PNNL-6415 Rev. 11
UC-600

Pacific Northwest National Laboratory
Operated by Battelle for the
U.S. Department of Energy

Hanford Site National Environmental Policy Act (NEPA) Characterization

D. A. Neitzel, Editor

E. J. Antonio
C. J. Fosmire
R. A. Fowler
S. M. Goodwin
D. W. Harvey
P. L. Hendrickson
D. J. Hoitink
T. M. Poston
A. C. Rohay
P. D. Thorne
M. K. Wright

September 1999

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

PNNL-6415 Rev.11

DISCLAIMER

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RLO 1830

Printed in the United States of America

Available to DOE and DOE contractors from the Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831; prices available from (615) 576-8401.

Available to the public from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161

PNNL-6415 Rev. 11
UC-600

Hanford Site
National Environmental Policy Act (NEPA) Characterization

D. A. Neitzel, Editor

E. J. Antonio
C. J. Fosmire
R. A. Fowler
S. M. Goodwin
D. W. Harvey
P. L. Hendrickson
D. J. Hoitink
T. M. Poston
A. C. Rohay
P. D. Thorne
M. K. Wright

September 1999

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest National Laboratory
Richland, Washington 99352

Preface

This document describes the U.S. Department of Energy's (DOE) Hanford Site environment. It is updated each year and is intended to provide a consistent description of the Hanford Site environment for the many NEPA documents being prepared by DOE contractors. No conclusions or recommendations are provided. This year's report is the eleventh revision of the original document published in 1988 and is (until replaced by the 12th revision) the only version that is relevant for use in the preparation of Hanford NEPA, SEPA and CERCLA documents.

The two chapters included in this document (Chapters 4 and 6) are numbered to correspond to the chapters where such information is presented in environmental impact statements (EISs) and other Site-related NEPA or CERCLA documentation. Chapter 4.0 (Affected Environment) describes Hanford Site climate and meteorology, geology, hydrology, ecology, cultural, archaeological and historical resources, socioeconomics, occupational safety, and noise.

Sources for extensive tabular data related to these topics are provided in the chapter. Most subjects are divided into a general description of the characteristics of the Hanford Site, followed by site-specific information, where available, of the 100, 200, 300, and other Areas. This division allows the reader to go directly to those sections of particular interest. When specific information on each of these separate areas is not complete or available, the general Hanford Site description should be used.

Chapter 6.0 (Statutory and Regulatory Requirements) is essentially a definitive NEPA Chapter 6.0, which describes applicable federal and state laws and regulations, DOE directives and permits, and environmental standards directly applicable to the NEPA documents on the Hanford Site. People preparing environmental assessments and EISs should also be cognizant of the document entitled *Recommendations for the Preparation of Environmental Assessments and Environmental Impact Statements* published by the DOE Office of NEPA Oversight.[a]

Pacific Northwest National Laboratory (PNNL) staff prepared individual sections of this document, with input from other Site contractors. More detailed data are available from reference sources cited or from the authors. The following sections of the document were reviewed by the authors and updated with the best available information through June 1999:

- Climate and Meteorology
- Ecology
- Cultural, Archaeological, and Historical Resources
- Socioeconomics
- All of Chapter 6.

Remaining sections were last revised in 1998. A new section, Occupational Safety, authored by E.J. Antonio with the assistance of Tracy Ikenberry, Dade Moeller & Associates, was added to this revision.

---

[a] U.S. Department of Energy (DOE). 1993. *Recommendations for the Preparation of Environmental Assessments and Environmental Impact Statements.* U.S. Department of Energy, Office of NEPA Oversight, Washington, DC.

Any interested individual seeking baseline data on the Hanford Site and its past activities may also use this information by which to evaluate projected activities and their impacts. The following personnel are responsible for the various sections of this document and can be contacted with questions:

Document Editor	D. A. Neitzel	(509) 376-0602	duane.neitzel@pnl.gov
Climate/Meteorology	D. J. Hoitink	(509) 372-6414	dana.j.hoitink@pnl.gov
Air Quality	C. J. Fosmire	(509) 372-6314	Christian.Fosmire@pnl.gov
Geology	S. M. Goodwin A. C. Rohay	(509) 376-8704 (509) 376-6925	shannon.goodwin@pnl.gov alan.rohay@pnl.gov
Hydrology	P. D. Thorne	(509) 372-4482	paul.thorne@pnl.gov
Ecology	T. M. Poston	(509) 376-5678	ted.poston@pnl.gov
Cultural, Archaeological and Historical Resources	M. K. Wright D. W. Harvey	(509) 372-1079 (509) 373-2945	mona.wright@pnl.gov david.harvey@pnl.gov
Socioeconomics	R. A. Fowler	(509) 372-4332	richard.fowler@pnl.gov
Noise	T. M. Poston	(509) 376-5678	ted.poston@pnl.gov
Occupation Safety	E. J. Antonio	(509) 375-3809	E.Antonio@pnl.gov
Statutory and Regulatory Requirements	P. L. Hendrickson	(509) 372-4294	paul.hendrickson@pnl.gov

The suggested citation for this document is Neitzel, D. A. (Ed.). 1999. *Hanford Site National Environmental Policy Act (NEPA) Characterization*. PNL-6415, Rev. 11, Pacific Northwest National Laboratory, Richland, Washington.

To enhance the usability of the document, a copy is available, upon request, from Duane A. Neitzel at (509) 376-0602. The document is also available electronically at http://www.hanford.gov.

Acknowledgements

As the editor of Revision 11, I hope you find this document useful in preparing Hanford Site NEPA documents or as a useful source of information about the Hanford environment. Many people are responsible for the years of work that went into preparing this description of the Hanford Site. Authors of individual sections of this document took great care to accurately describe their work. As the editor I thank them.

To prepare this eleventh revision of the Hanford Site NEPA characterization someone had to contact all the individual section authors, send revised sections out for review, revise, and reassemble the document. I thank J. P. Duncan and A. L. Bunn for all their help in seeing these tasks were completed. J. P. Duncan also maintains the electronic copy of the document throughout the year.

I also thank C. E. Cushing, retired from Pacific Northwest National Laboratory (PNNL), for all his past efforts and contributions to this document.

D. A. Neitzel

[This Page Intentionally Left Blank]

Acronyms

AEA	Atomic Energy Act
ALE	Fitzner/Eberhardt Arid Lands Ecology
ARPA	Archaeological Resources Protection Act
BCCAA	Benton County Clean Air Authority
BCRFD	Benton County Rural Fire Department
BHI	Bechtel Hanford, Inc.
BNSF	Burlington Northern Santa Fe
BPA	Bonneville Power Administration
BWIP	Basalt Waste Isolation Project
CAA	Clean Air Act
CBC	Columbia Basin College
CEQ	Council on Environmental Quality
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CLUP	Comprehensive Land Use Plan
Corps	U.S. Army Corps of Engineers
CWA	Clean Water Act
DART	Data Acquisition in Real Time
dB	decibels
dBA	A-weighted sound level
DCG	Derived Concentration Guides
DOE	U.S. Department of Energy
DOE-RL	U.S. Department of Energy, Richland Operations Office
DOH	Washington Department of Health
DOI	Department of Interior
DWS	drinking water standards
Ecology	Washington State Department of Ecology
EDNA	environmental designation for noise abatement
EIS	Environmental Impact Statement
EN	Energy Northwest
ENCO	Enterprise Companies
E.O.	Executive Order
EPA	U.S. Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FFCA	Federal Facilities Compliance Act
FFTF	Fast Flux Test Facility
FR	Federal Register
FY	fiscal year
Hz	Hertz
HCRL	Hanford Cultural Resources Laboratory
HEHF	Hanford Environmental Health Foundation
HMS	Hanford Meteorological Station
HRA-EIS	Hanford Remedial Action Environmental Impact Statement
L_{eq}	equivalent sound level
LERF	Liquid Effluent Retention Facility
LLWPA	Low-Level Radioactive Waste Policy Act

