla River have been recently targeted for upriver fall Chinook and spring Chinook enhancement projects. Economic activity on the reservation includes a new grain elevator, a Tribal bingo operation, and farming. Several projects are proposed, most significantly a 260-hectare (640-acre) industrial park located on the reservation along Interstate 84. Other available transportation resources include the Union Pacific Railroad, Amtrack, Pendleton Municipal Airport, and the Port of Umatilla on the Columbia River. The Tribe provides outpatient health care and contracts with the local hospital and medical clinics for inpatient care. Education is provided primarily by three local school districts (Pendleton, Athena-Weston, and Pilot Rock, Oregon).

The Indian people of the Umatilla Reservation traditionally comprised the Sahaptian-speaking Umatilla and Walla Walla bands, and the linguistically distinct Cayuse. Like other Plateau Indian groups, these bands viewed the earth as holy and derived their subsistence from the fruits of the earth. All groups observed annual renewal rituals commemorating the first

roots of the season or the first salmon taken. The Salmon Feast and Root Feast are elements of the traditional religion that have survived to the present.

In 1855, the Umatilla, Cayuse, and Walla Walla bands signed a treaty with the Territorial Governor that was ratified by Congress in 1858 and proclaimed by the President in 1859. Through this treaty, the Confederated Bands ceded their aboriginal homelands in what is now southeastern Washington and northeastern Oregon and the present Umatilla Reservation was established (see Fig. 3-52). As with the Yakimas, the 1855 Treaty with the Confederated Bands contained eleven articles that delineated the terms of the agreement.

The Hanford Site is located in part on lands ceded to the United States Government by the Umatillas as part of the 1855 treaty agreement (see Fig. 3-52). As part of their treaty agreement, the Umatillas were granted sovereign status, and were generally assured the right to fish at all their usual and accustomed places. The treaty also extended the privilege of hunting, gathering of roots and berries, and pasturing of livestock on open and unclaimed areas of their traditional lands. The Hanford Site is a secured facility operated by the U.S. Department of Energy in the interest of national security and does not fall within the category of open and unclaimed land.

3.6.6.3 Reservation setting for the Nez Perce Indian Tribe

The Nez Perce Indian Reservation is situated in the counties of Nez Perce, Lewis, Clearwater, and Idaho in north-central Idaho. The principal Tribal headquarters is located at Lapwai, Idaho, with another center at Kamiah, Idaho. The reservation consists of approximately 306,000 hectares (757,000 acres), of which about 11.5 percent is Tribally owned. About 20,667 hectares (51,000 acres) are individually allotted to Tribal members. Lewiston, Idaho, is approximately 8 kilometers (5 miles) from the reservation boundary (see Fig. 3-51), about 200 kilometers (135 miles) from the reference repository location.

The Nez Perce Indian Reservation is composed of plateaus and mountains that are cut by many canyons. Elevations range from 200 meters (700 feet) to approximately 1,300 meters (4,000 feet). Loess-covered plateaus lie in the north and central areas. South of these plateaus are the Blue Mountains and to the east are the northern Rocky Mountains. From these mountains the Clearwater, Salmon, Imnaha, and Grande Ronde Rivers flow into the Snake River. Forty-three percent of the Nez Perce Indian Reservation is used for agriculture, 32 percent is commercial timber, and 24 percent is pasture. Approximately 45 hectares (112 acres) of the agricultural land are currently being irrigated. Conifer forest vegetation is typical of higher elevations. Former camas meadows are now cultivated on the Camas Prairie. Steppeland grasses characterize the vegetation of valleys and bottomlands. Streams throughout the reservation support anadromous fish.

The Indian population of the Nez Perce Indian Reservation in 1985 was estimated to be between 2,000 and 3,000. Resources on the reservation include over 10,000 timbered hectares (25,000 acres), much of this managed under the Tribal Forest Development Program. There are approximately 15,000 hectares (37,000 acres) of dryland crop production on the reservation, farmed mostly by non-Indians. Dworshak Reservoir and the Clearwater River are the primary water resources. The Nez Perce Tribe operates a printing and publications shop, a limestone quarry, a marina located in Orofino, Idaho, and a merchandise and grocery store. Nonetheless, unemployment among Tribal members in 1985 was estimated at approximately 64 percent of the available work force. Transportation resources include U.S. Highway 12 which runs east-west through the reservation; train, bus, and truck lines have stops on the reservation. Lewiston is served by commercial airlines and is the only seaport in Idaho. Health care is available primarily from the Lewiston Community Hospital.

The traditional culture of the Nez Perce Indians was similar to other Plateau peoples like the Umatillas and Yakimas. The Nez Perces were Sahaptian speakers who shared the same basic religious elements of the Salmon Feast and Root Feast. Missionary activity among the Nez Perces during the 19th century, however, had the effect of dividing ethnic unity. As a result of White encroachment and increasing religious disunity, the Nez Perce War of 1877 occurred. The Nez Perces are best known for the brilliant maneuvers of Chief Joseph during this war. Many of the traditional Nez Perces were later relocated to the Colville Reservation.

The original Nez Perce reservation was established by the Walla Walla Treaty Council in 1855. Since the United States did not make any subsequent treaties in which all bands were present and able to speak for themselves, the fundamental rights of the Nez Perce Tribe and the obligations of the Federal Government to the Nez Perces stem from the Treaty of 1855. As with the Yakimas and Umatillas, this treaty includes eleven articles that delineate the conditions, rights, and obligations of the agreement between the Nez Perces and the United States Government.

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CHAPTER 4 SUMMARY

A detailed understanding of the geologic and hydrologic conditions of the reference repository location is needed to determine its suitability for waste disposal. Such an understanding is possible through site characterization. Chapter 4 summarizes those site-characterization activities expected to affect the environment and the local communities.

Section 4.1 outlines the activities associated with planned field studies, the exploratory shaft program, and other studies that would constitute site characterization. The overall emphasis of the field studies would be to reduce uncertainty concerning the geologic system and the ground-water flow system, so that compliance with the regulatory criteria can be examined. Work activities include the following:

- Lithologic characterization--To characterize the stratigraphy, intraflow structures, primary fractures, and mineralogy-petrology of the basalt sequence within and in the vicinity of the reference repository location.

- Tectonic characterization--To define the past, present, and projected structural and tectonic setting of the reference repository location.

- Hydrologic parameter testing--To identify the surface boreholes and hydrologic tests that characterize ground-water flow paths within and surrounding the reference repository location. This information is important to understanding ground-water travel times and radionuclide migration to the accessible environment.

- Ground-water monitoring--To identify the basic strategy and boreholes needed for acquiring hydraulic head data across the reference repository location and vicinity.

- Hydrochemical studies--To characterize the ground-water chemistry within the reference repository location and vicinity and the transport characteristics of significant radionuclides along likely ground-water flow paths from the repository.

The discussion of the exploratory shaft program describes activities related to shaft construction, testing, and final disposition. Briefly, a Phase I shaft will be sunk to provide access to the Cohassett flow. A Phase II shaft will be drilled 152 meters (500 feet) south of the Phase I shaft to meet U.S. Department of Energy safety requirements. A shaft station will be constructed in the candidate horizon in the Phase I shaft to allow in situ characterization and expansion of underground facilities. In situ studies will include geologic, hydrologic, and geomechanics tests. Final disposition of shaft facilities has not been determined; alternative uses are presented.

Laboratory studies will be performed as integral parts of the field activities. In addition, socioeconomic, environmental, meteorological, and archaeological studies conducted in conjunction with site characterization will update projections on the expected effects of repository-related activities.

Section 4.2 covers the expected effects from activities associated with planned site characterization. Section 4.2.1 discusses potential impacts that site-characterization activities are expected to have on the physical environment. These include potential impacts to the local geologic, hydrologic, and environmental settings. Drilling of the shafts is expected to have no significant adverse impact on the geology of the site. Drilling of the shafts will not result in effluent discharges to surface waters. Also, because of the insolubility of basalt, no adverse impacts are expected to occur as a result of leachate from the spoils pile. On the other hand, the drilling of the shafts could affect the local ground-water environment.

Potential impacts on the environmental setting as a result of site characterization are discussed in terms of the ecosystem, air quality, noise, aesthetics, archaeological, cultural and historical resources, and radiological effects. Included in this discussion is a table that summarizes the expected impacts on native biota due to site-characterization activities. Adverse environmental impacts are expected to be minimal, with the most significant potential from construction at the exploratory shaft site.

The potential socioeconomic (Section 4.2.2) effects of site characterization are projected in terms of population distribution, economic conditions, community services, social conditions, fiscal conditions and government structure, and land use, access, and surface and mineral rights. The relatively small projected population growth associated with site characterization is forecast to have negligble impacts on the local communities.

Section 4.2.3 discusses potential transportation effects due to site characterization. Transportation effects during site characterization are expected to be minimal. Such expected effects will result from construction of an additional access road to the exploratory shaft and operation of motor vehicles by project personnel.

Section 4.2.4 discusses occupational safety and health concerns related to site characterization. The principal risks will be similar to those associated with most underground mining operations.

Much of the information presented in this chapter references background data presented in Chapters 2 and 3. Chapter 5 will discuss the expected effects of actually locating and operating a repository at the Hanford Site, and is structured similarly to Chapter 4. Table 4-A provides a cross-reference matrix to direct the reader to sections in the rest of the document related to topics presented in this chapter.

Table 4-A. Sections related to Chapter 4 discussions

	Chapter 2	Chapter 3	Chapter 4	Chapter 5	Chapter 6
Field studies			4.1.1		
Lithologic characterization	2.1.1.1/2.1.1.2	3.2.2/3.2.3	4.1.1.1		
Tectonic characterization	2.1.2	3.2.3	4.1.1.2		6.3.1.7/6.3.3.4
Hydrologic parameter testing		3.3.2	4.1.1.3		6.3.1.1
Ground-water monitoring	2.1.4	3.3.2	4.1.1.4	5.2.1.2.2	6.3.1.1
Hydrochemical characterization	2.1.4.1	3.3.2	4.1.1.5		6.3.1.1
Exploratory shafts			4.1.1.6		6.3.3.2.6
Surface-water hydrology	2.1.3	3.3.1	4.1.1.7	5.2.1.2.1	
Other activities			4.1.2		
Laboratory tests			4.1.2.1		
Socioeconomic activities	2.3.9*	3.6	4.1.2.2/4.2.2	5.2.3	6.2.1.7/6.2.2.2
Environmental studies	2.3.8*	3.4	4.1.2.3/4.2.1.3	5.2.1.3	6.2.1.6/6.2.2.2
Geochemistry studies			4.1.2.4		6.3.1.2
Expected effects on the physical environment			4.2.1		
Geology	2.1.1	3.2	4.2.1.1	5.2.1.1	
Hydrology	2.1.3/2.1.4	3.3	4.2.1.2	5.2.1.2	6.3.1.1/6.3.3.3
Environmental setting	2.3.8*	3.4	4.1.2.3/4.2.1.3	5.2.1.3	6.2.1.6
Socioeconomic effects	2.3.9*	3.6	4.1.2.2/4.2.2	5.2.3	6.2.1.7/6.2.2.2
Population distribution	2.3.6	3.6.1	4.2.2.1	5.2.3.1	6.2.1.2
Economic conditions		3.6.2	4.2.2.2	5.2.3.2	
Community services		3.6.3	4.2.2.3	5.2.3.3	
Social conditions		3.6.4	4.2.2.4	5.2.3.4	
Fiscal conditions and government structure		3.6.5	4.2.2.5	5.2.3.5	
Land use, access, and surface and mineral rights		3.4.1	4.2.2.6	5.2.3.6	6.2.1.1/6.2.1.3/ 6.3.1.8
Transportation impacts		3.5	4.2.3	5.2.2/5.1.7	6.2.1.8/6.2.2.2
Occupational safety and health risks			4.2.4	5.3	6.3.3.2
Alternative site-characterization activities			4.3		6.3.3.2.6

*Disqualifier analysis.

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Chapter 4

EXPECTED EFFECTS OF SITE-CHARACTERIZATION ACTIVITIES

Extensive geologic and hydrologic data must be collected before a site can be selected for repository development. Sufficient data have not been collected at any of the five nominated sites to make such a judgment possible. Therefore, the U.S. Department of Energy will carry out a site-characterization program to collect the needed data. Such a program is required by the Nuclear Waste Policy Act of 1982, the regulations for repositories promulgated by the U.S. Nuclear Regulatory Commission in 10 CFR 60 (NRC, 1985), and the implementation guidelines that are included in the General Siting Guidelines (DOE, 1984b). In accordance with the Nuclear Waste Policy Act of 1982, the program will be carried out at the three sites selected by the process described in Chapter 1. This chapter describes the potential effects that site characterization could have on the environment if the site is one of the three selected.

A significant part of site characterization will be the investigations performed in an exploratory shaft facility. At each of the three sites, one or more shafts will be sunk below the surface, to the level where a repository could be built. Underground drifts connecting these shafts and underground rooms will be excavated. In these shafts and rooms, the U.S. Department of Energy will conduct tests and take measurements that will supply data needed to characterize the site.

Field studies of the site also will take place during site characterization. These include geologic and hydrologic investigations at ground surface and in boreholes not connected with the exploratory shaft facility, surveys of soil conditions, and monitoring of seismic activity.

Concurrent with site characterization, the U.S. Department of Energy will conduct a site-investigation program to collect nongeotechnical information. Included will be studies of environmental conditions (e.g., meteorology, air quality, plant and animal communities, and noise levels), archaeological, cultural, and historical resources, population density and distribution, transportation network, and social and economic conditions in the area that could be affected by the repository.

Before sinking exploratory shafts, the U.S. Department of Energy is required by the Nuclear Waste Policy Act of 1982 to prepare a site-characterization plan that includes (1) a description of the site, (2) a description of the site-characterization activities, including the extent of planned excavations and plans for any onsite testing, and (3) plans for the decommissioning of the exploratory shaft facility, as well as the mitigation of any significant adverse environmental impacts caused by site characterization if the site were not selected for repository development. This plan will be submitted for review and comment to the U.S. Nuclear Regulatory Commission, the Governor and the legislature of the State, and the governing body of any affected Indian Tribe; it also will be made available to the public. Furthermore, the

Nuclear Waste Policy Act of 1982 requires the U.S. Department of Energy to hold public hearings in the vicinity of the site selected for characterization. The purpose of the hearings will be to inform residents of that area of the site-characterization plan and to receive their comments. During the site-characterization program, the U.S. Department of Energy is required by the Nuclear Waste Policy Act of 1982 to report at least once every 6 months to the U.S. Nuclear Regulatory Commission, the State, or the affected Indian Tribes the nature and extent of site characterization.

4.1 SITE-CHARACTERIZATION ACTIVITIES

This section discusses characterization activities that are planned for the reference repository location. The Nuclear Waste Policy Act of 1982 defines site characterization as

> ". . . (A) siting research activities with respect to a test and evaluation facility at a candidate site; and (B) activities, whether in the laboratory or in the field, undertaken to establish the geologic condition and the ranges of the parameters of a candidate site relevant to the location of a repository, including borings, surface excavations, excavations of exploratory shafts, limited subsurface lateral excavations and borings, and in situ testing needed to evaluate the suitability of a candidate site for the location of a repository, but not including preliminary borings and geophysical testing needed to assess whether site characterization should be undertaken."

4.1.1 FIELD STUDIES

The overall emphasis of field studies would be to reduce uncertainty in the current understanding of the ground-water flow system and geologic environment so that compliance with regulatory criteria can be examined. This would require the development of the geohydrologic data base and conceptual and numerical models describing the geologic setting, ground-water movement, and potential for radionuclide transport. Steps in the development of a geohydrologic model are outlined in Figure 4-1. Much of the existing site data, as noted in this environmental assessment, have been summarized in other reports (e.g., Myers, Price et al., 1979; Gephart et al., 1979; Myers and Price, 1981; DOE, 1982; Long and WCC, 1984), or is based on results of work under way by the Basalt Waste Isolation Project staff or subcontractor personnel. Review of portions of this data base and investigation effort has been completed by several organizations, including the U.S. Nuclear Regulatory Commission (NRC, 1983), U.S. Geological Survey (Robertson, 1983), State of Washington (1983), and Pacific Northwest Laboratory (Burnham, 1983). The critiques provided by these organizations are being utilized in the development of plans and program strategy for site-characterization activities.

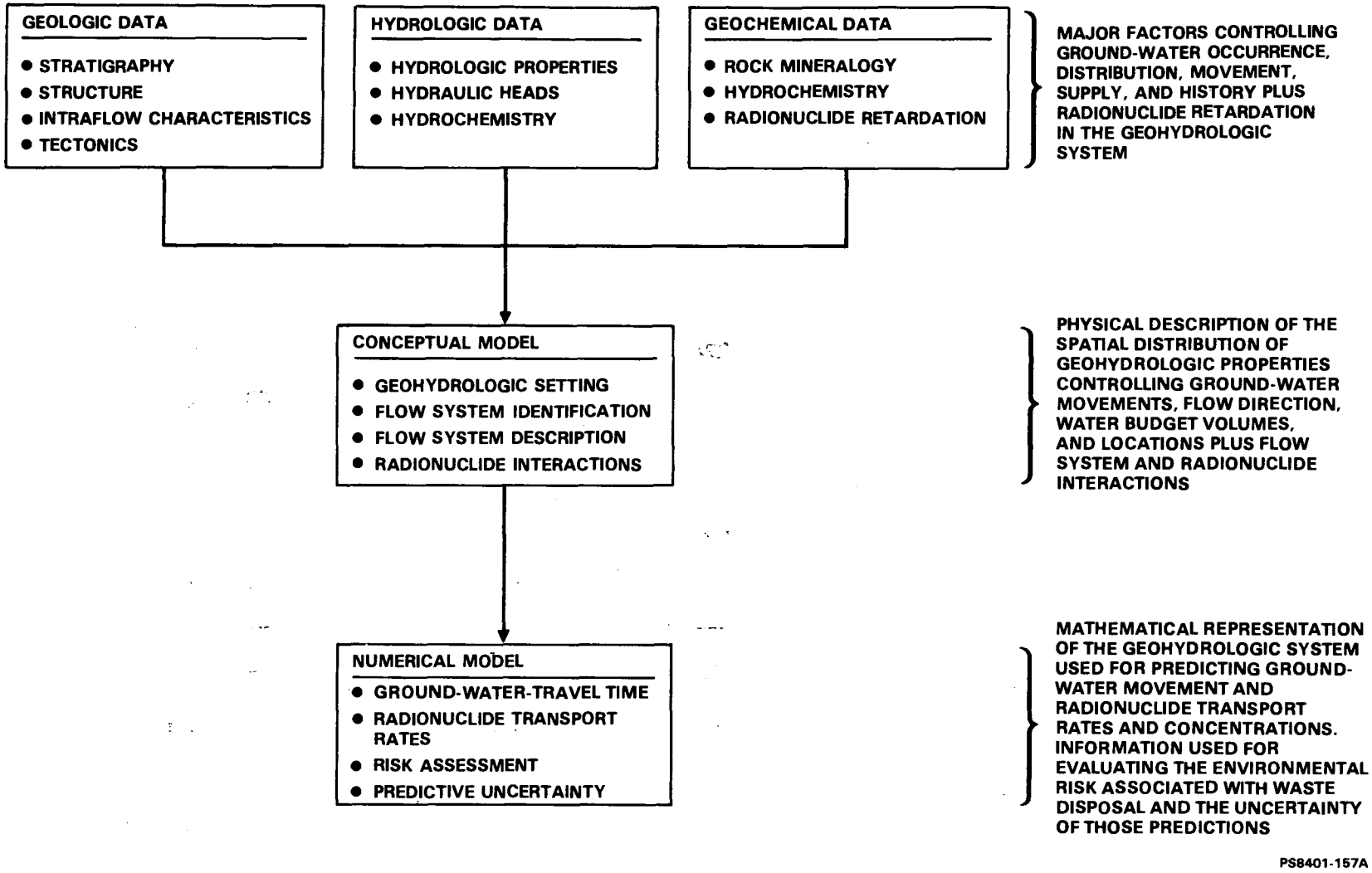

Figure 4-1. Development of a subsurface geohydrologic model.

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4.1.1.1 Lithologic characterization

The objective of these studies is to characterize the stratigraphy, intraflow structures, primary fractures, and mineralogy and petrology of the basalt flows within and in the vicinity of the reference repository location. Studies needed to define the lithologic characteristics of interbeds would also be included. Data needs for lithologic characterization would be met primarily by investigations of outcrops, core, and borehole logs and through laboratory studies of rock samples.

4.1.1.1.1 Stratigraphic setting

Stratigraphic studies would entail the acquisition and detailed interpretation of outcrop and borehole data within the Pasco Basin to refine the known stratigraphic framework and to determine more precisely the variations in thickness, geometry, and attitude (strike and dip) of basalt flows and interbeds. Analytical data would be used to identify and (or) confirm rock stratigraphic units, chemical stratigraphic units, magnetostratigraphic units, and borehole geophysical log stratigraphic units. Detailed study of field exposures of the Cohassett and adjacent flows would be oriented toward determining typical, short-range (tens of meters (feet)) and long-range (hundreds of meters (feet)) variations in flow thicknesses.

4.1.1.1.2 Intraflow structures

Studies of intraflow structures involve the acquisition and detailed interpretation of data relating to variations in flow top, flow interior, and other primary features, particularly for the Cohassett flow. Outcrop studies would entail examination of photographs and (or) maps of actual cliff exposures wherein intraflow structure variations could be directly measured. Intraflow structures in boreholes would be determined by detailed core logging, petrographic analysis, and borehole geophysics. Studies would include an evaluation of the kriging method to characterize statistically the thickness variations of intraflow structures within the candidate horizon adjacent flows.

4.1.1.1.3 Primary fracture characterization

Work would include an analysis of the orientation, distribution, aperture infilling, and origin of primary fractures, primary structural features, and heterogeneities within the Cohassett flow and surrounding strata. Fracture orientation and spacing data would be compared with petrographic data (quantitative model analysis and qualitative texture analysis) from surface exposures of the candidate horizon and surrounding strata. These data would be used to determine the extent to which petrography could be used to predict fracture spacing at depth from core samples by utilizing known fracture characteristics in surface exposures

and by primary fracture spacing from the core itself. Aperture infilling data would be obtained from detailed measurement of fracture width and estimation of relative proportions of infilling minerals in core samples.

4.1.1.1.4 Mineralogy and petrology

Work would include the characterization of the mineralogy and petrology of the Cohassett flow, adjacent flows, and interbeds. Composition of fracture aperture infillings (secondary minerals) would also be addressed. Such data would be provided by X-ray diffraction, electron microprobe, and optical and electron microscopy. Subsurface and surface data would be used to predict the mineralogical and petrological properties of the Cohassett flow, adjacent flows, and interbeds in and around the reference repository location and to serve as basic input to hydrochemical models.

4.1.1.2 Tectonic characterization

The objective of this work is to define the past, present, and projected structural setting of the reference repository location area and relationships between structural models and models of regional tectonics. Such data would be primarily fulfilled by geological, geophysical, and instrumental monitoring studies.

4.1.1.2.1 Structural setting

Geological and geophysical studies to characterize the structural setting of the reference repository location would be performed. Determinations of the locations, geometry, age, and evolution of secondary structures (e.g., faults, folds, secondary fractures) would be carried out through a combination of geologic mapping, paleomagnetic studies, kinematic modeling, borehole studies, trenching studies, and geophysical surveys within the Pasco Basin and vicinity. Study of selected areas within the region also would be conducted to enhance and support interpretations of more site-specific findings.

4.1.1.2.2 Contemporary deformation

Seismic surveillance and geodetic data would be utilized to assess the nature and magnitude of contemporary deformation in and around the reference repository location. This work would include continuation of regional seismic monitoring by a network of surface seismometers already established in eastern Washington. The regional network would be supplemented by portable and permanent surface and subsurface seismometers deployed to gather detailed data on microseismic activity within the Pasco

Basin, Cold Creek syncline, and reference repository location. The relationships between earthquakes and their causal mechanisms would be studied. Contemporary deformation data also would be provided by periodic resurveying of existing and newly established trilateration arrays and leveling stations within the Pasco Basin area.

4.1.1.2.3 Tectonic modeling

This item includes work to integrate all geological, geophysical, geodetic, and seismic data collected for site characterization. Work would involve a review and assessment of structural and tectonic models with specific application to the Pasco Basin and the reference repository location. Pertinent models would be evaluated in terms of their impact on preclosure and postclosure repository performance. Interpretations would serve as the basis for input to seismic design of a repository.

4.1.1.3 Hydrologic parameter testing

The objective of this work is to complete the hydrologic tests needed for evaluating those ground-water flow characteristics within and surrounding the reference repository location critical to understanding ground-water movement and possible effect of radionuclide migration to the accessible environment. Test facilities specifically designed for hydrologic testing would be used for characterization within and in the vicinity of the reference repository location. Elsewhere on the Hanford Site existing and planned boreholes would be tested. A limited number of wells located off the Hanford Site also may be drilled and (or) tested. These would be located in areas considered important to understanding the regional geohydrologic setting.

4.1.1.3.1 Large-scale hydrologic stress tests

Multiple-hole tests would be designed to stress selected flow tops and interbeds across large distances (several thousand meters (feet)). These tests would provide large-scale measurement of transmissivity and storativity. By monitoring hydraulic heads above, below, and within basalt flows, vertical leakage across basalt flow interiors may be estimated.

4.1.1.3.2 Small-scale hydrologic tests

Single borehole hydrologic tests stress rock volumes in the immediate vicinity of the borehole. Such tests are reconnaissance in nature and would provide small-scale measurement of transmissivity and hydraulic head measurements recorded on a progressive drill-and-test basis or following borehole completion.

4.1.1.3.3 Tracer tests

Single and multiple borehole tests would use conservative and, nonconservative (sorptive) tracers to provide estimates of effective porosity and dispersivity for selected basalt flow tops and interbeds. The use of low-level radioactive and nonradioactive tracers is planned. Using surface boreholes, the possibility of tracers moving from one flow top to another would be examined as a means of calculating the effective porosity and dispersivity of a flow interior. Tracer tests would be conducted as part of the large- and small-scale hydrologic testing.

4.1.1.3.4 Mud effects

These tests would evaluate the possible effect the drilling muds have had on past hydrologic test results in both low- and high-transmissive rock zones. Test results would assist in quantifying the uncertainty in previous hydrologic tests, which were mostly conducted on holes drilled with muds.

4.1.1.4 Ground-water monitoring

The ground-water monitoring studies would identify the basic strategy for acquiring hydraulic head data across the reference repository location and portions of the Columbia Plateau. In addition, these studies would determine borehole locations, stratigraphic intervals, and criteria on which monitoring frequency is established.

4.1.1.4.1 New piezometers

Locations would be identified where new piezometers are planned. This would include single and cluster piezometric sites. Data collected would center on understanding spatial and stratigraphic head distributions and their changes as a function of time. These data also would help evaluate the reliability of historical head data collected on a progressive drill-and-test basis.

4.1.1.4.2 Existing piezometers

The existing ground-water monitoring network would be maintained and expanded as new piezometers are available. A selection of existing boreholes open across several basalt flows presently have instrumentation installed for hydraulic head monitoring within one or more flow tops. Existing regional wells outside the Hanford Site that are suitable for monitoring have been identified and will be integrated into a regional monitoring network. If wells are unavailable outside the Hanford Site where head data are considered critical, new wells will be drilled.

4.1.1.4.3 Drill and test hydraulic heads

As exploratory boreholes are drilled, hydraulic heads would be measured on a progressive drill-and-test basis. Although intermittent head measurements are considered less reliable than those collected continuously in piezometers, such information would serve as a useful preliminary indication of local head distributions.

4.1.1.4.4 Bridge plug installations

In open, deep boreholes on the Hanford Site not undergoing active hydrologic testing or monitoring, bridge plugs would be installed in open sections to minimize fluid communication within the holes. This would reduce the chances of disturbing the natural hydraulic head patterns on the Hanford Site or in the reference repository location. Several of the deep boreholes on the Hanford Site have multiple-bridge plugs installed in them.

4.1.1.5 Hydrochemical characterization

Hydrochemical studies would characterize the ground-water chemistry beneath the Hanford Site and the transport characteristics of significant radionuclides along likely ground-water flow paths from the proposed repository. These studies will focus on the reference repository location and vicinity. Regional ground-water sampling data would be compiled from U.S. Geological Survey sources in areas where such data are considered important to understanding the chemical evolution and isolation potential of ground water near the proposed repository site and where comparative water-quality studies are needed.

4.1.1.5.1 Ground-water sampling

Sampling of ground waters from existing and new boreholes for determining the spatial and stratigraphic changes in mass chemistry, stable isotopes, radioisotopes, dissolved gases, and trace elements would be done. This information is needed to quantify the in situ ground-water environment for understanding its evolution and effect on waste transport.

4.1.1.5.2 Sampling techniques

Work is in progress to evaluate and improve, as necessary, ground-water-sampling techniques to assure high-quality samples. This includes estimation of the effects of drilling mud on sample quality and development of down-hole-sampling devices (see Subsection 4.1.1.3.4).

4.1.1.5.3 Radionuclide transport

Transport characteristics of significant radionuclides would be studied, including those properties that retard radionuclide migration (e.g., sorption, precipitation, filtration) and those that prevent retardation reactions from occurring (e.g., complexation, colloid migration). These transport characteristics would involve identification of key radionuclides, understanding interactions among waste, rock, and ground water and definition of the geohydrologic properties of likely flow paths for radionuclides. Using laboratory study data, measured field sorption characteristics of a select list of radionuclides would be extrapolated to other significant radionuclides.

4.1.1.5.4 Geochemical modeling

Numerical modeling of the ground-water chemistry would be conducted to understand its origin and evolution and the potential for future changes that may influence radionuclide transport.

4.1.1.6 Exploratory shafts

The exploratory shaft program is an extension of planned field studies that would involve the drilling of two 2.8-meter- (9.2-foot-) diameter shafts and excavation of underground drifts. This facility would provide access to the Cohassett flow for in situ geohydrologic and geomechanics characterization. Shaft and drift construction would address questions on the constructibility, rock stability, and ground-water-inflow conditions of a repository in basalt. Information gained would be combined with data collected from boreholes to develop a more thorough understanding of the actual subsurface environment of the candidate horizon and surrounding basalt flows. To be in compliance with DOE Orders 5480.1A and 5480.4 (DOE, 1981a, 1984a), two shafts would be required to assure personnel safety.

The exploratory shaft program is divided into two phases. Phase I consists of construction of a first shaft, porthole testing through the shaft casing, shaft station breakout, shaft station geomechanics testing, and geologic characterization. Phase II includes the construction of a second shaft, excavation of drifts, constructibility monitoring, performance of in situ tests, and geologic and hydrologic characterization. The principal construction and characterization activities of the exploratory shaft program are discussed below.

4.1.1.6.1 Construction

The Phase I shaft would be blind-hole drilled, lined with a water-tight steel casing, and the annular space between the casing and rock wall would be filled with grout. The shaft would have a 183-centimeter (72-inch) inside diameter, and would be emplaced deep enough to permit shaft station breakout in the Cohassett flow interior. Figure 4-2 illustrates the dimensions and depth of the shaft concept. The depth to which the exploratory shafts would be drilled is 1,034 meters (3,393 feet) to provide access to the candidate horizon.

During drilling, the shaft would be filled with a fluid consisting of water, bentonite clay, and a biodegradable polymer. This fluid would provide hydrostatic support to the shaft wall, lubricate and cool the drill bit and reamers, and carry rock chips to the surface by fluid circulation. The shaft would penetrate several aquifers (Subsection 6.3.3.3.3). The hydrostatic pressure of the drilling fluid would minimize ground-water inflow. When drilling is completed, a steel liner would be floated into place. Following liner emplacement, a cement grout would be pumped into the bottom of the annular space between the liner and the hole wall. Grouting would continue upward until the entire liner is sealed in place.

Ground-water inflow would be a risk associated with breakout from the shaft. To examine directly the effectiveness of the cement grout seal surrounding the liner and the water-inflow potential of the candidate horizon prior to breakout, boreholes would be drilled through specially designed portholes in the shaft casing.

The initial breakout point would be the shaft station (Fig. 4-3). This station would be a 2.7- by 4- by 15.2-meter- (9- by 13- by 50-foot-) long drift constructed in the Cohassett flow interior. A combination of mechanical and conventional smooth-wall-blasting techniques will be used to construct the shaft breakout station. The shaft station would serve two purposes: First, it would help verify that the Cohassett flow interior is suitable for drift construction; second, the station would provide working space to mobilize Phase II underground construction equipment.

At the completion of Phase I, the drill rig would be moved 152 meters (500 feet) south where the Phase II shaft would be drilled. The inside diameter of the second shaft would be the same as the first shaft (183 centimeters (72 inches)), and would be drilled to the candidate horizon. It would be constructed using the blind-hole-drilling method, and would follow a construction sequence similar to that of the Phase I shaft.

As noted in Subsection 3.3.1.3.5, a probable maximum flood could cover the southwest portion of the reference repository location. This includes the area of the exploratory shaft facilities.

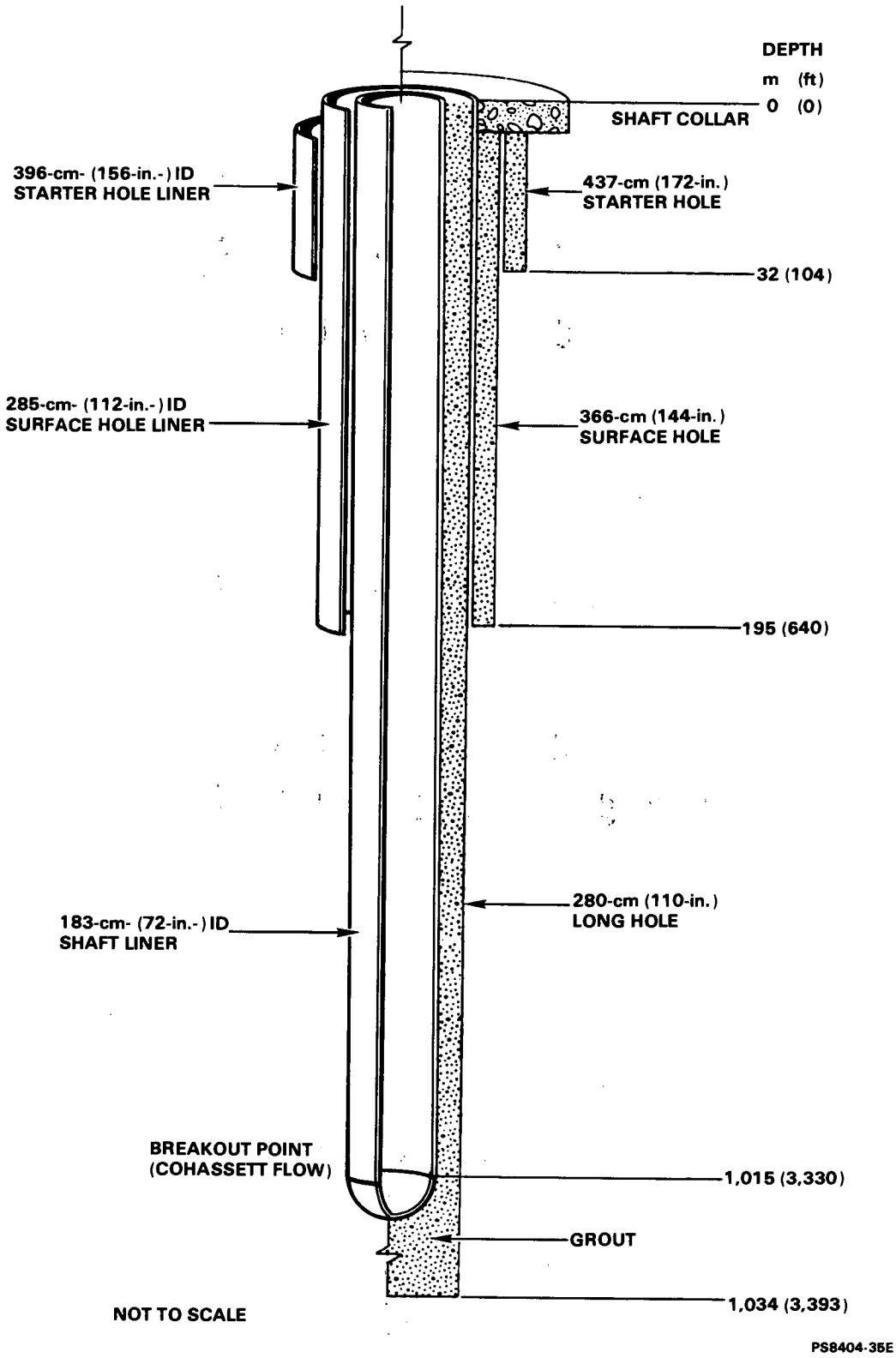

Figure 4-2. Drilled shaft concept.

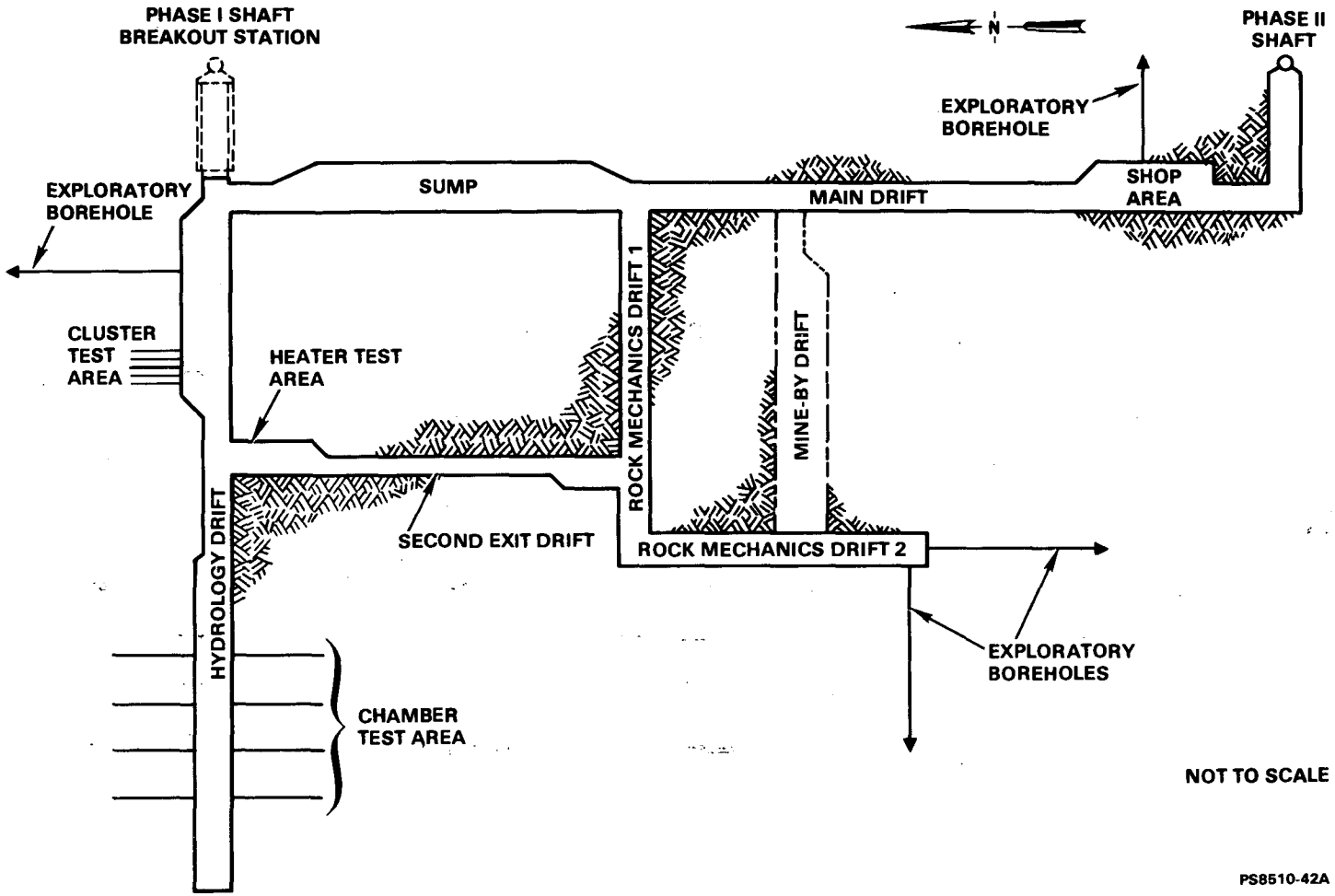

Figure 4-3. Conceptual arrangement of the exploratory shaft underground facilities.