MCL	Maximum Contaminant Level
MMI	Modified Mercalli Intensity
NAAQS	national ambient air quality standards
National Register	The National Register of Historic Places
NEPA	National Environmental Policy Act
NESHAP	National Emission Standards for Hazardous Air Pollutant
NHPA	National Historic Preservation Act
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NPPC	Northwest Power Planning Council
NPR	New Production Reactor
NPS	National Park Service
NRC	U.S. Nuclear Regulatory Commission
NWPA	Nuclear Waste Policy Act
OFM	Office of Financial Management
OSHA	Occupational Safety and Health Administration
PCBs	polychlorinated biphenyls
PHMC	Project Hanford Management Contract
$PM_{2.5}$	Particulate Matter (2.5 micrometers or less)
PM_{10}	Particulate Matter (10 micrometers or less)
PNNL	Pacific Northwest National Laboratory
PSD	Prevention of Significant Deterioration
PUREX	Plutonium-Uranium Extraction
RCRA	Resource Conservation and Recovery Act
RCW	Revised Code of Washington
RM	River Mile
ROD	Record of Decision
SARA	Superfund Amendments and Reauthorization Act
SDWA	Safe Drinking Water Act
SEPA	State (of Washington) Environmental Policy Act
SIP	state implementation plans
SR	State Route
State Register	State Register of Historic Places
Supply System	Washington Public Power Supply System
TCP	Traditional Cultural Place
TEDF	Treated Effluent Disposal Facility
Tri-Party Agreement	Hanford Federal Facility Agreement and Consent Order
Tri-Cities	Kennewick, Pasco, and Richland
TRIDEC	Tri-Cities Economic Development Council
TSCA	Toxic Substances Control Act
TSP	total suspended particulates
USC	United States Code
UO_3	Uranium Trioxide
VOC	volatile organic compounds
WAC	Washington Administrative Code
WDF	Washington Department of Fisheries
WHC	Westinghouse Hanford Company
WSR	Washington State Register
WSU-TC	Washington State University, Tri Cities
YN	Yakama Nation
$\overline{X}/Q'$	atmospheric diffusion factors

Contents

[This Page Intentionally Left Blank]

Figures

Tables

4.0 Affected Environment

The U.S. Department of Energy (DOE) Hanford Site lies within the semiarid Pasco Basin of the Columbia Plateau in southeastern Washington State (Figure 4.0-1). The Hanford Site occupies an area of about 1450 km^2 (about 560 mi^2) north of the confluence of the Yakima River with the Columbia River. The Hanford Site is about 50 km (30 mi) north to south and 40 km (24 mi) east to west. This land, with restricted public access, provides a buffer for the smaller areas currently used for storage of nuclear materials, waste storage, and waste disposal; only about 6% of the land area has been disturbed and is actively used. The Columbia River flows through the northern part of the Hanford Site and, turning south, forms part of the Site's eastern boundary. The Yakima River runs near the southern boundary of the Hanford Site and joins the Columbia River at the city of Richland, which bounds the Hanford Site on the southeast. Rattlesnake Mountain, Yakima Ridge, and Umtanum Ridge form the southwestern and western boundaries. The Saddle Mountains form the northern boundary of the Hanford Site. Two small east-west ridges, Gable Butte and Gable Mountain, rise above the plateau of the central part of the Hanford Site. Adjoining lands to the west, north, and east are principally range and agricultural land. The cities of Kennewick, Pasco, and Richland (the Tri-Cities) constitute the nearest population centers and are located southeast of the Hanford Site.

The Hanford Site encompasses more than 1500 waste management units and groundwater contamination plumes that have been grouped into 62 operable units. Each unit has complementary characteristics of such parameters as geography, waste content, type of facility, and relationship of contaminant plumes. This grouping into operable units allows for economies of scale to reduce the cost and number of characterization investigations and remedial actions that will be required for the Hanford Site to complete environmental clean-up efforts (WHC 1989). The 62 operable units have been aggregated into four areas: 22 in the 100 Area (17 source, 5 groundwater), 33 in the 200 Areas (29 source and 4 groundwater), 3 in the 300 Area (2 source and 1 groundwater), and 4 in the 1100 Area[a]. The 1100 Area operable units were de-listed from the National Priorities List in 1996. Those persons contemplating National Environmental Policy Act (NEPA)-related activities on the Hanford Site should be aware of the existence and location of the various operable units. Current maps showing the locations of the operable units can be obtained from the environmental restoration contractor.

4.1 Climate and Meteorology

D. J. Hoitink and C. J. Fosmire

The Hanford Site is located in a semiarid region of southeastern Washington State. The Cascade Mountains, beyond Yakima to the west, greatly influence the climate of the Hanford area by means of their "rain shadow" effect. This mountain range also serves as a source of cold air drainage, which has a considerable effect on the wind regime on the Hanford Site.

Climatological data are available from the Hanford Meteorological Station (HMS), which is located between the 200 East and 200 West Areas. Data have been collected at this location since 1945, and a summary of these data through 1998 has been published by Hoitink et al. (1999).

[a] Source: Personal communication with L. Dietz, BHI, August 1999.

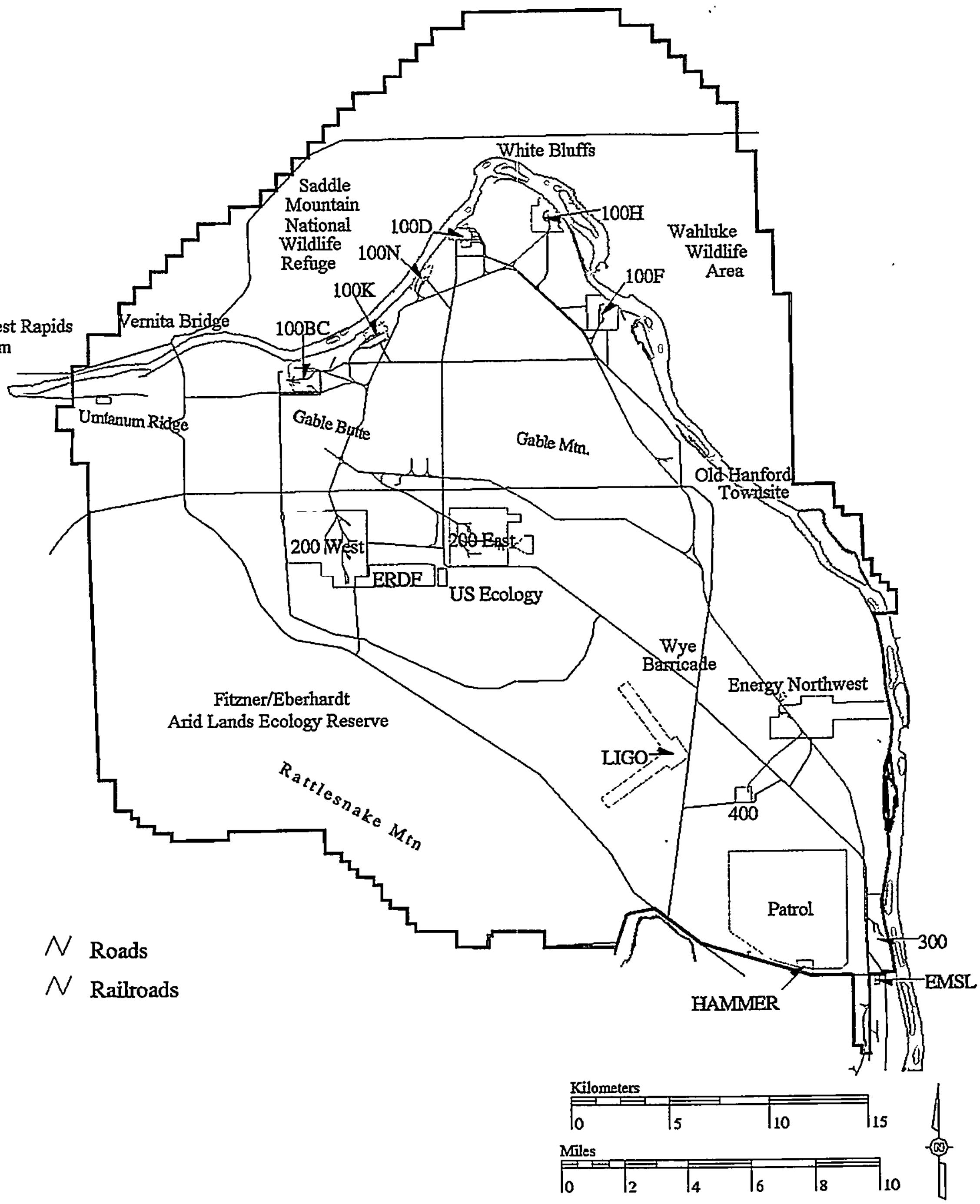


Figure 4.0-1. DOE's Hanford Site.

Data from the HMS are representative of the general climatic conditions for the region and describe the specific climate of the 200 Area Plateau. Local variations in the topography of the Hanford Site may cause some aspects of climate at portions of the Hanford Site to differ significantly from those of the HMS. For example, winds near the Columbia River are different from those at the HMS. Similarly, precipitation along the slopes of the Rattlesnake Hills differs from that at the HMS.

4.1.1 Wind

Wind data are collected at the HMS at the surface (2.1-m [~7-ft] above ground) and at the 15.2-, 61.0-, and 121.9-m (50-, 200-, and 400-ft) levels of the 125-m (410-ft) HMS tower. Three 60-m (200-ft) towers, with wind-measuring instrumentation at the 10-, 25-, and 60-m (33-, 82-, and 200-ft) levels, are located at the 300, 400, and 100-N Areas. In addition, wind instruments on 26 9.1-m (30-ft) towers distributed on and around the Hanford Site (Figure 4.1-1) provide supplementary data for defining wind patterns. Instrumentation on each of the towers is described in Table 4.1-1. Stations 8W and 19S are no longer active.

Prevailing wind directions on the 200 Area Plateau are from the northwest in all months of the year (Figure 4.1-2). Secondary maxima occur for southwesterly winds. Summaries of wind direction indicate that winds from the northwest quadrant occur most often during the winter and summer. 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 for the HMS are reported in Hoitink et al. (1999). Monthly average wind speeds are lowest during the winter months, averaging 10- to 11-km/h (6- to 7-mi/h), and highest during the summer, averaging 13- to 15-km/h (8- to 9-mi/h). Wind speeds that are well above average are usually associated with southwesterly winds. However, the summertime drainage winds are generally northwesterly and frequently reach 50-km/h (30-mi/h). These winds are most prevalent over the northern portion of the Hanford Site.

4.1.2 Temperature and Humidity

Temperature measurements are made at the 0.9-, 9.1-, 15.2-, 30.5-, 61.0-, 76.2-, 91.4-, and 121.9-m (3-, 30-, 50-, 100-, 200-, 250-, 300-, and 400-ft) levels of the 125-m (410-ft) tower at the HMS. Temperatures are also measured at the 2-m (~6.5-ft) level on the twenty-six 9.1-m (30-ft) towers located on and around the Hanford Site. The three 60-m (200-ft) towers have temperature-measuring instrumentation at the 2-, 10-, and 60-m (~6.5-, 33-, and 200-ft) levels.

Monthly averages and extremes of temperature, dew point, and humidity are contained in Hoitink et al. (1999). Ranges of daily maximum temperatures vary from normal maxima of 2°C (35°F) in late December and early January to 35°C (95°F) in late July. There are, on the average, 52 days during the summer months with maximum temperatures ≥32°C (90°F) and 12 days with maxima greater than or equal to 38°C (100°F). From mid-November through early March, minimum temperatures average ≤0°C (32°F), with the minima in late December and early January averaging -6°C (21°F). During the winter, there are, on average, 3 days with minimum temperatures ≤–18°C (~0°F); however, only about one winter in two experiences such temperatures. The record maximum temperature is 45°C (113°F), and the record minimum

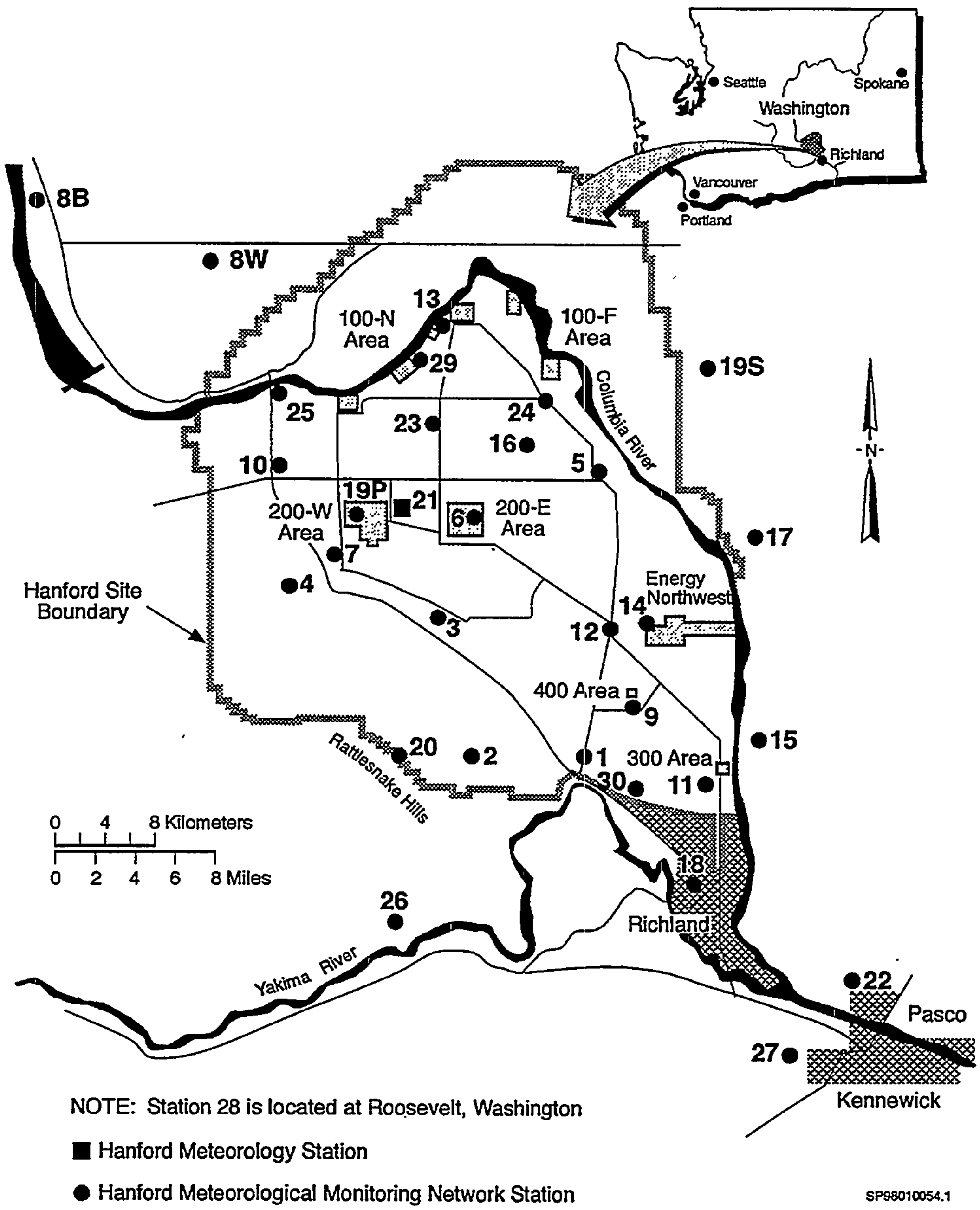


Figure 4.1-1. Hanford Meteorological Monitoring Network.

Table 4.1-1. Station Numbers, Names, and Instrumentation for each Hanford Meteorological Monitoring Network Site.

Site Number	Site Name	Instrumentation
1	Prosser Barricade	WS, WD, T, P
2	EOC	WS, WD, T, P
3	Army Loop Road	WS, WD, T, P
4	Rattlesnake Springs	WS, WD, T, P
5	Edna	WS, WD, T
6	200 East Area	WS, WD, T, P, AP
7	200 West Area	WS, WD, T, P
8B	Beverly	WS, WD, T, P
8W[a]	Wahluke Slope	WS, WD, T, P
9	FFTF (60 m)	WD, T, TD, DP, P, AP
10	Yakima Barricade	WS, WD, T, P, AP
11	300 Area (60 m)	WS, WD, T, TD, DP, P, AP
12	Wye Barricade	WS, WD, T, P
13	100-N Area (60 m)	WS, WD, T, TD, DP, P, AP
14	Energy Northwest (Supply System)	WS, WD, T, P
15	Franklin County	WS, WD, T
16	Gable Mountain	WS, WD, T
17	Ringold	WS, WD, T, P
18	Richland Airport	WS, WD, T, AP
19P	Plutonium Finishing Plant	WS, WD, T, AP
19S[a]	Sagehill	WS, WD, T
20	Rattlesnake Mountain	WS, WD, T, P
21	Hanford Meteorology Station (125 m)	WS, WD, T, P, AP
22	Tri-Cities Airport	WS, WD, T, P
23	Gable West	WS, WD, T
24	100-F Area	WS, WD, T, P
25	Vernita Bridge	WS, WD, T
26	Benton City	WS, WD, T, P
27	Vista	WS, WD, T, P
28[b]	Roosevelt, Washington	WS, WD, T, P, AP
29	100-K Area	WS, WD, T, P, AP
30	HAMMER	WS, WD, T

Legend:
- WS - Wind Speed
- WD - Wind Direction
- T - Temperature
- TD - Temperature Difference
- DP - Dewpoint Temperature
- P - Precipitation
- AP - Atmospheric Pressure

[a] Station no longer active.
[b] Roosevelt is located on the Columbia River west/southwest of the Site.