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The underground layout of the exploratory shaft facilities shown in Figure 4-3 is considered preliminary. Design reconfigurations and test strategy changes may take place as studies progress.

4.1.1.6.2 Geologic characterization

The geologic emphasis in the exploratory shaft underground facilities would be on mapping and evaluating the fracture characteristics of the Cohassett flow. This would be accomplished by completing detailed fracture logging of core samples and drift walls. Particularly significant are the four exploratory boreholes that would be horizontally drilled approximately 305 meters (1,000 feet) into the flow interior from the Phase II drifts (see Fig. 4-3). Fracture mapping of the tunnel walls would take place concurrent with construction. The fracture data would provide a knowledge of in situ fracture distributions, widths, mineral infillings, and origins. This would be important to understanding the specific near-field geologic environment of a repository built in the Cohassett flow interior.

4.1.1.6.3 Hydrologic characterization

Hydrologic tests undertaken within the exploratory shaft facility would focus on characterizing the Cohassett flow interior. Properties measured or calculated would include hydraulic conductivity, storativity, effective porosity, and possibly dispersivity and diffusion. Test methodology, duration, and success would be dependent on the in situ conditions encountered at depth. At present, the following four test approaches are planned:

1. Chamber tests—A large-scale test of the hydraulic conductivity of a flow interior using a drift monitored by boreholes cored from within and (or) adjacent to the drift.

2. Cluster tests--A borehole cluster room for development off of the access drift to the chamber test room. Cross-hole hydrologic and tracer tests would measure hydraulic conductivity, effective porosity, and possibly dispersivity and diffusion within the interior of the candidate horizon.

3. Exploratory borehole tests--These boreholes would be cored and logged for fracture characteristics. Afterwards, hydrologic tests would measure hydraulic conductivity distributions in four directions from the underground drifts. This information would provide a better understanding of the areally distributed hydraulic conductivity within a basalt interior as determined from boreholes drilled at right angles to the predominantly vertical fracture patterns of a flow interior.

4. Other borehole tests—Many boreholes cored within the cluster area, chamber room, and from the shafts themselves would be hydrologically tested. Plans include coring and testing in holes penetrating flow interiors and flow tops. Ground-water samples would be collected from boreholes penetrating adjoining flow tops. Monitoring of hydraulic heads could also take place.

Modifications to the above test approaches may take place as test strategies are refined. Directly observing the quantity and distribution of ground-water (and gas) inflow into the drifts also would help in selecting the ground-water conceptual model most descriptive of the behavior of the ground water in the basalt flow interiors in the exploratory shaft (see Subsection 3.3.2.2).

4.1.1.6.4 Geomechanics characterization

Geomechanics tests and monitoring would be performed within the exploratory shaft facilities during Phases I and II. Concurrently, laboratory testing of basalt would be conducted to characterize its physical, mechanical, and thermal properties, in addition to supporting the evaluation of the in situ test results. These in situ and laboratory tests would be important to determine if rock conditions are suitable for waste emplacement, isolation, and possible retrievability (Subsections 6.3.1.3 and 6.3.3.2). Rock mass properties and in situ conditions would be measured and the performance of engineered systems would be evaluated. These activities will provide the following information:

1. Mechanical and thermal properties of rock mass.

2. Magnitudes and orientations of in situ stresses.

3. Nature and extent of construction-related damaged rock zone.

4. Stability of waste-emplacement holes and waste-emplacement drifts during excavation and under thermal loading conditions.

5. Nature and extent of heater-related damaged rock zone.

6. Performance of rock-support systems.

Of particular importance in geomechanics characterization would be the mine-by and heater tests (see Fig. 4-3). These are tests in which the stability and performance of prototypic repository room and waste-emplacement boreholes would be monitored. This monitoring would measure in situ conditions and elevated temperature conditions resulting from heater testing. Geoengineering properties of the rock mass also would be obtained in these tests.

4.1.1.6.5 Final disposition

The Nuclear Waste Policy Act of 1982 requires that the characterization plan for a candidate site contain provisions for the decontamination and decommissioning of the exploratory shaft facility. The current plans for site characterization at the reference repository location do not include the use of high-level radioactive waste. The use of short-lived radioactive tracers for hydrologic tests is not expected to result in a need for decontamination, since these tracer materials decay to undetectable levels in several days or weeks. The disposition of the exploratory shaft facility would depend on whether or not the reference repository location is selected as a repository site. Potential Federal actions lead to the following three possible exploratory shaft dispositions.

1. A site-characterization program may show that the reference repository location is unsuitable for a radioactive waste repository. In this case, the exploratory shaft facility would be decommissioned.

2. The reference repository location may be shown suitable, but the first repository may be built at another site. In this case, the exploratory shaft facility would not be decommissioned until a final decision was made as to whether or not the reference repository location is a candidate for a second repository.

3. The reference repository location may be shown suitable and be selected for the first repository. In this case, the exploratory shaft facility will be utilized in Phase I repository construction. Such incorporation may assist in meeting the two-phase waste receipt repository design discussed in Section 5.1.

Because final decisions about techniques for shaft sealing may require data from site characterization, the following decommissioning strategies are only representative of those that might be implemented.

1. If an alternative use for the exploratory shaft facility is identified prior to decommissioning, a limited standby decommissioning would occur after site characterization. The utilities, hoists, and ventilation systems would be left in place, and periodic maintenance would preserve the overall integrity of the facility. Adequate surface physical security would be retained to prevent unauthorized access to the exploratory shaft facility.

2. A second strategy would entail the permanent decommissioning of the entire facility. Decommissioning of the shaft would require removal of all internal shaft hardware and utilities. Underground utilities (e.g., electrical cable and water lines) would remain. The shaft would be backfilled with a mixture of crushed basalt and bentonite, cement plugs, and grouting as required to mitigate hydraulic interconnection between aquifers within

the shaft. The lining would remain in place, with the exception of plug areas, if required. In these areas, short sections of the liner would be removed to allow plug materials to seal directly to the basalt wall of the shaft. This would also ensure that electrical and water lines in the annular space between the liner and rock wall could not serve as conduits for ground-water migration. The surface structures and utilities would be removed and the surface area would be returned to its original state as closely as is practicable by recontouring and replanting.

In the event that the reference repository location is eliminated from consideration as a potential repository site and it is decided to decommission the facilities, decommissioning would begin as soon as possible.

4.1.1.7 Surface-water hydrology

The objective of this work is to complete those surface-water studies needed to establish the required baseline hydrologic conditions for evaluating potential repository impacts and ground-water and surface-water exchanges. Studies would likely focus on the Hanford Site and vicinity, with Columbia Plateau studies completed as needed. Possible studies include those involving river(s) water quality, flow rates, flow volumes, past and future drainage channels, and ground-water and surface-water relationships. In addition, a detailed evaluation of drainage patterns, soil characteristics, and infiltration potential along Cold Creek will be completed to further define the flash flood potential on the reference repository location from this ephemeral stream.

4.1.2 OTHER ACTIVITIES

4.1.2.1 Laboratory tests

Laboratory tests would be performed as an integral part of field activities. In many instances, rock and ground-water samples would be collected in the field but analyzed in the laboratory. Extensive studies would be conducted in laboratory and hot-cell facilities to determine materials properties.

4.1.2.2 Socioeconomic activities

The U.S. Department of Energy does not expect site-characterization activities to result in any significant adverse socioeconomic impacts. An increase of approximately 430 workers is expected; this employment impact

is considered insignificant at the county or community level. Worker in-migration is not expected to affect community services or social conditions significantly.

The U.S. Department of Energy will establish a monitoring program to assess the potential socioeconomic impacts of site characterization presented in this chapter. A socioeconomic monitoring and corrective action plan will be prepared and released at approximately the same time as the site-characterization plan. This plan will (1) describe the monitoring activities in the study region, (2) outline the process of reporting monitoring data to the State and local governments and affected Indian Tribes, and (3) identify the mechanisms by which the U.S. Department of Energy would determine appropriate and timely corrective action for any unexpected significant adverse social or economic impacts that are identified by the monitoring program.

States and affected Indian Tribes may apply for grants under the Nuclear Waste Policy Act of 1982 to engage in appropriate monitoring, testing, or evaluation activities with respect to the U.S. Department of Energy site-characterization activities. Additionally, general local governments are eligible to apply for funding under the grants-equal-to-taxes provisions of the Nuclear Waste Policy Act of 1982 when site-characterization activities commence.

4.1.2.3 Environmental studies

In conjunction with site characterization, an environmental-monitoring and -mitigation program would be developed to address significant adverse impacts due to site-characterization activities. A larger scale environmental baseline program would also be implemented to further characterize those areas impacted by potential repository activities. Both programs would include the study of ecosystems, meteorology, air quality, water quality, noise, archaeological and cultural resources, and background radiation.

Ecosystem investigations would include the study of native plant communtities and the determination of distribution, densities, and activities of animal species. Early emphasis would be on the identification of and impacts to threatened or endangered species known to frequent the Hanford Site and surrounding area. This activity would support potential mitigation efforts.

Hanford Site air-quality, water-quality, noise, and background radiation studies would be enhanced to address potential impacts associated with site characterization and potential repository activities. These activities also would support potential mitigation efforts.

The Hanford Meteorological Station is located within the reference repository location. A data base of approximately 40 years has been collected at the meteorological station (see Section 3.4.3). Meteorological conditions would continue to be monitored to support air-quality and radiological studies.

The Hanford Site has undergone archaeological surveys that showed Indian activities at the Hanford Site and surrounding areas were primarily concentrated along the Columbia River (see Section 3.4.6). Archaeological surveys of the Hanford Site would be conducted, concentrating on areas where site-characterization activities and surface facilities are expected to be located.

4.1.2.4 Geochemistry studies

Geochemistry studies summarized here refer to geochemical processes occurring in the near-field environment, including the waste package. The majority of data would be collected from laboratory experiments that simulate expected repository conditions (e.g., temperature, pressure, ground water).

4.1.2.4.1 Reduction-oxidation conditions and other ground-water characteristics in the waste package and adjacent rock

The redox condition in the waste package system would have a major effect on the oxidation state of multivalent radionuclides (e.g., actinides, technetium-99). This in turn would affect radionuclide solubilities and release rates from the waste package into the host rock. Tests are being conducted to determine the rate of return to the reducing environment following emplacement as a result of hydrothermal reaction between crushed basalt in the packing material and ground water (e.g., measurement of oxygen consumption rates, development of high-temperature Eh-pH probes used in hydrothermal experiments, and measurement of redox-sensitive elemental pairs such as arsenate(III/V) in hydrothermally altered solutions). Other changes in near-field ground-water characteristics (e.g., major cation and anion concentrations and pH) are being measured as a function of time in laboratory hydrothermal experiments.

4.1.2.4.2 Radionuclide reactivity and transport in the waste package and adjacent host rock

Radionuclide transport rates through the packing material into the host rock would provide the source term for far-field transport analyses (Subsection 6.4.2.4). Laboratory tests are being performed to determine radionuclide solubility and sorption reactions and maximum steady-state

concentrations in hydrothermal solutions altered by reaction with waste form, container, packing, and host rock. Diffusion coefficients also are being measured as required input to analytical models describing radionuclide transport through the packing material.

4.2 EXPECTED EFFECTS OF SITE CHARACTERIZATION

A wide variety of geologic and hydrologic techniques would be employed to survey and characterize areas of the Hanford Site. Most processes (e.g., aerial and satellite photography, magnetometer surveys, and surface-water sampling) would have no significant adverse environmental impact. Borehole drilling would have the potential for adverse impact to require an environmental evaluation of each proposed drill site. Since the beginning of the screening process in 1978, the Basalt Waste Isolation Project has drilled, reentered, and deepened or conducted tests in more than 100 boreholes on the Hanford Site.

Of all the site-characterization activities, construction of the shafts and related facilities would present the greatest potential for adverse environmental impacts (Subsection 4.2.1.3.1). This section addresses the effects on the physical environment and the socioeconomic conditions of the area.

4.2.1 EXPECTED EFFECTS ON THE PHYSICAL ENVIRONMENT

The potential effects of site-characterization activities on the physical environment are divided into three categories: Geology, hydrology, and environmental setting.

4.2.1.1 Geology

Drilling of boreholes and shafts and excavation of underground facilities are expected to have no significant adverse impacts on the geologic conditions in and around the reference repository location.

4.2.1.2 Hydrology

Site-characterization effects on hydrology are presented in two parts: Potential impacts on surface-water hydrology and ground-water hydrology.

4.2.1.2.1 Surface-water

Water used for construction and operation activities would be pumped from the Columbia River by the Hanford water system, located 10.4 kilometers (6.5 miles) north of the reference repository location. The water system can supply about 0.8 cubic meter (30 cubic feet) per second to the 200 Areas where the connection for the exploratory shaft line is made. The present water line is sufficient to meet the needs of the exploratory shaft program. The water-use requirements of the program will be minor in comparison to the flow of the Columbia River and current U.S. Department of Energy uses.

Subsection 4.1.1.3 outlines the hydrologic parameter testing planned as part of site characterization. This study would include conducting hydrologic stress tests, some of which would require discharge of moderate quantities of ground water; at least eight such tests are planned. In conjunction with each test 5×10^2 to 1×10^4 cubic meters (0.4 to 8 acre feet) of ground water would be discharged over a 30- to 45-day period. The area(s) of water release has not yet been determined.

Hydrologic testing

During most hydrologic testing, surface discharges of ground water from the Saddle Mountains, Wanapum, and Grande Ronde Basalts will occur. Water application to the land surface during hydrologic testing would be accomplished through discharge to engineered pits. This activity would increase the amount of soil moisture and increase the rate of vertical water percolation. For evaluating impact, it is assumed water is discharged from the Grande Ronde Basalt. In the vicinity of the reference repository location, this water is characterized by relatively high concentrations of sodium (approximately 350 milligrams per liter), chloride (approximately 450 milligrams per liter), and fluoride (approximately 20 milligrams per liter). These waters are not suitable for human consumption without treatment (see Subsection 6.3.1.1.9). The possibility that precipitation reactions (due to evaporation or decreases in temperature and pressure) might occur in the holding ponds has not been evaluated. However, estimates of the rates of evaporation (100 to 105 centimeters (39 to 41 inches)) and infiltration (420 liters per square meter (10 gallons per square foot) per day) (Oberg, 1966; Sisson and Fecht, 1981; Sisson and Graham, 1982a, 1982b; Fuchs, 1983, 1984a, 1984b) for this part of the Hanford Site suggest that the latter process is dominant in the reference repository location. Other useful references for determining a local water balance are Gutknecht et al. (1980) and Emery and McShane (1978). Therefore, the opportunity for significant precipitation resulting from evaporation appears limited.

Ponding would be minimized to lessen attraction for waterfowl and other animals. Significant adverse impact to the local flora and fauna is not expected.

The application of hydrologic test water to the unconsolidated and partially saturated sediments would have minimal impact on surface and ground waters. The total volume of ground-water discharge during testing

is unlikely to exceed 10^5 cubic meters (80 acre feet), a value that is less than 2 percent of the amount of water discharged in the 200 West Area during 1983 (5.2×10^6 cubic meters (4,300 acre feet)) (Law and Allen, 1984).

Significant chemical differences exist between Grande Ronde Basalt and unconfined aquifer ground waters in and around the reference repository location (see Section 3.3.2). However, as noted above, the total volume of water discharge expected during all hydrologic tests conducted for site characterization is a small percentage of the annual water discharge from routine Hanford Site operations. Consequently, as subsurface ground-water infiltration occurs, little water-quality degradation is expected.

The total salt (dissolved solids) production from water discharge during several years of site characterization is approximately equal to the yearly salt volume discharge of a pivot irrigation system. For example, such an irrigation system might cover some 53 hectares (130 acres) that would have a yearly water application of approximately 150 centimeters (60 inches). The quantity of salt discharged during all site-characterization activities would be a small percentage (1 percent or less) of that annually discharged in the Pasco Basin or surrounding Columbia Plateau from crop irrigation.

No manmade radioactivity is expected to be associated with the deep ground waters to be discharged. Water quality of the deep basalt ground waters is discussed in Subsection 6.3.1.1.9.

Exploratory Shaft

Uncertainty exists as to the volume of ground water expected during dewatering activities of the exploratory shafts. Water used in the shaft construction would be mixed with bentonite in a surface pit to form a drilling mud. This mud would be piped into the shaft and moved downward past the drilling bit and over the cutting surface. The mud would collect drill cuttings and be pumped to the surface and into the mud pits where the rock chips would settle by gravity from the mixture. Rock chips would be removed from the mud pits and the mud recirculated. There is no expected environmental impact from the mud.

The spoils pile would consist of bentonite, minor amounts of biodegradable organic polymers, and basalt chips. The spoils would be stored adjacent to the mud pits, pending site decommissioning. Several options are under consideration for disposal of the basalt chips. The spoils could be stabilized in place or trucked to an existing gravel quarry. Disposal would create no known significant adverse impacts.

Fugitive dust from the spoils pile is not expected to create a significant adverse environmental impact. Dust control of the pile could be achieved by three methods: Placing coarse basalt over the pile, wetting the pile to keep the fine materials moist, and washing the fines off the face of the pile and into the pile interior.

4.2.1.2.2 Ground water

The drilling and testing of boreholes and construction of the exploratory shafts could have three potential effects on the ground-water flow system in the reference repository location. First, borehole and shaft construction might interfere with the measurement of natural variations in baseline ground-water levels. The extent of such interference would depend on how well isolation is maintained between aquifers during drilling by the use of muds and lost circulation materials. Second, borehole and shaft construction might provide a vertical conduit for some increased ground-water mixing that otherwise would not have existed. That is, in the localized area around the boreholes and shafts, previously isolated aquifers might become connected (e.g., as a result of poor seals and open boreholes). Third, drilling fluid losses might interfere with measurements of flow-top permeabilities near the boreholes and shafts. To determine if any of these interferences is present, site-characterization activities would proceed as a logical, sequential process. Prior to exploratory shaft construction, selected baseline monitoring would be conducted to determine the natural, undisturbed fluctuation in water levels in various basalt flow tops. If changes to these natural hydraulic head trends occur after construction of the shafts, man-induced changes could be differentiated from natural variability. Large-scale hydrologic tests could be completed before and after shaft sinking to determine whether or not shaft construction had a measurable effect on aquifer interconnection or flow-top permeabilities.

Leachate production would be minimal at the mud pits and spoils pile. The bentonite mixed with this material would form a permeability barrier to water movement. The mud pits would be clay lined along the bottom and sides to prevent water loss. The spoils pile would also contain bentonite that would reduce the downward flow of water. Water drainage from the spoils could be redirected into the mud pit. Rock dust and clay particulates would filter out of the leachate at land surface and not impact surface or ground waters. Chemical composition of the leachate would be monitored during site characterization.

Waste water resulting from drainage of the spoils pile would enter the unconsolidated and unsaturated sediments of the reference repository location. The distance to the water table is approximately 50 meters (165 feet) below land surface. Water applied to the land surface would infiltrate the unsaturated flow system. The rate of infiltration in partially saturated conditions is much slower than saturated flow, and no adverse impact to the unconfined aquifer is expected. The volume of infiltrating water from testing, spoils pile drainage, and sewage effluent would be minor in comparison to current infiltration at adjacent U.S. Department of Energy facilities (Eddy et al., 1983; Wilbur et al., 1983).

4.2.1.3 Effects on the environment

Expected site-characterization effects on the environmental setting are presented in six parts: Ecosystems; air quality; noise; aesthetics; archaeological, cultural, and historical resources; and radiological.

4.2.1.3.1 Ecosystems

Table 4-1 summarizes the expected effects of site-characterization activities on ecosystems. The major projected impact is on the terrestrial ecosystem. Effects on the aquatic ecosystem are expected to be minimal because most activities would not be carried out in the vicinity of aquatic habitats.

Terrestrial

The most significant environmental impacts to the terrestrial ecosystem from site characterization are expected to include habitat loss from the selective clearing and grading of terrain for the exploratory shaft, boreholes, utilities, and spoils pile. No significant adverse impacts are expected from mine-water or sanitary waste disposal.

Borehole locations would be selected to acquire data while minimizing environmental impact. It is recognized that in the shrub-steppe ecology of the Hanford Site, land surface disturbance would constitute the greatest potential for significant adverse environmental impact, because of the potential for increased wind erosion and loss of wildlife habitat. Each potential drill site would be examined to assure that it is (1) located as closely as is possible to existing roads, (2) not within a known or potential archaeological, cultural, or historical site, and (3) not expected to impact adversely any threatened or endangered plant or animal species.

Land surface disturbance at the typical drill site would be limited to selective clearing and grading of a 1.2-hectare (3.0-acre) site, to construction of approximately 300 meters (1,000 feet) of single-lane dirt road, to digging and lining of a 6- by 9- by 1.2-meter (20- by 30- by 4-foot) mud pit, and to laying of a 45- by 90-meter (150- by 300-foot) compacted gravel drilling-support pad. At the conclusion of testing, current plans call for refilling all mud pits, and returning the drill sites as closely as is practicable to their natural state.

The primary impact associated with exploratory shaft construction was the selective clearing and grading of 18 hectares (46 acres) of shrub-steppe terrain. More than half the plants within this area were destroyed and all the animals were displaced during initial exploratory shaft construction activities undertaken in 1982. Biological monitoring shows that no federally endangered or threatened species reside at the exploratory shaft site (see Subsection 3.4.2.5). The Swainson's hawk and long-billed curlew nest near the exploratory shaft site; however, the

Table 4-1. Summary of expected effects on native biota from Basalt Waste Isolation Project site-characterization activities (sheet 1 of 2)

Activities	Organisms that may be affected				
	Endangered and threatened animal species	Swainson's hawk and other birds of prey	Long-billed curlew	Other wildlife	Native plant communities*
Off-road travel for engineering, environmental, and archaeological surveys	May cause minor temporary disturbance to wintering bald eagles if conducted near Columbia River. Potential impact can be eliminated by conducting surveys between August and October	May cause some nest desertion if conducted during spring nesting season. Minimized by following recommendations of Fyfe and Olendorff (1976)	May cause some nest desertion if conducted during spring nesting season. Minimized by following recommendations of Fyfe and Olendorff (1976)	No permanent impact expected	No permanent impact expected
Borehole drilling and testing field studies	May cause minor temporary disturbance to wintering bald eagles if conducted near Columbia River. Potential impact can be eliminated by conducting surveys between August and October	May cause some nest desertion if conducted during spring nesting season. Minimized by following recommendations of Fyfe and Olendorff (1976)	May cause some nest desertion if conducted during spring nesting season. Minimized by following recommendations of Fyfe and Olendorff (1976)	May cause minor temporary displacement of animals that are sensitive to noise and (or) human activity	Will cause loss of native plants at borehole sites. A minor impact is expected because of limited area. Locations near proposed endangered or threatened plant species will be avoided
Exploratory shaft construction	No impact because of remoteness of site from bald eagle habitat	May cause some nest desertion if conducted during spring nesting season. Minimized by following recommendations of Fyfe and Olendorff (1976)	May cause some nest desertion if conducted during spring nesting season. Minimized by following recommendations of Fyfe and Olendorff (1976)	May cause minor temporary displacement of animals that are sensitive to noise and (or) human activity	Several hectares (acres) of native plant community physically destroyed by construction activity. Total impacted area is small compared to the hundreds of hectares (acres) of similar plant community type nearby

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Table 4-1. Summary of expected effects on native biota from Basalt Waste Isolation Project site-characterization activities (sheet 2 of 2)

Activities	Organisms that may be affected				
	Endangered and threatened animal species	Swainson's hawk and other birds of prey	Long-billed curlew	Other wildlife	Native plant communities*
Exploratory shaft operation	No impact because of remoteness of site from bald eagle habitat	Noise and increases in local traffic would not result in impacts beyond those resulting from construction of exploratory shafts	May cause some nest desertion if conducted during spring nesting season. Minimized by following recommendations of Fyfe and Olendorff (1976)	May cause minor temporary displacement of animals that are sensitive to noise and (or) human activity	No permanent impact expected
Potential for accidental range fires from site-characterization activities	No permanent impact expected	Fire may result in temporary loss of prey resources to the birds	Fire may destroy nests or result in temporary loss of nesting bhabitat	Fire may cause a temporary reduction in animal populations through loss of habitat	Composition of native plant community would be altered if fire occurs
Increased travel on established roads in support of all above activities	No impact because of remoteness of site from bald eagle habitat	No permanent impact expected	No permanent impact expected	May be an increased probability of vehicle collision with animals	No permanent impact expected

*Includes those plant species proposed for endangered and threatened status.

7 0 1 0 8 9 0 6 0 5

Ferruginous hawk does not. These species are candidates for the Federal endangered or threatened species list (FWS, 1985). Site personnel have been instructed to avoid visiting, for the purpose of observing, or otherwise entering adjacent areas inhabited by endangered or threatened species or candidate species.

Other environmental effects directly related to the construction of the shafts would be those resulting from the digging of mud pits and from accumulating drill cuttings and basalt chips in the spoils pile. The mud pit complex constructed in 1982 covers approximately 0.4 hectare (1.0 acre) with a series of shallow pits. The bottom of the pits is lined with clay to prevent seepage.

The approximate volume of material to be removed during Phase I of the exploratory shaft program is 6,400 cubic meters (225,000 cubic feet). This volume is expected to increase to approximately 12,800 cubic meters (450,000 cubic feet) on removal, because of fragmentation and loose packing in a spoils pile. The same volume of material would be removed from the Phase II shaft. In addition, up to 9,300 cubic meters (328,000 cubic feet) of basalt mined from the drifts would be added to the spoils pile. The possible mechanisms by which the spoils pile could cause environmental impacts are dust emissions (Subsection 4.2.1.3.2), chemical leaching (see Subsection 4.2.1.2.1), and mechanical slip or collapse. A conservative mining practice would be followed in establishing the slope of the spoils pile sides, taking into consideration the changes in angle of repose caused by saturation during heavy rainfall. This would preclude impacts due to landslip or collapse of the spoils pile.

The laying of the site water line from the 200 West Area to the exploratory shaft site required clearing a 6.1-meter- (20-foot-) wide strip of ground 4.8 kilometers (3 miles) long. Construction of the overhead power line caused partial disturbance to a 4.6-meter by 10.5-kilometer (15-foot by 6.5-mile) area. Natural vegetation is being allowed to reestablish itself along the rights-of-way.

Mine-water disposal from the exploratory shaft sumps may require a method of primary treatment to assure that water quality will not have a detrimental effect on the environment. The exact methods required will depend on the quantity and composition of mine-water contaminants, as determined through testing. The preferred method for mine-water disposal will be based on these test results.

With the exception of sanitary waste, which is disposed of through the septic tank drain field, all construction wastes and refuse would be collected and trucked from the site for disposal in the existing Hanford Site landfill facility (see Fig. 3-37). Structural materials of the septic tank drain field are virtually inert, and the installed system is small compared to similar active systems for the 200 Areas (DOE, 1982). The existing system has had no noted significant environmental impacts.

The potential effect on the terrestrial ecosystem associated with the operational phase of the exploratory shaft program would be minor compared to the potential impacts of construction. A significant source of dust and noise would be the commuter vehicles used by site personnel at the

beginning and end of each shift. This traffic may impact wildlife by collisions and noise disturbances; black-tailed hares, mule deer, coyote, badger, and burrowing owls would be the primary animals at risk. Collisions of wildlife with vehicles are expected to occur at the same rate as on other roadways.

In the event that the shafts would be decommissioned (see Subsection 4.1.1.6.5), the effects of the decommissioning process would be very similar in type and magnitude to the effects of site preparation. The major exception is that further wildlife disruption would be relatively minor, since the site would be inhabited continuously by personnel until decommissioning, and most major wildlife disturbances already would have occurred.

Aquatic

The majority of site-characterization activities would not be conducted in the vicinity of any aquatic habitat; therefore, the potential for impact is minimal. However, any activities carried out along the Columbia River have the potential of disturbing the bald eagle winter habitat. Such impacts could be minimized by conducting major activities near the river during the months of August through October.

The Columbia River and its biotic resources are briefly described in Subsection 3.4.2.6. There are no expected impacts to the Columbia River from site characterization, because the reference repository location is located some 10 kilometers (6 miles) from the Columbia River. The only postulated effect on the river will be the withdrawal of a small amount of the total river flow from an existing river pump station.

During site characterization, water will be provided by the Hanford water system, which has sufficient existing capacity (i.e., 0.85 cubic meter (30 cubic feet) per second to the 200 Areas) to meet the needs of the exploratory shaft program. The minimum regulated flow of the Columbia River at the Hanford Site is 1,019 cubic meters (36,000 cubic feet) per second and the annual average flow is 3,420 cubic meters (120,800 cubic feet) per second. The withdrawal of 0.85 cubic meter (30 cubic feet) per second (0.08 percent) from the 1,019-cubic-meter (36,000-cubic-foot) per second minimum flow is not expected to have any impact to important fisheries resources (including salmon spawning) or other biota in the Columbia River.

4.2.1.3.2 Air quality

Site-characterization activities are expected to be conducted over a period of approximately 6 years. Figure 4-4 shows the tentative schedule of activities that might affect air quality. These activities have a maximum likelihood of adversely affecting air quality during the third year. At that time, the work force reaches a maximum (Subsection 4.2.2.1), site preparation, exploratory shaft drilling, hydrologic testing, and other field activities are continuing and underground development has

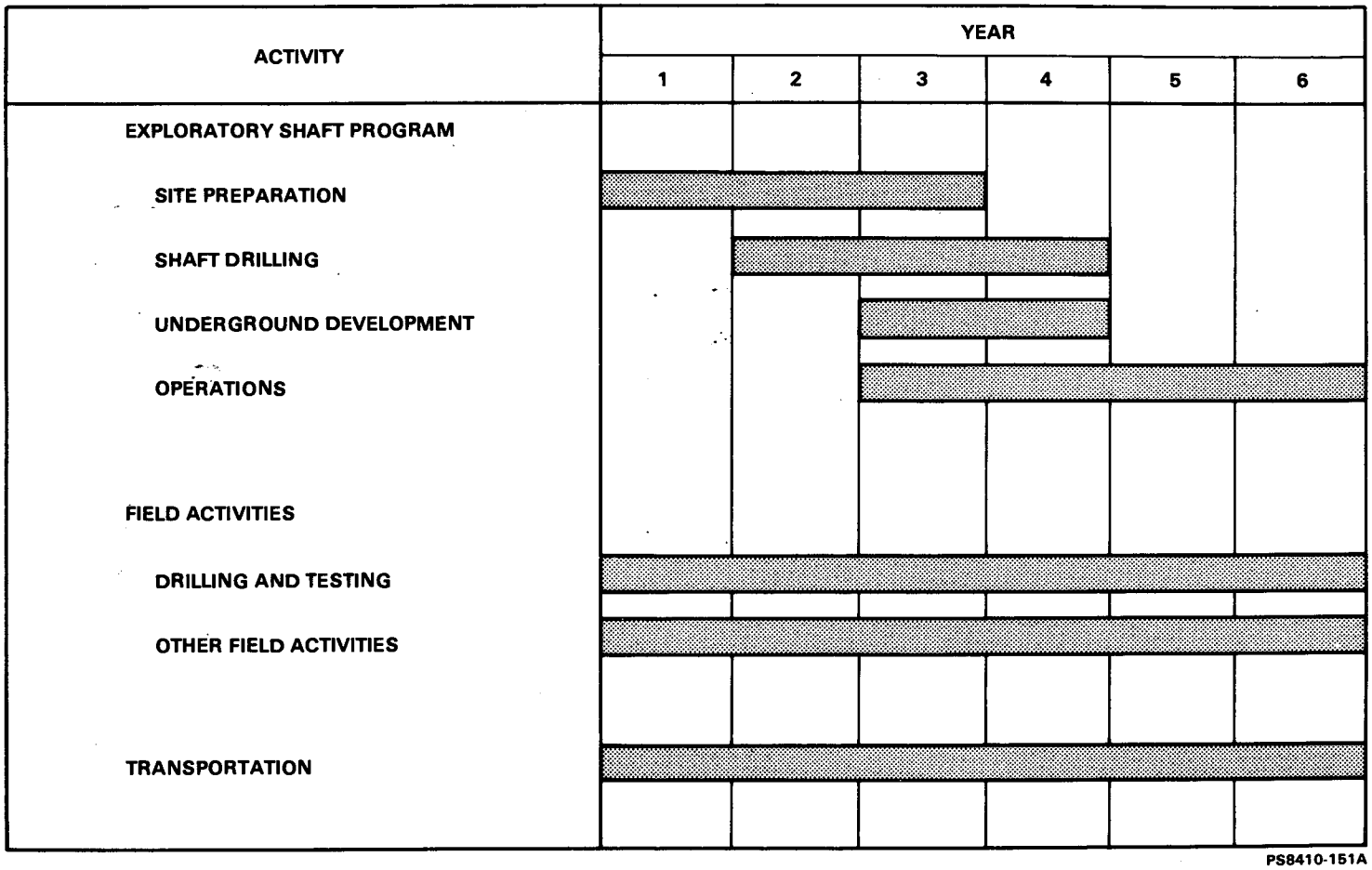

Figure 4-4. Sequence of site-characterization activities used to determine air-quality impacts.

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begun. Therefore, the third year of site-characterization activities is used to assess the potential air-quality impacts. The potential for characterization activities to affect air quality adversely arises from fugitive dust, combustion products from internal combustion engines, and generation of electric power by mobile sources.

Site preparation involves selective land clearing and road construction. Potential air-quality impacts are related to combustion products from the equipment used and dust raised by the site-preparation activities. It is estimated that 4,800 hours of bulldozer and 4,800 hours of heavy truck operation would be required in each year of site preparation. This equipment is assumed to be diesel powered.

Two shafts will be drilled. Drilling would be 24 hours per day, 365 days per year, until the shafts are completed. A single drill rig would be used for the two shafts. The drill would be powered by an electric motor that is assumed to be rated at 2.2×10^6 watts (3,000 horsepower). The spoils removed from the shafts would be moved to the spoils pile using a diesel-powered dragline. A 4.4×10^5-watt (600-horsepower) rating is assumed for the diesel engine. During shaft drilling, the dragline is assumed to operate 4 hours per day. Approximately 6,400 cubic meters (230,000 cubic feet) of material would be removed from each shaft.

The spoils contain the basalt chips resulting from drilling. The chips are assumed to be primarily 0.6 to 1.2 centimeters (0.25 to 0.50 inch) in diameter with some finer particles. Spoils from the shaft are wet and remain wet while being moved to the spoils pile. As a result, dust emissions would be minimal.

After the shaft drilling is complete, a steel liner would be installed and the space between the liner and rock wall would be filled with cement grout. This grout would be provided by a portable, closed system. It is estimated that 500 cubic meters (18,000 cubic feet) of grout would be required. Insignificant air-quality impacts would result from the grouting operation. The dry materials for the grout would be obtained from offsite sources.

When the first shaft has been completed, a series of drifts would be constructed. The material from these drifts would be moved a distance of approximately 400 meters (1,300 feet) from the shaft to the spoils pile by truck. Approximately 9,300 cubic meters (328,000 cubic feet) of fragmented material would be removed from the drifts. It is estimated that approximately 1,200 truck loads would be required to move the material. The trucks used for this task are assumed to be similar to those used in site preparation. The potential air-quality impacts of this operation are related to emissions from the trucks and fugitive dust.

During and following the underground development, routine operations would involve the use of hoists for vertical transportation in the shafts and compressors for ventilation. There would be two electrically powered

hoists. It is expected that each of the hoist motor ratings would be 3.7×10^5 watts (500 horsepower) or less. The compressor motor is expected to be rated at 7.5×10^5 watts (1,000 horsepower).

Ten or more borehole sites may be required for site characterization. Typical drilling activity is assumed to involve drilling several boreholes at a time. This is expected to peak in the third year of site characterization with approximately 14,400 total drilling hours. The borehole drilling rigs use diesel power. The diesel engines for these rigs are assumed to be rated at 3.7×10^5 watts (500 horsepower).

Many of the field activities would require the use of light-duty vehicles (most likely gasoline-powered trucks) for transportation of people and equipment. These activities are expected to be at their maximum in the third year of site characterization. It is estimated that there would be 2,400 hours of light vehicle use during that year; approximately 50 percent of this time the vehicles would be parked. The remaining 50 percent is assumed to be divided equally between low-speed driving (less than 57 kilometers (35 miles) per hour) and high-speed driving (approximately 90 kilometers (55 miles) per hour).

The electric motors required for the exploratory shaft drilling rig, the hoists, and the compressors are expected to have a combined output rating of 7.2×10^6 watts (9,600 horsepower) or less. Allowing for inefficiencies in the motors and other unspecified electrical requirements, the electrical demand of site-characterization activities from offsite sources is assumed to be approximately 1×10^7 watts (13,000 horsepower). This electric power would be purchased from the Bonneville Power Administration and delivered through the Pacific Northwest power grid. The majority (approximately 75 percent) of the power available to the region results from hydroelectric powerplants; an additional 6 percent is generated by nuclear facilities. Table 4-2 lists the northwest regional electric power projections through 1990. It also lists the surplus power and an estimate of the probability that the firm load requirement would exceed the available power. Assuming that the offsite sources of electric power for site characterization are not included in the predicted demand growth, additional firm load growth equal to the estimated power needs would not result in a regional power deficit. On these bases, it is reasonable to conclude that the generation of the power from offsite sources required for site-characterization activities would not adversely impact regional air quality.

The total emissions from internal combustion engines during the third year of site-characterization activities are summarized in Table 4-3. These emissions have been estimated using the activity descriptions provided above and emission factors published by the U.S. Environmental Protection Agency (EPA, 1977). Activity descriptions are biased toward the maximum likely activity; emissions estimates are similarly biased (i.e., they overestimate the actual emissions that would result from site-characterization activities). Emissions in the first two and last three years of site characterization would be lower than during the third year.