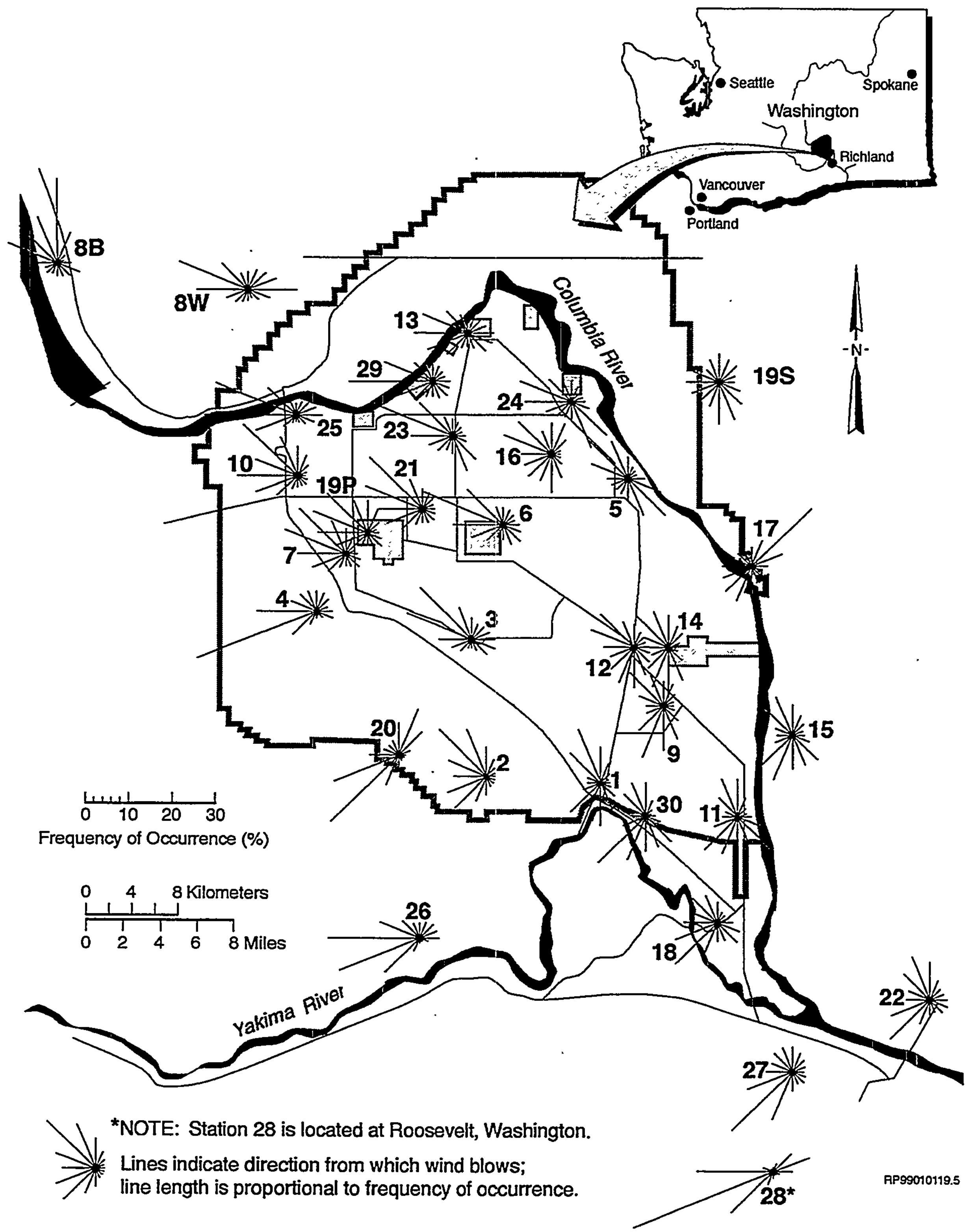


Figure 4.1-2. Wind Roses at the 10-m Level of the Hanford Meteorological Monitoring Network, 1982 to 1998.

temperature is -31°C (-23°F). Maximum temperatures reaching 45°C (113°F) can be expected only once every 100 years, and minimum temperatures reaching -31°C (-24°F) can also be expected once every 100 years. For the period 1946 through 1998, the average monthly temperatures range from a low of -0.9°C (30°F) in January to a high of 24.6°C (76°F) in July. The highest winter monthly average temperature at the HMS was 6.9°C (44°F) in February 1958, while the record lowest temperature was -11.1°C (12°F) during January 1950. The record maximum summer monthly average temperature was 27.9°C (82°F) in July 1985, while the record lowest temperature was 17.2°C (63°F) in June 1953.

Relative humidity/dew point temperature measurements are made at the HMS and at the three 60-m (200-ft) tower locations. The annual average relative humidity at the HMS is 54%. It is highest during the winter months, averaging about 75%, and lowest during the summer, averaging about 35%. Wet bulb temperatures >24°C (75°F) had not been observed at the HMS before 1975; however, on July 8, 9, and 10 of that year, there were seven hourly observations with wet bulb temperatures ≥24°C (75°F).

4.1.3 Precipitation

Precipitation measurements have been made at the HMS since 1945. Average annual precipitation at the HMS is 16 cm (6.3 in.). In the wettest year on record, 1995, 31.3 cm (12.3 in.) of precipitation was measured; in the driest year, 1976, only 7.6 cm (3 in.) was measured. The wettest season on record was the winter of 1996-1997 with 14.1 cm (5.4 in.) of precipitation; the driest season was the summer of 1973 when only 0.1 cm (0.03 in.) of precipitation was measured. Most precipitation occurs during the late autumn and winter, with more than half of the annual amount occurring from November through February. Days with >1.3 cm (0.50 in.) precipitation occur on average less than one time each year. Rainfall intensities of 1.3 cm/h (0.50 in./h) persisting for 1 hour are expected once every 50 years.

Winter monthly average snowfall ranges from 0.8 cm (0.32 in.) in March to 13.7 cm (5 in.) in December. The record monthly snowfall of 60 cm (23.4 in.) occurred in January 1950. The seasonal record snowfall of 142 cm (56 in.) occurred during the winter of 1992-1993. Seasonal snowfall totals of 142 cm (56 in.) are expected once every 200 years. Snowfall accounts for about 38% of all precipitation from December through February.

4.1.4 Fog and Visibility

Fog has been recorded during every month of the year at the HMS; however, 89% of the occurrences are from November through February, with less than 3% from April through September (Table 4.1-2). The average number of days per year with fog (visibility ≤9.6 km [6 mi]) is 47, while those with dense fog (visibility ≤0.4 km [0.25 mi]), is 25. The greatest number of days with fog was 84 days in 1985-1986, and the least was 22 in 1948-1949; the greatest number of days with dense fog was 42 days in 1950-1951, and the least was 9 days in 1948-1949. The greatest persistence of fog was 114 hours (December 1985), and the greatest persistence of dense fog was 47 hours (December 1957).

Other phenomena causing restrictions to visibility (i.e., visibility ≤9.6 km [6 mi]) include dust, blowing dust, and smoke from field burning. There are few such days; an average of 5 d/yr have dust or blowing dust and <1 d/yr has reduced visibility from smoke.

Table 4.1-2. Number of Days with Fog by Season.

Category	Winter	Spring	Summer	Autumn	Total
Fog	32	3	≤2	12	47
Dense fog	17	1	≤2	7	25

4.1.5 Severe Weather

High winds are associated with thunderstorms. The average occurrence of thunderstorms is 10 per year. They are most frequent during the summer; however, they have occurred in every month. The average winds during thunderstorms come from no specific direction. Estimates of the extreme winds, based on peak gusts, are given in Hoitink et al. (1999) and are shown in Table 4.1-3. Using the National Weather Service criteria for classifying a thunderstorm as "severe" (i.e., hail with a diameter ≥20 mm [1 in.] or wind gusts of ≥93 km/h [58 mi/h]), only 1.9% of all thunderstorm events surveyed at the HMS have been "severe" storms, and all met the criteria based on wind gusts.

Table 4.1-3. Estimates of Extreme Winds at the Hanford Site.

	Peak Gusts (km/h)	
Return Period (yr)	15.2 m Above Ground	61 m Above Ground
2	97	109
10	114	130
100	136	155
1000	157	181

Tornadoes are infrequent and generally small in the northwest portion of the United States. Grazulis (1984) lists no violent tornadoes for the region surrounding Hanford (DOE 1987). The HMS climatological summary (Stone et al. 1983) and the National Severe Storms Forecast Center database list 22 separate tornado occurrences within 161 km (100 mi) of the Hanford Site from 1916 through August 1982. On June 16, 1948, a tornado was observed near the east end of Rattlesnake Mountain (about 10 miles south of the HMS). Funnel clouds (not reaching the ground) were observed on March 24, 1961 (estimated 10 to 15 miles south-southwest of the HMS) and July 15, 1970 (about 10 miles south-southwest of the HMS on the north slope of Rattlesnake Mountain). Two additional tornadoes have been reported since August 1982. Generally, the tornadoes that have occurred within the region have been small and caused no major damage. No violent tornadoes (category F4 and F5 with wind speeds in excess of 207 mph) have been reported in northeast Oregon or southeast Washington.

Using the information in the preceding paragraph and the statistics published in Ramsdell and Andrews (1986) for the 5° block centered at 117.5° west longitude and 47.5° north latitude (the area in which the Hanford Site is located), the expected path length of a tornado on the Hanford Site is 7.6 km (5 mi), the expected width is 95 m (312 ft), and the expected area is about 1.5 km^2 (1 mi^2). The estimated probability of a tornado striking a point at Hanford, also from Ramsdell and Andrews (1986), is 9.6 x 10^{-6}/yr. The probabilities of extreme winds associated with tornadoes striking a point can be estimated using the distribution of tornado intensities for the region. These probability estimates are given in Table 4.1-4.

Table 4.1-4. Estimate of the Probability of Extreme Winds Associated with Tornadoes Striking a Point at Hanford (Ramsdell and Andrews 1986).

Wind Speed (km/h)	Probability Per Year
100	2.6 x 10^{-6}
200	6.5 x 10^{-7}
300	1.6 x 10^{-7}
400	3.9 x 10^{-8}

4.1.6 Atmospheric Dispersion

Atmospheric dispersion (the transport and diffusion of gases and particles within the atmosphere) is a function of wind speed, duration and direction of wind, intensity of atmospheric turbulence (wind motions at very small time scales that act to disperse gas and particles rather than transporting them downwind), and mixing depth. Often, the atmospheric turbulence cannot be measured directly and is estimated by the atmospheric stability. Atmospheric stability describes the thermal stratification or vertical temperature structure of the atmosphere. The more unstable the atmosphere, the more atmospheric turbulence is generated. When the atmosphere is considered to be unstable or neutral, i.e., the winds are moderate to strong, and the mixing depth is deep, conditions are favorable for dispersion.

These conditions are most common in the summer when neutral and unstable stratification exists, about 56% of the time (Stone et al. 1983). Less favorable dispersion conditions may occur when the wind speed is light and the mixing layer is shallow. These conditions are most common during the winter when moderately to extremely stable stratification exists, about 66% of the time (Stone et al. 1983). Less favorable conditions also occur periodically for surface and low-level releases in all seasons from about sunset to about an hour after sunrise as a result of ground-based temperature inversions and shallow mixing layers. Occasionally, there are extended periods of poor dispersion conditions associated with stagnant air in stationary high-pressure systems that occur primarily during the winter months (Stone et al. 1983).

Stone et al. (1972) estimated the probability of extended periods of poor dispersion conditions. The probability of an inversion, once established, persisting more than 12 hours varies from a low of about 10% in May and June to a high of about 64% in September and

October. These probabilities decrease rapidly for durations of >12 hours. Table 4.1-5 summarizes the probabilities associated with extended surface-based inversions.

Many dispersion models use joint frequency distribution of atmospheric stability, wind speed, and wind direction to compute diffusion factors for both chronic and acute releases. Tables 4.1-6 through 4.1-13 present joint frequency distribution of atmospheric stability, wind speed, and wind direction for measurements taken at the 100-N, 200 East (200 Areas), 300 and 400 Areas at two different heights (10-m and 61-m [33-ft and 200-ft]). The values presented in the joint frequency distributions are a percentage of the time that the wind is blowing toward the direction listed (e.g., S, SSW, SW). For each station, the joint frequency distributions were determined using local wind data measured at the 10-m (33-ft) towers and the HMS atmospheric stability data. For the 61-m (200-ft) joint frequency distributions, wind speed was estimated assuming the wind speed profile was represented by a power law. A more detailed description of the procedures used to develop the joint frequency distributions are found in Appendix H.1 of the *Recommended Environmental Dose Calculation Methods and Hanford-Specific Parameters* (Schreckhise et al. 1993).

Tables 4.1-14 through 4.1-20 present the annual sector-average atmospheric diffusion factors ($\overline{X}/Q\rho$) and Tables 4.1-21 through 4.1-29 present the 95% centerline atmospheric diffusion factor (E/Q) for the four major Hanford Areas (100-N Area, 200 Areas, 300 Area, and the 400 Area). For each area except the 400 Area, atmospheric diffusion factors are for a ground-level release and a release at 60 m (197 ft). For the 400 area, the diffusion factors are for a ground-level release and a release at 30 m (98 ft). These diffusion factors are presented as a function of direction and distance from the release point and were calculated using the GENII code (Napier et al. 1988) based on meteorological measurements averaged over the years 1983 through 1991.

Table 4.1-5. Percent Probabilities for Extended Periods of Surface-Based Inversions (based on data from Stone et al. 1972).

	Inversion duration		
Months	12 hr	24 hr	48 hr
January-February	54.0	2.5	0.28
March-April	50.0	<0.1	<0.1
May-June	10.0	<0.1	<0.1
July-August	18.0	<0.1	<0.1
September-October	64.0	0.11	<0.1
November-December	50.0	1.2	0.13

Table 4.1-6. Joint frequency distributions for the 100 Areas 10 m tower, 1983-1996 data (Hoitink and Burk 1997).

Average Wind Speed	Atmospheric Stability Class	Percentage of Time Wind Blows from the 100N Area Toward the Direction Indicated															
		S	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE
0.89	a	0.28	0.19	0.17	0.16	0.22	0.2	0.17	0.12	0.12	0.12	0.15	0.19	0.26	0.31	0.37	0.33
	b	0.11	0.08	0.1	0.08	0.11	0.14	0.11	0.07	0.06	0.06	0.08	0.1	0.12	0.13	0.17	0.14
	c	0.11	0.09	0.09	0.1	0.1	0.13	0.11	0.08	0.08	0.07	0.08	0.1	0.11	0.13	0.13	0.13
	d	0.51	0.42	0.45	0.54	0.82	1	0.82	0.65	0.59	0.55	0.6	0.66	0.75	0.73	0.69	0.59
	e	0.48	0.43	0.51	0.61	0.84	0.86	0.71	0.54	0.5	0.47	0.58	0.68	0.75	0.77	0.67	0.55
	f	0.45	0.4	0.54	0.61	0.77	0.66	0.51	0.34	0.31	0.33	0.48	0.69	0.79	0.83	0.7	0.57
	g	0.21	0.19	0.23	0.28	0.31	0.23	0.18	0.13	0.12	0.13	0.24	0.37	0.51	0.47	0.4	0.29
2.65	a	0.45	0.48	0.36	0.15	0.23	0.31	0.27	0.17	0.13	0.14	0.32	0.47	0.51	0.47	0.45	0.45
	b	0.14	0.16	0.11	0.06	0.11	0.13	0.13	0.09	0.05	0.04	0.12	0.18	0.2	0.14	0.15	0.12
	c	0.1	0.12	0.1	0.06	0.09	0.12	0.11	0.07	0.04	0.04	0.1	0.15	0.17	0.12	0.11	0.12
	d	0.4	0.46	0.4	0.38	0.53	0.7	0.75	0.41	0.3	0.33	0.56	1.01	0.98	0.76	0.52	0.42
	e	0.22	0.23	0.31	0.51	0.7	0.72	0.64	0.36	0.26	0.28	0.64	1.39	1.54	0.9	0.48	0.25
	f	0.13	0.14	0.2	0.51	0.71	0.49	0.3	0.16	0.11	0.15	0.34	0.8	0.92	0.56	0.31	0.15
	g	0.03	0.05	0.09	0.23	0.27	0.16	0.09	0.04	0.04	0.05	0.15	0.36	0.46	0.23	0.08	0.04
4.7	a	0.09	0.27	0.18	0.04	0.06	0.08	0.11	0.05	0.05	0.08	0.28	0.3	0.35	0.36	0.17	0.08
	b	0.02	0.07	0.06	0.02	0.02	0.02	0.04	0.02	0.02	0.02	0.07	0.08	0.11	0.1	0.04	0.03
	c	0.03	0.05	0.04	0.02	0.02	0.03	0.05	0.03	0.01	0.03	0.07	0.05	0.09	0.08	0.04	0.02
	d	0.14	0.21	0.16	0.07	0.07	0.14	0.3	0.15	0.09	0.17	0.34	0.53	0.83	0.64	0.22	0.14
	e	0.09	0.12	0.08	0.06	0.06	0.07	0.25	0.14	0.1	0.13	0.29	0.82	1.47	0.95	0.2	0.08
	f	0.06	0.07	0.04	0.05	0.04	0.04	0.08	0.04	0.02	0.02	0.07	0.27	0.24	0.14	0.05	0.04
	g	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0	0	0.02	0.06	0.03	0.02	0.01	0.01
7.15	a	0.04	0.1	0.08	0.01	0	0.01	0.03	0.02	0.01	0.04	0.21	0.15	0.23	0.36	0.18	0.03
	b	0.02	0.04	0.02	0	0	0	0.01	0.01	0.01	0.01	0.07	0.03	0.06	0.1	0.05	0
	c	0.01	0.02	0.02	0	0	0	0.01	0.01	0.01	0.01	0.05	0.03	0.05	0.07	0.03	0.01
	d	0.05	0.1	0.06	0.02	0.01	0.01	0.05	0.05	0.05	0.1	0.28	0.19	0.38	0.7	0.26	0.05
	e	0.04	0.09	0.05	0.02	0	0.01	0.02	0.02	0.02	0.06	0.13	0.15	0.47	0.67	0.15	0.03
	f	0.01	0.04	0.01	0	0	0	0	0	0	0	0.01	0.03	0.04	0.03	0.01	0.02
	g	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0
9.8	a	0	0.02	0.03	0.01	0	0	0	0	0	0.01	0.07	0.05	0.07	0.17	0.11	0
	b	0	0.01	0.01	0	0	0	0	0	0	0.01	0.03	0.02	0.02	0.05	0.03	0
	c	0	0.01	0.01	0	0	0	0	0	0	0.01	0.02	0.01	0.01	0.05	0.03	0
	d	0.02	0.04	0.03	0.01	0	0	0	0.01	0.01	0.06	0.11	0.06	0.08	0.25	0.15	0.01
	e	0.02	0.02	0.03	0.01	0	0	0	0	0.01	0.03	0.05	0.02	0.04	0.15	0.07	0.01
	f	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12.7	a	0	0	0	0	0	0	0	0	0	0	0.02	0.01	0.01	0.05	0.04	0
	b	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0.02	0.01	0
	c	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0.01	0	0
	d	0	0.02	0.01	0	0	0	0	0	0	0.03	0.03	0.02	0.02	0.06	0.02	0.01
	e	0	0.01	0.03	0	0	0	0	0	0	0.02	0.02	0	0	0.02	0.02	0
	f	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15.6	a	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	b	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	d	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0
	e	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	f	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	a	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	b	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	d	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	e	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0
	f	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.1-7. Joint Frequency Distributions for the 100-N Area 61 m Tower, 1983-1996 Data (Hoitink and Burk 1997).