Table 4-2. Northwest regional electric power projections

Power	Period					
	1985 through 1986		1987 through 1988		1989 through 1990	
	Average	Peak	Average	Peak	Average	Peak
Resource, MW	19,032	38,328	18,913	39,841	19,218	41,270
Firm load, MW	17,328	31,755	18,052	32,511	18,999	34,684
Surplus, MW	1,704	6,573	861	7,330	219	6,586
Probability of exceeding available power	1%		1%		1%	

NOTE: Based on data in Pacific Northwest Utilities Conference Committee (1984, pp. II-3 through II-5).

Table 4-3. Summary of maximum annual emissions from internal combustion engines during site-characterization activities

Combustion engine	Carbon monoxide, t (tons)	Nitrogen oxides, t (tons)	Sulfur oxides, t (tons)	Particulates, t (tons)
		Diesel		
Bulldozers	3.18 (3.50)	13.55 (14.93)	1.01 (1.11)	0.88 (0.97)
Heavy trucks	3.65 (4.02)	20.78 (22.89)	1.23 (1.36)	0.70 (0.77)
Dragline	2.51 (2.77)	11.60 (12.78)	0.77 (0.85)	0.83 (0.91)
Borehole drilling*	21.83 (24.05)	100.87 (111.11)	6.71 (7.39)	7.21 (7.94)
		Gasoline		
Trucks	1.27 (1.40)	0.24 (0.26)	0.01 (0.01)	0.02 (0.02)
Total	32.44 (35.74)	147.04 (161.97)	9.73 (10.72)	9.63 (10.61)

*Exploratory shaft drilling is done with offsite-generated electricity.

The total release estimated for all internal combustion sources is given for each of the pollutant categories in Table 4-3. However, it is necessary to consider the contribution of fugitive dust to completely define potential air-quality impacts due to site-characterization activities.

Fugitive dust emissions are likely to occur during several of the site-characterization activities, including site preparation, dragline operation, underground development, and preparation of the grout to fill the open space outside the exploratory shaft liners. These emissions are estimated by analogy with operations for which the U.S. Environmental Protection Agency has published emission factors and are based on the peak month of activity.

Transporting the material from the underground development to the spoils pile, dumping the material, and maintaining the spoils pile are assumed to result in fugitive dust emissions that are no greater than those from similar operations at locations that maintain aggregate storage piles. Fugitive dust emissions from the dragline operation are assumed to be no greater than those from sand and gravel processing, and the potential emissions from the preparation of the grout should be less than those associated with concrete batching.

Table 4-4 is a summary of the potential maximum annual particulate emissions from the third year of site characterization. The value shown for the underground development does not take credit for potential reduction of dust due to combining the wet spoils material from the exploratory shaft with material from the drifts. Combining these waste materials could result in a 90-percent reduction in dust. Frequent watering of the spoils pile would assure that the dust is held to a minimum.

Table 4-4. Estimates of particulate emissions including fugitive dust releases during the third year of site characterization

Source	Total emission	
	t	tons
Combustion products	9.6	10.6
Site preparation	16.8	18.5
Underground development	31.5	34.7
Dragline operation	0.7	0.7
Grout preparation	0.1	0.1
Total	58.6	64.6

The potential effects of the emission totals in Tables 4-3 and 4-4 on annual average pollutant concentrations have been estimated using a sector-average point-source Gaussian plume model, HANCHI (Glantz and Ramsdell, 1986). Three years of data from the Hanford Meteorological Station were used as input to the model. The model calculates a three-dimensional joint frequency distribution of wind speed, wind direction, and atmospheric stability; known as a wind rose. Ambient pollutant concentrations are calculated at specified downwind distances in 16 compass directions or sectors. A sector width of 22.5 degrees is assumed. Because the aboveground site-characterization activities occur in a relatively small area, it is assumed that emissions occur at a single point. This assumption may result in calculated concentrations being somewhat higher than would be actually observed (i.e., the calculated concentrations are conservative). Calculated concentrations for locations where the public would have access are presented in Table 4-5.

In addition to estimates of the potential increases in annual average concentrations, Table 4-5 contains estimates of the maximum short-term (averaging times of 24 hours or less) concentrations. The CHISHORT model was used to calculate these short-term concentrations (Glantz and Ramsdell, 1986). The following U.S. Environmental Protection Agency air-quality screening assumptions were used for this analysis:

- Dispersion conditions are very stable (Pasquill-Gifford stability class F).
- Wind speeds are low (2.5 meters (8.2 feet) per second).
- Wind blows in a given direction for 6 hours.

It was also assumed that the pollutants did not undergo any chemical transformations. Dry deposition processes were modeled in computing the maximum 24-hour particulate concentrations.

In summary, conservative estimates of airborne pollutant concentrations that might result from site-characterization activities have been made from conceptual plans. These estimates indicate that airborne pollutant concentrations resulting from site-characterization activities will be significantly less than pertinent State or Federal air-quality standards.

4.2.1.3.3 Noise

The remoteness of the reference repository location from human habitation and occupied Hanford Site facilities limits the effects of any high noise levels due to drilling. No local communities will be affected by noise resulting from site-characterization activities. However, wildlife species nesting and residing nearby may be impacted by noise. Noise may adversely affect the behavior of wildlife (Fletcher and Busnel, 1978). A program will be developed to quantify noise levels and wildlife impacts associated with site characterization. Because drilling activities would generate noise levels that could reach 110 decibels

Table 4-5. Potential increases in pollutant concentrations resulting from site-characterization activities

Pollutant	Type of standard[a]	Averaging time	Concentration standard		Maximum background concentrations[b]	Calculated increase concentrations[c]		
			Federal, µg/m³	State, µg/m³	µg/m³	1.5 km, µg/m³	22.5 km, µg/m³	44 km, µg/m³
Carbon monoxide	Primary	1 hr[d]	40,000	40,000	11,795.0	120	2.6	1.1
		8 hr[d]	10,000	10,000	6,525.0	93	1.9	0.8
Nitrogen dioxide	Primary and secondary	1 yr	100	100	20.0	4.1	0.2	0.1
Total suspended particulate	Primary	24 hr[d]	260	120 + bkg[e]	<150[f]	7.5	0.2	0.1
		1 yr[g]	75	40 + bkg[e]	37[f]	1.6	0.1	<0.1
	Secondary	24 hr[d]	150	150	--	7.5	0.2	0.1
		1 yr[g]	60	60	--	1.6	0.1	<0.1
Sulfur dioxide	Primary	24 hr[d]	365	260	5.7	3.1	0.1	<0.1
		1 yr	80	52	0.5	0.3	<0.1	<0.1
		1 hr[d]	--	1,018	49	37	0.8	0.3
		1 hr[h]	--	655	49	37	0.8	0.3
	Secondary	3 hr[d]	1,300	--	19.6	37	0.8	0.3

NOTE: To convert kilometers to miles, multiply by 0.62.

[a]Federal standards only, does not apply to State standards.

[b]Background concentrations for the region surrounding the Hanford Site are taken from a report by the U.S. Nuclear Regulatory Commission (NRC, 1982a, Table 4.33) and unpublished air-quality monitoring data collected by the Benton-Franklin-Walla Walla Counties Air Pollution Control Authority.

[c]Potential increases in pollutant concentrations at publicly accessible locations corresponding to Route 240, the Wye Barricade, and the 300 Area, which are 1.5, 22.5, and 44 kilometers from the reference repository location, respectively.

[d]Not to be exceeded more than once per year.

[e]bkg = background; applies east of the Cascade Mountain crest.

[f]This maximum value reflects the impact of exceptional natural events (e.g., dust storms, sand storms, range fires). In the absence of exceptional events, the maximum annual background concentration would not exceed 20 µg/m³ and the maximum 24-hour concentration would not exceed 30 µg/m³. The U.S. Environmental Protection Agency uses these lower values for evaluating new sources in eastern Washington State, thereby neglecting the impact of natural events.

[g]Annual geometric mean.

[h]Not to be exceeded more than two times in any consecutive 7 days.

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immediately adjacent to the noise sources, muffler systems would be used as standard practice on heavy equipment during site-characterization activities to minimize adverse environmental impacts.

4.2.1.3.4 Aesthetic

Characterization activities on the reference repository location would be visible from Route 240; however, the aesthetic impact would be minimal. Approximately 2.3 kilometers (1.4 miles) of existing gravel road would be upgraded by paving. A new gate and guard station would be added at the outside fence. The most prominent features, the drill rig and spoils pile, would not be near or on a line of sight to any scenic view or outlook. The site buildings would be small and similar to numerous other structures in the area.

4.2.1.3.5 Archaeological, cultural, and historical resources

In 1981 and 1982, archaeological field surveys were conducted to investigate the reference repository location. These surveys suggested a low potential for unidentified archaeological sites. An historic roadbed was located, but it was determined in consultation with the State Historic Preservation Officer not to be eligible for listing on the National Register of historic places. It was concluded that none of the repository activities will have an effect on significant cultural resources (Rice, 1984a, 1984b). A Programatic Memorandum of Agreement between the U.S. Department of Energy, the Advisory Council on Historic Preservation, and the Washington State Historic Preservation Office is being negotiated to outline procedures that will be followed in the event that unexpected cultural resources are encountered that may require mitigation during site-characterization activities. The Programatic Memorandum of Agreement would be consistent with the archaeology program for the Hanford Site.

4.2.1.3.6 Radiological

Drilling of boreholes may result in some mixing of the shallow unconfined ground water with the drilling mud. As the drilling mud is circulated up to the mud pit, some ground water may be brought to the surface. With this ground water, a potential exists for exhuming small amounts of radioactive tritium. The tritium concentration in the upper unconfined aquifers beneath the Hanford Site ranges from less than detectable levels to 3,000 picocuries per milliliter outside the 200 Areas. By carefully planning the placement of boreholes in locations of minimal tritium concentrations, it is not expected that the small (if any) amounts of exhumed tritium will create an adverse environmental or occupational impact. However, an appropriate ground-water monitoring program will supplement borehole placement and ground-water withdrawal during drilling activities. A potential source of short-term radiological

impact would be the use of radioactive tracers (see Subsection 4.1.1.3.3). Tracers used for these determinations typically have radiological half-lives of several hours to several days. Therefore, no significant radiological impacts would be expected from the use of tracers. No major radiological impacts due to site-characterization activities would be expected.

4.2.2 SOCIOECONOMICS

To some extent, the level and duration of site-characterization activities, staffing requirements and resources consumed, would govern the socioeconomic impacts produced. If subsurface data indicate that the site is unsuitable for use as a repository and no other productive uses are identified for the facilities, the shafts would be decommissioned (see Subsection 4.1.1.6.5). It is also possible that the shafts could be incorporated into the repository facility and eventually decommissioned as part of that facility.

4.2.2.1 Population distribution

A current staffing forecast for the expected work force needed during the site-characterization program is shown in Table 4-6.

To determine the impact of the site-characterization work force on the area population, the following assumptions have been made.

- Based on historical hiring efforts of the Basalt Waste Isolation Project during 1983 and 1985, it is estimated that approximately 90 percent of the scientists, engineers, management, and support personnel (i.e., 230 workers) will in-migrate to the area. The estimated average family size for these workers is three (Malhotra and Manninen, 1980). The locally available labor supply in the building trades sectors will likely preclude any significant in-migration (i.e., most projected openings for the underground and surface construction labor requirements will be filled locally).

- The addition of a total of 430 site-characterization workers creates 516 new jobs in the secondary sector of the economy.

- The new secondary sector job requirements will be filled with the locally available labor supply.

- Approximately 92.5 percent of the increased area population will reside in the study region (as estimated from the historical settlement patterns of Basalt Waste Isolation Project employees through June 1985) (see Section 3.6.1).

Table 4-6. Projected peak staffing for site characterization

Labor	Project baseline (March 1986)	Site characterization (April 1986 to September 1989)	Site characterization (October 1989 to September 1991)	Total increase over baseline
Construction—Underground operations				
Underground crew	0	35	35	35
Surface support	0	40	55	55
Construction—Surface operations				
Labor[a]	25	60	60[b]	35
Supervisory	30	70	80	50
Scientists and engineers	350	470	500	150
Management and support	260	345	365	105
Total	665	1,020	1,095	430

[a]Direct hire and subcontract.
[b]No data available; assume to be the same as April 1986 to September 1989.

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- The specific distribution among the cities impacted are Benton City, Washington, 3.2 percent, Kennewick, Washington, 25.6 percent, Pasco, Washington, 3.7 percent, Richland, Washington, 52.2 percent, and West Richland, Washington, 7.8 percent. About 7.5 percent of the in-migrants will likely settle outside the study region, notably cities of Prosser, Yakima, Sunnyside, Grandview, and Selah, Washington.

- The reservation areas of affected Indian Tribes lie outside the principal population sphere from which work force staffing would be derived. Significant population increases related to site characterization are not expected on reservation lands.

Site characterization could increase the Benton and Franklin bi-county area population by as many as 640 persons, or approximately 0.4 percent over the 1984 baseline population. The population increase within any one of the communities would be less than 1.5 percent. The subsequent effects on the Tri-Cities area and individual communities due to a 0.4-percent area population increase would be negligible. It is possible that some of these managerial and scientific jobs would be taken by unemployed workers currently in the work force; therefore, actual effects may be less than the above figures.

4.2.2.2 Economic conditions

Estimated resource requirements for the site-characterization program are presented in Table 4-7.

During construction of the shafts, local supplies and services would be purchased when they are readily available and competitively priced. Given the extent to which the local economy has developed in relation to large construction projects, it seems likely that a number of local firms would be able to provide materials and services. Given an estimated program cost of greater than 100 million dollars, the economic effects of the project could be very beneficial.

4.2.2.3 Community services

Community facilities and services in the study region expanded rapidly during the 1970's to accommodate the growing population and increased activity (see Section 3.6.3). With the sudden rampdown of the Washington Public Power Supply System and the accompanying decline in employment and population in the early 1980's, community services were left with excess capacity within the study areas, particularly Benton City, Kennewick, Pasco, Richland, and West Richland, Washington. Site-characterization activities will require a small work force relative to the study region base employment, and expected total population levels will not exceed the 1981-1982 levels. Therefore, there would be no significant effects on community services.

Table 4-7. Estimated equipment and material requirements by activity and fiscal year

1986	1987	1988
Surface facilities		
480-V motor control center		
50-kVA transformer (480-120/240V)		
5,000-kVA transformer (13.8 to 2.4 kV)		
Main 2,400-V switchgear		
2,400-V motor control center		
2,860-kW diesel generator		
Shaft facilities		
112-in.[a]-ID[c] casing (680 ft)[b]	112-in.-ID casing	Dewatering pumps
72-in.-ID casing (3,400 ft)	72-in.-ID casing	100-ft head frame
Drill mud	Drill mud	Shaft liner grout and seal
500-HP main hoist		
Emergency hoist		
100-ft head frame		
Shaft liner grout and seals		
Underground service system		
Four 300-HP dewatering pumps		
Ventilation cooling system		
Ventilation fans		
2,840-kW generator		
750-kW load center		
Compressed air ventilation system		
Motor control center hoist		
Emergency hoist		

[a]1 inch = 2.54 centimeters.
[b]1 foot = 0.3048 meter.
[c]ID = inside diameter.

4.2.2.4 Social conditions

The site-characterization work force and associated population influx are expected to be small and similar in demographic and social characteristics to previous and current residents of the study area. In-migrants are not likely to cause social disruption or conflict. These new residents are likely to be viewed as contributing to the continuing social and economic vitality of the area.

Some activities related to site characterization for the repository facility may have the potential to disturb sites of traditional significance to Indian religion. Gable Mountain is recognized as a site of traditional significance. One of the planned site-characterization studies therefore includes a survey of previously identified Indian religious and sacred sites to be conducted in consultation with religious leaders from the affected Tribes. The purpose of the survey will be to identify sacred sites and to determine the impact of site-characterization activities.

4.2.2.5 Fiscal conditions and government structure

The U.S. Department of Energy contractors on the Hanford Site pay sales, use, and business and occupation taxes in accordance with the laws of the State of Washington. Given the small work force requirement (430 people) and the existing infrastructure of a project with an estimated annual expenditure of greater than 100 million dollars, the fiscal effect on the local government would probably be small. Also, Section 116 of the Nuclear Waste Policy Act of 1982 provides that the Secretary of Energy shall grant to each State and unit of general local government in which a site for characterization is approved an amount equal to the amount the State or general local government would receive if they were authorized to tax site-characterization activities, development, or operation of a repository.

4.2.2.6 Land use, access, and surface and mineral rights

The exploratory shaft site is located on the Hanford Site, which is controlled by the U.S. Department of Energy, and is approximately 1.9 kilometers (1.2 miles) west of the nearest chemical processing facility. The U.S. Department of Energy has dedicated the exploratory shaft site to potential site-characterization activities; therefore, there would be no land-use conflicts due to these activities. Since minimal activity is expected on State of Washington-leased land, no potential conflict is foreseen during site characterization. Access to the exploratory shaft program site would be by a road from Route 240, 1.7 kilometers (1.1 miles) to the west. An automated gating system will control access to the exploratory shaft facility. Access would not interfere with other uses or security requirements of the Hanford Site.

As discussed in Subsection 6.2.1.1, lands designated for the reference repository location have been withdrawn from all forms of appropriation under the public land laws, including the mining and mineral leasing laws. Therefore, site-characterization activities would not impact surface or mineral rights. If site-characterization activities are conducted off U.S. Department of Energy-controlled lands, land use, access, and surface and mineral rights would be considered when selecting a location for those activities. Site-characterization activities are not expected to have any significant adverse impact on Federal- or State-protected lands or agricultural lands (see Section 4.2.1). Activities on the U.S. Army Yakima Firing Center (see Subsection 3.4.1.3) are not expected to interfere with or be impacted by site characterization.

4.2.3 TRANSPORTATION EFFECTS

Transportation effects during site characterization will result from two principal activities: (1) Construction of an additional access road to the exploratory shaft site and (2) operation of motor vehicles by project personnel.

An access road, consisting of approximately 1.7 kilometers (1.1 miles) of asphaltic concrete, has been proposed to connect Route 240 with the southeast corner of the exploratory shaft site. One-half of the road will be an upgrade of existing surfaced roadway and the remainder will be new construction. The road will be 7.3 meters (24 feet) wide, with 2.4-meter (8-foot) shoulders. It will require a minimum amount of leveling (cuts and fill) due to the existing level terrain, and will be enclosed by a 4-strand barbed wire fence, which is a continuation of the existing Hanford Site perimeter fence.

The major terrestrial impacts of exploratory shaft site preparation during the site-characterization phase are discussed in Subsection 4.2.1.3.1. The air-quality impacts associated with combustion engines and fugitive dust from exploratory shaft site-preparation activities, including road construction, are described in Subsection 4.2.1.3.2.

The peak work force at the reference repository location during site characterization is estimated to be 200. This work force is in addition to, and can be compared with, the existing work force within the reference repository location (200 West Area), which is approximately 1,400, and the work force in the vicinity (200 Areas), which is approximately 3,500.

It is assumed that the additional work force would select from among the transportation options in the same proportion as the current work force. On this basis, there would be 50 additional riders on plant buses (diesel powered) to the 200 West Area and an additional 75 private vehicles (averaging 2 workers each). The additional bus riders would be distributed among the three shifts; thus, they may be accommodated by vacancies in the current service. However, it is assumed that one additional round-trip bus to the 200 West Area would be required. These increases are small, compared with the current traffic. They are within the range of traffic variations due to fluctuations in the work force

associated with current Hanford Site operations. As identified in Subsection 4.2.1.3.1, increased travel on established Hanford Site roads is expected to have minimal effects on the native biota.

Truck traffic during site preparation and shaft construction will be localized on the exploratory shaft site. The spoils pile for mined material will be approximately 400 meters (1,300 feet) from the shaft opening. This traffic will, therefore, not interfere with other traffic on the Hanford Site. Truck traffic from offsite will be infrequent, resulting only from deliveries of materials and equipment necessary for shaft construction. Since no radioactive material shipments are associated with site characterization, there will be no transportation-related radiological effects.

State and regional highway conditions are described in Section 3.5.2.

4.2.4 OCCUPATIONAL SAFETY AND HEALTH RISKS

The system design description for the exploratory shaft program describes the principal risks, design basis casualty events, and protective systems for the exploratory shaft program (RKE/PB, 1983). The principal risks are similar to those associated with most underground mining preparations. Design basis casualty events are those projected problems, delays, and accidents that could happen in a shaft and mine operation. Protective systems are the remedies and actions, including physical as well as administrative controls and measures, that are taken to avoid or minimize the effects of casualty events. The principal safety issues identified are rock fall, flooding, explosion, fire, down-hole fall, inoperative hoist, inadequate air, power failure, electrical hazards, excessive noise, and heat stress.

The blind-hole-drilling method would be used to excavate the exploratory shafts. This method is generally considered one of the safest available. The safety benefits of this shaft-sinking method are that workers do not enter the shaft until after all drilling activities are completed and a steel liner has been emplaced for the entire shaft length. This method allows shafts to be excavated by personnel located at ground level without exposing them to routine mining hazards (e.g., rock falls, water inflow).

Development of the underground drifts and rooms required for in situ testing would use conventional drill-and-blast techniques. This method involves the drilling of small-diameter holes into the drift face, placement of explosives in the holes, and (after personnel leave the area) remotely detonating the explosives. Personnel then return to the area to remove the broken rock resulting from the blasting operation and to determine if rock bolts are needed for roof support. Then new holes are drilled for more explosives and the sequential process is repeated until the desired length and configuration of drifts are achieved.

This is a routine construction operation with associated personnel risks. These risks would be very limited for the exploratory shaft facility, since a relatively small amount of drifting is required (approximately 425 meters (1,400 feet)). Using injury and fatality rates for mining operations (DOE, 1980), it is predicted that no fatalities and 2.5 temporary disabling injuries could occur during underground construction activities.

The U.S. Department of Energy would follow the safety and environmental requirements contained in DOE Orders 5480.1A and 5480.4 (DOE, 1981a, 1984a), including the construction of a second shaft for worker safety. The use of specific safety standards (i.e., Federal Mine Safety and Health Act of 1977, Tunnel Safety Orders of the State of California, and Mine Safety Orders of the State of California) for mining and drifting operations is mandated in DOE Order 5480.1A (DOE, 1981a). The emergency response plans for the exploratory shaft program are in accordance with DOE Order 5500.3 (DOE, 1981b).

4.3 ALTERNATIVE SITE-CHARACTERIZATION ACTIVITIES THAT WOULD AVOID ADVERSE IMPACTS

Some data from the exploratory shaft program will be used to confirm or supplement other primary data sources. Data needs (e.g., rock mass performance characteristics, hydrologic properties of a flow interior, and distribution or existence of tectonic features) cannot be reliably obtained by any methods other than in situ testing using surface boreholes and exploratory shafts. Therefore, no alternative site-characterization activities would be suitable for fulfilling these data needs.

An alternative method for obtaining at-depth geologic and hydrologic data would be to drill a series of small-diameter boreholes to the Cohassett flow. Each borehole would only provide data on a limited subsurface area, since horizontal interpretations are difficult to make from a vertical borehole. This would require that a large number of boreholes be drilled instead of exploratory shafts. Such an approach would not yield sufficient data to meet the requirements of 10 CFR 60 (NRC, 1985) and would have deleterious results with respect to waste isolation and increased environmental impacts.

Alternatives to the proposed shaft design include alternate methods of shaft construction and varying the number of shafts, size, and location of underground test chambers. Some variations in the design of surface facilities also would be possible as a function of the shaft design. The environmental effects of such variations would be minimal, relating mostly to small differences in sizing of the surface support area and its facilities.

The only alternative method of sinking a shaft is drilling shot holes, blasting, and mechanically removing the fragmented rock. This is the principal mining technique in the mineral industry. Employing this method for the penetration of aquifers would require the use of auxiliary techniques to prevent flooding in the shaft. Depending on the volumetric

flow rates of the aquifers encountered, these techniques would involve some combination of shaft pumping, freezing of aquifers, and injecting high-pressure grout.

With the conventional drill-and-blast method, all three methods would be needed to prevent potentially high ground-water inflow into the shafts. Compared to the proposed support facilities for a bored shaft, the necessary support facility would be large, costly, and energy consumptive. Also, the large number of wells required to freeze the aquifer waters could interfere with testing following construction. In summary, use of the drill-and-blast method rather than blind-hole drilling would increase worker hazard, environmental impacts, and expenditures.

The preferred alternative for sinking shafts is the blind-hole-drilling method.

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CHAPTER 5 SUMMARY

Chapter 5 describes the conceptual design of the repository and the potential regional effects of locating and operating a repository at the reference location as required by the Nuclear Waste Policy Act of 1982. This discussion, however, does not indicate that the reference repository location has been or will be selected as a repository site. The reader should note that the design process is ongoing and the design will change; however, effects on the environment due to those changes are expected to be small.

The repository concept described in Section 5.1 includes the surface and subsurface facilities as well as the process by which high-level nuclear waste and spent fuel are to be emplaced within a repository. This conceptual design includes the following phases:

- Construction phase--Construction of the surface buildings and facilities, construction of the subsurface facilities, including the shafts, shaft pillar area, a portion of the main accesses, and airways.

- Operations phase--Completion of repository development and emplacement of waste.

- Retrieval phase--General maintenance and monitoring before backfilling (the waste is retrievable during this phase).

- Backfill phase--Backfilling of drifts (access openings) as required within the panel area.

The repository concept described in this chapter is based on the 1982 conceptual design (RKE/PB, 1983) and a series of ongoing or recently completed engineering studies. The engineering information presented in this chapter does not represent the final repository design. Rather, it should be treated as an early step in the normal design process that progresses through the various stages of refinement. These design refinements would resolve current uncertainties and serve as the bases for an environmental impact statement and a safety analysis report to be prepared at the end of site characterization.

A comparison of various design impacts of alternative repository design concepts with the 1982 conceptual design (RKE/PB, 1983) is provided in Section 5.1. Also provided is a summary of a qualitative estimate of the change in projected environmental, transportation, and socioeconomic impacts relative to the 1982 conceptual design, on which the environmental evaluations within this chapter are based.

The decommissioning phase (i.e., backfilling the main entries and shaft pillar as required, plugging and sealing the repository, and demolishing, removing, and burying the facilities) and the terminal phase are not considered in the 1982 conceptual design. These phases will be added as the design is updated.

This chapter also discusses the effects that the construction and operation of a repository could have on the physical environment (i.e., site geology, hydrology, and environmental setting), on transportation, and on socioeconomic conditions.

The drilling of shafts and subsurface excavation at the bottom of the shafts are not expected to affect significantly the geology of the site. Effects on surficial hydrology are expected to be minimal. Some interactions between the repository and ground water will take place, although the magnitude of the effect is uncertain at this time.

In a construction operation of this size, some environmental impacts are inevitable. Although the Hanford Site can be generally characterized as a remote area, wildlife (e.g., the Swainson's hawk) may be adversely affected. No threatened or endangered species, however, nest or reproduce on the reference repository location; consequently, the expected environmental effects of locating a repository on the Hanford Site are not considered to be significant.

Also covered under environmental setting are air quality, noise, aesthetics, archaeological, cultural, and historical resources, and radiological effects. No radiological effects are expected from construction activities, and the dose to the public from an operating repository is expected to be analogous to the low dose received by the public resulting from fuel-handling and -storage operations at a typical nuclear power station.

Radiological and nonradiological effects from transportation (by either rail or highway) associated with the construction and operation of a nuclear waste repository are expected to be minimal. Socioeconomic impacts will probably be small, with positive attributes outweighing negative attributes.

Chapter 5 closes with a discussion of occupational health and safety. Nonradiological safety and health risks are expected to be similar to those normally resulting from a large construction mining project, with radiation exposure to employees during operation expected to be well below all allowable limits.

In summary, the U.S. Department of Energy believes that the environmental, socioeconomic, and transportation impacts for the reference design concept are within reasonable limits or are mitigatable. Similarly, the current design concept has impacts comparable to those of the reference case and are also mitigatable. The U.S. Department of Energy believes, therefore, that the conclusions reached on the guideline findings would not materially change due to variations in the repository design concepts analyzed.

The reader is referred to Table 5-A for a cross-reference matrix that indicates other sections in this document that are related to topics discussed in this chapter.

Table 5-A. Sections related to Chapter 5 discussions

	Chapter 2	Chapter 3	Chapter 4	Chapter 5	Chapter 6
Design requirements used for the 1982 conceptual design				5.1.1	
Description of 1982 conceptual design				5.1.2	
Design studies				5.1.3	
Decommissioning and closure				5.1.4	
Waste package description				5.1.5	
Programmatic issues				5.1.6	
Expected effects on the physical environment			4.1.2.3/4.2.1.3	5.2.1	
Geology	2.1.1	3.2	4.2.1.1	5.2.1.1	
Hydrology	2.1.3/2.1.4	3.3.1/3.3.2	4.1.1.7/4.2.1.2	5.2.1.2	6.3.1.1/6.3.3.3
Environmental setting	2.3.8*	3.4	4.1.2.3/4.2.1.3	5.2.1.3	6.2.1.6
Expected effects of transportation		3.5	4.2.3	5.2.2/5.1.7	6.2.1.8/6.2.2.2
Radioactive waste shipment bases				5.2.2.1	
Types of nonradioactive shipments				5.2.2.2	
Highway transport		3.5.2		5.2.2.3.1	
Railroad transport		3.5.1		5.2.2.3.2	
Barge transport				5.2.2.4	
Expected effects on socioeconomic conditions	2.3.9* 2.3.6*	3.6	4.1.2.2/4.2.2	5.2.3	6.2.1.7/6.2.2.2
Population density and distribution		3.6.1	4.2.2.1	5.2.3.1	6.2.1.2
Economic conditions		3.6.2	4.2.2.2	5.2.3.2	
Community services		3.6.3	4.2.2.3	5.2.3.3	
Social conditions		3.6.4	4.2.2.4	5.2.3.4	
Fiscal conditions and government structures		3.6.5	4.2.2.5	5.2.3.5	
Land use, access, and surface and mineral rights		3.4.1	4.2.2.6	5.2.3.6	6.2.1.1/6.2.1.3/ 6.3.1.8
Occupational safety and health			4.2.4	5.3	6.3.3.2

*Disqualifier analysis.

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Chapter 5

REGIONAL AND LOCAL EFFECTS OF LOCATING A REPOSITORY AT THE REFERENCE REPOSITORY LOCATION

This chapter is intended to meet the requirements of Section 112(b)(1)(E)(vi) of the Nuclear Waste Policy Act of 1982, which mandates the environmental assessment include ". . . an assessment of the regional and local impacts of locating the proposed repository at such site." This chapter meets those requirements by describing the environmental, transportation, and socioeconomic effects of locating a proposed repository at the reference repository location on the Hanford Site.

5.1 THE REPOSITORY

The function of the repository is to isolate nuclear waste from the biosphere so that it poses no significant risk to public health and safety. The repository will be designed for a specific waste-disposal capacity. The Nuclear Waste Policy Act of 1982 limits the disposal capacity for spent fuel, or its equivalent as high-level waste, to 70,000 metric tons (77,000 tons) of heavy metal prior to startup of a second repository.

The current design concept described in this chapter is based on the 1982 conceptual design (RKE/PB, 1983) and a series of ongoing or recently completed engineering studies. The 1982 conceptual design was selected as the reference repository design, since it represents the most complete design information available for this environmental assessment. The 1982 conceptual design represents work performed in 1981 and 1982. Since the 1982 conceptual design was issued, the repository design has continued to evolve. Therefore, the engineering information presented does not represent the final repository design. Rather, it should be treated as an early step in the sequential design process that progresses from feasibility and engineering studies, through conceptual design and preliminary design, to final design.

There is no single document that completely represents the current design concept. A combination of the 1982 conceptual design and subsequent engineering studies has provided input to the current design concept. Identification of major repository components (surface, waste handling, and underground) referenced to the documents that best represent those components in the current design concept is as follows:

- Surface and waste handling--1982 conceptual design (RKE/PB, 1983) as modified by a repository capacity increase study (RKE/PB, 1984a).

- Underground (subsurface)--Repository underground layout study (RKE/PB, 1984e).

The waste-storage capacity of the 1982 conceptual design is 47,400 metric tons (52,200 tons) of heavy metal. The waste-storage capacity considered in the repository capacity increase study is 72,000 metric tons (79,200 tons) of heavy metal. The waste-storage capacity considered in the repository underground layout study is 70,000 metric tons (77,000 tons) of heavy metal.

Other engineering studies conducted to provide input to the current design concept are

- Shaft optimization study (RKE/PB, 1984b).
- Tunnel optimization study (RKE/PB, 1984c).
- Waste-emplacement optimization study (RKE/PB, 1984d).

A discussion of the 1982 conceptual design is provided in Section 5.1.2; discussions of the individual engineering studies are provided in Section 5.1.3.

A two-phase repository feasibility study (Rockwell, 1984) was conducted to investigate the effects of a two-phase waste-receipt rate on the design. This feasibility study considered a total spent fuel waste-receipt rate of 70,000 metric tons (77,000 tons) of heavy metal. A discussion of this study is provided in Subsection 5.1.3.3.

Under the current design concept, which reflects the waste-acceptance schedule given in the mission plan (DOE, 1985, Table 2-2), the total repository capacity includes

- Spent fuel equivalent to 62,000 metric tons (68,200 tons) of heavy metal.
- High-level waste (including defense high-level waste and West Valley commercial high-level waste) equivalent to 8,000 metric tons (8,800 tons) of heavy metal.

The storage capacity requirement of the current design concept is 70,000 metric tons (77,000 tons) of heavy metal. In Phase I, the yearly acceptance rate for the first 3 years is spent fuel equivalent to 400 metric tons (440 tons) of heavy metal. During the fourth and fifth years, spent fuel equivalent to 900 and 1,800 metric tons (1,000 and 2,000 tons) of heavy metal, respectively, would be received. In Phase II, the yearly acceptance rate is spent fuel equivalent to 3,000 metric tons (3,300 tons) of heavy metal and high-level waste equivalent to 400 metric tons (440 tons) of heavy metal.

The repository will receive defense high-level waste and West Valley high-level waste at a rate of 400 metric tons (440 tons) of heavy metal per year equivalent beginning in the year 2003. Using wastes from a

defense waste-processing facility as an example, the wastes will be in the form of borosilicate glass contained in canisters approximately 0.6 meter (2 feet) in diameter and 3 meters (10 feet) in length, weighing approximately 1,800 kilograms (4,000 pounds). The total defense waste received is scheduled to be 8,000 metric tons (8,800 tons) of heavy metal as shown in Table 5-1. This will result in the receipt of approximately 800 canisters per year. This rate will be in addition to the 3,000 metric tons (3,300 tons) of heavy metal per year of spent fuel received. Shipment may be by truck or rail. Truck shipments could involve up to four shipments per day for defense waste.

According to the current design concept, the Phase I waste-handling building will reach maximum capacity by 2002 and would be available to handle defense waste. The defense waste package would present no unusual handling problems, because it would have a lower thermal output and radiation level than spent fuel.

Defense waste-handling operations would consist of placing the canister into the emplacement container, welding, inspection, transport to the underground facility, and placement in the disposal location. Additional personnel required for these operations would be small. The number of personnel required to handle approximately four additional packages per day is insignificant compared to the present manpower estimate. The waste-handling shaft and access into the repository would easily accommmodate the additional packages, and mining activities could prepare the emplacement holes on schedule. Since repository area size is based on thermal loading considerations, it should not be necesary to increase the overall size of the repository. Overall, the impact of defense waste on repository operations is considered to be minimal.

The major differences between the (1) reference 1982 conceptual design, (2) two-phase feasibility study, (3) repository underground layout study and (4) current design concept are summarized in Table 5-1. The table also provides a qualitative estimate of the change in projected environmental, transportation, and socioeconomic impacts relative to the 1982 conceptual design, on which the evaluations discussed later in this chapter are based. The projected differences in impacts among the 1982 reference repository design, the two-phase feasibility study, the repository underground layout study, and the current design concept are considered to be relatively small or mitigatable.

The comparison presented in Table 5-1 of the current design concept with the reference repository design provides a reasonable representation of the range of impacts expected from a repository in basalt.

A brief description of the current design concept is provided to summarize the effects of the most recent engineering studies on the 1982 conceptual design. At present, the repository surface facility will occupy a space of approximately 2,100 by 1,100 meters (7,000 by 3,500 feet). The waste will be delivered to the repository from the reactors by rail or truck. It will be inspected and, if found contaminated, moved directly into a washdown and waste-handling building for

Table 5-1. Comparison of alternative repository design concepts (sheet 1 of 4)

Repository characteristics	Reference design[a]	Two-phase feasibility study[b]	Other design studies[c]	Current design concept	Changes in projected environmental impacts	Changes in projected transportation impacts	Changes in projected socioeconomic impacts
1. Incorporation of exploratory shafts	No	Yes: One 1.8 m (6 ft) one 3.7 m (12 ft)	No	Yes: Two 1.8 m (6 ft)	Incorporation of exploratory shaft(s) would result in a minimal decrease in the amount of excavated material. The impact from excavated material is directly related to the size of the spoils pile, which is based on total excavated metric tons (tons). Whether these spoils are stockpiled for future use as backfill or left on the surface and reclaimed, the resulting impact is a temporary loss of surface habitat. The excavated material from the shaft(s) is expected to be an insignificant fraction of the overall spoils, resulting in an insignificant reduction of impact.	There would be no significant differences in impacts among concepts.	There would be no significant differences in impacts among concepts.
2. Number and size of shafts	Two 3.7 m (12 ft) one 4.3 m (14 ft) one 4.9 m (16 ft)	One 1.8 m (6 ft) four 2.7 m (8.75 ft) four 3.7 m (12 ft)	Seven 3.7 m (12 ft) two 3.0 m (10 ft)	Seven 3.7 m (12 ft) two 3.0 m (10 ft) two 1.8-m (6-ft) exploratory shafts	The impact related to this repository characteristic would be a temporary loss of surface habitat from placement of excavated material. The overall impact is expected to be insignificant for all four concepts compared to the total amount of material excavated from the repository.	There would be no significant differences in impacts among concepts.	There would be no significant differences in impacts among concepts.
3. Total excavated rock, metric tons (tons)	6,572,800 (7,240,400)	11,487,300 (12,654,000)	11,902,500 (13,111,400)	(d)	A notable impact related to this repository characteristic would be a temporary loss of surface habitat from placement of excavated material. The estimated surface area temporarily lost is 81 hectares (200 acres) for the reference design and 190 hectares (470 acres) for the three other concepts. Such habitat loss, in that it is temporary and a diminutive fraction of the regional shrub-steppe habitat, would be insignificant in itself and among the concepts. The most notable potential impact would be the occasional generation of fugitive dust. Recent air-quality impact analyses indicate that levels of fugitive dust would be minimal at locations of public access (5ubsection 5.2.1.3.2). Standard mitigation measures would not only limit these emissions to insignificant levels, but afford little difference between concepts.	There would be no significant differences in impacts among concepts.	There would be no significant differences in impacts among concepts.
4. Total area, ha (acres): Surface Subsurface	80 (200) 540 (1,334)	190 (470) 824 (2,036)	(d) 800 (2,000)	(d) (d)	A notable impact related to this repository characteristic would be a temporary loss of surface habitat from placement of excavated material. The estimated surface area temporarily lost is 81 hectares (200 acres) for the reference design and 190 hectares (470 acres) for the three other concepts. Such habitat loss, in that it is	There would be no significant differences in impacts among concepts.	There would be no significant differences in impacts among concepts.

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Table 5-1. Comparison of alternative repository design concepts (sheet 2 of 4)

Repository characteristics	Reference design[a]	Two-phase feasibility study[b]	Other design studies[c]	Current design concept	Changes in projected environmental impacts	Changes in projected transportation impacts	Changes in projected socioeconomic impacts
4. Total area, ha (acres): Surface Subsurface (cont.)					temporary and a diminutive fraction of the regional shrub-steppe habitat, would be insignificant in itself and among the concepts. The most notable potential impact would be the occasional generation of fugitive dust. Recent air-quality impact analyses indicate that levels of fugitive dust would be minimal at locations of public access (Subsection 5.2.1.3.2). Standard mitigation measures would not only limit these emissions to insignificant levels, but afford little difference between concepts.		
5. Preclosure period (yr):[f] Construction Operation Decommission	8 50 (d)	4 50 42	4 50 (d)	(e) 50 (d)	The most notable impact related to the repository preclosure period would be the temporary loss of surface habitat from placement of excavated material and surface facilities. Even though the construction period for each concept varies by as much as a factor of 2.6, this difference is insignificant compared to the total time estimated for construction, operation, and decommissioning. Such habitat loss, in that it is temporary and a diminutive fraction of the regional shrub-steppe habitat, would be insignificant in itself and among the concepts. The most notable potential impact would be the occasional generation of fugitive dust. Recent air-quality impact analyses indicate that levels of fugitive dust would be minimal at locations of public access (Subsection 5.2.1.3.2). Standard mitigation measures would not only limit these emissions to insignificant levels, but afford little difference between concepts.	Radiological transportation impacts are reduced due to radioactive decay of the waste forms to an insignificant degree if waste shipments are delayed beyond the planned time. For a given waste quantity, variations in waste receiving period do not change overall transportation impacts, but do change annual transportation impacts in inverse fashion (i.e., lengthening the receiving period reduces annual transportation impacts). Impacts resulting from those differences are considered to be less significant than those resulting from the reference design.	Small differences among concepts in duration of periods will not result in significant differences in potential impacts.
6. Total capacity, metric tons (tons) of heavy metal	47,400 (52,200)	70,000 (77,000)	70,000 (77,000)	70,000 (77,000)	A notable impact related to this repository characteristic would be a temporary loss of surface habitat from placement of excavated material. The estimated surface area temporarily lost is 81 hectares (200 acres) for the reference design and 190 hectares (470 acres) for the three other concepts. Such habitat loss, in that it is temporary and a diminutive fraction of the regional shrub-steppe habitat, would be insignificant in itself and among the	For a given waste type (e.g., spent fuel), transportation impacts are roughly proportional to the amount of waste shipped. Transportation impact changes associated with other waste types are identified in Item 8. Impacts resulting from those differences are considered to be less significant than those resulting from the reference design.	Greater capacity may increase the size of peak work force and preclosure period; however, differences in impacts are not expected to be significant. Increased population and demands for community services and facilities are small compared to the existing populations and infrastructure.

7 0 1 6 8 0 9 3 6

Table 5-1. Comparison of alternative repository design concepts (sheet 3 of 4)

Repository characteristics	Reference design[a]	Two-phase feasibility study[b]	Other design studies[c]	Current design concept	Changes in projected environmental impacts	Changes in projected transportation impacts	Changes in projected socioeconomic impacts
6. Total capacity, metric tons (tons) of heavy metal (cont.)					concepts. The most notable potential impact would be the occasional generation of fugitive dust. Recent air-quality impact analyses indicate that levels of fugitive dust would be minimal at locations of public access (Subsection 5.2.1.3.2). Standard mitigation measures would not only limit these emissions to insignificant levels, but afford little difference between concepts.		
7. Peak receipt rate, metric tons (tons) of heavy metal per year	2,370 (2,650)	3,000 (3,300)	3,000 (3,300)	Spent fuel: 3,000 (3,300), West Valley high-level waste, and defense high-level waste: 400 (440)	Potential radiological impacts would be directly proportional to maximum waste receipts per year. The radiological impacts for the reference design are summarized in Subsection 6.2.2.1. Radiological releases from any repository concept will be regulated by 10 CFR 20, 10 CFR 60, and 40 CFR 191 and can be considered insignificant.	For a given annual waste type (e.g., spent fuel), transportation impacts are roughly proportional to the annual receipt rate. Changes in transportation impacts for alternative waste types are identified in Item 8. Impacts resulting from those differences are considered to be less significant than those resulting from the reference design.	Differences in receipt rates may result in differences in peak work force; however, changes in impacts are not expected to be significant.
8. Waste inventory	50% spent fuel 50% commercial high-level waste	100% spent fuel	100% spent fuel	89% spent fuel; 11% defense high-level waste and West Valley high-level waste	The reference design would have the highest potential impacts on a per metric ton (ton) of waste basis due to the greater spacing requirement; therefore, a greater volume of rock would be removed per metric ton (ton) of waste emplaced. The lower heat load per equivalent metric ton (ton) of heavy metal of defense high-level waste and West Valley high-level waste would permit closer spacing of waste containers. However, the equivalent metric tonnage (tonnage) per container would be less than for spent fuel. Consequently, the volume of rock excavated and total underground layout area to accommodate defense high-level waste and West Valley high-level waste may increase with the current design concept. Standard mitigation measures would limit this to insignificant levels, affording little difference between concepts.	Transportation impacts of replacing spent fuel by an equivalent amount (spent fuel weight basis) of high-level waste are increased for a mixture of defense high-level waste and West Valley high-level waste, and reduced for possible future commercial high-level waste. These changes result from shipping cask payload variations. Refer to Section 5.1.7 for a discussion of the relationships between shipments, payloads, and waste types. The differential impacts are less significant than those impacts resulting from the reference design.	There would be no significant differences in impacts among concepts.
9. Emplacement configuration	Long horizontal boreholes	Short horizontal boreholes	Short horizontal boreholes	Short horizontal boreholes	Short borehole emplacement would increase the size of the repository and the size of the spoils pile. The resulting potential impacts are identified in item 3 and are considered insignificant. However, short borehole emplacement would provide increased reliability for emplacement and retrieval; therefore, potentially decreasing worker exposure and decreasing potential long-term radiological impacts.	There would be no significant differences in impacts among concepts.	There would be no significant differences in impacts among concepts.

7 0 1 6 8 0 9 3 7

Table 5-1. Comparison of alternative repository design concepts (sheet 4 of 4)

Repository characteristics	Reference design[a]	Two-phase feasibility study[b]	Other design studies[c]	Current design concept	Changes in projected environmental impacts	Changes in projected transportation impacts	Changes in projected socioeconomic impacts
10. Waste handling buildings	1	1 offsite 1 onsite	1	2	There would be no significant differences in potential impacts among concepts.	There would be no significant differences in impacts among concepts. For the two-phase repository concept, an existing receiving facility on the Hanford Site would be inserted into the transportation route; the transportation impacts (excluding the waste receiving and handling impacts) of this additional receiving facility would be insignificant.	There would be no significant differences in impacts among concepts.
11. Peak utilities demand:							
Water, m^3/min (gal/min)	13 (3,400)	(g)	(g)	(g)	There would be no significant differences in potential impacts among concepts.	There would be no significant differences in impacts among concepts.	There would be no significant differences in impacts among concepts.
Electricity, kW/day	29,000	(g)	(g)	(g)			
Fuel m^3/day (gal/day)	5 (1,330)	(g)	(g)	(g)			
12. Peak work force:							
Construction	1,100	(g)	(d)	(d)	There would be no significant differences in potential impacts among concepts.	There would be no significant differences in impacts among concepts.	There would be no significant differences in impacts among concepts. The accompanying changes in population and increased demands for community services and facilities would be small compared to the existing populations and infrastructure.
Operations	900	950	(d)	(d)			
13. Access improvements:							
Road, km (mi)	4.8 (3.0)	2.0 (1.2)	(d)	(d)	The most notable impact related to this repository characteristic would be a temporary loss of surface habitat from access improvement. This impact is expected to be insignificant for all four concepts compared to the total amount of habitat lost due to the repository.	The access route distances shown are preliminary design-basis estimates that have not yet been verified by access route designs. The differences in access improvements among concepts are judged to be small; therefore, there would be no significant differences in transportation impacts among concepts.	There would be no significant differences in impacts among concepts.
Rail, km (mi)	4.8 (3.0)	6.6 (4.1)	(d)	(d)			

[a]1982 conceptual design (RKE/PB, 1983).

[b]Two-phase repository feasibility study (Rockwell, 1984).

[c]Repository underground layout study (RKE/PB, 1984e).

[d]Estimated to be nearly the same (within plus or minus 10 percent) as for the two-phase repository concept.

[e]Complies with mission plan (DOE, 1985).

[f]Preclosure periods defined as follows:

Construction--Start of construction to start of waste emplacement.

Operation--Start of waste emplacement to end of caretaker period (may include backfilling of portions of the underground facility if such work is started prior to the end of the caretaker period).

Decommission--End of caretaker period to completion of shaft and borehole sealing.

[g]Estimated to be nearly the same (within plus or minus 10 percent) as for the reference design case.

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cleanup and unloading. Once the shipment has been cleared from the inspection area, it will be taken into the protected holding area or moved directly into the washdown area.

The underground facilities will be located in the Cohassett flow and will occupy a space of approximately 1.9 by 4.3 kilometers (1.2 mile by 2.7 miles). Phase I and Phase II exploratory shafts will be incorporated into the repository design, although primary access to the repository will be through nine shafts, ranging in inside diameter from 3.1 to 3.7 meters (10 to 12 feet). The shafts will be excavated by the rotary blind-hole-drilling method. A ring-stiffened steel liner will be floated into place; the annulus space between the outside of the liner surface and the rock wall will be filled with grout. During the liner-installation process, ring-stiffened steel casing sections will be welded sequentially under controlled conditions and subjected to stringent inspection.

The underground facilities will be developed using conventional drill-and-blast mining methods, and the emplacement holes will be mechanically bored. Rock bolts will be used for ground support; shotcrete will be applied for additional support, as well as for a smooth-wall texture to reduce ventilation energy requirements. The maximum drift cross-section will be 7.5 by 3.4 meters (24.5 by 11 feet) in the emplacement rooms. The short horizontal borehole waste-emplacement method will be employed.

During drilling of the shafts, mud pits will be used as settling basins for the removal of basalt chips and soil material from the recirculated drilling fluid. Excavated material, after settling to the bottom of the mud pits, will be dredged and hauled to the spoils pile. On completion of shaft drilling, the drilling fluid will be hauled to another shaft construction location for further use. The fragmented basalt resulting from subsurface development will be transported to and accumulated in the spoils pile. The size of the spoils pile will be controlled by adjusting the depth of accumulated material. Sand and coarse aggregate will be produced by crushing and screening the basalt in the spoils pile. This material will be stored for subsequent use in the manufacture of concrete, shotcrete, and backfill. Waste water from the spoils pile drains to a retention basin and then is transported by pumping or gravity flow to a percolation pond.

The current design concept is based on receipt of 5-year old (out of reactor) or older spent fuel. The impact of spent fuel consolidation and waste packaging at the monitored retrievable storage facility has not been addressed. The maximum container dimensions are assumed to be 81 centimeters (32 inches) outside diameter by 437 centimeters (172 inches) long. The packing thickness is assumed to be 15 centimeters (6 inches) and the overall package length, including the packing shell, is assumed to be 540 centimeters (212 inches). The overall package outside diameter is assumed to be 116 centimeters (46 inches). Although onsite disposal of low-level repository-generated waste is planned, no standard method or container has been determined.

The current design concept schedule includes 6 years for construction, 25 years for operation and waste receipt, and, if required, 31 years for retrievability. Emplaced waste can be retrieved, starting at any time up to 50 years after waste-emplacement operations are initiated. Thus, the repository life could extend for 87 years (DOE, 1985).

The U.S. Department of Energy strategy (DOE, 1985) for developing a repository consists of two design phases. The first phase consists of conceptual design, which includes the site-characterization plan conceptual design and the advanced conceptual design. The second phase consists of Title I and II design, which includes the license application design and the final procurement and construction design. The Basalt Waste Isolation Project is now developing the site-characterization plan conceptual design. These designs will serve as the basis for an environmental impact statement and safety analysis report prepared at the end of site characterization.

Currently, there are several programmatic issues affecting repository design that have not been finalized. Three of these issues are monitored retrievable storage, minimum waste age, and retrievability. A discussion of these issues and potential changes to the repository design are discussed in Section 5.1.6.

5.1.1 REQUIREMENTS FOR THE 1982 CONCEPTUAL DESIGN

The 1982 conceptual design (RKE/PB, 1983) is the reference repository design that is being modified as part of the sequential design process. The expected quantities and some of the waste forms have changed since the design requirements for the 1982 conceptual design were established. Furthermore, additional geotechnical data have been obtained that affected the design. Nonetheless, the discussion of the 1982 conceptual design does provide a foundation on which to evaluate the general methodology for waste disposal and to assess environmental effects.

Types of nuclear waste containers that were considered in the 1982 conceptual design are listed below.

- Containers of spent fuel assemblies from commercial boiling water reactors and pressurized water reactors.
- Containers of canisters of vitrified commercial high-level waste.
- Drums of solidified transuranic waste.

The 1982 conceptual design served the following purposes.

- Allowed comparison of site characteristics and design concepts to evaluate how the engineered structures could fit into the natural site system.

- Oriented the design process so that early program generic requirements (DOE, 1981b), regulatory requirements (NRC, 1985), and functional and operating needs could be evaluated.

- Provided a basis for developing order-of-magnitude cost and schedule estimates.

- Provided a basis for preclosure safety analyses, which will support updated design concepts. Such analyses identified safety and operating risks, which could be addressed in more detailed design efforts (Section 6.4.1).

- Provided a basis for the assessments in Section 5.2.

5.1.1.1 Repository life cycle

The 1982 conceptual design (RKE/PB, 1983) described the projected construction, operations, retrieval, and backfill phases of the proposed repository. Decommissioning was not considered in this early design, but will be included as the design evolves (Section 5.1.4). All phases are briefly described below.

- The construction phase included construction of the surface buildings and facilities, as well as the subsurface facilities (including the shafts, shaft pillar area, a portion of the main accesses, and airways) required for the excavation of emplacement panels for an initial 5-year period of waste receipts with emplacement holes for receipts during a 1-year period.

- The operations phase included the completion of repository development and the emplacement of waste and is subdivided into four overlapping periods of activity.

  - Mining development included the completion of remaining waste panels, main accesses, and airways.

  - General mining operations included general mining, administration, maintenance, upkeep, and ground control.

  - Emplacement hole drilling provided openings for emplacement of waste containers.

  - Waste-emplacement period included activities associated with waste emplacement and could include emplacement of packing around the waste containers.

- The retrieval phase included maintenance and monitoring before backfilling; the waste is retrievable during this phase, if necessary.

- The backfill phase included backfilling of drifts (access openings) within the waste-storage panel area. Packing around the waste in the emplacement opening would be installed during this period if it were not done during the waste-emplacement period.

5.1.1.2 Projected work force and major material commitments

The manpower requirements (Table 5-2) that were projected in the 1982 conceptual design (RKE/PB, 1983) were based on an expected capacity of 47,400 metric tons (52,200 tons) of heavy metal.

Table 5-2. Approximate manpower requirements based on the 1982 conceptual design (RKE/PB, 1983)

Design phase	Approximate manpower		
	Minimum	Maximum	Average
Construction	200	1,100	450
Operations	500	900	815
Retrieval	ND	ND	110
Backfill	ND	ND	200

ND = not determined.

The projected requirements for major materials that would be needed to implement the 1982 conceptual design are listed below.

- Structural steel—25,100 metric tons (27,600 tons).
- Rebar—11,120 metric tons (12,230 tons).
- Rail track—14,500 meters (47,560 feet).
- Concrete (includes shotcrete)—120,200 cubic meters (157,200 cubic yards).

5.1.2 DESCRIPTION OF 1982 CONCEPTUAL DESIGN

The 1982 conceptual design (RKE/PB, 1983) predates the adoption of the 70,000-metric-ton (77,000-ton) design capacity; this design was based on an ultimate capacity to dispose of spent fuel and commercial high-level

waste equivalent to a total of 47,400 metric tons (52,200 tons) of heavy metal. Design of the subsurface facilities was based on an equal split between spent fuel and commercial high-level waste on the basis of weight. It was assumed that the spent fuel would be removed from the reactor core a minimum of 10 years prior to shipment to the repository or would be converted to commercial high-level waste. The waste-receipt rate was 1,072 containers of spent fuel per year or the metric ton (ton) of heavy metal equivalent of commercial high-level waste or any combination thereof. The design provided the option of waste retrieval, starting up to 50 years after the initial waste emplacement.

The 1982 conceptual design included descriptions of generic design concepts to meet general design requirements for any repository. The following subsections provide a description of a repository as a basis for the environmental analysis that is contained in Section 5.2. These generic concepts are not expected to change significantly during the evolution of the repository design.

An illustration of the repository facilities based on the 1982 conceptual design is provided in Figure 5-1. The components of the repository are the surface facilities, the access shafts, and the subsurface facilities, including the shaft pillar area and waste-storage areas.

Figure 5-2 shows the sequential emplacement process for spent fuel or commercial high-level waste as described in the 1982 conceptual design. The shipping cask would arrive at the repository site by truck or rail and would be moved into the waste-handling facility (Fig. 5-3). The waste container would be removed from the shipping cask and then moved to the primary hot cell to be inspected and repaired if required. The containers would be loaded into the waste-transport shaft cage, and transported down the shaft to the shaft pillar area (Fig. 5-4). Containers would be transported from the shaft pillar area via the main entries (see Fig. 5-4) to the emplacement room by the waste transporter. Once the waste transporter is in the emplacement room, the container would be loaded in a long emplacement borehole (Fig. 5-5). Containers would be left in the emplacement borehole and could be retrieved, if retrieval became necessary. Following the retrieval period, the emplacement holes would be packed and the underground openings backfilled with an engineered material of low permeability (this design concept is based on a mixture of bentonite and crushed basalt).

5.1.2.1 Surface facilities

Most of the surface facilities (Fig. 5-6) described in the 1982 conceptual design (RKE/PB, 1983) would be located in a central process area. The central process area would include all accesses to the surface and subsurface facilities. The subsurface facilities for a 47,400-metric-ton (52,200-ton) of heavy metal capacity repository cover a 540-hectare (1,334-acre) area. The central process area (80 hectares (200 acres)) is located on the surface directly above it and is surrounded by a double security fence.

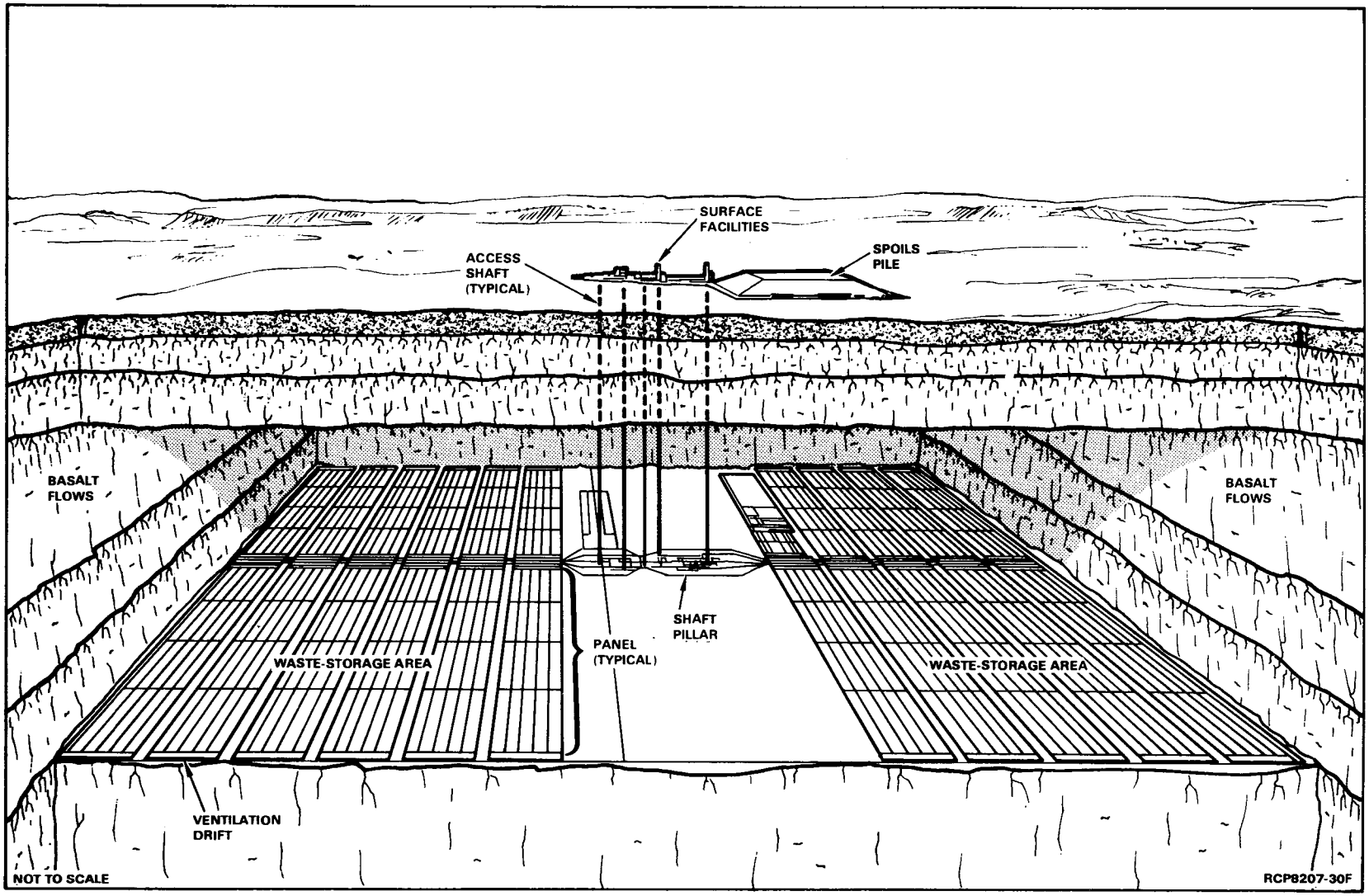

Figure 5-1. Illustration of the repository facilities based on the 1982 conceptual design (RKE/PB, 1983).

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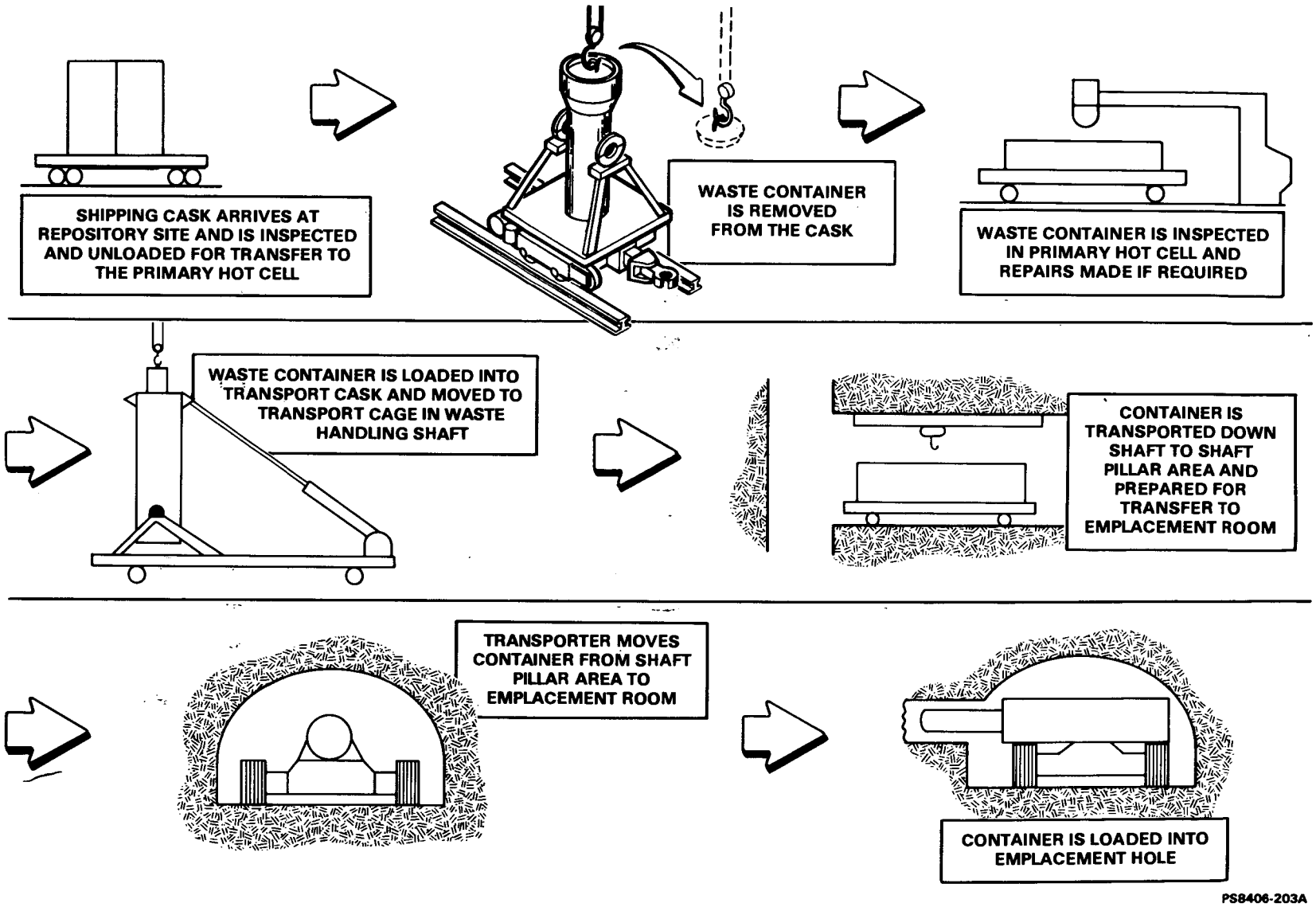

Figure 5-2. Generalized emplacement process based on the 1982 conceptual design (RKE/PB, 1983).

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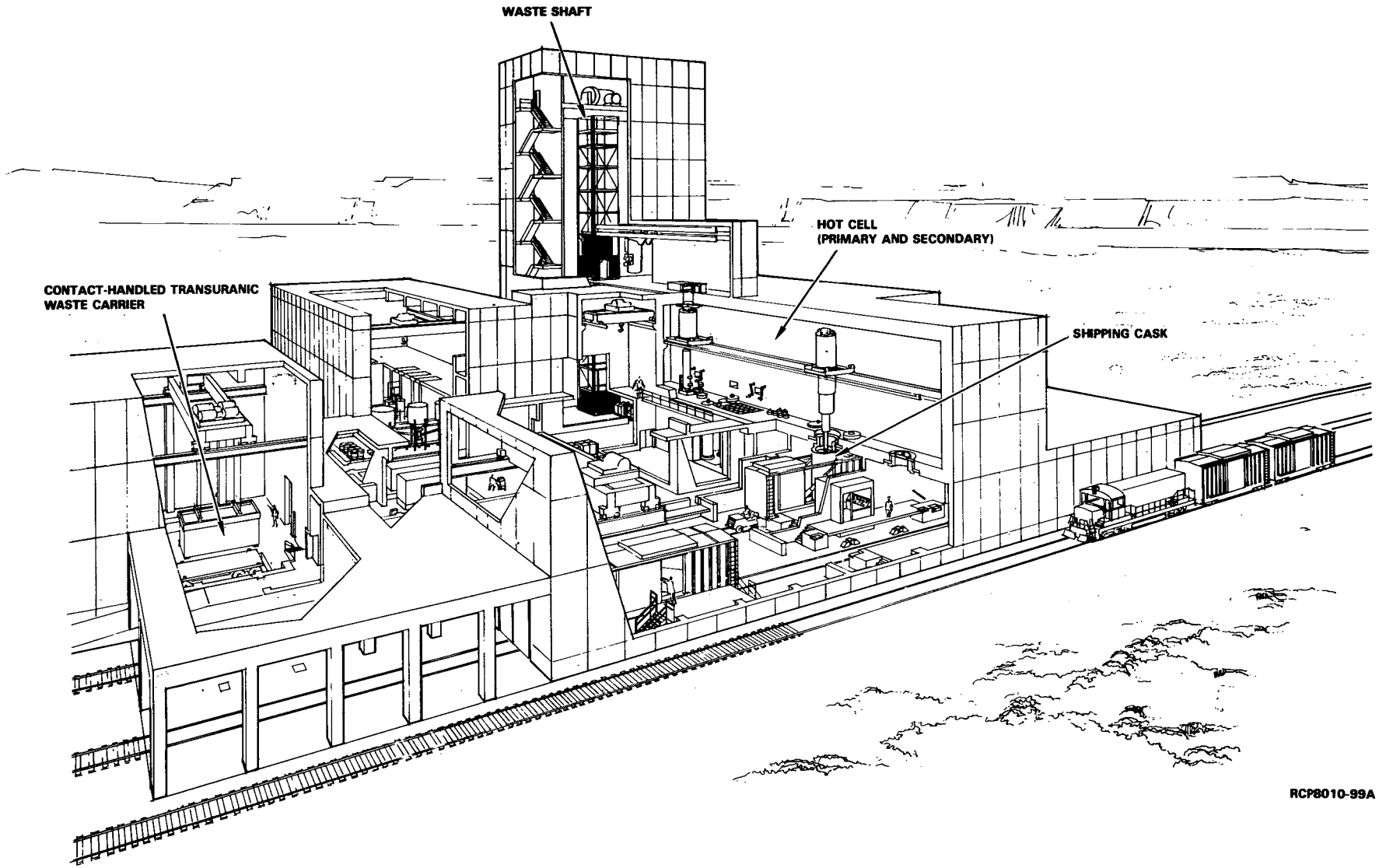

Figure 5-3. Waste-handling facility based on the 1982 conceptual design (RKE/PB, 1983).

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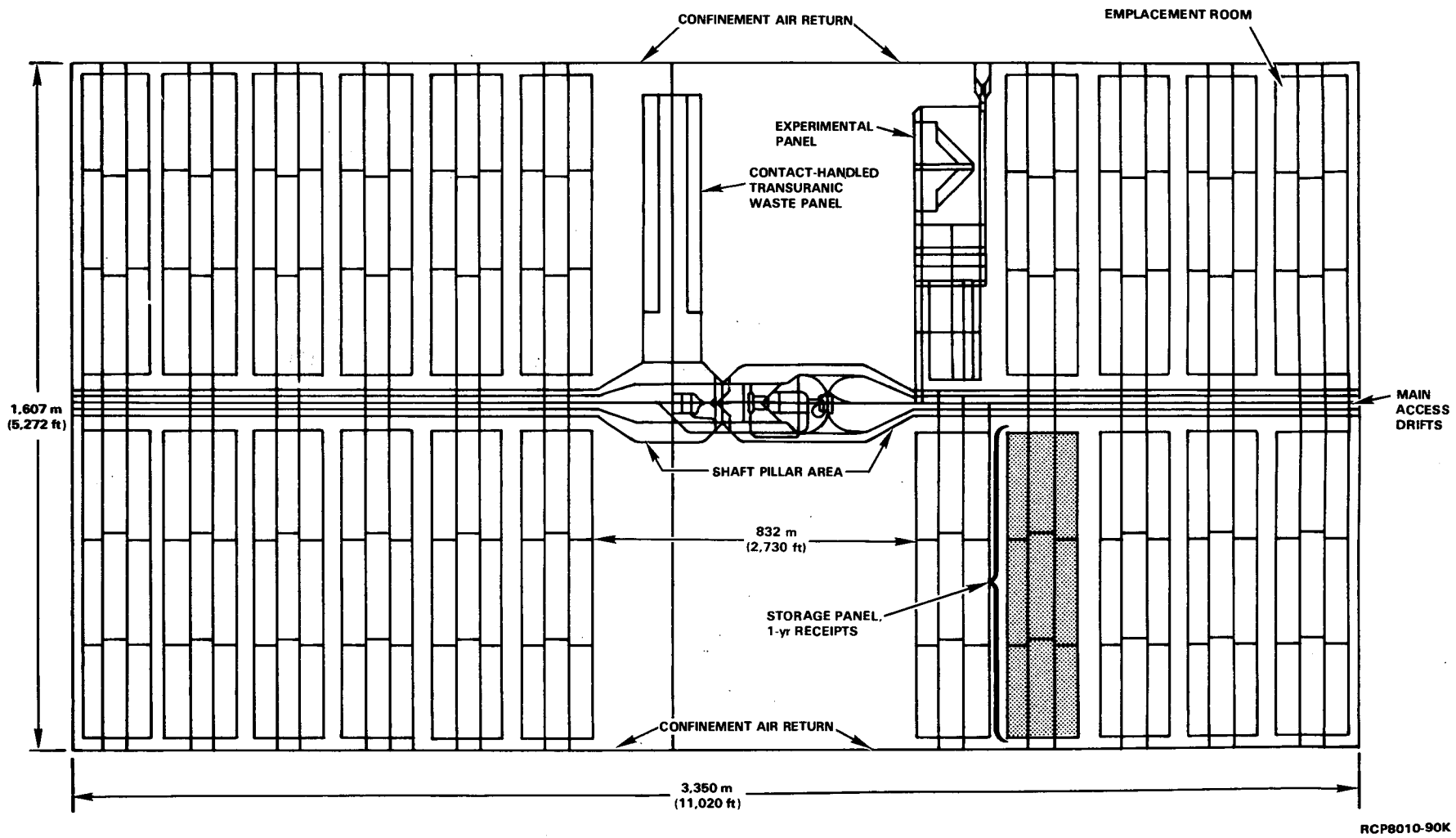

Figure 5-4. Underground repository layout based on the 1982 conceptual design (RKE/PB, 1983).

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7 0 1 6 8

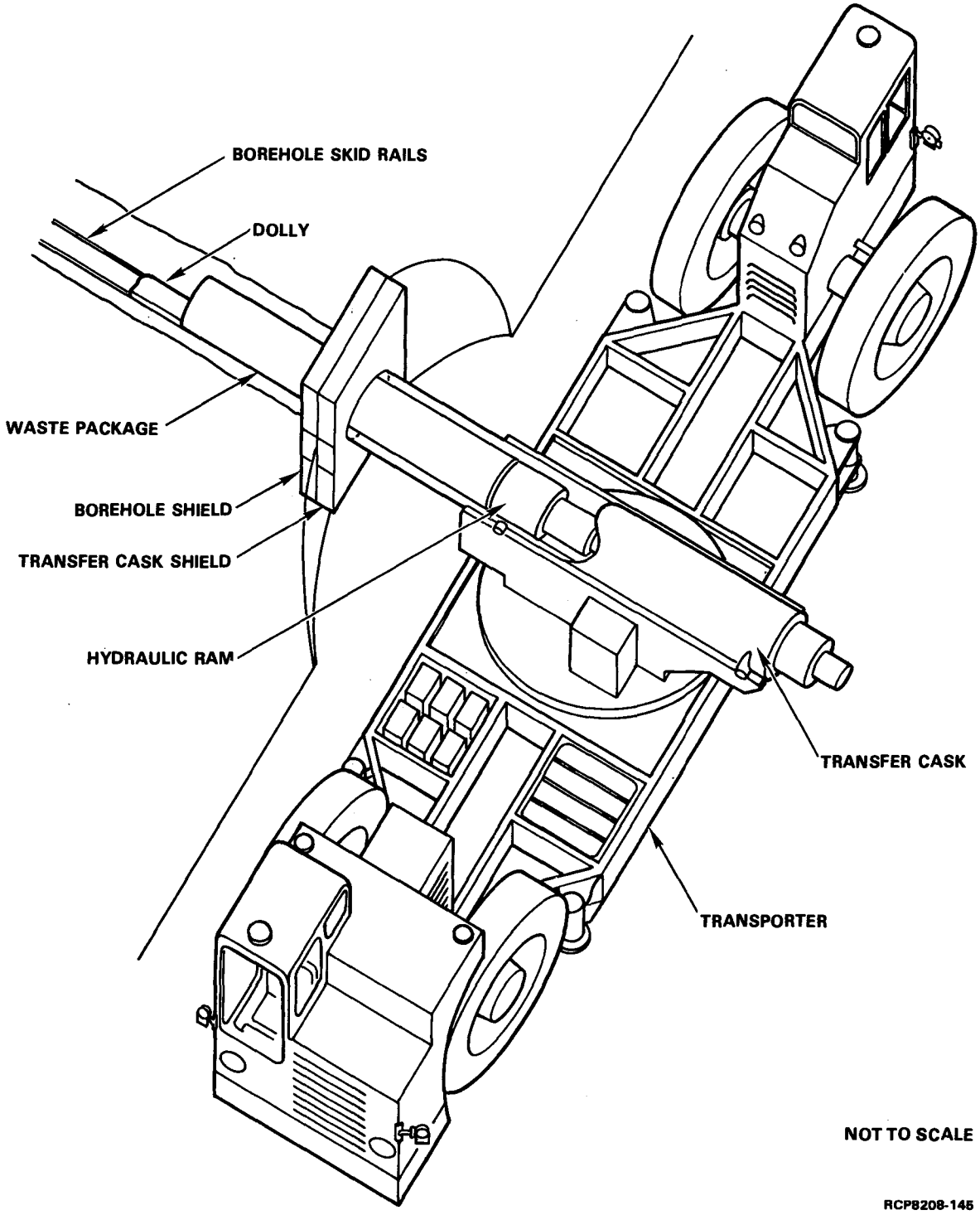

Figure 5-5. Transporter in emplacement operation based on the 1982 conceptual design (RKE/PB, 1983).