Average Wind Speed	Atmospheric Stability Class	Percentage of Time Wind Blows from the 100N Area Toward the Direction Indicated															
		S	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE
0.89	a	0.23	0.22	0.17	0.16	0.2	0.21	0.18	0.14	0.11	0.1	0.12	0.12	0.17	0.22	0.24	0.26
	b	0.13	0.1	0.09	0.08	0.1	0.14	0.09	0.06	0.06	0.06	0.06	0.08	0.1	0.09	0.12	0.11
	c	0.11	0.1	0.07	0.07	0.11	0.11	0.11	0.07	0.06	0.06	0.07	0.08	0.1	0.1	0.09	0.11
	d	0.51	0.43	0.41	0.45	0.66	0.76	0.65	0.5	0.43	0.37	0.36	0.47	0.52	0.54	0.5	0.48
	e	0.4	0.36	0.43	0.52	0.67	0.62	0.56	0.42	0.33	0.29	0.33	0.36	0.48	0.43	0.37	0.34
	f	0.32	0.34	0.47	0.61	0.82	0.69	0.55	0.36	0.25	0.23	0.24	0.24	0.29	0.35	0.35	0.3
	g	0.17	0.16	0.24	0.35	0.49	0.38	0.21	0.15	0.12	0.1	0.1	0.11	0.15	0.18	0.2	0.17
2.65	a	0.44	0.5	0.3	0.13	0.19	0.29	0.25	0.19	0.12	0.11	0.21	0.37	0.39	0.28	0.27	0.29
	b	0.15	0.19	0.1	0.06	0.12	0.12	0.15	0.09	0.05	0.05	0.1	0.14	0.17	0.13	0.11	0.09
	c	0.11	0.15	0.11	0.05	0.11	0.13	0.11	0.08	0.05	0.05	0.08	0.13	0.15	0.12	0.09	0.09
	d	0.5	0.51	0.42	0.34	0.53	0.65	0.79	0.43	0.31	0.23	0.37	0.54	0.75	0.65	0.46	0.35
	e	0.29	0.33	0.3	0.42	0.68	0.73	0.63	0.38	0.25	0.19	0.26	0.43	0.76	0.9	0.59	0.29
	f	0.26	0.24	0.22	0.46	0.89	0.77	0.49	0.24	0.14	0.1	0.14	0.22	0.49	0.7	0.45	0.23
	g	0.11	0.09	0.13	0.23	0.43	0.35	0.18	0.07	0.05	0.04	0.06	0.06	0.16	0.28	0.23	0.14
4.7	a	0.12	0.29	0.18	0.05	0.06	0.1	0.11	0.06	0.05	0.06	0.19	0.22	0.31	0.24	0.13	0.08
	b	0.05	0.1	0.05	0.02	0.02	0.03	0.05	0.04	0.03	0.03	0.08	0.08	0.12	0.1	0.04	0.03
	c	0.03	0.08	0.05	0.03	0.02	0.04	0.05	0.03	0.01	0.02	0.06	0.06	0.1	0.07	0.03	0.04
	d	0.22	0.29	0.19	0.1	0.1	0.18	0.37	0.17	0.12	0.12	0.23	0.29	0.51	0.41	0.2	0.18
	e	0.18	0.2	0.17	0.14	0.17	0.21	0.4	0.2	0.15	0.15	0.24	0.37	1.04	1.03	0.32	0.17
	f	0.13	0.12	0.08	0.11	0.14	0.16	0.22	0.12	0.05	0.05	0.05	0.14	0.42	0.57	0.19	0.1
	g	0.03	0.04	0.03	0.03	0.05	0.06	0.06	0.02	0.02	0.02	0.02	0.04	0.08	0.14	0.09	0.04
7.15	a	0.06	0.17	0.09	0.03	0.02	0.03	0.05	0.03	0.02	0.04	0.2	0.17	0.26	0.31	0.1	0.03
	b	0.03	0.05	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.05	0.05	0.06	0.08	0.04	0.02
	c	0.03	0.02	0.01	0.01	0	0.02	0.03	0.02	0.01	0.02	0.05	0.03	0.06	0.08	0.02	0.01
	d	0.12	0.15	0.09	0.05	0.05	0.05	0.14	0.11	0.08	0.12	0.23	0.2	0.5	0.7	0.24	0.07
	e	0.1	0.14	0.1	0.07	0.04	0.06	0.16	0.13	0.08	0.1	0.2	0.26	1.26	1.67	0.24	0.06
	f	0.08	0.1	0.05	0.05	0.04	0.04	0.09	0.05	0.03	0.02	0.03	0.07	0.31	0.28	0.06	0.03
	g	0.02	0.02	0	0.01	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.04	0.05	0.02	0.01
9.8	a	0.06	0.08	0.05	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.11	0.09	0.15	0.29	0.12	0.02
	b	0.03	0.02	0.01	0	0	0.01	0.01	0	0.01	0.01	0.05	0.02	0.04	0.08	0.05	0.01
	c	0.01	0.02	0.01	0	0.01	0.01	0	0	0.01	0.01	0.03	0.04	0.02	0.06	0.03	0.01
	d	0.09	0.1	0.07	0.03	0.03	0.03	0.06	0.05	0.04	0.07	0.16	0.14	0.31	0.68	0.25	0.03
	e	0.05	0.08	0.07	0.03	0.03	0.03	0.04	0.04	0.03	0.06	0.1	0.1	0.47	0.97	0.17	0.03
	f	0.04	0.05	0.03	0.02	0.03	0.02	0.02	0.01	0.01	0	0.01	0.01	0.09	0.08	0.02	0.01
	g	0	0	0	0	0.01	0.01	0	0	0	0	0	0	0.01	0.02	0	0
12.7	a	0.01	0.03	0.03	0	0	0	0	0	0	0.01	0.04	0.04	0.05	0.12	0.1	0
	b	0.01	0.01	0.01	0	0	0	0	0	0	0	0.02	0.01	0.02	0.04	0.02	0
	c	0.01	0.01	0.01	0	0	0	0	0	0	0.01	0.02	0.01	0.01	0.03	0.02	0
	d	0.04	0.06	0.04	0.02	0.01	0.01	0.02	0.02	0.01	0.06	0.1	0.07	0.11	0.32	0.14	0.02
	e	0.03	0.06	0.06	0.01	0.01	0.01	0.01	0.02	0.01	0.03	0.05	0.04	0.12	0.29	0.09	0.02
	f	0.01	0.02	0	0	0.01	0.01	0	0	0	0	0	0	0.02	0.02	0	0
	g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15.6	a	0	0	0	0	0	0	0	0	0	0	0.01	0.01	0.01	0.04	0.01	0
	b	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0.01	0
	c	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0.01	0	0
	d	0.01	0.01	0.01	0	0	0	0	0	0	0.03	0.05	0.03	0.03	0.06	0.02	0
	e	0.01	0.02	0.02	0	0	0	0	0	0	0.02	0.02	0.01	0.01	0.05	0.03	0.01
	f	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	a	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0
	b	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	d	0	0	0	0	0	0	0	0	0	0.03	0.01	0	0.01	0.01	0	0
	e	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0.02	0.01	0
	f	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.1-8. Joint Frequency Distributions for the 200 Areas 10 m Tower, 1983-1996 Data (Hoitink and Burk 1997).

Average Wind Speed	Atmospheric Stability Class	Percentage of Time Wind Blows from the 200 Area Toward the Direction Indicated															
		S	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE
0.89	a	0.28	0.31	0.34	0.25	0.23	0.22	0.18	0.13	0.11	0.1	0.08	0.07	0.1	0.1	0.16	0.21
	b	0.14	0.15	0.16	0.11	0.11	0.09	0.08	0.05	0.05	0.04	0.04	0.04	0.05	0.07	0.09	0.12
	c	0.15	0.15	0.14	0.1	0.09	0.09	0.09	0.06	0.04	0.04	0.05	0.05	0.06	0.07	0.1	0.13
	d	0.87	0.76	0.72	0.55	0.6	0.65	0.64	0.42	0.36	0.31	0.35	0.38	0.49	0.59	0.77	0.83
	e	0.4	0.29	0.27	0.26	0.3	0.35	0.46	0.41	0.36	0.35	0.44	0.49	0.55	0.66	0.65	0.57
	f	0.25	0.16	0.15	0.15	0.15	0.2	0.25	0.24	0.26	0.29	0.35	0.36	0.43	0.45	0.42	0.33
	g	0.1	0.09	0.1	0.07	0.08	0.08	0.1	0.1	0.1	0.1	0.14	0.11	0.14	0.15	0.17	0.15
2.65	a	0.64	0.45	0.35	0.32	0.35	0.37	0.34	0.23	0.17	0.2	0.27	0.2	0.17	0.26	0.6	0.7
	b	0.26	0.17	0.11	0.1	0.1	0.12	0.1	0.07	0.06	0.06	0.09	0.07	0.07	0.14	0.29	0.31
	c	0.22	0.13	0.1	0.08	0.08	0.09	0.1	0.05	0.05	0.05	0.06	0.06	0.06	0.1	0.25	0.28
	d	0.64	0.46	0.3	0.27	0.31	0.36	0.43	0.29	0.23	0.24	0.3	0.39	0.55	1.05	1.72	1.12
	e	0.29	0.16	0.11	0.1	0.21	0.28	0.35	0.41	0.31	0.29	0.53	0.98	1.68	2.09	1.71	0.77
	f	0.15	0.07	0.05	0.06	0.09	0.11	0.3	0.33	0.31	0.37	0.65	1.23	1.74	1.89	1.57	0.59
	g	0.04	0.03	0.02	0.02	0.04	0.04	0.13	0.18	0.19	0.2	0.32	0.65	0.68	0.78	0.69	0.19
4.7	a	0.19	0.22	0.11	0.04	0.04	0.03	0.04	0.04	0.05	0.13	0.31	0.36	0.21	0.23	0.61	0.3
	b	0.04	0.04	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.04	0.06	0.1	0.08	0.09	0.22	0.09
	c	0.04	0.03	0.02	0.01	0	0	0.01	0.01	0.02	0.04	0.05	0.08	0.07	0.08	0.2	0.09
	d	0.14	0.13	0.06	0.04	0.05	0.04	0.07	0.09	0.11	0.19	0.34	0.52	0.57	1.11	1.45	0.37
	e	0.07	0.06	0.04	0.02	0.02	0.02	0.06	0.1	0.11	0.15	0.37	0.66	1.09	1.95	1.78	0.25
	f	0.02	0.01	0.01	0.01	0.01	0.01	0.04	0.09	0.04	0.03	0.08	0.3	0.33	0.53	0.72	0.11
	g	0	0	0	0	0	0	0.02	0.04	0.01	0.02	0.04	0.18	0.1	0.16	0.32	0.03
7.15	a	0.03	0.06	0.04	0.01	0	0	0.01	0.01	0.02	0.06	0.23	0.33	0.15	0.17	0.44	0.11
	b	0.01	0.01	0.01	0	0	0	0	0	0.01	0.03	0.06	0.08	0.03	0.05	0.12	0.02
	c	0.01	0.01	0.01	0	0	0	0	0	0.01	0.02	0.04	0.07	0.03	0.03	0.08	0.02
	d	0.03	0.05	0.03	0.01	0	0	0.01	0.03	0.06	0.16	0.38	0.35	0.24	0.6	0.85	0.11
	e	0.01	0.05	0.02	0	0	0	0	0.02	0.05	0.11	0.25	0.23	0.15	0.47	0.93	0.06
	f	0	0	0	0	0	0	0	0.01	0	0	0.01	0.02	0.01	0.01	0.02	0
	g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9.8	a	0	0.01	0.01	0	0	0	0	0	0	0.02	0.08	0.11	0.04	0.02	0.15	0.02
	b	0	0.01	0	0	0	0	0	0	0	0.01	0.03	0.03	0.01	0.01	0.04	0
	c	0	0	0	0	0	0	0	0	0	0.01	0.02	0.01	0.01	0.01	0.03	0
	d	0.01	0.02	0	0.01	0	0	0	0	0.01	0.08	0.16	0.09	0.03	0.11	0.26	0.02
	e	0	0.02	0.01	0	0	0	0	0	0.01	0.05	0.07	0.04	0.01	0.05	0.18	0.01
	f	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0
	g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12.7	a	0	0	0	0	0	0	0	0	0	0	0.01	0.02	0	0	0.01	0
	b	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0
	c	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0
	d	0	0	0	0	0	0	0	0	0	0.03	0.04	0.02	0.01	0.01	0.01	0
	e	0	0	0	0	0	0	0	0	0	0.02	0.01	0.01	0	0	0.01	0
	f	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15.6	a	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	b	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	d	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	e	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	f	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	a	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	b	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	d	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	e	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	f	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.1-9. Joint Frequency Distributions for the 200 Areas 61 m Tower, 1983-1996 Data (Hoitink and Burk 1997).