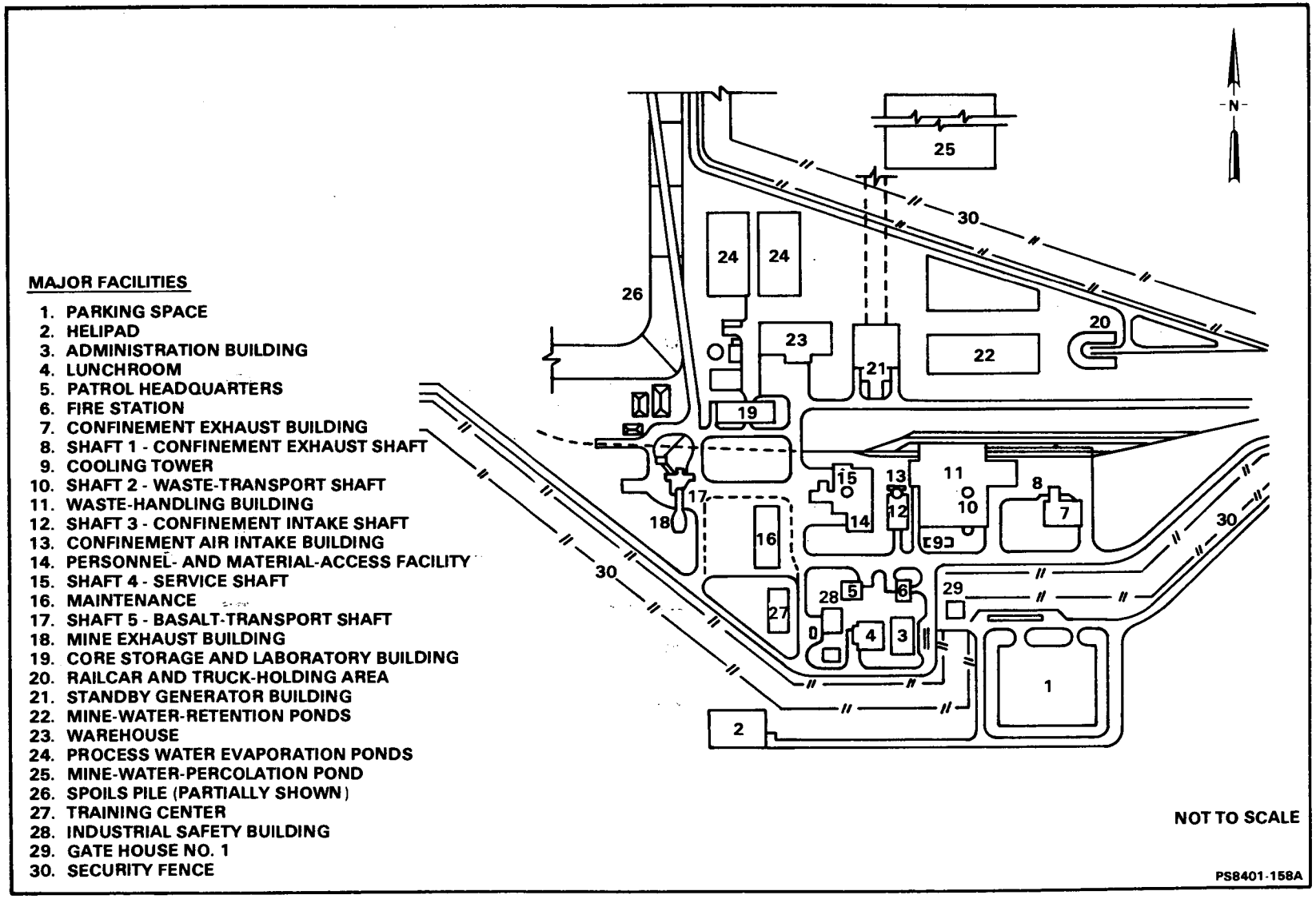

Figure 5-6. Surface facilities plan for the central process area based on the 1982 conceptual design (RKE/PB, 1983).

7 0 1 6 8 0 9 4 9

The 1982 conceptual design was based on placing the underground repository facilities in the Umtanum flow. The candidate horizon is now the Cohassett flow (see Section 2.2.3). The selection of the Cohassett flow will have minimal effect on the design of the surface facilities.

According to the 1982 conceptual design, water would be supplied from the Columbia River to the reference repository water-treatment plant through a pipeline approximately 12 kilometers (7.4 miles) long. Two new pumps would be installed at the existing river pumping station.

Two new transmission lines, routed over separate parallel rights-of-way on the Hanford Site, would connect the repository to the Hanford Site power system. A new telephone line would connect the surface facilities at the repository to the Hanford Site telephone network.

Only facilities that would affect the handling or monitoring of nuclear waste or other potential pollutants are discussed in the following subsections. The location, size, capacity, and other requirements of these facilities may change somewhat in future design activities as characterization and design activities evolve.

5.1.2.1.1 Ventilation

The waste-handling facility, located on the surface, would be ventilated by two separately controlled systems: (1) A confinement system for waste handling and (2) a system for the support and administrative areas. The subsurface facilities also would be ventilated by two separately controlled systems: (1) A confinement system for waste handling and (2) a system for the mining development area.

The confinement ventilation system would use redundant fans and air-filtering systems. A radiation-monitoring system (Subsection 5.1.2.1.2) would extend throughout the confinement airways and in the exhaust shaft. This would permit detection of unacceptable levels of airborne radioactive or toxic materials in sufficient time to switch the airflow to high-efficiency particulate air filters. The layout of the ventilation circuit would be such that ventilation air would flow from zones of uncontaminated air to potentially contaminated zones. The capacity of the ventilation system would be large enough to provide ventilation for emplacement and occasional retrieval activities during the operations phase, retrieval or maintenance during the caretaker phase, and waste panel backfilling activities.

The intake (fresh) ventilation air would be cooled in the repository. A cooling tower on the surface may also be necessary to dissipate heat to the atmosphere. The size of the cooling plant would be adequate to meet the cooling requirements.

5.1.2.1.2 Radiation-monitoring system

A radiation-monitoring system would be furnished for the surface facilities. The radiation-monitoring system would be part of an overall program to assure the safety of the public and repository personnel under normal and abnormal conditions. To do so, this system would be designed to monitor credible ranges and to record at a central location all normal and abnormal conditions of radioactivity that are important to public and repository safety and systems control. Radiation-monitoring instrumentation would be the type normally used in nuclear facilities.

The instrumentation system would include systems for radiation monitoring, process control, mined openings, environmental monitoring, power distribution, and fire alarms. Radiation instrumentation would be furnished for radiation sensing, personnel examination, and process control.

Radiation monitoring would be performed on incoming trucks and railcars. The monitors would also be utilized to detect contamination on vehicles prior to leaving the facilities.

5.1.2.1.3 Radioactive waste control and disposal

A system would be provided to collect, process, and immobilize the solid radioactive waste generated by repository operations (RKE/PB, 1983). This remotely operated system would include the following:

- Collection of solid radioactive waste.
- Shredding and size reduction of radioactive waste.
- Incineration that would result in a low-temperature low-level radioactive ash product suitable for immobilization.
- Immobilization of ash in 0.2-cubic-meter (55-gallon) drums.
- Prevention of uncontrolled escape of radioactive airborne particulates.
- Removal, bagging, and disposal of noncombustible materials.
- Transportation of low-level radioactive waste to the Hanford low-level waste-disposal site.

A liquid radioactive waste system would be installed at the repository to collect, treat, and dispose of liquid radioactive wastes generated by repository operations. The liquid radioactive waste sources would include shower water, reverse osmosis concentrate, ion-exchange resin

sluicing water, cask-flushing and -venting water, radiation-monitoring system drains, floor drains and sumps at the waste-handling facility, hot cell process tank drain, floor drains from the health physics laboratory in the industrial safety center, liquid radioactive waste vault sump, and floor drains from the confinement exhaust ventilation building.

A gaseous radioactive waste system would also be installed that would process gaseous radioactive wastes from gas-emitting sources at the surface facilities. This process would remove radioactive liquid droplets and particles. The gas would then be discharged to the primary confinement ventilation system of the waste-handling facility, which in turn would exhaust waste air and gases to the exhaust stack via high-efficiency particulate air filters.

5.1.2.1.4 Nonradioactive waste control and disposal

A system for disposal of nonradioactive repository-generated waste is provided in the 1982 conceptual design (RKE/PB, 1983). This system would accommodate disposal of solid waste, process liquids, subsurface repository drainage water, and sanitary sewage.

Hazardous wastes would be disposed of in accordance with the Resource Conservation and Recovery Act of 1976 (Subsection 6.2.1.6.3). Such wastes could include solvents, empty chemical containers, and unused decontamination solutions.

Inert solid waste would be collected and sorted, if economically justifiable, to recover reusable materials. The residue would be compacted, bagged or baled, depending on waste type, hauled to the Hanford Site central landfill area (see Fig. 3-37), and buried.

The nonradioactive process liquids-disposal system would dispose of laboratory wastes, cooling tower blowdown, and washdown wastes from the maintenance shop and warehouse. Two evaporation ponds would be provided for disposal of these liquid process wastes: One pond would undergo sludge removal, while the other is in operation. Removed sludge would be hauled to a sludge-disposal area on the Hanford Site.

The water from subsurface facilities would be discharged to one of two lined retention ponds on the surface in the central process area. Flow-measuring devices would be provided on the discharge lines, and provisions would be made for vadose zone and ground-water monitoring. The discharge lines to the pond would be continuously sampled for radioactivity. If none were found, the retention pond would be drained by gravity to ultimate disposal through a percolation pond. If radioactivity were present, the retention pond would not be drained and a portable deionizer would be used to remove radioactivity from the pond water. The deionized water then would be discharged to the percolation pond and the resin beads would be disposed of in the radioactive waste incinerator.

The sanitary sewage system would collect sanitary sewage from the repository buildings, transfer the sewage to the treatment plant, treat the sewage, and dispose of the treatment plant effluent. Liquid effluent would be chlorinated and disposed of at the repository location by surface percolation. Sludge would be hauled from the repository site to a sludge-disposal area on the Hanford Site.

5.1.2.2 Subsurface facilities

The principal components of the 1982 conceptual design (RKE/PB, 1983) subsurface facilities are the shaft pillar area, shafts, and underground drifts (see Fig. 5-1).

The shaft pillar area would provide a minimum number of openings for access, ventilation, and travel. It is best described in terms of its functional areas and its major accessways. The accessways consist of five shafts: Basalt transfer, service, confinement air intake, waste transport, and confinement exhaust.

The main accesses to emplacement panels described in the 1982 conceptual design would be the airways and travel routes between the shafts and the waste panel areas (see Fig. 5-4). The main accesses would provide the following:

- Accessways connecting the waste shaft to the waste-emplacement locations.
- Haulageways and accessways for bulk materials, mining equipment, supplies, and personnel.
- Accessways for utilities, dewatering lines, and maintenance facilities.
- Airways for mining and confinement air systems.

The waste panels described in the 1982 conceptual design would be divided into emplacement pillars designed to contain spent fuel and processed high-level waste containers. A waste panel would be a discrete area encompassing emplacement rooms or corridors. Waste containers would be placed into long horizontal boreholes from the emplacement room. The waste panels (during the operations phase of the repository) would be serviced by two independent ventilation circuits from the confinement ventilation system and the radiation-monitoring system (see Subsections 5.1.2.1.1 and 5.1.2.1.2).

5.1.3 DESIGN STUDIES

Since completion of the 1982 conceptual design (RKE/PB, 1983), several engineering studies have been conducted to determine repository-development needs and performance requirements and to provide additional information to supplement the reference design (Table 5-3). The results of the studies in Subsections 5.1.3.1 and 5.1.3.2 constitute the basis for the most recent single-phase concept, identified in Table 5-1 as other design studies.

5.1.3.1 Optimization and alternative studies

The repository capacity increase study (RKE/PB, 1984a) identified changes in the 1982 conceptual design (RKE/PB, 1983) for an increase in the total storage capacity to 72,000 metric tons (79,200 tons) of heavy metal. This was 2,000 metric tons (2,200 tons) higher than the Nuclear Waste Policy Act of 1982 limit of 70,000 metric tons (77,000 tons). Using the 1982 conceptual design as a basis for evaluation and comparing it to the two-stage repository concept, there would be no significant increase in capital construction costs (for the first 5 years) resulting from an increase in capacity from 47,400 to 72,000 metric tons (52,200 to 79,200 tons) of heavy metal. The operating costs, however, would increase significantly due to the extended 6-year operational period. The increase in volume mined for the emplacement panels would be 21 percent, even though the repository storage capacity would increase 52 percent. The additional ventilation capacity would require 57-percent increase for fan horsepower and a 44-percent increase in precooling air. No significant impacts are estimated in total staffing requirements as shown on Table 5-3.

The shaft optimization study (RKE/PB, 1984b) determined the required shaft diameters based on operational requirements, technology requirements for drilling large-diameter shafts, and shaft-lining requirements. The shaft optimization study indicated that the largest shaft diameter required for the repository would have a 3.7-meter (12-foot) inside diameter. This does not preclude the use of larger sized shafts. Separating the ventilation functions into several shafts allows the use of 3.7-meter- (12-foot-) diameter shafts. This is also feasible and nearly as economical. Based on technical evaluation and judgment, single-pass drilling is preferred over multi-pass drilling. Both drilling methods are feasible and the choice may depend on rig availability and other nontechnical issues. A solid steel, as opposed to a concrete and steel composite liner, was recommended for all shafts.

The tunnel optimization study (RKE/PB, 1984c) determined requirements for repository layout, excavation methods, rock support, and drift size and shape based on recent geomechanics findings. The results of this study are listed below.

- Layout--The findings indicated that a central shaft pillar area with an overall rectangular shape would provide the best layout. This activity required integration with findings of the waste-emplacement optimization study (RKE/PB, 1984d).

Table 5-3. Comparison of requirements and results for design concept development activities

Item	1982 conceptual design[a]	Repository capacity increase study[b]		Shaft optimization study[c]	Tunnel optimization study[d]	Waste-emplacement optimization study[e]	Repository underground layout study[a,f]
		TSR	ER				
Requirements							
Years of emplacement	20	5 + 21	30	20	20	20	5 + 20
Total metric tons (tons) of heavy metal to be emplaced	47,400 (52,140)	72,000 (79,200)	72,000 (79,200)	47,400 (52,140)	47,400 (52,140)	47,400 (52,140)	70,000 (77,000)
Metric tons (tons) waste receipt rate per year	2,370 (2,600)	1,800[g] (1,980)[g] 3,000[h] (3,300)[h]	2,400 (2,640)	2,370 (2,600)	2,370 (2,600)	2,370 (2,600)	1,800[g] (1,980)[g]
Results							
Subsurface areal extent, ha (acres)	540 (1,334)	760 (1,880)	725 (1,790)	(i)	(i)	(i)	800 (1,978)
Spoils pile, ha (acres)	17 (42)	23 (58)	24 (59)	(i)	(i)	(i)	(i)
Total surface operations staffing	493	504	493	(i)	(i)	(i)	(i)
Total peak subsurface operations staffing	374	446	374	(i)	(i)	(i)	(i)
Emplacement concept[j]	Multiple	Multiple	Multiple	(i)	(i)	Single	Single

[a]Raymond Kaiser Engineers, Inc./Parsons Brinckerhoff Quade & Douglas (RKE/PB, 1983).

[b]Raymond Kaiser Engineers, Inc./Parsons Brinckerhoff Quade & Douglas (RKE/PB, 1984a). TSR = two-stage repository based on the 1,800 and 3,000 metric tons (1,980 and 3,300 tons) of heavy metal receipt rates; ER = extended repository.

[c]Raymond Kaiser Engineers, Inc./Parsons Brinckerhoff Quade & Douglas (RKE/PB, 1984b).

[d]Raymond Kaiser Engineers, Inc./Parsons Brinckerhoff Quade & Douglas (RKE/PB, 1984c).

[e]Raymond Kaiser Engineers, Inc./Parsons Brinckerhoff Quade & Douglas (RKE/PB, 1984d).

[f]Raymond Kaiser Engineers, Inc./Parsons Brinckerhoff Quade & Douglas (RKE/PB, 1984e).

[g]Expected during the first 5 years of operations.

[h]Over a 21-year period following the first 5 years of operation.

[i]Not considered in study.

[j]Multiple indicates the emplacement of multiple containers in one long borehole; single indicates one container per short borehole.

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- Excavation methods—The drill-and-blast method was recommended for waste panel development.

- Rock support—Use of cement-grouted dowels (grouted rock bolts) with microsilica shotcrete was the preferred alternative.

- Drift size and shape—The preferred shape in the waste panel (heated) areas was nearly elliptical, approximately 6.7 meters (22 feet) wide by 3.3 meters (10.7 feet) high. The height and width would be primarily dictated by the size of the container transporter and the requirements for loading of containers in emplacement boreholes perpendicular to the emplacement room. The main entries, which would have much lower heat loads from the stored waste, might use a circular configuration because of the lower thermal stress superimposed on the in situ stress.

A separate waste-emplacement optimization study (RKE/PB, 1984d) considered the emplacement, retrieval, and effect of the thermal loading of the containers on the repository as a whole. The principal finding of this study indicated that storage of containers in horizontal boreholes perpendicular to the emplacement room offers the most advantages. Short emplacement boreholes (9 meters (30 feet) or less) appeared to offer an advantage over long boreholes (61 meters (200 feet) or more), as there was a much higher expectation that emplacement and then retrieval, if necessary, of waste containers could be accomplished successfully.

The short emplacement boreholes used in the waste-emplacement optimization study are 76 centimeters (30 inches) in diameter. The diameter of the boreholes may be increased should performance analysis indicate a need to provide a thicker container and (or) packing (backfill). This study included near-field performance analysis for mitigating radionuclide migration.

An alternate waste package study (Westinghouse, 1985), completed in draft form and in conjunction with the waste-emplacement optimization study, formed the basis for selection of a reference waste package concept to be used in waste package advanced conceptual design (Section 5.1.4). The alternate waste package study considered 23 alternate designs for spent fuel containers using emplacement geometry, container materials, packing form, and spent fuel configuration (i.e., consolidated fuel rods versus intact fuel assemblies) as design variables. Combining the preferred features from both studies resulted in the following emplacement options: (1) Long in-drift emplacement (305 meters (1,000 feet)); (2) short in-drift emplacement (6 meters (20 feet)); and (3) short borehole emplacement (6 meters (20 feet)). All options employed a container wall thickness suitable for radiation attenuation to mitigate ground-water radiolysis, as well as to meet corrosion and structural requirements. The short borehole option was selected as the reference concept for waste package advanced conceptual design.

The shaft, tunnel, and waste-emplacement optimization studies described above used a maximum storage capacity of 47,400 metric tons (52,200 tons) of heavy metal as in the 1982 conceptual design. These

studies incorporated geotechnical data from investigations conducted since the 1982 conceptual design was issued.

5.1.3.2 Repository underground layout study

The detailed repository underground layout study (RKE/PB, 1984e) used the generic requirements document (DOE, 1984b) as a basis for design requirements. Integration of new design requirements, either generic or site specific, will be included in the updated conceptual design. The impact of the generic design requirements for surface facilities, waste handling, monitoring, and water handling have not been evaluated.

5.1.3.2.1 Design functions

The repository underground layout is based on a single phase of waste receipt to accommodate 70,000 metric tons (77,000 tons) of heavy metal with a minimum age of 10 years (RKE/PB, 1984e). Expected waste-receipt rates are up to 1,800 metric tons (1,980 tons) of heavy metal per year during the first 5 years of operation and up to 3,000 metric tons (3,300 tons) of heavy metal per year thereafter until capacity is reached. The repository capacity and waste-receipt rates used to generate the 1982 conceptual design (RKE/PB, 1983) are discussed in Section 5.1.2.

5.1.3.2.2 Design features

Table 5-4 presents the waste-emplacement features for the repository underground layout study (RKE/PB, 1984e) as compared to the 1982 conceptual design (RKE/PB, 1983). The container data and packing requirements resulted in part from the alternate waste package study (Westinghouse, 1984). The emplacement borehole diameter is derived from container and packing requirements. The emplacement borehole length and number of containers per emplacement borehole were evaluated in the waste-emplacement optimization study (RKE/PB, 1984d). As shown in Table 5-4, the length of emplacement room per container is much lower for multiple container storage, as used in the 1982 conceptual design, than for the repository underground layout study. The values shown consider symmetrical storage (i.e., two storage boreholes directly across from each other) for the 1982 conceptual design and repository underground layout study. The selected short borehole emplacement concept provides greater confidence for emplacement and retrieval as compared to multiple container storage per borehole.

Table 5-5 summarizes geomechanical data included in the 1982 conceptual design and repository underground layout study. The basalt flow used for the repository underground layout study is the Cohassett flow. The rock strength for the Umtanum flow (one of the four proposed candidate horizons; see Section 2.2.3) in the 1982 conceptual design is approximately the same as the Cohassett flow. Furthermore, the direction of

Table 5-4. Design comparisons of waste-emplacement features

Description	1982 conceptual design (RKE/PB, 1983)	Repository underground layout study (RKE/PB, 1984e)
Container heat generation (pressurized water reactor), W	1,650	2,200
Container outside diameter cm (in.)	41.7 (16.4)	50.3 (19.8)
Container length, cm (in.)	411 (162)	411 (162)
Packing method*	Pneumatic	Prepackaged sections
Packing thickness, cm (in.)	15.2 (6)	15.2 (6)
Emplacement borehole diameter, cm (in.)	76.2 (30)	89.0 (35)
Emplacement borehole pitch (center to center spacing), m (ft)	18.3 (60)	6.7 (22)
Emplacement borehole length, m (ft)	61 (200)	6.1 (20)
Containers of pressurized water reactor spent fuel per emplacement borehole	13	1
Emplacement room container length, m (ft)	0.7 (2.3)	3.3 (10.8)

*Packing is a mixture of bentonite and crushed basalt.

Table 5-5. Design comparisons of geomechanical data

Description	1982 conceptual design (RKE/PB, 1983)	Repository underground layout study (RKE/PB, 1984e)
Reference basalt flow	Umtanum	Cohassett
Depth to bottom of flow interior, m (ft)	1,170 (3,838)	983 (3,224)
Estimated total thickness of flow interior, m (ft)	65.5 (215)	68.1 (223)
Intact compressive strength, MPa (lbf/in^2)	207 (30,000)	290 (42,050)
Allowable rock stress in emplacement borehole, MPa (lbf/in^2)	186 (27,000)	200 (29,100)
Allowable rock stress in emplacement room, MPa (lbf/in^2)	166 (24,000)	157 (22,800)
In situ stress ratio (maximum horizontal to vertical)	2:1	2.5:1
Maximum in situ stress magnitude, MPa (lbf/in^2)	60 (8,700)	58 (8,410)
Maximum in situ stress direction	East-west	N. 3° W.

maximum horizontal stress used in the 1982 conceptual design was incorrectly assumed to be east-west. Subsequent in situ test results have determined the maximum stress is oriented north-south. A comparison of the allowable rock stresses and the intact compressive strength illustrates a trend in the underground repository layout study toward more conservatism in geomechanical design requirements. Although the intact compressive strength is higher for the Cohassett flow than the value used for the Umtanum flow in the 1982 conceptual design, the allowable stresses remain very similar.

Table 5-6 compares the ventilation requirements in the 1982 conceptual design and the repository underground layout study. Other than the decrease in ambient rock temperature, the requirements have not changed significantly. The increases in total storage capacity and required emplacement room length due to single-container storage contribute significantly to the total ventilation capacity requirements.

Table 5-6. Design comparisons of ventilation requirements

Description	1982 conceptual design (RKE/PB, 1983)	Repository underground layout study (RKE/PB, 1984e)
Maximum number of shafts	5	9
Maximum allowable shaft inside diameter, m (ft)	No limit defined	3.7 (12)
Main airway (drift) maximum velocity, m/min (ft/min)	457 (1,500)	457 (1,500)
Service shaft maximum velocity, m/min (ft/min)	610 (2,000)	610 (2,000)
Ventilation shafts maximum velocity, m/min (ft/min)	1,067 (3,500)	1,220 (4,000)
Ambient rock temperature, °C (°F)	57 (134)	52 (125)

5.1.3.2.3 Design approach and assumptions

The repository underground layout study (RKE/PB, 1984e) was developed using the following methodology and assumptions.

- Ventilation network analysis and climatic simulation to estimate worker environment.

- Drill-and-blast excavation technique as recommended in the tunnel optimization study (RKE/PB, 1984c).

- Rail haulage system for rock as recommended in the 1982 conceptual design (RKE/PB, 1983). However, due to the increase in required waste-storage capacity, evaluation of the practicality of rail haulage was made. The efficiency of the rock-handling system from the heading face through the shaft hoisting system will be considered in future design activities.

- Water entering the underground drainage-transport system is suspect with regard to radioactive contamination. Drainage is designed to be away from the shaft pillar area, thus protecting the shaft pillar that is critical for operations and emergency response.

- Waste-handling requirements and design as in the 1982 conceptual design. Minor modifications have been made to the width of the emplacement rooms under the assumption that the current waste package concept requires greater room width for emplacement activities.

- Geotechnical design methodology to estimate emplacement borehole pitch, container-to-container spacing, pillar width, and emplacement room shape. Repository requirements (e.g., waste type, age, and amount) and geologic conditions (e.g., in situ stress, rock mass strength, rock mass mechanical and thermal properties) would have to be considered for the repository design.

The in situ stress of basalt in the reference repository location was determined from boreholes using the hydrofracturing technique. Measurements taken in the Cohassett flow indicate a mean value of approximately 2.5 for the ratio of maximum horizontal to vertical stress. Two measurements of 2.3:1 and 2.7:1 were available in the Cohassett flow prior to starting the repository underground layout study. Thirteen additional measurements within other Grande Ronde Basalt flows had horizontal to vertical stress ratios of 2.5:1 or less. One test measured a stress ratio of 2.7:1 (Kim et al., 1984). In situ measurements will be conducted at the exploratory shaft facility to obtain further data (see Subsection 4.1.1.6.4).

The rock mass strength has been estimated through a sequence of steps, starting with the development of an intact rock failure envelope (intact strength curve) based on Hoek and Brown (1980, pp. 137

through 140) failure criteria. To account for the jointed and interlocking nature of the basalt rock mass, the intact rock failure envelope has been reduced proportionally to the test results of Rosengren and Jaeger (1968). A further reduction in the failure envelope (rock mass strength curve) has been made to account for the influence of opening size (volumetric effects) on the rock mass strength. Hardy and Hocking's (1979) failure criteria, which account for size effects, have been used to determine the rock mass strength reduction factors for the emplacement boreholes and drifts (i.e., emplacement rooms). The reduced rock mass strength for each size of opening was then used to establish the allowable stress (both in situ and thermal-induced) concentration criteria for design purposes (Subsection 6.3.3.2.4).

Linear elastic analysis has been used to calculate the rock stresses around the openings. This is a very conservative analysis that does not account for the redistribution of stress away from the opening surface due to inelastic deformation of the rock mass immediately adjacent to the opening.

A rock mass volume for each opening size was selected to compare excavation- and thermal-induced stresses with rock mass strength. The rock mass volume was determined in the roof and floor, as the stresses are highest at these locations due to the existing high-horizontal to vertical stress ratio. The rock mass volume in the roof and floor was estimated to have a depth of one-sixth the excavation width and a length of one-third the excavation width. Rock stresses were averaged over the depth of this representative rock volume and were compared with the rock mass strength of the same representative rock volume. The emplacement borehole pitch and emplacement room spacing were determined such that the average rock stress is less than the allowable stress (i.e., spacing distance is inversely proportional to the average stress).

The rock-reinforcement system will improve the stability and deformation characteristics of the underground excavations. However, no credit was taken for the grouted dowel (rock bolt) and shotcrete rock-reinforcement system that is suggested for general use in the repository. Additional information on rock support system design and opening stability is provided in Subsections 6.3.3.2.4, 6.3.3.2.6, and 6.3.3.2.10.

In summary, due to the lack of in situ rock mass property data and the use of linear elastic models, a conservative design methodology has been used to provide a preliminary repository layout. Until the design parameters and methodology can be verified with site-specific in situ data, the proposed repository layout can only be considered tentative. Further design considerations regarding rock support are presented in Subsection 6.3.3.2.4.

5.1.3.2.4 Repository underground layout study results

The physical dimensions for the repository underground layout study (RKE/PB, 1984e), on which the current design concept is based, are shown in Table 5-7. The repository length to width ratio has changed slightly

from the 1982 conceptual design (RKE/PB, 1983), but the areal extent has increased by approximately 50 percent. This increase is due primarily to the following:

- The storage capacity has increased by approximately 50 percent, conforming to the limits in the Nuclear Waste Policy Act of 1982.
- The emplacement concept with single-container storage and less pitch between boreholes has yielded a 470-percent increase in the length of emplacement room per container stored. However, this is partially offset by a pillar-width reduction from 65 to 30 meters (212 to 100 feet).

Table 5-7. Design comparisons of physical dimensions

Description	1982 conceptual design (RKE/PB, 1983)	Repository underground layout study (RKE/PB, 1984e)
Overall underground dimensions, m (ft)	1,610 x 3,360 (5,270 x 11,020)	1,930 x 4,150 (6,330 x 13,600)
Areal extent, ha (acres)	540 (1,334)	800 (1,978)
Total length of emplacement rooms, m (ft)	27,600 (90,600)	156,100 (512,000)
Size of emplacement rooms, m (ft)	3.1 x 6.1 (10 x 20)	3.1 x 7.0 (10 x 23)
Pillar width, m (ft)	65 (212)	31 (100)

The maximum quantity of ventilation air required (Table 5-8) has increased by approximately 250 percent. This increase is partially attributable to the storage capacity increasing by approximately 50 percent.

Some dissolved methane has been found in the ground water at the reference repository location (Subsection 6.3.3.2.10). The repository underground layout study examined the potential for methane buildup to explosive concentrations. The study determined that the ventilation system as designed had sufficient airflow in every opening to dilute expected methane inflows to below the 0.25-percent concentration acceptable in limited nongassy mines (MSHA, 1983). Monitoring for methane will be provided throughout the facility. Advance warning of methane buildup will be provided by the monitoring system and appropriate corrective measures will be taken to prevent development of a hazardous condition.

Table 5-8. Design comparisons of ventilation features

Description	1982 conceptual design (RKE/PB, 1983)	Repository underground layout study (RKE/PB, 1984e)
Maximum air volume and phase, m^3/min (ft^3/min)	Backfilling, 11,980 (4.2×10^5)	Operations, 30,300 (1.07×10^6)
Room cool-down time for backfilling, d	90	53
Number and diameter of shafts		
Waste handling	One 3.7-m (12-ft) ID	One 3.7-m (12-ft) ID
Service and air intake	One 4.9-m (16-ft) ID	One 3.7-m (12-ft) ID
Basalt hoisting and air exhaust	One 4.3-m (14-ft) ID	One 3.7-m (12-ft) ID
Mine air intake	Not applicable	One 3.1-m (10-ft) ID
Mine air exhaust	Not applicable	One 3.1-m (10-ft) ID
Confinement air intake	One 3.7-m (12-ft) ID	Two 3.7-m (12-ft) ID
Confinement air exhaust	One 3.4-m (11-ft) ID	Two 3.7-m (12-ft) ID

ID = inside diameter.

The number of shafts has increased from five in the 1982 conceptual design to nine (see Table 5-8). This is an 80-percent increase in the number of shafts, but the cross-sectional area has increased only 40 percent. The 3.7-meter (12-foot) maximum shaft inside diameter was taken from the shaft optimization study (RKE/PB, 1984b). Another study (McKinney, 1984) concluded that even larger shafts could be single-pass drilled to repository depth.

In conclusion, the repository underground layout is similar to the 1982 conceptual design layout. It has been sized to accommodate 70,000 metric tons (77,000 tons) of heavy metal. Some of the ventilation shafts are located on the outer periphery of the repository in the shaft pillar to enhance constructibility and safety.

5.1.3.3 Two-phase waste-receipt repository study

In 1984 a feasibility study of the two-phase waste-receipt approach to a repository (see Table 5-1) was conducted (Rockwell, 1984). The features of this two-phase concept included the following:

- Ninety-six-year schedule from the start of construction to completion of decommissioning.
- A spent fuel storage capacity of 70,000 metric tons (77,000 tons) of heavy metal based on
  - A Phase I waste-acceptance rate of 400 metric tons (440 tons) of heavy metal per year for 5 years.
  - A Phase II waste-acceptance rate of 500 and 1,400 metric tons (550 and 1,540 tons) of heavy metal per year for the fourth and fifth years, respectively, and 3,000 metric tons (3,300 tons) of heavy metal per year thereafter.
- Utilization of the exploratory shafts to expedite repository construction.
- Inclusion of one and possibly both exploratory shafts for repository operation.
- Utilization of a Washington Public Power Supply System building near the reference repository location as a limited waste-packaging and -handling facility.

The two-phase repository feasibility study (Rockwell, 1984) evaluated the 1982 conceptual design (single-phase waste-receipt concept) for a two-phase waste-receipt rate. The two-phase concept was developed in the same time frame as the repository underground layout study (RKE/PB, 1984e). However, the two-phase concept has not been examined as closely as the single-phase design concept. Certain assumptions and approaches used in this feasibility study will be verified or evaluated in future design activities.

5.1.4 DECOMMISSIONING AND CLOSURE

Following the planned 25-year caretaker phase during which retrievability must be ensured and after the performance confirmation program has been completed, the U.S. Department of Energy would receive U.S. Nuclear Regulatory Commission approval for an amended license for closure of the repository. At that time, decommissioning of the repository would begin. To decommission the subsurface facilities, salvageable materials would be brought to the surface. During closure, all subsurface access areas (e.g., shafts) would be sealed.

All surface structures would be decontaminated and (or) dismantled. Some contaminated material may be placed underground prior to the sealing of shafts. The surface areas would be reclaimed. Permanent markers would be erected to inform future generations about the presence of the repository. Development of such markers or a marking system is in progress. All records concerning the repository would be maintained by appropriate Federal, State, and local governments. It is expected that the records and markers would be kept in perpetuity.

5.1.5 WASTE PACKAGE DESCRIPTION

A waste package is needed for containment of the high-level radioactive waste during transfer and emplacement operations at the repository. In addition, the waste package provides postemplacement containment of radionuclides. The waste package is one subsystem of a system of multiple barriers controlling release of radionuclides to the accessible environment (other subsystems are the repository seals and the host rock itself). The waste package consists of three major components: Waste form, container, and packing (Fig. 5-7). The waste form may be either unprocessed spent fuel or canisters of vitrified high-level waste. The container is a hermetically sealed (welded) metal vessel containing the waste form. The packing is a mixture of crushed basalt and a swelling clay used to fill the space between the container and the host rock surface surrounding the container in the emplacement hole. The packing is fabricated in preformed sections and assembled within a shell. The waste package is emplaced in short horizontal boreholes that extend from the walls of emplacement rooms of the repository (Fig. 5-8). The emplacement sequence for the packing and container is shown conceptually in Figure 5-9.

5.1.5.1 Waste form

The waste form contributes to the waste package barrier function of slow release of radionuclides for potential postemplacement breach of the container (a minimum of 300 to 1,000 years after permanent closure of the repository) (NRC, 1985) when the waste form comes in contact with ground water. The waste form is also required to be resistant to dispersal (airborne). This contributes to the waste package barrier function during waste package fabrication, transfer, and emplacement.

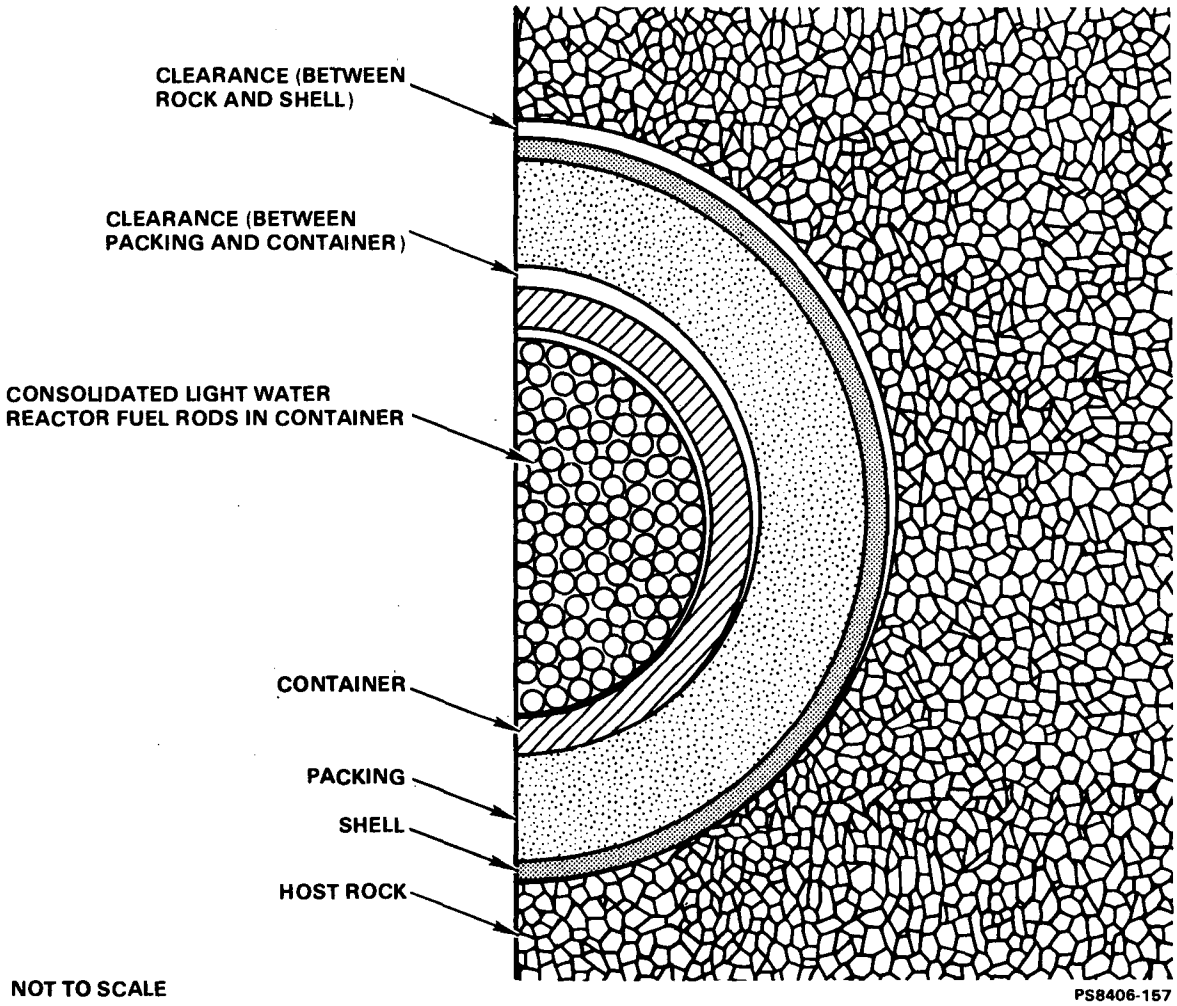

Figure 5-7. Typical cross section of waste package consolidated light water reactor fuel pins.

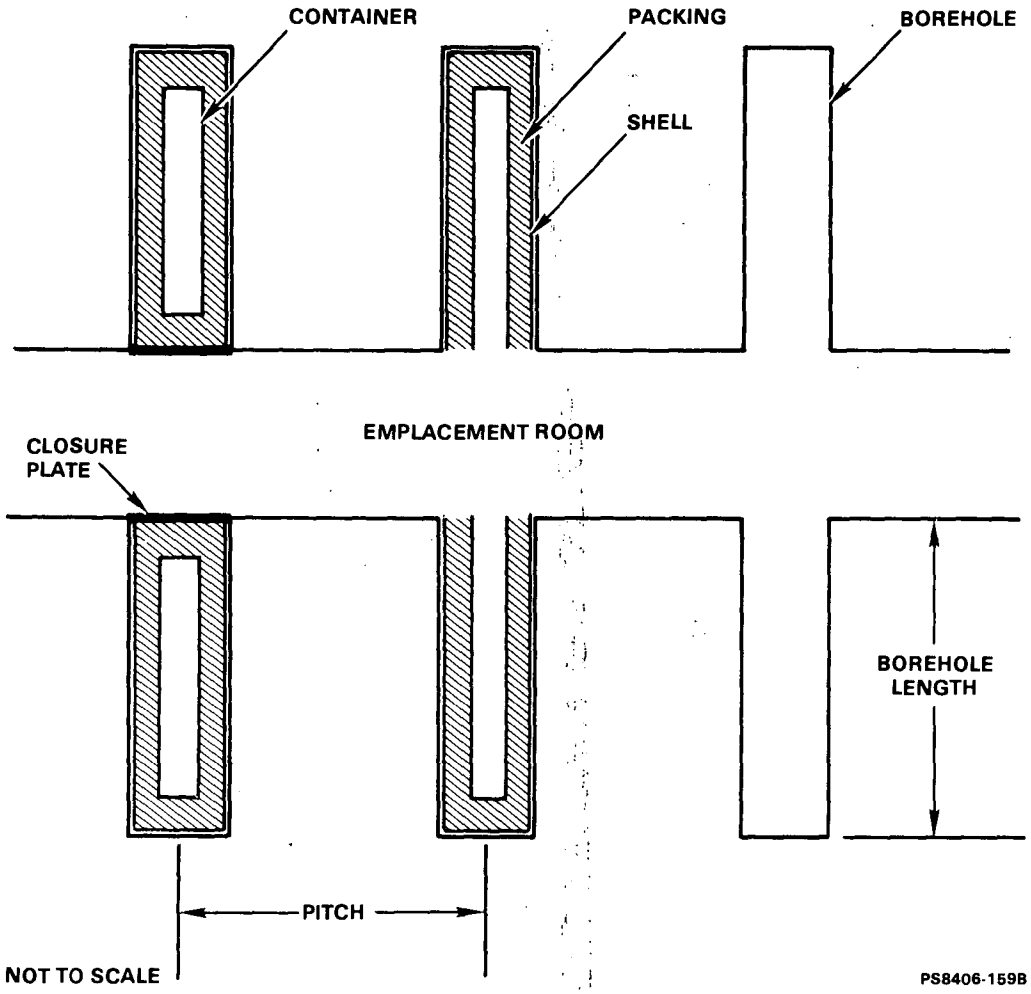

Figure 5-8. Typical plan view for waste emplacement.

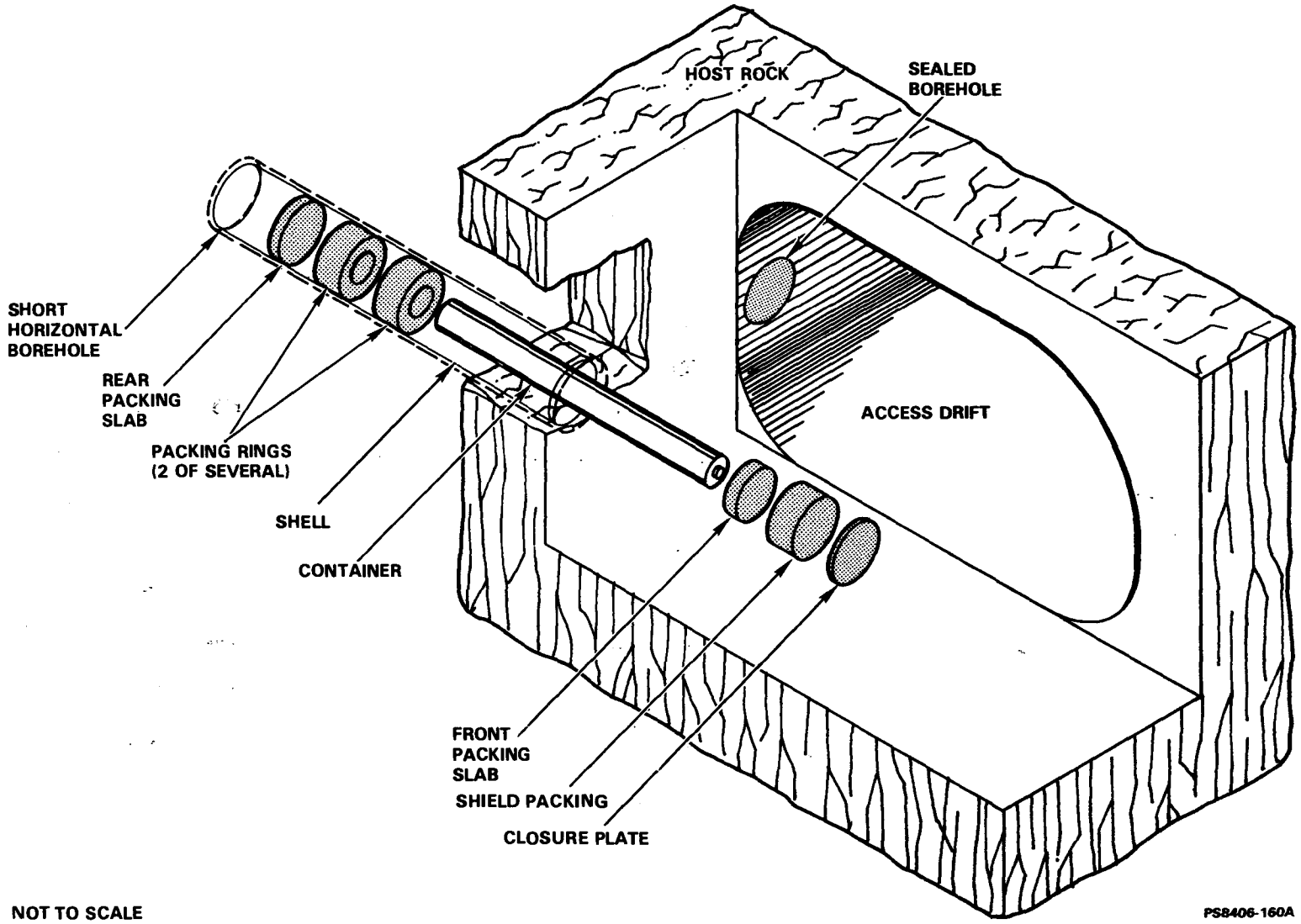

Figure 5-9. Cutaway showing waste package emplacement sequence.

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Potential waste forms are spent fuel rods and high-level waste from reprocessing of commercial and defense spent fuel. Spent fuel may be in the form of intact fuel assemblies or fuel rods that have been removed from their assemblies and consolidated into a container (i.e., consolidated spent fuel). A typical cross-section of a waste package containing consolidated spent fuel is shown in Figure 5-7. The dimensions and weights for spent fuel and commercial high-level waste are given in Table 5-9.

Table 5-9. Waste package characteristics (Henry, 1984)

Parameter	Spent fuel	Commercial high-level waste
Container outside, diameter cm (in.)	50.3 (19.8)	45.6 (18.0)
Required borehole diameter, cm (in.)	89 (35)	84 (33)
Waste container overall length, cm (in.)	411 (162)	325 (128)
Loaded weight of container, t (tons)	7.6 (8.4)	2.7 (3.0)

Consolidated spent fuel compacted rods are placed in waste containers approximately 50 centimeters (20 inches) in outer diameter by 411 centimeters (162 inches) long. There is a wide variety of spent fuel characteristics (e.g., sizes and numbers of fuel rods per assembly, heat-generation rates, fuel burnup) that must be accommodated by the waste container. The waste container design will provide internal components to accommodate different spent fuel characteristics.

Commercial high-level waste consists of vitrified waste (i.e., borosilicate glass) enclosed in a stainless steel canister. For example, the canister for commercial high-level waste is 32.4 centimeters (12.8 inches) in outside diameter by 300 centimeters (118 inches) long. This canister is enclosed in a low-carbon steel container at the repository. The reference high-level waste case is based on processing wastes resulting from commercial spent fuel that would have been 10 years out of the reactor.

Waste package concepts are being considered for accommodating defense high-level waste at the repository. The defense high-level waste is expected to be similar to commercial high-level waste in dimension, but with up to twice the decay heat level.

5.1.5.2 Container

The container is required to contain the waste form during transfer and emplacement operations at the repository and for a minimum period following repository decommissioning. The containment period required (NRC, 1985) is a minimum of 300 to 1,000 years. The internal diameter of the reference consolidated spent fuel containers is sized to accept the rods from four pressurized water reactor assemblies or nine boiling water reactor assemblies. The rods will be installed in a tight fit for the largest expected number and size of fuel rods. The internal length of the reference spent fuel container is sized to accept the longest expected fuel rods with a small clearance between the container head and fuel rod ends.

The container thickness is based on the structural requirements necessary to withstand hydrostatic pressure, additional thickness for a 1,000-year corrosion allowance, and any additional thickness that may be required to reduce ground-water radiolysis to acceptable levels.

The reference container material is low-carbon steel. Alternate materials are being investigated and include, for example, Fe9Cr1Mo (low-alloy steel) and cupronickel 90-10.

5.1.5.3 Waste container configuration and packing

The packing has no preemplacement functions. After emplacement, it is required to limit ground-water intrusion to the container and to reduce radionuclide release by controlling ground-water Eh and pH and by providing a low-permeability environment between the waste container and the surrounding rock.

As shown in Figure 5-8, the packing material is packaged or preformed in an annular shape, installed in an outer carbon steel shell, and emplaced in a short horizontal borehole, followed by the waste container. The current reference packing material is 75 percent crushed basalt and 25 percent bentonite and has a minimum thickness of 15 centimeters (6 inches). The function of the shell is to facilitate handling and emplacement of the waste package components. The shell also has the potential to facilitate retrieval of the waste container by preserving the packaging in a dry state and by providing additional structural strength.

5.1.6 PROGRAMMATIC ISSUES AFFECTING DESIGN

Some fundamental programmatic issues affecting design of facilities for disposal of high-level nuclear waste have not yet been finalized or sufficiently evaluated to establish a repository design basis. Three of these are (1) monitored retrievable storage, (2) minimum waste age, and (3) retrievability and are discussed below.

5.1.6.1 Monitored retrievable storage

Section 141 of the Nuclear Waste Policy Act of 1982 directs the U.S. Department of Energy to study the need for and the feasibility of construction of monitored retrievable storage facilities for spent fuel and high-level waste. It also directs the U.S. Department of Energy to submit to Congress a proposal that establishes a program for the siting, construction, and operation of monitored retrievable storage facilities. The U.S. Department of Energy plans to submit this proposal to Congress in 1986.

The U.S. Department of Energy analyzed the provisions of the Act and programmatic options in the mission plan (DOE, 1985) and is evaluating a waste-management system that consists of storage and disposal components. A monitored retrievable storage facility is that portion of the system that would handle most, if not all, waste-preparation functions before emplacement of wastes in a repository.

The primary function of the monitored retrievable storage facility is waste preparation for emplacement of waste in a repository. The role of the facility in providing backup storage is secondary; although temporary backup storage could be provided if the startup of the repository were delayed. Performing the waste-preparation functions (i.e., spent fuel consolidation and packaging) in a monitored retrievable storage facility would simplify the design, construction, and operation of the repository facilities. The repository would receive on a regular basis standard, uncontaminated packages that would be ready for disposal, instead of irregular receipts of transport casks containing contaminated spent fuel assemblies that would need to be prepared for disposal. A monitored retrievable storage facility would also provide a hub for the logistics of managing spent fuel transportation and cask fleet operations servicing. By shipping consolidated fuel to the repository, possibly in dedicated trains, the number of cross-country shipments could be significantly reduced. Qualitatively, environmental impacts discussed in this document should encompass those of a repository design coupled with a monitored retrievable storage facility, if Congress authorizes such a facility.

Considering that necessary facilities and activities at the repository site would be less in an integrated monitored retrievable storage and repository system, since waste consolidation would be accomplished at the monitored retrievable storage site, the nonradiological environmental impacts discussed in this environmental assessment should encompass those for a repository design coupled with the monitored retrievable storage facility, if Congress authorizes such a facility.

Appendix A presents general background information on transportation topics and issues. Qualitatively, the nonradiological environmental impacts discussed will encompass those involving transportation, coupled with the monitored retrievable storage facility, if Congress authorizes such a facility. The monitored retrievable storage transportation analysis is found in Appendix A. It should be noted that the monitored retrievable storage impacts are not included in Table 5-1.

5.1.6.2 Minimum waste age

The U.S. Department of Energy has not yet conducted studies to assess the impact of accommodating the potential impact of accepting 5-year-old waste that might be received by a repository. Therefore, Table 5-1 does not fully reflect this consideration. The regulations in 10 CFR 961 (DOE, 1983) designate fuel aged as little as 5 years out of reactor as standard spent fuel. The mission plan (DOE, 1985) and 10 CFR 961 (DOE, 1983) specify that the U.S. Department of Energy will accept fuel for disposal on an oldest first basis. Therefore, for most of the first repository-receiving and waste-emplacement period, the average age of spent fuel received will be greater than 10 years, with an estimated 5 to 10 percent of the fuel aged as little as 5 years. The current design concept is based on 10-year-old fuel. The U.S. Department of Energy believes that the incremental impacts on the environment due to any receipts of 5-year-old waste received will be minor, but will be reevaluated as part of the repository design process.

If the monitored retrievable storage facility were approved by Congress, it may be desirable to further age the 5-year-old fuel at the monitored retrievable storage facility prior to disposal in the repository. A cost-benefit analysis of aging will be performed in conjunction with the studies discussed above if the monitored retrievable storage facility were approved by Congress.

5.1.6.3 Retrievability

Section 122 of the Nuclear Waste Policy Act of 1982 mandates that the repository shall be designed and constructed to permit retrieval of any spent fuel emplaced in the repository during an appropriate period of operation. The reasons for such retrieval may pertain to public health and safety, or the environment, or may be for the purpose of permitting the recovery of the economically valuable contents of such spent fuel.

The Civilian Radioactive Waste Management Program position on retrievability is that the repository be designed, constructed, and operated so that retrieval capability be retained. This condition will be maintained until the satisfactory completion of a performance confirmation program as stipulated by 10 CFR 60 (NRC, 1985) and until decommissioning activities are authorized by the U.S. Nuclear Regulatory Commission.

The repository operations area will be designed so that the emplaced waste could be retrieved on a reasonable schedule, starting at any time up to 50 years after waste-emplacement operations are initiated, unless a different time period is specified by the Secretary of the U.S. Department of Energy and approved by the U.S. Nuclear Regulatory Commission (Nuclear Waste Policy Act of 1982; NRC, 1985). For design purposes, it is assumed that the actual retrieval would take approximately as long as the period

used for waste emplacement and repository construction. This length of time is consistent with 10 CFR 60 (NRC, 1985) that require public health and safety considerations be of primary importance in waste-retrieval operations.

Figure 5-10 provides the repository schedule, representing the beginning of the retrieval option 56 years after the start of construction. This schedule includes a 31-year retrieval option period subsequent to operations and maintained retrieval. This retrieval option period is the time during which retrieval could occur, and is based on an assumption that the time required for retrieval would be approximately equal to the periods of initial construction (6 years) and operation (25 years).

The capability to retrieve the waste packages would be demonstrated prior to a decision to backfill the waste package storage rooms and would be maintained even if the storage rooms have been backfilled. Therefore, the backfill decision would be based on an evaluation of the advantages of early backfilling versus the disadvantages of increased retrieval difficulty.

The U.S. Department of Energy developed a position on retrievability to describe and document design, construction, operation, and maintenance equipment requirements. An evaluation of the effects of these requirements on the repository design and the associated equipment needs has not been completed. These retrieval effects would be analyzed and addressed during site characterization and subsequent design phases supporting the license application.

5.1.7 TRANSPORTATION ASSESSMENT SUMMARY

The changes in projected transportation impacts associated with alternative repository concepts are identified in Table 5-1. These impacts pertain to the radiological and nonradiological transportation impacts addressed in Section 5.2.2, which addresses regional transportation impacts, and Appendix A, which addresses national transportation impacts.

Only variations in waste type and quantity given in Table 5-1 are considered significant from a transportation standpoint. Transportation changes are not likely to have a significant impact on the overall waste-disposal system, since transportation is only one of several areas of potential impact. For a given waste type, transportation impacts are roughly proportional to the quanitity of material shipped. Annual transportation impacts are roughly inversely proportional to the duration over which the material is shipped.

The transportation impact changes related to waste type result from differences in shipping cask payloads, which in turn affect shipment frequencies, total cask miles, and associated transportation impacts. Shipping cask design requirements for safety under normal and accident conditions are identical for all types of high-level waste shipping casks.

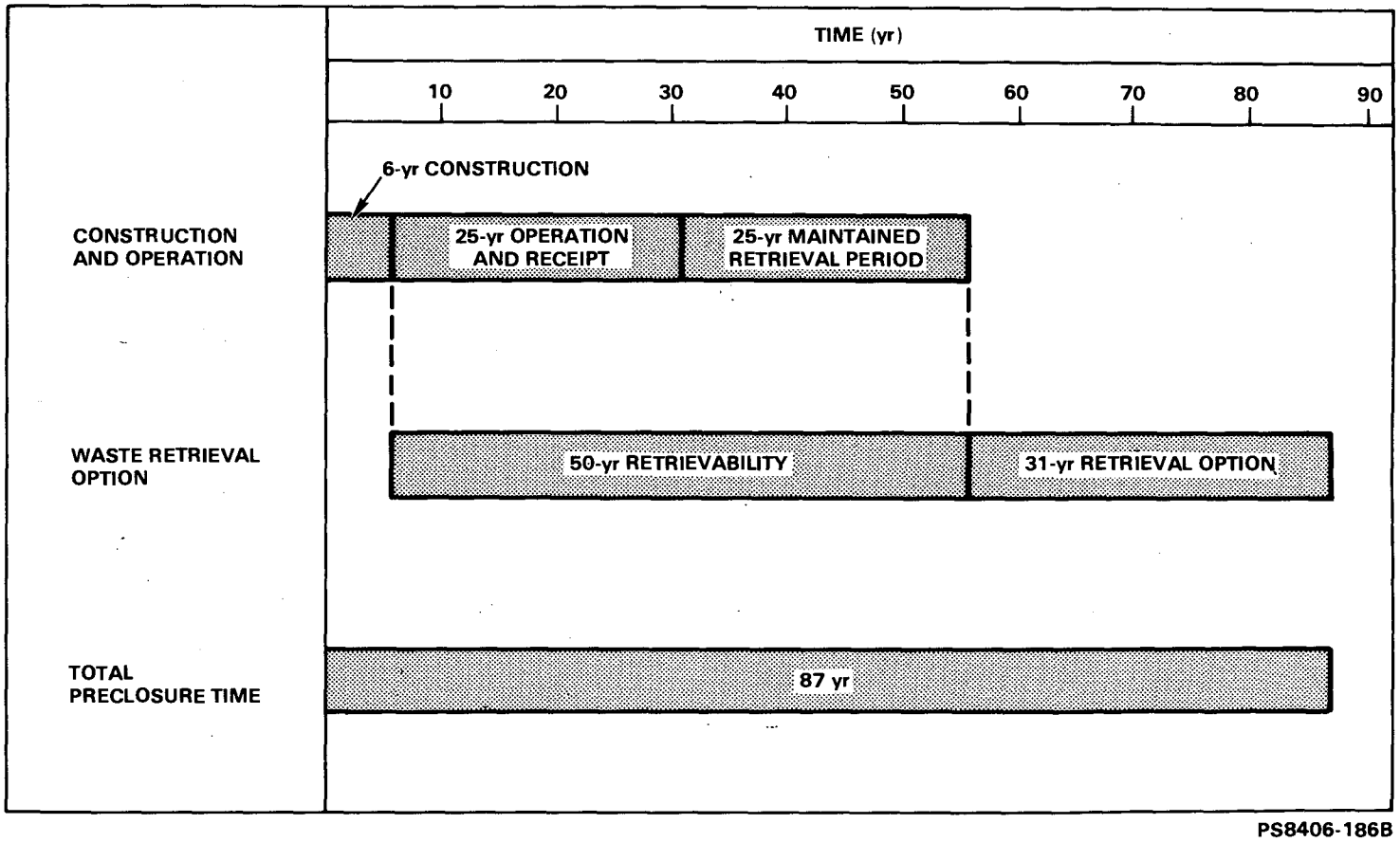

Figure 5-10. Operating period for construction, operation, and retrieval.

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The capacity of a truck cask for defense high-level waste or West Valley high-level waste is currently estimated, on a metric ton equivalency basis, to be about one-half the capacity of a spent fuel truck cask. The corresponding comparison for rail shipments indicates that a rail cask for defense high-level waste will hold about one-third as much as a spent fuel rail cask, and a rail cask for West Valley high-level waste will hold about one-half as much as a spent fuel rail cask. Therefore, replacing approximately 8,000 metric tons (8,800 tons) of heavy metal equivalent of spent fuel in the total repository inventory of 70,000 metric tons (77,000 tons) by a corresponding amount of high-level waste will increase the number of shipments by a factor of 2 to 3 for this portion of the repository receipts. The total shipments will increase by about 25 percent to a repository having a capacity of 70,000 metric tons (77,000 tons). The total radiological and nonradiological impacts of transportation will also increase by about 25 percent.

The possible substitution of future commercial high-level waste for the corresponding quantity of spent fuel would decrease overall transportation impacts. Forecasts of future waste compositions and canister and cask capacities for high-level waste from reprocessing operations indicate that shipping cask payloads will be increased. A corresponding reduction in shipment frequencies and overall transportation impacts may be possible.

5.2 EXPECTED REGIONAL AND LOCAL EFFECTS

This section describes the regional and local effects (i.e., physical environment, transportation, and socioeconomics) expected if a repository were constructed and operated at the reference repository location. These effects are based on the 1982 conceptual design (RKE/PB, 1983) (see Section 5.1.2) and are summarized in Table 5-10. The 1982 conceptual design is currently evolving (see Section 5.1.3), which could change some effects. However, it is not expected that design modifications and (or) refinements would significantly change regional and local effects (see Table 5-1). A final impact analysis will be presented in an environmental impact statement if the reference repository location at the Hanford Site were recommended for site characterization.

5.2.1 EXPECTED EFFECTS ON THE PHYSICAL ENVIRONMENT

In a major construction and operation project, it is inevitable that there will be some effects on the physical environment. The expected effects of locating a repository on the Hanford Site are expected to be manageable. The expected effects are divided into three categories: Geology, hydrology, and environmental setting.

Table 5-10. Summary of expected effects on the physical environment from construction and operation of a repository at the Hanford Site

Category	Expected effect
Geology	No identifiable effect
Hydrology Surface water Ground water	 No significant effect; no connection to surface water No identifiable effect from normal operations
Ecosystems Terrestial Aquatic	 Major effect would be loss of ground cover in central process area Two federally protected bird species have been sighted in area; however, no nests have been observed at the reference repository location No effect
Air quality	Temporary increase in particulate levels (on repository site only) during site clearing; no significant effect off Hanford Site
Noise	Temporarily high-decibel level (on repository site only) during principal construction period; no significant effect off Hanford Site
Aesthetics	No significant effect in reference repository location and vicinity
Archaeological, cultural, historical	No potential resources identified or known to exist at the reference repository location
Radiological impacts	No significant radiation dose off Hanford Site; limited to a small fraction of background dose Negligible long-term effect if migration in ground water occurs
Transportation	Negligible effects (radiological and nonradiological) by either rail or truck; at most a small fraction of background dose
Socioeconomic	No definitive adverse effects on local or regional infrastructure identified Beneficial effect on employment opportunities
Occupational safety	Usual nonradiological safety and health effects from construction and operation Employee radiation exposure well below all allowable limits

NOTE: These effects are based on the 1982 conceptual design (RKE/PB, 1983).

5.2.1.1 Geology

Shaft drilling and subsurface excavation at the bottom of the shafts are expected to have no significant effect on the geology of the repository site. Localized phenomena (e.g., rock fall) may be possible (see Subsection 6.3.1.3).

5.2.1.2 Hydrology

Repository-related effects on hydrology are presented in two parts: Surface-water hydrology and ground-water hydrology.

5.2.1.2.1 Surface water

There are no perennial surface streams in the vicinity of the reference repository location; thus, no effects on surface-water hydrology are expected. Water that may be encountered in shaft drilling and subsurface excavation and that needed for spoils pile dust control will be disposed of in ponds (Subsection 5.1.2.1.4). The lack of surface runoff features suggests that the relatively porous surficial sediments will prevent surface-water runoff from the proposed repository surface facilities.

There are no expected impacts to the Columbia River from construction and operation of a repository at the reference repository location, because the repository surface facilities would be located some 10 kilometers (6 miles) from the Columbia River. The only postulated effect on the river will be the withdrawal of a small amount of the total river flow from a proposed river pumping station.

While all repository-construction activities are not known at this time, the 1982 conceptual design (RKE/PB, 1983) includes plans to install two new pumps at an existing river pumping station. This pumping activity would be similar to that of the Hanford water system.

The Hanford water system provides 0.85 cubic meter (30 cubic feet) per second to the 200 Areas. The minimum regulated flow of the Columbia River at the Hanford Site is 1,019 cubic meters (36,000 cubic feet) per second and the annual average flow is 3,420 cubic meters (120,800 cubic feet) per second. The withdrawal of 0.85 cubic meter (30 cubic feet) per second (0.08 percent) for repository activities from the 1,019 cubic meters (36,000 cubic feet) per second minimum flow is not expected to have any impact on the water quality or quantity of the Columbia River.

5.2.1.2.2 Ground water

Some interactions between the repository and ground water would be probable, but the magnitude of the effect is uncertain at this time. Long-term effects (10,000 years) are discussed in Section 6.4.2. Various ground-water strata would be intersected during shaft drilling (see Subsection 6.3.3.3.3); however, significant alteration of the hydrologic setting is not expected since the shaft would be cased and grouted.

5.2.1.3 Environmental setting

Repository effects on the environmental setting are presented in six parts: Ecosystems; air quality; noise; aesthetic; archaeological, cultural, and historical; and radiological.

5.2.1.3.1 Ecosystems

Typically, effects associated with construction of a repository would be no greater than those associated with other major construction projects on the Hanford Site (PSPL, 1981; WPPSS, 1977; DOE, 1982). Throughout the design, construction, and operations phases of the repository and any support activities and utility construction, every effort would be made to lessen significant adverse impacts and maintain the existing preconstruction integrity of habitats and wildlife communities. Planned impact minimization programs would include plant and animal studies, enabling assessment of potential impacts on the native biota from construction and operation of a repository. Such studies would include consultation with Federal and State wildlife agencies and would support technical and programmatic impact minimization efforts. A summary of the expected effects on the native biota is given in Table 5-11.

Repository construction and operation would have some expected effects on the local ecosystem, although insufficient information is available to quantify these effects. Expected adverse impacts to the habitat would include the loss of habitat from production due to construction of surface facilities and the temporary loss of habitat during construction of utility rights-of-way. Adverse impacts to the native biota would include varying levels of disturbance due to the presence and noise of repository activities.

The major habitat impacts at the repository site would result from the selective clearing and grading of greater than 80 hectares (200 acres) of shrub-steppe terrain (i.e., all of the central process area plus an area outside the central process area for a parking lot, helicopter landing pad, and a mine-water percolation pond). Although the permanent loss of this habitat would be significant on a local scale, the area

Table 5-11. Summary of expected effects on native biota from construction and operation of a repository at the Hanford Site (sheet 1 of 2)

Activities	Organisms that may be impacted					
	Threatened and endangered animal species	Swainson's hawk, other birds of prey	Long-billed curlew	Other wildlife	Native plant communities*	Aquatic ecosystem
Access road construction	No effect	Could cause disturbance to nesting birds, particularly if traffic stops to view wildlife	Could cause disturbance to nesting birds, particularly if traffic stops to view wildlife	Could cause disturbance to nesting birds, particularly if traffic stops to view wildlife	Would destroy and thus remove some native land from productivity. Areas identified as supporting proposed threatened and endangered plant species would be avoided	No effect
Helicopter flights	No effect if helicopter flights follow predetermined routes, which would be removed from wildlife	No effect if helicopter flights follow predetermined routes, which would be removed from wildlife	No effect if helicopter flights follow predetermined routes, which would be removed from wildlife	No effect if helicopter flights follow predetermined routes, which would be removed from wildlife	No effect	No effect
Buried pipeline construction	Would disturb bald eagles wintering along the Columbia River. Effect could be minimized by careful planning of pipeline route and timing of construction	Would affect nesting birds if construction occurs near nest sites	Would affect nesting birds if construction occurs near nest sites	Would directly affect some wildlife species that utilize the plant communities destroyed by digging the pipeline	Would destroy and thus remove some native plant communities from productivity. Areas identified as supporting proposed threatened and endangered plant species would be avoided	No effect
Pump operation	No effect; existing pump facilities would be used	No effect	Noise from pumps could disrupt some nesting activity and brood rearing	Noise, installation, and maintenance of pumps could disturb Canada goose brood-rearing areas	No effect	Potential entrainment of aquatic biota in pumps can be minimized by fish return systems
Transmission and telephone line installation	No effect	Could provide nest sites for raptorial birds. Lines could electrocute birds of prey perching on wires or poles	Construction of power and telephone lines would impact curlews if construction occurs from March through July. Could eliminate impacts by constructing lines at other times	Mechanical disturbance of habitats by machinery would affect wildlife	Mechanical disturbance of the soil would eliminate or alter a few hectares (acres) of native habitat	No effect

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Table 5-11. Summary of expected effects on native biota from construction and operation of a repository at the Hanford Site (sheet 2 of 2)

Activities	Organisms that may be impacted					
	Threatened and endangered animal species	Swainson's hawk, other birds of prey	Long-billed curlew	Other wildlife	Native plant communities*	Aquatic ecosystem
Visitors' center construction	No effect	Construction noise and presence of equipment, people, and visitors' center would disturb birds of prey nesting nearby	Construction noise and presence of equipment, people, and visitors' center would disturb nesting curlews	The wildlife associated with the land required for visitors' center would be displaced or destroyed	Would remove several hectares (acres) of native landscape from productivity. Areas identified as supporting proposed threatened and endangered plant species would be avoided	No effect
Rights-of-way management	No effect	No measurable effect	No measurable effect	Vegetation in the rights-of-way would be dominated by cheatgrass. Wildlife that utilize cheatgrass would benefit; species requiring native habitats would not	Would change the species composition of plants along rights-of-way. Areas identified as supporting proposed threatened and endangered plant species would be avoided	No effect
Construction and fencing of spoils piles, parking lot, helicopter pad, and central process areas	Slight potential effect due to loss of habitat; no other effects	Construction noise and presence of equipment and people would disturb birds of prey nesting nearby	Construction noise and presence of equipment and people would disturb nesting curlews. Birds associated with the land required for these facilities would be displaced	Wildlife associated with the land required for these facilities would be displaced or destroyed	Native plant communities associated with the land required for these facilities would be lost from productivity. Areas identified as supporting proposed threatened and endangered plant species would be avoided	No effect
Mine-water percolation pond	Slight potential effect due to loss of habitat; no other effects	No measurable effect	Construction noise and presence of equipment and people would disturb nesting curlews. Birds associated with the land required for these facilities would be displaced	Wildlife associated with the land required for these facilities would be displaced or destroyed	The native plant communities associated with the land required for this facility would be lost from productivity. Areas identified as supporting proposed threatened and endangered plant species would be avoided	No effect

NOTE: Based on the 1982 conceptual design (RKE/PB, 1983).

*Includes proposed threatened or endangered plant species.

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selected for surface facilities would not be ecologically unique or sensitive or would not significantly impact the production capacity of the regional habitat.

The temporary loss of habitat during construction of utility rights-of-way would be significantly influenced by the locations of the routes. Incoming utilities would consist of water, electric power, and telephone. Water would be supplied from the Columbia River by an existing river pump station, which would be modified by the addition of new pumps and other appurtenant equipment. A buried pipeline would connect these pumps to the repository surface facilities. Two transmission lines, routed over separate parallel rights-of-way, would connect the repository to the Hanford Site power system, and an overhead telephone line would connect the repository surface facilities to the Hanford Site telephone network. This temporary loss of habitat would be minimized through the careful location and timing of construction activities. Available techniques would be used to reclaim disturbed lands.

Throughout the design, construction, and operation phases of the repository, every effort would be made to lessen significant adverse impacts on the habitat. Studies would be performed to characterize the surrounding habitat to assess and support the minimization of adverse impacts. Operational activities would include the minimization of vegetation removal, and any topsoil stripped at this time would be stockpiled for future replacement and planting. The repository work force would not be permitted access to any known or potential areas of sensitive habitat. By utilizing existing Hanford Site roads and utilities, environmental effects away from the reference repository location would be minimized.

Adverse impacts to the native biota would include varying levels of disturbance due to the presence and noise of repository activities. One area of potential impact would be the disturbance of native fauna as a result of surface facilities and utilities, resulting in potential nest and habitat abandonment. Of primary concern is the potential for impacting federally recognized threatened or endangered animal species. At this time, however, no such species are known to nest within the reference repository location (see Subsection 3.4.2.5). During recent field investigations, a threatened bird species, the bald eagle (*Haliaeetus leucocephalus*), and an endangered bird species, the peregrine falcon (*Falco peregrinus*) (FWS, 1984), were sighted infrequently within the reference repository location boundaries; however, their presence is not common. Three additional bird species that nest in the vicinity of the reference repository location are now being considered as potential candidates for protection on the Federal threatened and endangered species list. These are the ferruginous hawk (*Buteo regalis*), the Swainson's hawk (*Buteo swainsoni*), and the long-billed curlew (*Numenius americanus*) (FWS, 1985). Although not yet given official protection, these species are being included in biological investigations. Disturbance to native fauna would be minimized through careful planning and monitoring of repository and utility construction and programmatic control of unnecessary access to impact-sensitive areas (Subsection 5.2.1.3.3 contains noise information).

Another area of concern would be potential adverse impacts to native flora resulting from uncontrolled physical disturbance. Again, of primary concern is the potential for impact to federally recognized threatened or endangered plant species (FWS, 1984). At this time, no such plant species are known to exist on the reference repository location (FWS, 1984). However, several vascular plant species that do occur on the Hanford Site currently are being considered by the U.S. Fish and Wildlife Service as threatened species (FWS, 1985). Included in this category are the Columbia milk-vetch (Astragalus columbianus), the Hood River milk-vetch (Astragalus hoodianus), and the persistentsepal yellowcress (Rorippa calycina Variety columbiae). Two State-sensitive species, gray cryptantha (Cryptantha leucuphasa) and a sandwort (Arenaria franklinii Variety thompsonii) have been located at the Hanford Site near the reference repository location (State of Washington, 1984, 1985). The presence of these or other potentially sensitive species on the reference repository location has not been established during recent investigations; however, these investigations are continuing. Disturbance to native flora would be minimized through careful planning and monitoring of repository and utility construction and programmatic control of unnecessary access to impact-sensitive areas.

Also included among concerns for the ecosystem are affected Indian Tribe fishing rights. The Yakima Indian Nation, the Confederated Tribes of the Umatilla Indian Reservation, and the Nez Perce Indian Tribe have been designated by the U.S. Department of the Interior as affected Indian Tribes based on their off-reservation treaty fishing rights (see Section 3.6.6). However, the U.S. Department of the Interior also states that no scientific data are available to indicate that a repository would have adverse impacts on fisheries (DOI, 1983a, 1983b, 1984). It is expected that repository activities will have few if any effects on the Columbia River fisheries or off-reservation treaty fishing rights of the affected Indian Tribes.

Indian religious concerns regarding potential repository impacts to sacred sites will be addressed during site characterization. These concerns may potentially include construction impacts at Gable Mountain, visitation rights to traditional cemeteries, protection of archaeological heritage sites and traditionally used fishing stations.

Finally, neither construction nor operation of the proposed repository is expected to have any measurable effects on local or regional water quality due to the absence of discharges to surface waters. The Columbia River and its biotic resources are briefly described in Subsection 3.4.2.6. There are no expected impacts to the Columbia River from construction of a repository at the reference repository location, because the repository surface facilities would be located some 10 kilometers (6 miles) from the Columbia River. The only postulated effect on the river will be the withdrawal of a small amount of the total river flow from an existing river pumping station.

While all repository-construction activities are not known at this time, the 1982 conceptual design (RKE/PB, 1983) includes plans to install two new pumps at an existing river pumping station. These activities are

not expected to have any adverse impacts on the aquatic habitat. Impingement and entrainment of aquatic biota have been well studied at the Hanford Site. Due to the size of the most important organisms, pump entrainment can be avoided. If impingement becomes a problem as a result of the addition of the two pumps, fish return systems can be used to return the fish to the river with little or no mortality.

5.2.1.3.2 Air quality

The primary sources of air-quality impacts would be the release of nonradiological pollutants at the reference repository location resulting from fuel combustion by construction equipment and the generation of fugitive dust by mechanical activity. The nonradiological pollutants that would be emitted in measurable quantities include sulfur dioxide, nitrogen dioxide, carbon monoxide, and total suspended particulates. The emission rate for each of these primary pollutants would depend on the numbers and types of equipment used, the quantity and nature of fuel consumed, and the efficiency of emission-control equipment and procedures. Preliminary drafts of construction plans and operation procedures afford initial estimates of the maximum annual, weekly, and daily emission totals that are expected for each pollutant (Glantz and Ramsdell, 1986). These estimates of project emissions are presented in Table 5-12. It is expected that these estimates will be refined as construction plans and operation procedures evolve.

Table 5-12. Source quantities of nonradiological pollutants (Glantz and Ramsdell, 1986)

	Annual maximum, kg/yr*	Weekly maximum, kg/wk*	Daily maximum (24 h), kg/day*
Carbon monoxide	25,000	490	100
Sulfur dioxide	6,300	120	25
Nitrogen dioxide	92,000	1,800	350
Total suspended particulates	650,000	13,000	2,600

NOTE: Estimated from preliminary construction schedules and operation plans.
*1 kilogram = 2.2 pounds.

Limits on the ambient ground-level concentrations of pollutants are set in Federal, State, and local ambient air-quality standards. The

standards specify the maximum pollutant concentrations allowed for averaging periods that include 1 hour, 3 hours, 8 hours, 24 hours, and 1 year. The standards for Benton, Franklin, and Walla Walla Counties in the State of Washington are given in Table 3-23. These standards may be used to evaluate potential air-quality impacts due to repository activities, including construction and operation of the repository.

Route 240 passes through the Hanford Site and approaches within several kilometers (miles) of projected emission locations. However, motorists traveling this route would only be within the proximity of the reference repository location for periods of less than 10 minutes. Pollutant concentrations would need to be well above the levels specified in the standards for substantial exposure to occur. A comparison of ambient air-quality standards with the maximum pollutant concentrations that could occur provides a conservative indication of the magnitude of the environmental impacts of the project.

The annual environmental impacts of project emissions were predicted using the HANCHI atmospheric dispersion model described in Glantz and Ramsdell (1986). Hourly measurements of wind direction and speed and atmospheric stability in the reference repository location were used in the model to simulate atmospheric conditions. Annual average pollutant concentrations were computed at specific distances downwind from the center of the exploratory shaft location in each of 16 transport sectors.

Model results for selected locations are presented in Table 5-13. These locations represent areas of potential public exposure to air pollutant concentrations due to repository activities. These results indicate that the maximum annual average concentrations predicted for each pollutant are less than ambient air-quality standards. Although deposition processes were not modeled for annual calculations, concentrations of total suspended particulates meet allowable limits at locations where the public has access. If deposition processes were included in this model, predicted concentrations of total suspended particulates would be substantially less.

Maximum short-term air-quality impacts for 1-, 3-, 8-, and 24-hour periods were simulated using the CHISHORT atmospheric dispersion model described in Glantz and Ramsdell (1986). The following U.S. Environmental Protection Agency air-quality screening assumptions were used for this analysis:

- Dispersion conditions are very stable (Pasquill-Gifford stability class F).
- Wind speeds are low (2.5 meters (8.2 feet) per second).
- Wind blows in a given direction for 6 hours.

It was also assumed that the pollutants did not undergo any chemical transformations. Deposition was simulated for fugitive dust emissions in computing the maximum 24-hour particulate concentrations.

Table 5-13. Maximum annual ground-level pollutant concentrations

Pollutant	Type of standard[a]	Concentration standard		Maximum background concentrations[b]	Calculated increased concentrations[c]		
		Federal, μg/m3	State, μg/m3	μg/m3	1.5 km, μg/m3	22.5 km, μg/m3	44 km, μg/m3
Nitrogen dioxide	Primary and secondary	100	100	20	2.5	0.1	<0.1
Total suspended particulate	Primary[d]	75	40+bkg[e]	37[f]	18	1.1	0.4
	Secondary[d]	60	60	--	18	1.1	0.4
Sulfur dioxide	Primary	80	52	0.5	0.2	<0.1	<0.1

NOTE: To convert kilometers to miles, multiply by 0.62.

[a]Federal standards only, does not apply to State standards.

[b]Background concentrations for the region surrounding the Hanford Site are taken from a report by the U.S. Nuclear Regulatory Commission (NRC, 1982a, Table 4.33) and unpublished air-quality monitoring data collected by the Benton-Franklin-Walla Walla Counties Air Pollution Control Authority.

[c]Potential increases in pollutant concentrations at publicly accessible locations corresponding to Route 240, the Wye Barricade, and the 300 Area, which are 1.5, 22.5, and 44 kilometers from the reference repository location, respectively.

[d]Annual geometric mean.

[e]bkg = background; applies east of the Cascade Mountain crest.

[f]This maximum value reflects the impact of exceptional natural events (e.g., dust storms, sand storms, range fires). In the absence of exceptional events, the maximum annual background concentration would not exceed 20 μg/m3 and the maximum 24-hour concentration would not exceed 30 μg/m3. The U.S. Environmental Protection Agency uses these lower values for evaluating new sources in eastern Washington State, thereby neglecting the impact of natural events.

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The maximum emission rates that were used for this analysis could not be directly estimated from project plans (Larvie, 1985). Maximum emission rates for 8-hour periods were assumed to be three times the maximum daily emission rate. Maximum 1- and 3-hour-emission rates were assumed to be equal to the maximum 8-hour emission rate. These assumptions result in a conservative estimate of maximum emission rates.

Model results indicate that the maximum short-term concentrations predicted for particulates, sulfur dioxide, and carbon monoxide are less than ambient air-quality standards at locations where the public has access (Table 5-14). All concentrations at the Hanford Site boundaries, where members of the public have the possibility for long-term exposure, are well below the ambient standards. Therefore, impacts to air quality in populated areas are minimal. Concentrations do not exceed the standards along the portion of Route 240 near the proposed surface facilities. Short-term concentrations were calculated using U.S. Environmental Protection Agency air-quality screening assumptions to define meteorological conditions.

The results of this analysis show that the nonradiological air-quality impacts from project construction and operation activities should be minor. Further nonradiological air-quality modeling will continue as the repository design is refined.

5.2.1.3.3 Noise

During the repository construction phase, there would be temporarily elevated noise levels from heavy equipment (e.g., earthmovers, bulldozers, and scrapers). Elevated noise levels also would occur during drilling operations associated with the sinking of the shafts and road or railroad access construction.

Effective muffler systems would be used on heavy equipment during construction to minimize adverse environmental and occupational impacts. The remoteness of the repository from human habitation and occupied Hanford Site facilities would further limit the effects of any construction noise levels. No local communities will be affected by noise resulting from construction of the facilities or road or railroad access to the site; no measurable elevation of background noise levels at the Hanford Site boundaries is anticipated. Effects of noise on wildlife residing nearby are currently unquantifiable (see Subsection 5.2.1.3.1 for a further assessment of noise impacts on native fauna). It can be expected that temporary habitat abandonment would occur in the vicinity of elevated noise (Fletcher and Busnel, 1978, pp. 303 through 305).

The 1982 conceptual design (RKE/PB, 1983) has provisions for a helicopter landing pad (see Fig. 5-6). Helicopter noise would be disturbing to wildlife and could affect deer, coyote, badger, hares, and birds of prey, in particular. It is not expected that helicopter noise would present any additional measurable effects over that from current aircraft and surface traffic in the vicinity of the reference repository location.

Table 5-14. Maximum short-term ground-level pollutant concentrations

Pollutant	Type of standard[a]	Averaging time	Concentration standard		Maximum background concentrations[b]	Calculated increase concentrations[c]		
			Federal, μg/m3	State, μg/m3	μg/m3	1.5 km, μg/m3	22.5 km, μg/m3	44 km, μg/m3
Carbon monoxide	Primary	1 hr[d]	40,000	40,000	11,795	94	2	0.8
		8 hr[d]	10,000	10,000	6,525	71	1.5	0.6
Total suspended particulate	Primary	24 hr[d]	260	120+bkg[e]	<150[f]	83	1.7	0.7
	Secondary	24 hr[d]	150	150	--	83	1.7	0.7
Sulfur dioxide	Primary	24 hr[d]	365	260	5.7	2	<0.1	<0.1
		1 hr[d]	--	1,018	--	24	0.5	0.2
		1 hr[g]	--	655	--	24	0.5	0.2
						24		
	Secondary	3 hr[d]	1,300	--	19.6		0.5	0.2

NOTE: To convert kilometers to miles, multiply by 0.62.

[a]Federal standards only, does not apply to State standards.

[b]Background concentrations for the region surrounding the Hanford Site are taken from a report by the U.S. Nuclear Regulatory Commission (NRC, 1982a, Table 4.33) and unpublished air-quality monitoring data collected by the Benton-Franklin-Walla Walla Counties Air Pollution Control Authority.

[c]Potential increases in pollutant concentrations at publicly accessible locations corresponding to Route 240, the Wye Barricade, and the 300 Area, which are 1.5, 22.5, and 44 kilometers from the reference repository location, respectively.

[d]Not to be exceeded more than once per year.

[e]bkg = background; applies east of the Cascade Mountain crest.

[f]This maximum value reflects the impact of exceptional natural events (e.g., dust storms, sand storms, range fires). In the absence of exceptional events, the maximum annual background concentration would not exceed 20 μg/m3 and the maximum 24-hour concentration would not exceed 30 μg/m3. The U.S. Environmental Protection Agency uses these lower values for evaluating new sources in eastern Washington State, thereby neglecting the impact of natural events.

[g]Not to be exceeded more than two times in any consecutive 7 days.

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A program would be developed to quantify the repository-related noise levels and any resultant effects on wildlife. This activity would support additional impact minimization efforts if warranted.

5.2.1.3.4 Aesthetic

The general level of aesthetics at the reference repository location is not expected to be affected by construction and operation of the repository. The appearance of the surface facilities from Route 240 would be comparable to other visible facilities on the Hanford Site. A spoils pile, 591 meters (1,940 feet) wide by 591 meters (1,940 feet) long by 14 meters (46 feet) high, also will be visible from Route 240, but its appearance is not expected to alter significantly the aesthetic value of the reference repository location.

5.2.1.3.5 Archaeological, cultural, and historical resources

Archaeological surveys conducted to date suggest that there is low potential for archaeological resources within the reference repository location (Rice, 1984a, 1984b). An historic roadbed has been identified and evaluated, but no National Register eligible sites are known to exist. A Programatic Memorandum of Agreement between the U.S. Department of Energy, the Advisory Council on Historic Perservation, and the Washington State Historic Preservation Office is being negotiated to outline procedures that will be followed in the event that unexpected cultural resources are encountered during site-characterization activities. The Programatic Memorandum of Agreement would be consistent with the archeaology program for the Hanford Site. No project effects are expected at National Register archaeological sites at Rattlesnake Springs or along the Columbia River. The Gable Mountain locality is now under evaluation for archaeological sites.

5.2.1.3.6 Radiological

Spent fuel would be handled remotely during receiving, inspection, and placement into containers prior to transporting it in heavily shielded casks to the waste-storage area (see Section 5.1.2). The transporter casks would be shielded to the extent that surface radiation levels on the order of 1 millirem per hour are anticipated. With remotely conducted container emplacement, no operating personnel are expected to be exposed to a significant amount of radiation.

Radioactive emission and radiation doses from repository facilities were estimated from the 1982 conceptual design (RKE/PB, 1983) for the reference repository location (see Subsection 6.2.1.5 and Section 6.4.1). The radiation doses from normal operations of the surface facilities most likely would result from receiving, disassembling, and repacking spent fuel canisters.

Routine radiological releases from geologic repositories during normal operation would consist principally of radon decay products and radon emanating from exposed rock faces. These releases would also occur from backfilling operations, but are negligible compared to radon releases that would occur during repository construction (DOE, 1980). A summary of 70-year whole-body doses to the regional population from the releases of naturally occurring radionuclides during repository construction is given in a report by the U.S. Department of Energy (DOE, 1980). Based on calculated doses to the regional population, no health effects are expected from construction or operation of a geologic repository for spent fuel or for reprocessing wastes (DOE, 1980). Preclosure performance assessment is discussed in detail in Section 6.4.1.

Population exposure in the distant future (10,000 years) is also expected to be negligible even if some ground-water transport does occur. Postclosure performance assessment, including radionuclide releases out to 10,000 years, is discussed in Section 6.4.2.

5.2.2 EXPECTED EFFECTS OF TRANSPORTATION

This section focuses on the potential regional and local effects of transporting nuclear waste to a repository located at the Hanford Site. Regional radiological and nonradiological effects for normal and accident conditions have been estimated based on nationally applicable risk factors presented in Appendix A, expected types and numbers of shipments, and regional population density data along probable routes. National transportation effects for a repository located at the Hanford Site, also described in Appendix A, are identified in this section for comparison purposes. Additional topics discussed in this section are the possibility of barge transport to the Hanford Site and the implications of repository siting on Hanford Site defense waste transportation.

Due to the focus of this section on regional transportation effects, much general information on transportation effects has been omitted. The general transportation information that has national, rather than site-specific, significance and that covers all candidate repository sites is presented in Appendix A.

The transportation effects of two scenarios for the high-level nuclear waste program, a reference case and an alternate case, are covered in this section. The reference case, also called the authorized system, is one in which spent fuel and other high-level wastes are transported directly from source locations to the repository for disposal. The alternate case, also called the improved performance system, is one in which spent fuel is shipped from nuclear power reactors to an intermediate facility, called a monitored retrievable storage facility, prior to shipment to a repository. The monitored retrievable storage facility is assumed to be located in Oak Ridge Tennessee. Spent fuel treatment and packaging operations that would otherwise be performed at the repository

would be conducted instead at the monitored retrievable storage facility. These monitored retrievable storage operations, together with interim storage capability, would improve the efficiency of subsequent transportation and repository receiving operations.

The scope of the regional transportation effects presented in this section and the findings associated with the transportation siting guidelines as described in Subsection 6.2.1.8 are dependent on a working definition for the word region. For the transportation-related regional analyses discussed, the extent of the region analyzed has been selected to satisfy at least a minimum definition in which the region extends from the site to the nearest intersection with an interstate highway or mainline railroad. Although a maximum extent of the region has not been defined, the intent of the General Siting Guidelines (DOE, 1984b) is to focus on effects near the repository sites being considered. Transportation routes from the Hanford Site that satisfy the minimum definition of region are short and do not traverse heavily populated areas. Calculated transportation risks for this minimum region would be very small and of interest only to local members of the exposed population. Therefore, the region used for transportation analyses in this section has been extended along interstate highways and mainline railroads to the next major population centers.

5.2.2.1 Radioactive waste shipment bases

Nuclear waste is generated from a variety of sources across the United States. The types of nuclear waste currently planned for repository disposal are as follows:

- Spent nuclear fuel from commercial nuclear power reactors.
- Defense high-level waste from the U.S. Department of Energy defense-related nuclear fuel-reprocessing operations at the Savannah River Plant, South Carolina, the Hanford Site, Washington, and the Idaho National Engineering Laboratory, Idaho.
- West Valley high-level waste from cleanup of the commercial spent fuel-reprocessing plant at West Valley, New York.

For the improved performance system, the repository would receive wastes generated by the spent fuel disassembly and packaging operations at the monitored retrievable storage facility. For the authorized system, these wastes would instead be generated at the repository. The repository will be designed to have sufficient operational flexibility to accommodate, with design modifications, the receipt and disposal of other waste types pending future nuclear fuel cycle development and waste-management decisions.

A detailed explanation of the waste shipment bases used in the transportation analyses is contained in Appendix A. Since the impacts of the authorized system (reference case) and the improved performance system (alternate case) are presented in this section, additional information on these two systems and their associated transportation operations is provided below.

5.2.2.1.1 Authorized system

The term authorized system denotes that this reference case is that authorized by the Nuclear Waste Policy Act of 1982. The Act also calls for a study of monitored retrievable storage and a recommendation to the Congress on whether a monitored retrievable storage facility should be included within the overall waste-management system. If the monitored retrievable storage facility were approved by Congress, the improved performance system, which includes a monitored retrievable storage facility, will replace the currently authorized system as the reference case.

Under the authorized system, there is no intermediate facility between the waste sources and the repository. Each of the three waste types identified above is shipped directly to the repository by either truck or rail transport. Barge transport to the Hanford Site is considered to be an open option for the small fraction of spent fuel that will be shipped from western nuclear power reactors, as discussed later in this subsection. None of the waste shippers will package the waste for repository emplacement; the only packaging performed at the waste source will be that needed for storage at the source location and for subsequent transport. All of these waste types will be sealed in an emplacement container prior to emplacement in a repository.

The projected total waste shipments used as the basis for the transportation analyses of the authorized and improved performance systems are shown in Table 5-15. The numbers of shipments are for 100-percent-truck and 100-percent-rail scenarios to provide bounding cases for any split between truck and rail transport. The shipment projections for spent fuel are subdivided by reactor type and the projections for defense high-level waste shipments are subdivided by source location. The average daily waste shipments that correspond to the total waste shipments in Table 5-15 are shown in Table 5-16.

Table 5-15 also shows assumed shipping cask payloads in terms of numbers of waste packages (or numbers of spent fuel assemblies for spent fuel shipments direct to the repository). These payloads are based on preliminary cask design concepts developed for these future shipments. In the case of spent fuel shipping casks, the assumed payloads are greater than those of existing spent fuel shipping casks, since the spent fuel age (i.e., time following reactor discharge) for shipments to the repository will be five or more years, which is much greater than that of the short-

Table 5-15. Projected total nuclear waste shipments to a repository at the Hanford Site (shipment bases for transportation analyses) (sheet 1 of 2)

Waste category	Total packages	100% truck		100% rail	
		Payload	Total shipments	Payload	Total shipments
1. Spent fuel direct to repository[a]					
Pressurized water reactor	87,222	2	43,611	14	6,190
Boiling water reactor	134,710	5	26,942	36	3,737
Total	221,932	--	70,553	--	9,927
2. Consolidated spent fuel from monitored retrievable storage to repository[b,c]					
Pressurized water reactor	22,104	--	--	6	3,684
Boiling water reactor	14,630	--	--	5	2,926
Total	36,734	--	--	--	6,610
3. Defense high-level waste direct to repository[d]					
Savannah River	11,600	1	11,600	5	2,320
Hanford	2,250	1	2,250	5	450
Idaho National Engineering Laboratory	9,000	1	9,000	5	1,800
Total	22,850	--	22,850	--	4,570
4. West Valley high-level waste direct to repository[d]	800	1	800	7	115

7 0 1 6 8 0 9 9 3

Table 5-15. Projected total nuclear waste shipments to a repository at the Hanford Site (shipment bases for transportation analyses) (sheet 2 of 2)

Waste category	Total packages	100% truck		100% rail	
		Payload	Total shipments	Payload	Total shipments
5. Secondary waste to repository from spent fuel disassembly and packaging operations[c]					
Hardware	27,277	--	--	20	1,364
High-activity waste	25,383	--	--	20	1,270
Contact-handled transuranic waste	11,400	--	--	72	159
Total	64,060	--	--	--	2,793
Total authorized system (Items 1, 3, and 4)			94,203		14,612
Total improved performance system (Items 2, 3, 4, and 5) Plus railcar shipments[e]			23,650 9,403		14,088

[a]For Item 1, packages and payloads listed pertain to fuel assemblies rather than packages.

[b]For Item 2, packages contain consolidated rods from either four pressurized water reactor or nine boiling water reactor fuel assemblies; payloads are in numbers of packages.

[c]For Items 2 and 5, 91-metric ton (100-ton) casks are assumed; shipments are numbers of casks rather than numbers of dedicated trains. The total of 9,403 casks in Items 2 and 5 would be carried by 1,322 dedicated trains.

[d]The assumed packages for defense high-level waste (Item 3) and West Valley high-level waste (Item 4) each contain wastes equivalent to those from about 0.5 metric ton (0.55 ton) of spent fuel. Shipping cask payloads are in numbers of packages.

[e]These railcar shipments are included in the truck shipment column for completeness, since only rail shipment from the monitored retrievable storage facility to the repository is being considered. The railcar shipments shown include consolidated spent fuel and associated secondary wastes from spent fuel disassembly and packaging operations.

7 0 1 6 8 0 6 0 9 4

Table 5-16 Projected average daily waste cask shipments to a repository at the Hanford Site

System or waste type	Transport mode	
	100% truck	100% rail
Authorized system		
100% spent fuel[a]	12	2
Defense and West Valley high-level waste[b]	4	1
Total	16	3
Improved performance system		
Consolidated spent fuel and associated secondary wastes[a]	(c)	2[d]
Defense and West Valley high-level waste	4	1
Total	4	3

[a]Assumes receipt of 3,000 metric tons of uranium per year during 50 weeks per year, 6 days per week.

[b]Based on peak receipt rate of 1,190 canisters per year, 50 weeks per year, 6 days per week.

[c]These wastes are shipped only by dedicated train; the 100 percent truck case will also receive rail shipments as shown in the 100 percent rail column for these wastes.

[d]These values correspond to numbers of railcars via dedicated train and are equivalent to about one dedicated train every five days.

cooled (3 to 6 months) spent fuel for which existing shipping casks were designed. The increased spent fuel age results in a significant reduction in heat-generation rate and radiation dose rate. Although these new-generation shipping casks have not yet been built and operated, their designs will be within existing technology and will meet or exceed all regulatory safety requirements.

5.2.2.1.2 Improved performance system

Under the improved performance system, a monitored retrievable storage facility is provided to receive spent fuel that would be destined directly for the repository under the authorized system. At the monitored retrievable storage facility, the intact spent fuel assemblies would be disassembled into individual fuel rods and packaged to reduce volume for subsequent shipment to and emplacement in the repository. Spent fuel consolidation is the term used to describe the spent fuel disassembly and packaging operation. Under current plans, spent fuel consolidation would be performed at the repository receiving facility for the authorized system. There are two monitored retrievable storage facility options for the canister or container that would be used to enclose the consolidated spent fuel rods: (1) The container used at this facility could be the container planned for repository emplacement, thus eliminating the need for the repository to provide this container; or (2) this facility could package consolidated spent fuel rods in a thin-walled canister that would be used for facility handling and storage and subsequent spent fuel transport. This would leave the repository the task of enclosing this canister within an emplacement container. For either of these canister or container options, the spent fuel content per package would be the same and would be equivalent to the planned spent fuel content of the emplacement container for the repository. For a repository in basalt, the currently planned spent fuel package will hold either four pressurized water reactor fuel assemblies or nine boiling water reactor fuel assemblies.

For analyses in this subsection, only spent fuel is assumed to be routed through the monitored retrievable storage facility. Defense high-level waste and West Valley high-level waste are assumed to be shipped directly to the repository from their source locations. However, shipment of some of these high-level wastes to the monitored retrievable storage facility is being considered to allow load consolidation for subsequent rail shipment to the repository.

Current monitored retrievable storage facility planning includes an option for spent fuel shipment directly to the repository from western reactors (west of 100 degrees west longitude). This is because the preferred monitored retrievable storage facility locations are in the East and the candidate sites for the first repository are located in the West. Under this option the western spent fuel, less than 10 percent of the total spent fuel, would be consolidated and packaged as required at the

selected repository site. The regional transportation risks for the East-West spent fuel split option are not specifically analyzed in this subsection. These risks would be expected to be only slightly different from those for the case in which all spent fuel is routed through the monitored retrievable storage facility.

Three secondary wastes that result from operation of the monitored retrievable storage facility are assumed to be transported to the repository under the improved performance system. These secondary wastes, which include spent fuel hardware, high-activity waste, and contact-handled transuranic waste, would be generated at the repository if the monitored retrievable storage facility operations were performed at the repository, as in the authorized system.

All shipments from the monitored retrievable storage facility to the repository would be by rail using dedicated trains (i.e., each train would consist only of railcars containing spent fuel or radioactive waste from the monitored retrievable storage facility). For the transportation analyses, each dedicated train is assumed to consist of five spent fuel railcars and up to five additional railcars containing the secondary wastes.

To estimate the maximum and minimum numbers of spent fuel shipments from the monitored retrievable storage facility, two cask design options have been considered: (1) A 91-metric ton (100-ton) cask containing emplacement containers of spent fuel (minimum payload) and (2) a 136-metric ton (150-ton) cask containing thin-walled canisters of spent fuel. For transportation analyses included in this section, only the 91-metric ton (100-ton) cask option is included, since this minimum payload cask would result in maximum shipment frequencies. This would provide a conservative upper bound on the transportation impacts.

The projected total waste shipments used as the basis for the transportation analyses of the improved performance system are shown in Table 5-15 along with the corresponding information for the authorized system. Similarly, the average daily waste shipments that correspond to the total waste shipments are shown in Table 5-16. The transportation impacts of other alternative monitored retrievable storage facility scenarios are covered in Appendix A.

5.2.2.2 Types of nonradioactive shipments

Shipment of nonradioactive materials to and from the repository is a concern from the standpoint of transportation system adequacy and traffic safety. During the repository construction period, construction supplies and equipment (e.g., concrete or its constituents, rebar, steel plate, piping, wire, drilling and excavating supplies, and purchased plant equipment items) would be transported to the repository site via truck, rail, and perhaps barge. Similarly, during the repository operation

phase, other types of supplies and equipment (e.g., backfill materials and replacement equipment and parts) would also be transported to the site. Shipments from the repository would consist primarily of empty spent fuel casks and empty material transport vehicles. Nonradioactive waste shipments from the repository would be minimal; current plans are to store all excavated rock onsite, much of which would be used later for backfilling excavated openings.

The quantities and shipping frequency of nonradioactive material to the repository are not estimated in this report, because (1) repository design is in an early conceptual stage and is subject to change, (2) firm construction schedules are not established, and (3) quantity and safety of these shipments are judged to be of less concern than for the radioactive material shipments, even though short-term shipment frequencies (i.e., during construction) could be high enough to impact routine local traffic patterns.

5.2.2.3 Regional impacts of nuclear waste transport

This subsection addresses the regional radiological and nonradiological impacts of nuclear waste transportation to a repository located at the Hanford Site. These regional impacts are subsets of the national impacts discussed in greater detail in Appendix A; these national impacts are merely summarized in tabular form in this subsection for comparison purposes. The impacts discussed cover the authorized and improved performance systems.

Highway transport and rail transport are discussed individually and projected impacts are presented for the 100-percent-truck and 100-percent-rail bounding cases. Many factors will influence the actual modal split between truck and rail shipments. One such factor is preference for rail shipments due to the higher payload capacity; a counterbalancing factor is the inability of many current nuclear power reactor sites to ship by rail. Other factors that may play roles in determining the modal split are cost and risk comparisons and competitive market factors. It is currently estimated that, initially, about 50 to 70 percent of the spent fuel (uranium weight basis) will be shipped by rail and that the rail fraction will gradually increase to 70 percent or greater. However, since there is a high uncertainty inherent in any predictions of the modal split, risk projections are provided for the 100-percent-truck and 100-percent-rail bounding cases rather than for a specific modal split. The risk projections for a particular modal split would lie between these two bounding cases. For shipments from a monitored retrievable storage facility to the repository in the improved performance system, only dedicated train shipments are being considered. For completeness, these rail impacts are included in the 100-percent-truck impacts for the improved performance system.

For the highway and railroad portions of the impact projections, alternate routes are shown for shipments from the eastern United States to the Hanford Site. One pair of highway and railroad routes approaches the Hanford Site from the northeast, the other pair approaches from the southeast. Thus, the terms northern route and southern route appear in the text and supporting tables to describe the alternate highway and railroad routes. No attempt is made to compare alternate routes; instead, data are provided to support a judgment that the projected transportation impacts for any of the alternate routes are acceptable. The existence of alternate highway and railroad routes to the Hanford Site is advantageous, since it is unlikely that a given route would be used to the exclusion of the others and the corresponding impacts for such a given route are thereby reduced. However, projected impacts are provided for each alternate route as though all shipments would use that route to show conservatively high impacts for each route; such conservatively high impacts would not be expected.

5.2.2.3.1 Highway transport

The existing highway routes to the repository are described in Section 3.5.2. Highway shipments to the Hanford Site travel via one of two major east-west interstate highways: Interstate 90 to the north and Interstate 84 to the south (see Fig. 3-44). Exit points from these interstate highways depend on the direction of travel, which is assumed to be from east to west since most radioactive waste shipments would originate east of the Hanford Site. The State of Washington is authorized to designate specific routes to be used within its borders from the interstate highways to the repository access roads.

For transportation impacts presented in this subsection, it was assumed that trucks heading west on Interstate 90 will exit onto U.S. Highway 395 near Ritzville, Washington, and follow U.S. Highway 395 south to Pasco, Washington (see Fig. 3-45). Near Pasco, these shipments would exit U.S. Highway 395 onto U.S. Highway 12, and travel west across the Columbia River, through Kennewick to Richland, Washington. At the southern end of Richland, these trucks would enter Route 240, bypass the urban portion of the city of Richland, and enter the Hanford Site.

It was assumed that trucks heading west on Interstate 84 would exit onto U.S. Highway 395 near Stanfield, Oregon, and follow U.S. Highway 395 north to its intersection with U.S. Highway 730. These shipments would follow U.S. Highway 730 for a short distance to the west and cross the Columbia River via a bridge on the eastern edge of Umatilla, Oregon. On the Washington side of the Columbia River, these trucks would connect with and follow State Route 14 north to Kennewick, Washington, where they would connect with U.S. Highway 12. From this point, the route is the same as that traveled by trucks coming from the north.

An extension of Interstate 82 and a new Interstate 182 are currently under construction. These new interstate highways would provide a replacement route for State Route 14 and a means of bypassing U.S. Highway 12 between Kennewick and Richland, Washington (see Fig. 3-45). The new routes will result in reduced transportation risk, since some of the existing populated areas will be bypassed.

To allow evaluation of regional transportation impacts by truck, route-specific population density data along these transportation corridors have been utilized (Kelley and Bigelow, 1985). These data consist of mean population densities within 1 kilometer (0.6 mile) of the highway and the corresponding highway segment lengths over which the population densities apply. Although the regional highway system is generally considered to extend only to the nearest interstate highway, data presented include portions of Interstate 90 to Coeur d'Alene, Idaho, and Interstate 84 to Boise, Idaho. These data are summarized in Table 5-17.

Tables 5-18 and 5-19 present the regional transportation risk projections for truck shipments via the northern (Interstate 90) and southern (Interstate 84) routes, respectively. Tabulated values represent total risks for all nuclear wastes shipped to the repository in accordance with Table 5-15 shipment data. The regional transportation risk projections for these two alternate routes should not be compared with each other, due to differences in highway lengths and uncertainty in the rural population density assumption. The corresponding national transportation risks (see Appendix A) also are presented in the tables for comparison to the regional data. Risk projections are provided for the authorized system and the improved performance system discussed earlier in this subsection. For the improved performance system, the national risk values also include spent fuel shipments from nuclear power reactors to the monitored retrievable storage facility (assumed to be located near Oak Ridge, Tennessee), in addition to spent fuel and secondary waste shipments from the monitored retrievable storage facility to the repository. For the regional transportation risk analyses for shipments from the monitored retrievable storage facility, it was conservatively assumed that all dedicated train shipments consisted of 10 railcars (i.e., 5 for spent fuel, 2 for spent fuel hardware, 2 for high-activity waste, and 1 for contact-handled transuranic waste).

Regional transportation risk projections presented in Tables 5-18 and 5-19 were calculated using route-specific population density and corresponding segment length data as presented in Table 5-17 and unit risk factors as described in Appendix A. The unit risk factors have been scaled for the regional calculations to compensate for specific mean population densities that differ from the national average population density data used in developing the unit risk factors; the method of scaling unit risk factors is described in Appendix A. See Appendix A for more detailed discussions of the transportation risk calculations.

Table 5-17. Regional population density data along highway routes to the Hanford Site

Northern route via Interstate 90 from Coeur d'Alene, Idaho		Southern route via Interstate 84 from Boise, Idaho	
Population density, persons per km^2[a,b]	Corresponding highway segment length[c]	Population density, persons per km^2[a,b]	Corresponding highway segment length[c]
	km[a]		km[a]
698	8.8	555	15
174	13	128	11.5
866	12	281	8
1,020	3.25	406	9
2,198	4	204	6
139	11	263	7
90	2	504	8
269	3	366	8
24	7	308	10
1,112	6	609	6
609	6	333	6.2
333	6.5	929	4
929	4	291	11
291	11	6[d]	379
6[d]	220		
Total	317.55	Total	489

NOTE: After Kelley and Bigelow (1985).

[a]Population densities shown are those within 1 kilometer (0.62 mile) of highway.

[b]1 square kilometer = 0.4 square mile.

[c]Segment lengths are not in sequential order.

[d]Assumed value for rural areas in which precise population density data are lacking.

Table 5-18. Transportation risk projections, 100-percent truck transport, 100 percent via regional northern (Interstate 90) route

Risk parameter	Authorized system		Improved performance system[a]	
	Regional	National[b]	Regional	National[b]
Radiological fatalities				
Normal				
Occupational	0.18	1.9	0.04	0.9
Nonoccupational	0.92	10	0.20	4.8
Accident				
Nonoccupational	0.004	0.04	0.003	0.05
Total	1.1	12	0.24	5.7
Nonradiological fatalities				
Normal				
Nonoccupational	0.04	0.4	0.01	0.3
Accident				
Occupational	0.69	8.4	0.29	5
Nonoccupational	2.4	30	2.4	33
Total	3.1	39	2.7	39
Nonradiological injuries				
Accident				
Occupational	1.4	17	18	200
Nonoccupational	40	470	13	250
Total fatalities	4.2	51	2.9	45
Total injuries	41	487	31	450

[a]The values shown for the improved performance system reflect all truck shipments from reactors to the monitored retrievable storage facility (in National column) and include dedicated train transport from the monitored retrievable storage facility to the repository (in both columns) to show complete and total risk.

[b]National values are for comparison purposes only and are not specific to the regional northern (Interstate 90) route.

Table 5-19. Transportation risk projections, 100-percent truck transport, 100 percent via regional southern (Interstate 84) route

Risk parameter	Authorized system		Improved performance system[a]	
	Regional	National[b]	Regional	National[b]
Radiological fatalities				
Normal				
Occupational	0.26	1.9	0.06	0.9
Nonoccupational	1.36	10	0.30	4.8
Accident				
Nonoccupational	0.003	0.04	0.002	0.05
Total	1.6	12	0.36	5.7
Nonradiological fatalities				
Normal				
Nonoccupational	0.0	0.4	0.00	0.3
Accident				
Occupational	1.1	8.4	0.45	5
Nonoccupational	4	30	3.6	33
Total	5.1	39	4.1	39
Nonradiological injuries				
Accident				
Occupational	2.2	17	26	200
Nonoccupational	63	470	20	250
Total fatalities	6.7	51	4.5	45
Total injuries	65	487	46	450

[a]The values shown for the improved performance system reflect all truck shipments from reactors to the monitored retrievable storage facility (in National column) and include dedicated train transport from the monitored retrievable storage facility to the repository (in both columns) to show complete and total risk.

[b]National values are for comparison purposes only and are not specific to the regional southern (Interstate 84) route.

5.2.2.3.2 Railroad transport

As described in Section 3.5.1, two major rail lines (i.e., Burlington Northern and Union Pacific) serve the Hanford Site. For shipments from the east, these two rail lines generally follow the same routes as the highway system (see Fig. 3-43). The Union Pacific route follows Interstate 84 from Boise, Idaho, to Hinkle, Oregon, then follows the Columbia River to the Hanford Site. The Burlington Northern route crosses Idaho north of Interstate 90, passes southwest through Spokane to Pasco, Washington, and heads west to the Hanford Site. Hinkle, Oregon, and Pasco, Washington, are the locations of regional classification yards for the Union Pacific and Burlington Northern, respectively.

A compilation of route-specific population density data along regional railroad lines (Kelley and Bigelow, 1985) has been utilized in the calculations of regional rail transportation impacts. The data used are presented in Table 5-20 for two alternate railroad routes; these data for rail transportation corridors are analogous to the data for regional highway transportation corridors presented earlier (see Table 5-17).

Tables 5-21 and 5-22 present the regional transportation risk projections for rail shipments via the northern (Burlington Northern) and southern (Union Pacific) routes, respectively. Tabulated values represent total risks for all nuclear wastes shipped to the repository in accordance with Table 5-15 shipment data. The authorized system and the improved performance system are covered, and the corresponding data for national transportation impacts also are provided for comparison purposes. Table formats are analogous to the previously presented tables on truck transportation impacts (see Tables 5-18 and 5-19).

The methods used to prepare the projections in Tables 5-21 and 5-22 also are analogous to the projections for truck transport, and are described in greater detail in Appendix A. The route-specific population density data for rail corridors (Table 5-20), the corresponding rail segment lengths, and the national unit risk factors (Appendix A), scaled for population density differences, were the primary parameters used in the calculations.

5.2.2.4 Potential barge transport of western spent fuel

For either the authorized system or the improved performance system, there is an option for barge shipment of a small amount of spent fuel to a repository located at the Hanford Site. This option is considered a possibility for the Hanford Site due to the proximity of the Columbia River (approximately 32 kilometers (20 miles) from existing port facilities). The Columbia River is a navigable waterway from the Pacific Ocean via a series of locks provided on dams used for hydroelectric power generation. Barge shipment into Puget Sound via the Strait of

Table 5-20. Regional population density data along railroad routes to the Hanford Site

Northern route (via Burlington Northern from Sandpoint, Idaho)		Southern route (via Union Pacific from Boise, Idaho)	
Population density, persons per km^2[a,b]	Corresponding railroad segment length[c] km[a]	Population density, persons per km^2[a,b]	Corresponding railroad segment length[c] km[a]
550	2	363	16
195	0.8	706	8
159	15	303	3
529	9	310	6
584	3.25	269	7
1,404	5	360	7
304	7	178	6
557	4.75	902	4
284	1	610	6
495	2	309	7
156	8	929	4
902	4	469	7
610	6	6[d]	472
309	7		
929	4		
469	7		
6[d]	288		
Total	373.8	Total	553

NOTE: Taken from Kelley and Bigelow (1985).

[a]Population densities shown are those within 1 kilometer (0.62 mile) of the railroad.

[b]1 square kilometer = 0.4 square mile.

[c]Segment lengths are not in sequential order.

[d]Assumed value for rural areas in which precise population density data are lacking.

Table 5-21. Transportation risk projections, 100-percent rail transport, 100 percent via regional northern (Burlington Northern) route

Risk parameter	Authorized system		Improved performance system[a]	
	Regional	National[b]	Regional	National[b]
Radiological fatalities				
Normal				
Occupational	0.03	0.1	0.01	0.1
Nonoccupational	0.03	0.2	0.01	0.1
Accident				
Nonoccupational	0.002	0.02	0.003	0.04
Total	0.06	0.3	0.02	0.3
Nonradiological fatalities				
Normal				
Nonoccupational	0.00	0.2	0.00	0.3
Accident				
Occupational	0.02	0.2	0.13	1.5
Nonoccupational	0.28	2.8	1.9	22
Total	0.30	3.2	2	24
Nonradiological injuries				
Accident				
Occupational	2.6	26	18	210
Nonoccupational	0.54	5.4	3.9	43
Total fatalities	0.36	3.5	2	24
Total injuries	3.1	31	22	253

[a]The values shown for the improved performance system reflect commercial rail shipments from reactors to the monitored retrievable storage facility and dedicated train transport from the monitored retrievable storage facility to the repository.

[b]National values are for comparison purposes only and are not specific to the regional northern (Burlington Northern) route.

Table 5-22. Transportation risk projections, 100-percent rail transport, 100 percent via regional southern (Union Pacific) route

Risk parameter	Authorized system		Improved performance system[a]	
	Regional	National[b]	Regional	National[b]
Radiological fatalities				
Normal				
Occupational	0.03	0.1	0.01	0.1
Nonoccupational	0.03	0.2	0.01	0.1
Accident				
Nonoccupational	0.001	0.02	0.003	0.04
Total	0.06	0.3	0.02	0.3
Nonradiological fatalities				
Normal				
Nonoccupational	0.00	0.2	0.00	0.3
Accident				
Occupational	0.03	0.2	0.19	1.5
Nonoccupational	0.41	2.8	2.8	22
Total	0.44	3.2	3	24
Nonradiological injuries				
Accident				
Occupational	3.9	26	27	210
Nonoccupational	0.8	5.4	6	43
Total fatalities	0.5	3.5	3	24
Total injuries	4.7	31	33	253

[a]The values shown for the improved performance system reflect commercial rail shipments from reactors to the monitored retrievable storage facility and dedicated train transport from the monitored retrievable storage facility to the repository.

[b]National values are for comparison purposes only and are not specific to the regional southern (Union Pacific) route.

Juan de Fuca is not likely, due to the increased barging distance, the need for intermodal transfer from barge to rail at a Puget Sound facility, and the remaining distance from Puget Sound to the Hanford Site.

Only nuclear power reactors located in the western portion of the United States (e.g., west of 100 degrees west longitude) would be considered as candidate spent fuel sources for barge shipment to a repository at the Hanford Site. The possibility of barge shipments from eastern reactors via the Panama Canal does not appear reasonable or probable because of the additional cost and time required for such shipments, and because of administrative concerns related to safeguarding shipments that traverse foreign countries and travel on the open sea.

There are only about six nuclear power reactor locations in the western United States that could be considered as candidate spent fuel sources for barge shipment to the Hanford Site. These nuclear plants are forecast to generate less than 10 percent of the total spent fuel destined for repository disposal. One plant in Oregon (Trojan) and two plants in California (Humboldt Bay and Diablo Canyon) could ship directly by barge if the proper dock facilities were made available. It does not appear that there is any way for a barge to land at the San Onofre plant in California. Rancho Seco in California and Palo Verde in Arizona are at inland locations, and rail shipments would have to be made to a suitable port for intermodal transfer to a barge.

One potential advantage of barge transport of spent fuel is a high payload capacity. A single barge can readily transport approximately six spent fuel rail casks, unless lock restrictions require a smaller barge size and payload. However, this high-payload capacity requires an adequate spent fuel supply to avoid partial loads, which would eliminate the cost advantages of barge transport. Since a relatively small quantity of spent fuel will be generated by western reactors, barge transport would require some combination of careful scheduling, storage areas for spent fuel accumulation awaiting barge pickup, and perhaps a milk-run approach in which a single barge would pick up spent fuel from multiple locations. Another factor influencing the cost competitiveness of barge versus rail transport is that a major fraction of the total distance traveled must be by barge to compensate for the additional handling costs for intermodal transfers near both ends of the journey.

Appendix A includes a summary of a study of barge transport. The scenario used barge transport from eastern reactors within a reasonable distance of a navigable waterway to an intermodal transfer point located at a Gulf Coast or Mississippi River port; rail shipments would be used from this port to the repository location. The study included not only the cost-effectiveness considerations mentioned above, but also considerations of comparative risks. The study results indicated that barge transport does not provide reductions in either occupational or nonoccupational radiation exposures in comparison to rail transport. Since this preliminary study was based on simplifyng assumptions that may be overly conservative, future barge studies will use more rigorous analysis techniques to improve comparability of analytical results for barge and rail transport.

In view of the foregoing discussions, barge transport of spent fuel from western reactors to the Hanford Site does not appear to have obvious advantages sufficient to outweigh the disadvantages. For that reason, barge transport to the Hanford Site has not been a topic of specific and detailed study. Additional studies of this barge transport option are expected to be conducted in support of future repository site selection.

5.2.2.5 Hanford Site defense high-level waste transportation impacts

The transportation impacts presented earlier in this section include those of transporting defense high-level waste from three current source locations to a repository at the Hanford Site. The Hanford Site is one of these source locations. For the projected impacts in this subsection, the transportation of Hanford Site defense high-level waste to a repository located at the Hanford Site has negligible impact due to the short transport distance and the lack of a non-occupationally exposed population.

5.2.3 EXPECTED EFFECTS ON SOCIOECONOMIC CONDITIONS

This section compares the work force requirements for the repository with the expected baseline conditions in the study region at the time of the projected start of construction on the repository. As shown in Figure 5-11, the expected effects in several categories of socioeconomic conditions are considered a joint product of the employment requirements of the repository and labor supply in the region. The difficult aspect of the analysis was to forecast a future baseline with respect to economic and demographic conditions in the region. Two uncertain aspects of this forecast are (1) the extent and duration of the employment decline triggered by the rampdown of the Washington Public Power Supply System nuclear project construction and (2) the sources and prospects for future economic recovery and growth in the region over the next three decades (see Section 3.6.2).

Baseline employment and population are estimated separately for the period through 1985 and from 1986 to 2010. Total employment and population were forecast to bottom out in 1984 and then resume a pattern of growth that would regain the 1981 peak level of employment and population again by 1989, under a high-growth forecast that assumes a restart in 1988 of Washington Public Power Supply System nuclear project WNP-1, which is currently mothballed. By mid-1984, the Washington Public Power Supply

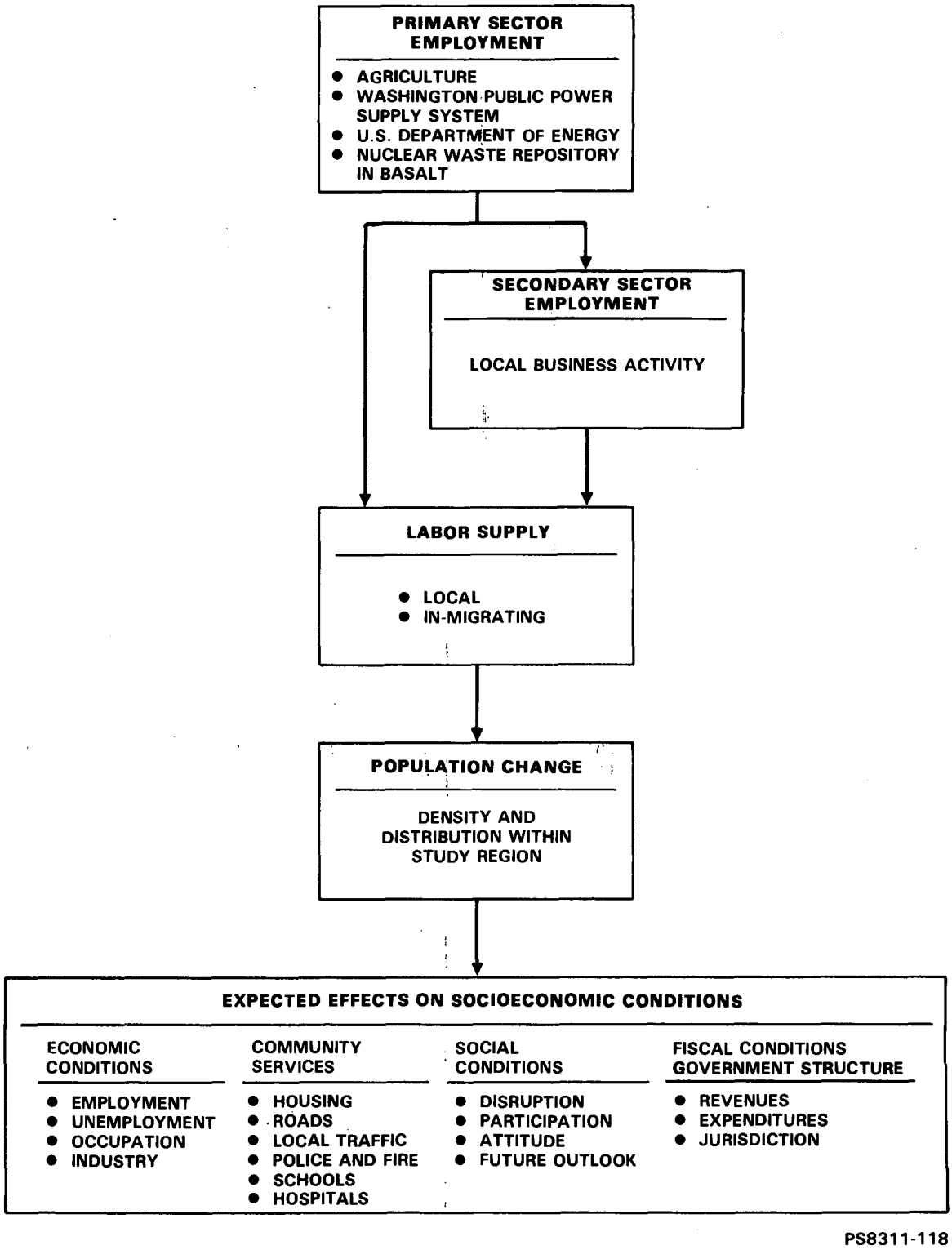

Figure 5-11. Socioeconomic impact assessment framework.

System work force in the study area had declined to approximately 1,750 workers; it has stabilized at a budgeted level of 1,700 workers through June 1986. This represents a loss of approximately 10,000 Washington Public Power Supply System jobs between 1981 and 1984 in Benton and Franklin Counties. Over the same period, the U.S. Department of Energy and agricultural employment is expected to increase by approximately 2,300 jobs, for a net loss of approximately 7,700 jobs in the primary sector. Recognizing that population multipliers observed during periods of increasing employment are not likely to be relevant during periods of declining employment, the following assumptions were made to generate population estimates between 1981 and 1985. It was assumed that 25 percent of the workers losing their jobs would leave the area and that the average family size of workers leaving the area would be three (Malhotra and Manninen, 1980). Based on these assumptions, the Benton and Franklin Counties study area could be expected to experience a 16-percent loss in employment accompanied by approximately a 6-percent loss in population declines during this period. These declines are equivalent to annual rates of decline of -4.5 and -1.6 percent, respectively, compared with rates of growth for the previous 4-year period of 7.8 and 5.3 percent. This is a significant loss of economic activity that would leave the area with excess absorptive capacity in housing and other public services through at least 1989, and possibly longer if the Washington Public Power Supply System nuclear project WNP-1 restart is delayed or terminated.

It is speculative to predict how the Benton and Franklin Counties study area will grow after 1985. However, it is likely that the economy in this region would continue to be primarily influenced by the Washington Public Power Supply System, U.S. Department of Energy, and agricultural employment requirements, as it was in the 1970's. Assumptions were made under the high forecast for each of these sectors that produce the employment and population forecasts shown in Figure 5-12 for the period 1986 to 2010. These include the following:

- Washington Public Power Supply System nuclear project WNP-1 will be restarted in 1988 and completed by 1993.
- U.S. Department of Energy and its contractor employment will grow at an average annual rate of 5 percent until 1991 and at 2 percent thereafter.
- Agricultural employment will grow at an average annual rate of 6 percent until 1991 and at 3 percent thereafter until 2010.

The assumption regarding the Washington Public Power Supply System nuclear project WNP-1 restart is based on internal studies. The U.S. Department of Energy-related employment growth is based on increased use of its Hanford site facilities and contractors for defense and energy research. A 6-percent growth rate in the agricultural sector is based on the possibility of another 0.2 million hectares (0.5 million acres) being brought under irrigation as a result of the proposed second phase of the Columbia

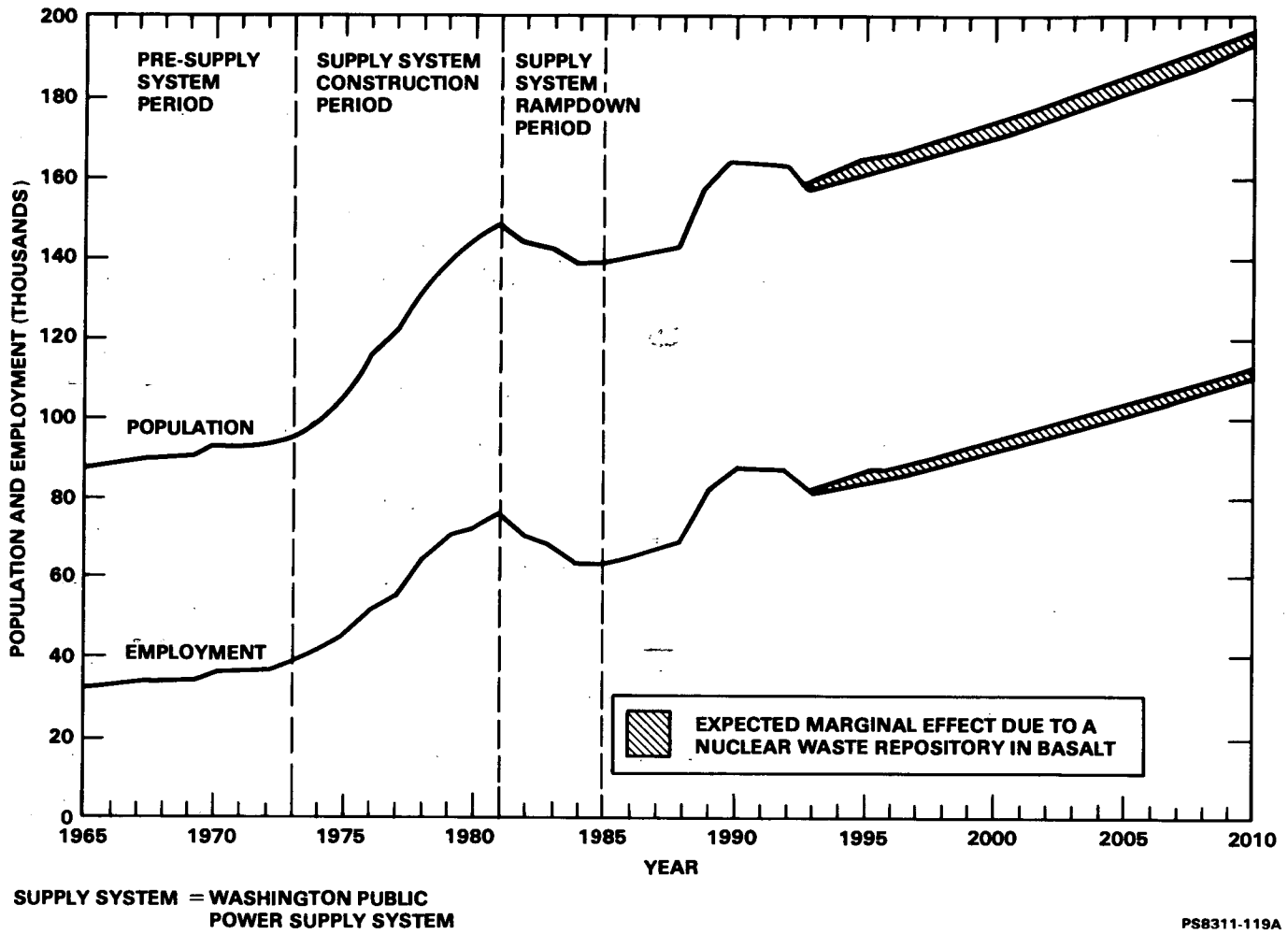

Figure 5-12. Employment and population projections in the study region.

7 0 1 6 8 1 0 1 2

Basin Irrigation Project. The projected growth in primary sector employment beyond 1985 is used to forecast the growth in secondary sector employment and total employment. A slow recovery in the regional economy in 1985 was caused by the reduction in primary sector employment experienced between 1981 and 1985. Taking this into account, it is assumed that from 1985 onward, increases in primary sector employment would have a smaller effect on total employment until the peak employment of 1981 is again achieved, and a larger effect thereafter (see Cluett et al., 1984, for a more detailed discussion of the procedures and assumptions used to derive the appropriate multipliers). After 1985, employment is forecast to grow at 1.5 percent per year and population at 1.0 percent per year. These rates are more consistent with the pre-Washington Public Power Supply System-growth phase than with the high rates of growth during Washington Public Power Supply System construction.

While lower growth scenarios can be assumed, and they may even be more plausible, the high scenario was selected because it brings the region closer to the capacity of its infrastructure. Work force and population growth due to construction and operation of the repository would be more likely to alter regional socioeconomic conditions under high-baseline-growth assumptions. If, under conservative conditions, impacts appear unlikely, then they could be said to be even less likely under any other plausible scenario.

The relevant aspects of the 1982 conceptual design (RKE/PB, 1983; see Section 5.1) to socioeconomic conditions include scheduling of project construction and operation, work force requirements, and resource requirements.

Work on the repository is projected to begin in approximately 1994 and last for approximately 90 years (through the backfill phase). This assessment focuses on the construction phase and the first few years of operations, during which time most of the work-force-related effects can be expected.

The construction work force is expected to peak in the fifth year at approximately 1,100 workers with an average of approximately 450 workers per year throughout the initial development phase. During operations, the work force would be more constant at an average level of approximately 815 workers per year. The work force level would tend to decline thereafter, especially during the last 50 years of the project. Very little information is currently available on the skill composition of the work force; however, it is assumed that between 20 and 30 percent of the total work force requirement would be miners. This is important for a socioeconomic assessment because miners are in short supply in the regional labor force and, therefore, a high proportion of them could be expected to in-migrate.

The development of a repository at the Hanford Site would clearly have additional effects that go beyond population changes. Constructing and operating a large, mined repository would involve the acquisition of

materials and supplies and would have an effect on the local economy. These resource requirements are not precisely specified at this time. They are indirectly accounted for in the following subsection as part of the secondary economic effects of the repository development activity.

5.2.3.1 Population density and distribution

The demographic effects of the repository are evaluated in terms of the total growth in regional population that is projected to be caused by the project. The maximum increase in population size over the base population caused by repository construction and operation is estimated to be 3,900, which assumes a higher proportion of in-migrants and a larger secondary response. This would be achieved by about 1995. Thereafter, the population effects of the project would decline with declining work force size requirements to approximately 2,900 above the base population in 1999 through 2010. These population estimates account for persons in-migrating to work directly on the repository, secondary employment growth caused by the project, and family dependents associated with both groups. They represent an upper bound estimate. If it is assumed that only 75 percent of all mining personnel in-migrate and 25 percent of all other personnel in-migrate, then a likely estimate of the peak population increase would be approximately 1,700 in 1995, declining to approximately 1,100 between 1999 and 2010. This analysis would assume the maximum estimate as a conservative approach to assessing potential impacts.

The repository-related peak population effect represents approximately 2.4 percent of the forecast baseline population expected to reside in the study region in 1995 under the high-growth scenario discussed earlier. The average repository-related population growth during this period is likely to be less than 2 percent of the baseline population (see Fig. 5-12). Since this population would be dispersed residentially throughout the Richland-Kennewick-Pasco, Washington, metropolitan area, and to a lesser degree to other communities within commuting distance, the effects on population density are expected to be negligible. This is substantiated by a review of the historical settlement patterns of the Basalt Waste Isolation Project employees. It was found that as of June 1985 approximately 92.5 percent of the employees are located within the study area. The work force distribution among the three major communities is Richland, the closest community in commuting distance to the Hanford Site, 52.2 percent; Kennewick, 25.6 percent; and Pasco, 3.7 percent. The distribution among the smaller cities is West Richland, Washington, 7.8 percent and Benton City, Washington, 3.2 percent. The increased population was estimated for high- and low-growth scenarios (i.e., assuming 3,900 and 1,700 new in-migrants). The in-migrants were distributed among the communities, using the Basalt Waste Isolation Project settlement patterns. The maximum high-growth scenario during the peak 1995 year would result in the following community growth rates: Richland, 5.5 percent; Kennewick, 2.6 percent; Pasco, 0.7 percent; West Richland, 7.2 percent; and Benton City, 5.4 percent. The most likely

estimated increased population growth would result in the following growth rates during the peak year: Richland, 2.4 percent; Kennewick, 1.1 percent; Pasco, 0.3 percent; West Richland, 3.2 percent; and Benton City, 2.4 percent.

The distribution of the remaining 7.5 percent estimated population increase among the communities outside the study area would result in less than a 1.5 percent increase over the 1980 population level of any community. Further, Section 3.6.1 discussed how population growth in the region historically has been concentrated around the largest existing communities. The process of annexation of residential land adjacent to urban core areas has helped maintain a fairly constant urban density in recent years. Future settlement of the new population that would be attracted to the region by the repository can be expected to follow a similar pattern, with most of the settlement occurring in or near the Tri-Cities. The relatively small numbers of in-migrants that are expected should not have a measurable effect on population density in this area. Since most of the new settlement is expected to be small and to take place in existing urban residential areas that have available housing, no adverse impacts on agricultural lands are likely. The overall effect on demographic conditions is small relative to the projected baseline and also compared with historical population changes experienced in the study region.

5.2.3.2 Economic conditions

The employment requirements of the proposed repository, compared with the availability of skilled workers in the study area, determine whether and how many new workers must in-migrate. Associated secondary employment effects (e.g., demand for locally available supplies and services) would result in even more workers moving into the area. These persons also may bring their family dependents. This population influx is responsible for the service demands and associated socioeconomic impacts that a project may cause. Income and living standards, major markets, business growth, and capital availability can largely be traced to changes in employment. An economic base approach is used to estimate the employment-based impacts of the proposed repository. Future economic, demographic, and social effects were forcast by examining the way in which rapid growth in employment affected population growth and community service demands.

In the Tri-Cities area, income and living standards are relatively high and the population is young and educated. A high proportion of the work force has construction and technological skills that are well suited to work at the Hanford Site, including repository development. The area has many of the attributes of a regional trade center with a well-developed, complex economy. The principal components of the economy are characterized in terms of major employers and industry categories (see Section 3.6.2). The proposed repository development is not expected to alter significantly these characteristics of the region. For example,

U.S. Department of Energy and agricultural employment are dependent on factors other than the proposed repository development. Growth in the agricultural sector is expected to continue in the future as new land comes under irrigation, and expectations of the U.S. Department of Energy employment growth are based on increased use of U.S. Department of Energy facilities and defense nuclear materials production and energy research.

The maximum repository-related increase in employment and population would be observed in the mid-1990's. At that time, the total employment in the region could increase by greater than 2,400 jobs, and the population in the region could increase by almost 3,900 persons. Thereafter, the repository-related employment would decline to approximately 1,200 jobs as the construction activity winds down. Secondary employment should remain relatively stable during the transition from the construction to the operations phase. During the operations phase, the repository could be expected to generate more than 1,800 direct and indirect jobs and increase population by nearly 2,800; although in reality, this number will be smaller since some portion of the jobs will be taken by persons already living in the study region. The expected marginal growth effects that the construction and operation of the repository would have on employment and population are illustrated in Figure 5-12. Table 5-23 shows in 5-year increments the projected baseline population in the study region (without the repository) between 1980 and 2010, the total potential impact of repository-related new population growth in the region (assuming all new jobs are filled by in-migrants), and an estimate of the more likely size of repository-related population in-migration.

Under the maximum growth scenario assumed for this analysis, the region is not projected to have excess resources or capacity after the mid-1990's. On the other hand, it is not projected to be overextended either. For the first time since the early 1980's, the region would be entering a phase of economic activity exceeding the levels it had reached in the past. Even though the region will have caught up with former levels of population and employment, the rate of growth would be considerably less than that caused by growth in the Washington Public Power Supply System construction activity (see Section 3.6.2). Also, during the early 1990's the projected restart of Washington Public Power Supply System nuclear project WNP-1 would be nearing completion as the repository would be starting construction. Many workers could then be available to start work on the repository. To account for the possibility that many repository-related jobs could be filled by workers already living in the study area, two alternative population growth scenarios were presented in Table 5-23; however, the more conservative approach with a higher proportion of in-migrants is taken in the analysis of potential impacts.

The repository-related employment and population peak growth rates are not projected to exceed 2.4 and 1.1 percent per year, respectively (see Table 5-23). The average annual growth rates computed from the proposed start of repository construction would be 1.4 and 0.8 percent per year, respectively.

Table 5-23. Projected baseline population and repository impact: 1990 to 2010

Year	Baseline population[b]	All repository-related jobs filled by in-migrants		Some repository related jobs filled by in-migrants[a]	
		Maximum population impact	Maximum increase (%) to baseline population	Likely population impact	Likely increase (%) to baseline population
1990	164,762	742	0.4	375	0.2
1995	160,956	3,890	2.4	1,735	1.1
2000	170,435	2,969	1.7	1,190	0.7
2005	181,127	2,826	1.6	1,111	0.6
2010	193,193	2,826	1.5	1,111	0.6

[a]Assumes 75 percent of mining jobs and 25 percent of nonmining jobs are taken by in-migrants.

[b]Projected for Benton and Franklin Counties without construction and operation of a repository; based on Cluett et al. (1984).

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During Washington Public Power Supply System construction from 1973 to 1978, Benton and Franklin Counties experienced an employment growth of 36,640 jobs, or 10.0 percent per year, and a population growth of 52,971 persons, or 6.3 percent per year. This implies an employment-based population multiplier of 1.4. Considering the relatively successful accommodation of the study area to those growth rates, it is not likely that the repository construction, under its current conceptualization and the baseline conditions forecast for the area, will lead to adverse socioeconomic impacts.

5.2.3.3 Community services

In-migrants moving into the region in the 1990's to work on the repository would find available services that were developed during the high-growth decade of the 1970's (see Section 3.6.3). Housing vacancies are expected to be higher in the 1990's than they were in the peak years of the early 1980's, provided that economic activity and population growth do not exceed the 1980 peak level. Road networks and other community support infrastructures, including health, schools, police, fire, water and sewer, and other community services are not expected to be at or very near capacity before the year 2000, due to the significant employment and population losses after 1981.

The potential effects the repository would have on community services were estimated by comparing a forecast of likely demand for the service due to the direct and indirect effects of the repository with estimates of the available supply of that service. Using housing as an example and assuming the baseline conditions discussed in Section 3.6.3, potential repository effects on regional housing availability can be estimated. At the beginning of the repository construction in the 1990's, population in the study region is expected to be somewhat below the 1981 level (just prior to the Washington Public Power Supply System rampdown phase). In 1981, there were an estimated 2,000 vacant dwelling units in the Tri-Cities alone (see Table 3-33), not including mobile homes and trailers. Even if conservative assumptions are made of no further growth in housing units in the Tri-Cities and of the removal of 50 percent of the excess housing due to dilapidation, this would leave an estimated 1,000 vacant units, plus the vacant housing in the remaining area of the counties and vacant mobile homes. Assuming there are three persons per household (Malhotra and Manninen, 1980), the estimated project-related population increase of 3,900 persons would require approximately 1,300 housing units. The excess requirement of 300 units could most likely be assumed to be available through mobile homes, trailers, and in other parts of the study area outside the Tri-Cities. Futhermore, it is probable that the housing capacity would be more than adequate for the project-related population increase due to several additional factors. In fact, housing continued to increase in the area even after the population decline began in 1981, which would imply an even greater number of vacant dwellings than were used for this estimate. Also, new building

undoubtedly would take place during the period of growth assumed between 1985 and 1990. In addition, if Washington Public Power Supply System nuclear project WNP-1 is undertaken, the calculation of a population increase of 3,900 is probably an overestimate. This is because part of the necessary primary and secondary work force would already be in the study area and available for the repository work force. Table 5-23 provides a more likely forecast of the population growth attributable to the direct and indirect effects of the repository, assuming a portion of the available jobs is taken by persons already living in the study region.

In addition to housing, traffic congestion is another major aspect of the Tri-Cities region that has been particularly sensitive to population increase and, in particular, to the traffic volume associated with activities on the Hanford site. Traffic volume has decreased since 1981 in conjunction with the decrease in Washington Public Power Supply System activities. Also, due to an increased emphasis on transportation planning, the traffic congestion situation has been improving in other ways apart from the decrease in construction activity and population. These improvements (e.g., better intersection design and completion of the Interstate 182 bridges across the Columbia and Yakima Rivers) (see Fig. 3-45) will serve to alleviate certain aspects of congestion that would otherwise have been anticipated as construction activity at the Hanford Site and population in the study area increased. The geographic setting of the metropolitan area, with the linear arrangement of the communities and the location along the Columbia River, will continue to contribute to some degree of traffic congestion. However, this congestion would be related directly to Hanford Site access and limited to times of peak commuting traffic. The staggering of shift hours and the increased use of mass transportation to the Hanford Site have been used to minimize commuter congestion and could be utilized in the future. Furthermore, the total amount of increased traffic to the Hanford Site in conjunction with the repository would be far lower than that associated with the traffic related to the Washington Public Power Supply System peak construction period.

Although the period of extraordinarily high growth experienced in the study area between 1973 and 1981 had put pressure on the utilities and services of the region, there do not appear to have been any substantial gaps in the services to the population. Section 3.6.3 discussed the current conditions in the major community services (see also Cluett et al., 1984; PSPL, 1981). None of these services is expected to be significantly impacted by the projected growth in employment and population due to the repository. Most community services would have excess capacity at the time of repository construction in 1990. In addition, the planning and development of increased capacity in community services often establishes a momentum that leads to facility expansion beyond the need dictated by current conditions. This appears to have occurred in the study area, particularly by the largely unexpected Washington Public Power Supply System cutbacks in 1981 (see Section 3.6.3). However, with declining population and economic activity, revenues would drop and operating budgets would need to be readjusted. As the region proceeds through the

projected decline and recovery phase, all the community services would be affected, including the staffing levels and space utilization requirements of health and social services, education, and public safety. However, given adequate lead time and notification regarding future development activities in the region, the affected departments and agencies are expected to adjust adequately to changing economic and population conditions.

5.2.3.4 Social conditions

During the last decade, a highly skilled labor force has settled permanently around the Hanford Site with confidence that continued growth and employment opportunity were virtually assured. The unexpected rampdown of the two major Washington Public Power Supply System nuclear projects in mid-1981 came as a shock to this area. While it is clear that a significant decline in employment and population has taken place in the interim, it also appears that many residents have not yet decided whether to stay or leave. This decision depends on a number of factors, including perceptions of employment opportunities elsewhere and the likelihood that this area will experience an ecomonic turnaround. No single major development has been identified that can replace the void created by the Washington Public Power Supply System rampdown, but slow, steady expansion of the U.S. Department of Energy activities and agricultural development is projected (see Fig. 5-12).

Viewed against this background, the repository development would be a relatively small but positive contributor to area recovery from the decline of the early 1980's. Whatever effects on social conditions the repository might cause, they would likely be on balance positive. If the repository occurs as an isolated Hanford Site activity, long-term beneficial effects are doubtful. However, the size of the expected in-migrating work force would be small enough, relative to the projected baseline population, that increases in social disruption (e.g., crime, family problems, mental health problems) due to the repository are unlikely.

One area of potential social concern is the likelihood of debate over the transportation of nuclear waste materials into the study region and related attention to local versus State concurrence rights. The Confederated Tribes and Bands of the Yakima Indian Nation, the Confederated Tribes of the Umatilla Indian Reservation, and the Nez Perce Indian Tribe are special interest groups that have expressed concern with regard to Hanford Site activities. They have been designated affected Indian Tribes by the U.S. Department of the Interior under the Nuclear Waste Policy Act of 1982 because of their off-reservation treaty fishing rights. Negotiations for a consultation and cooperation agreement have been initiated with the Yakimas and Umatillas and would be undertaken with the Nez Perce if they so desire.

People living in the study area are looking to the latter half of the 1980's and the 1990's for indications of economic viability. A slow but sustained recovery is projected for the area, and the proposed repository would serve as a stabilizing factor. Large construction projects such as the repository do not have to bring adverse socioeconomic impacts.

5.2.3.5 Fiscal conditions and government structures

As was the pattern during the high-growth period of the 1970's, it seems probable that the greater benefits of the growth associated with the repository would again accrue to Richland and Kennewick, Washington, and, to a lesser degree Pasco, Washington. However, the increased accessibility of Pasco, due to the Interstate 182 bridges, could make residential development in Pasco more desirable than it was previously and increase the share of new activity it would receive in the future. This would place a greater burden on Pasco to be administratively prepared to take advantage of the opportunity for greater revenues and to plan for meeting greater demands on or for facilities, infrastructures, and services.

The kinds of fiscal issues that could be important for assessing the potential for socioeconomic impacts focus largely on the balance between revenues and expenditures. The lag time between the receipt of revenues and the need for expenditures to maintain the quality of service also needs consideration. Revenues likely generated from the construction and operation of the repository would be derived directly and indirectly from expenditures for material resources and wages. The indirect economic or fiscal benefits that could be expected have been largely accounted for in the secondary employment growth in the region (see Section 3.6.5 and Cluett et al., 1984). Furthermore, U.S. Department of Energy contractors on the Hanford Site pay sales, use, and business and occupation taxes in accordance with the laws of the State of Washington. Special assistance also could be made available to compensate for the tax-exempt status of the Federal land on which the site would be located. Compensation also could be available for any project-induced school impacts. Aside from the usual role of the State with respect to the distribution of resources to local-level jurisdictions, the State would be the negotiating point for the U.S. Department of Energy with respect to financial assistance related to the construction and operation of the repository. This negotiating body is the Nuclear Waste Board of the State of Washington.

It is not possible to say what would be the result of the current economic downturn associated with the Washington Public Power Supply System rampdown. In general, in view of the record of fiscal adaptability in the Tri-Cities during the high-growth period in the 1970's, the less-steep-growth curve projected due to construction and operation of the repository would probably not create serious problems in management or financing for the area.

The Nuclear Waste Policy Act of 1982 provides financial assistance to States and affected Indian Tribes for participation in the repository-siting process. The following is a discussion of each specific provision in the Act that pertains to financial assistance to States and affected Indian Tribes.

Section 116(c)(1)(A) of the Act provides that the Secretary of the U.S. Department of Energy will make grants to each State with a potentially acceptable site within its boundaries and to Indian Tribes designated as affected by the U.S. Department of the Interior. The funds are granted for the purpose of consultation and cooperation in repository-siting decisions. The Act specifies that any salary or travel expense that would ordinarily be incurred by that State may not be funded. The Act provides that, for States in which a candidate site for a repository is approved and for affected Indian Tribes, the U.S. Department of Energy shall make grants only for the purpose of enabling the State to

- Review site-characterization activities to determine potential economic, social, public health and safety, and environmental impacts of a potential repository.
- Develop a request for impact mitigation funding that would be provided after repository construction is authorized.
- Engage in any monitoring, testing, or evaluation activities with respect to site-characterization programs at the site.
- Provide information regarding the site to residents of the State and Tribe.
- Request information from and make comments and recommendations to the U.S. Department of Energy regarding the repository-siting process.

Financial assistance to a State in which the U.S. Nuclear Regulatory Commission has authorized construction of a repository is provided in Section 116(c)(2)(A) of the Act. This financial assistance is designed to mitigate impacts of the development of a repository and payments will begin within 6 months after the U.S. Nuclear Regulatory Commission has granted a construction authorization.

Section 116(c)(2)(B) provides that, to be funded for impact mitigation, a State must submit a report on economic, social, public health and safety, and environmental impacts of a repository. This report is to be submitted after completion of site characterization and before the U.S. Department of Energy has recommended the site to the President for application for construction authorization. As soon as is practicable following the granting of a construction authorization, the U.S. Department of Energy will seek to enter into a binding agreement with the State. The agreement would set forth the amount of impact assistance funding and the procedures to be followed in providing such assistance.

In Sections 116(c)(3) and 118(b)(4), the Act provides for the U.S. Department of Energy to grant to the State and local government in which a site is approved for site characterization an amount each fiscal year equal to the amount they would receive were they authorized to tax site characterization, development, and operation of repository activities as they tax other industrial activities. These grants are commonly referred to as grants-equal-to-taxes. The Act provides that the U.S. Department of Energy will grant to an affected Indian Tribe on whose reservation construction of a repository is approved an amount equal to what they would receive if authorized to tax the repository as they tax other commercial activities.

While provisions for financial assistance to States and affected Indian Tribes are similar, the provisions for local governments are not as extensive. Except for the grants-equal-to-taxes provision discussed in the previous paragraph, local governments are not explicitly eligible for grants directly from the U.S. Department of Energy.

5.2.3.6 Land use, access, and surface and mineral rights

The predominant land use in the six-county region surrounding the Hanford Site is agricultural. If there are any problems in marketing the region's agricultural products due to locating a repository, the future land use in the region could be affected.

It is assumed that three conditions must be present to affect negatively consumer purchases of agricultural products grown near a repository: (1) The consumer must be able to identify clearly the product with the locality in which it was grown, (2) the consumer must be aware that a repository is located in the region where the product is grown, and (3) the consumer must identify the existence of a repository with a health hazard that is transmitted through the food chain.

Much of the agricultural production from the Hanford Site region is exported to western Washington, to other States, or abroad, and it is not clear how closely the exported products are identified with the Hanford Site region in the minds of most consumers. In addition, radioactive materials have been managed at the Hanford Site for the past 40 years with no apparent adverse impact on agricultural markets, even though there have been several well-publicized radioactive releases to the environment. While there may be some temporary impacts on agriculture due to the perception of consumers concerning a repository, the U.S. Department of Energy does not expect these impacts to be large or long lasting.

The reference repository location is within the Hanford Site, which is owned by the Federal Government and controlled by the U.S. Department of Energy. Through the site-screening process (see Section 2.2) the U.S. Department of Energy avoided areas on the Hanford Site in which the proposed repository would present a land-use conflict.

Access to the repository surface facilities would require the addition of less than 5 kilometers (3 miles) of new road (see Section 3.5.3). Site access would not interfere with other uses or security requirements on the Hanford Site; hence, no access impacts are projected.

As discussed in Section 3.4.1, lands designated for the reference repository location have been withdrawn from all forms of appropriation under the public land laws, including the mining and mineral leasing laws. The repository surface facilities would occupy a relatively small portion of the reference repository location and would be approximately 5 kilometers (3 miles) from State of Washington-leased lands and 3 kilometers (2 miles) from the Arid Lands Ecology Reserve (see Fig. 3-37). Also, the planned subsurface facility would not extend beneath any State of Washington-leased land. Therefore, the repository would not affect surface or mineral rights or present a land-use conflict.

Section 5.2.1 identifies potential effects on the physical environment due to repository construction and operation. Such activities are not expected to affect or conflict with current land use of any Federal- or State-protected areas. In an environmental impact statement issued by the U.S. Department of the Army in 1977 (DOA, 1979, pp. 67-109), no current or proposed activity on the Yakima Firing Center was identified that would significantly impact nuclear-related operations on the Hanford Site. These included assessments of land use, environmental, or socioeconomic impacts resulting from any current or proposed activity on the Yakima Firing Center.

5.3 OCCUPATIONAL SAFETY AND HEALTH RISKS

Mining safety hazards associated with repository construction, operation, and closure are discussed in Subsection 6.3.3.2 and summarized below. Potentially hazardous conditions that could affect personnel safety include the possibility of (1) excavated opening instabilities, (2) low-energy rock bursts, (3) water inflow under high pressure, (4) presence of methane, and (5) high rock temperature. Potentially hazardous conditions could be mitigated using existing technology and would not cause unusually high risks to personnel health and safety.

In any major construction or mining operation, injuries and fatalities could occur. While a design-specific analysis of expected injury and fatality rates cannot be performed at this time, a generic

analysis was reported in a final environmental impact statement (DOE, 1980). That analysis indicated (after adjusting the analysis for a 70,000-metric-ton (77,000-ton) capacity) that a repository constructed in basalt could have 40 disabling injuries and 1 fatality associated with surface facility construction. It was also estimated that 976 disabling injuries and 21 fatalities could occur due to underground mining operations. These rates were based on statistical analyses of past construction and underground mining operations (other than coal), and are believed to represent an upper limit for injuries and fatalities. Actual numbers of injuries and fatalities are expected to be lower due to compliance with U.S. Department of Energy regulations and other mitigation measures.

The U.S. Department of Energy would follow the safety and environmental requirements contained in DOE Orders 5480.1A and 5480.4 (DOE, 1981a, 1984a), including the construction of a second shaft worker for worker safety. The use of specific safety standards (i.e., Federal Mine Safety and Heath Act, Tunnel Safety Orders of the State of California, and Mine Safety Orders of the State of California) for mining and drifting operations is mandated in DOE Order 5480.1A (DOE, 1981a). Emergency response plans for the exploratory shaft program are in accordance with DOE Order 5500.3A (DOE, 1981c).

An emergency response plan is in place for the Hanford Site and is discussed in Subsection 6.2.1.2.5. Specific plans for repository activities will be developed as the repository design progresses.

Personnel safety associated with normal repository operations and abnormal and (or) accident conditions is discussed in Section 6.4.1. Under normal operating conditions, waste handling poses some potential for radiation exposure to personnel. Potential radiological hazards that could result from normal and abnormal repository operations are summarized in Subsection 6.4.1.4.

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