Average Wind Speed	Atmospheric Stability Class	Percentage of Time Wind Blows from the 200 Area Toward the Direction Indicated															
		S	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE
0.89	a	0.11	0.13	0.15	0.11	0.11	0.12	0.07	0.05	0.03	0.02	0.04	0.03	0.05	0.03	0.05	0.07
	b	0.09	0.09	0.08	0.07	0.07	0.06	0.06	0.03	0.02	0.03	0.02	0.02	0.02	0.03	0.05	0.07
	c	0.09	0.08	0.1	0.08	0.07	0.06	0.06	0.04	0.02	0.02	0.02	0.02	0.03	0.04	0.04	0.08
	d	0.58	0.53	0.51	0.43	0.45	0.49	0.52	0.35	0.24	0.22	0.22	0.2	0.27	0.35	0.44	0.54
	e	0.29	0.22	0.2	0.18	0.22	0.28	0.32	0.25	0.18	0.17	0.17	0.17	0.23	0.25	0.31	0.32
	f	0.2	0.13	0.12	0.11	0.14	0.14	0.19	0.14	0.13	0.12	0.13	0.12	0.17	0.19	0.23	0.21
	g	0.07	0.05	0.05	0.05	0.06	0.07	0.1	0.07	0.07	0.06	0.08	0.09	0.09	0.11	0.12	0.1
2.65	a	0.61	0.5	0.46	0.41	0.43	0.41	0.43	0.3	0.2	0.18	0.18	0.17	0.12	0.16	0.43	0.58
	b	0.25	0.2	0.16	0.12	0.14	0.13	0.12	0.1	0.07	0.06	0.07	0.05	0.06	0.09	0.22	0.27
	c	0.23	0.16	0.13	0.09	0.1	0.1	0.12	0.07	0.05	0.06	0.06	0.05	0.04	0.08	0.21	0.28
	d	0.79	0.56	0.39	0.32	0.39	0.37	0.5	0.34	0.22	0.23	0.24	0.25	0.35	0.63	1.29	1.1
	e	0.37	0.23	0.18	0.16	0.22	0.23	0.34	0.34	0.18	0.18	0.25	0.34	0.5	0.8	0.95	0.66
	f	0.28	0.13	0.11	0.08	0.1	0.12	0.22	0.23	0.18	0.17	0.23	0.3	0.53	0.79	0.81	0.6
	g	0.09	0.05	0.04	0.03	0.04	0.03	0.08	0.11	0.1	0.1	0.13	0.19	0.33	0.41	0.32	0.23
4.7	a	0.32	0.29	0.18	0.08	0.08	0.06	0.09	0.09	0.09	0.15	0.28	0.27	0.14	0.19	0.64	0.41
	b	0.09	0.08	0.04	0.03	0.03	0.02	0.02	0.03	0.03	0.04	0.08	0.09	0.05	0.09	0.28	0.15
	c	0.06	0.05	0.03	0.02	0.02	0.01	0.02	0.02	0.02	0.04	0.05	0.07	0.05	0.07	0.21	0.13
	d	0.2	0.16	0.09	0.06	0.08	0.08	0.13	0.14	0.12	0.16	0.26	0.31	0.31	0.83	1.55	0.48
	e	0.21	0.1	0.09	0.06	0.09	0.08	0.15	0.21	0.13	0.15	0.27	0.54	0.95	1.72	1.52	0.45
	f	0.14	0.06	0.04	0.02	0.04	0.03	0.09	0.2	0.08	0.06	0.15	0.35	0.78	1.34	1.41	0.49
	g	0.04	0.01	0	0	0	0	0.03	0.05	0.03	0.03	0.06	0.15	0.33	0.47	0.64	0.27
7.15	a	0.05	0.11	0.07	0.02	0.01	0	0.01	0.02	0.02	0.09	0.29	0.37	0.15	0.16	0.48	0.11
	b	0.02	0.02	0.02	0.01	0	0	0	0.01	0.01	0.03	0.05	0.09	0.04	0.06	0.14	0.03
	c	0.01	0.01	0.01	0	0	0	0	0.01	0.01	0.03	0.05	0.07	0.04	0.05	0.12	0.02
	d	0.06	0.08	0.04	0.02	0.01	0.01	0.04	0.08	0.08	0.17	0.34	0.46	0.39	0.85	1.18	0.15
	e	0.07	0.05	0.04	0.02	0.02	0.01	0.05	0.1	0.09	0.14	0.31	0.64	0.9	2.11	1.71	0.15
	f	0.04	0.03	0.03	0.01	0.01	0	0.03	0.08	0.03	0.03	0.06	0.23	0.39	0.88	1.3	0.15
	g	0	0	0	0	0	0	0.02	0.04	0.01	0	0.01	0.05	0.08	0.2	0.61	0.1
9.8	a	0.01	0.03	0.04	0.01	0	0	0	0	0.01	0.03	0.16	0.21	0.06	0.1	0.31	0.03
	b	0	0.01	0	0	0	0	0	0	0	0.01	0.05	0.05	0.01	0.03	0.08	0.01
	c	0	0	0	0	0	0	0	0	0	0.01	0.04	0.04	0.02	0.03	0.05	0.01
	d	0.02	0.03	0.02	0.01	0	0	0	0.02	0.04	0.11	0.29	0.28	0.15	0.51	0.68	0.04
	e	0.02	0.04	0.02	0	0	0	0.01	0.02	0.04	0.09	0.24	0.28	0.2	0.78	1.04	0.03
	f	0	0	0	0	0	0	0	0.01	0.01	0	0.02	0.03	0.04	0.08	0.19	0.01
	g	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0.03	0.08	0
12.7	a	0	0	0.01	0	0	0	0	0	0	0.02	0.09	0.1	0.02	0.02	0.16	0.01
	b	0	0.01	0	0	0	0	0	0	0	0.01	0.04	0.03	0.01	0.01	0.05	0
	c	0	0	0	0	0	0	0	0	0	0.01	0.02	0.02	0	0.01	0.04	0
	d	0.01	0.02	0.01	0.01	0	0	0	0.01	0.01	0.1	0.23	0.12	0.04	0.24	0.48	0.01
	e	0	0.02	0.01	0	0	0	0	0	0.02	0.07	0.13	0.08	0.04	0.19	0.39	0
	f	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0
	g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15.6	a	0	0	0	0	0	0	0	0	0	0	0.02	0.02	0	0	0.02	0
	b	0	0	0	0	0	0	0	0	0	0	0.01	0.01	0	0	0.01	0
	c	0	0	0	0	0	0	0	0	0	0	0.01	0.01	0	0	0.01	0
	d	0	0	0	0	0	0	0	0	0	0.04	0.08	0.03	0.01	0.03	0.06	0
	e	0	0	0	0	0	0	0	0	0	0.03	0.04	0.01	0.01	0.03	0.05	0
	f	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	a	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	b	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	d	0	0	0	0	0	0	0	0	0	0.01	0.03	0.01	0	0	0	0
	e	0	0	0	0	0	0	0	0	0	0.01	0.01	0	0	0	0	0
	f	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.1-10. Joint Frequency Distributions for the 300 Area 10 m Tower, 1983-1996 Data (Hoitink and Burk 1997).

Average Wind Speed	Atmospheric Stability Class	Percentage of Time Wind Blows from the 300 Area Toward the Direction Indicated															
		S	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE
0.89	a	0.08	0.06	0.08	0.1	0.11	0.11	0.12	0.11	0.08	0.06	0.05	0.04	0.03	0.03	0.06	0.07
	b	0.06	0.05	0.03	0.04	0.06	0.05	0.07	0.05	0.04	0.03	0.04	0.04	0.03	0.03	0.04	0.06
	c	0.05	0.03	0.04	0.04	0.05	0.06	0.07	0.06	0.04	0.03	0.02	0.03	0.03	0.02	0.04	0.05
	d	0.35	0.21	0.17	0.17	0.22	0.37	0.4	0.43	0.38	0.36	0.37	0.3	0.3	0.28	0.42	0.49
	e	0.34	0.18	0.13	0.13	0.19	0.34	0.51	0.56	0.57	0.46	0.46	0.4	0.44	0.47	0.54	0.49
	f	0.26	0.16	0.12	0.08	0.15	0.26	0.48	0.51	0.51	0.37	0.37	0.32	0.32	0.4	0.48	0.45
	g	0.17	0.08	0.04	0.04	0.08	0.11	0.2	0.22	0.21	0.16	0.17	0.14	0.15	0.18	0.25	0.23
2.65	a	0.23	0.3	0.39	0.41	0.55	0.56	0.53	0.27	0.21	0.26	0.26	0.16	0.08	0.05	0.08	0.19
	b	0.13	0.15	0.13	0.15	0.19	0.21	0.26	0.15	0.11	0.13	0.11	0.06	0.03	0.03	0.04	0.11
	c	0.13	0.13	0.11	0.12	0.15	0.19	0.24	0.13	0.11	0.12	0.11	0.05	0.02	0.03	0.06	0.12
	d	0.99	0.53	0.32	0.34	0.57	1	1.34	0.73	0.66	0.67	0.56	0.37	0.23	0.24	0.61	1.2
	e	1.07	0.34	0.09	0.1	0.25	1.07	1.77	1.06	1.06	0.76	0.61	0.45	0.35	0.42	0.69	1.22
	f	0.65	0.15	0.03	0.02	0.1	0.92	1.82	0.97	0.66	0.42	0.25	0.14	0.14	0.18	0.42	0.81
	g	0.29	0.05	0.01	0	0.03	0.33	0.8	0.4	0.22	0.12	0.07	0.04	0.04	0.06	0.19	0.37
4.7	a	0.27	0.52	0.35	0.09	0.11	0.21	0.27	0.13	0.19	0.47	0.58	0.29	0.08	0.06	0.09	0.14
	b	0.11	0.16	0.08	0.03	0.03	0.08	0.09	0.05	0.09	0.22	0.23	0.11	0.04	0.02	0.04	0.08
	c	0.11	0.14	0.08	0.03	0.02	0.06	0.1	0.05	0.07	0.16	0.2	0.09	0.02	0.01	0.05	0.09
	d	0.75	0.46	0.24	0.09	0.1	0.21	0.4	0.25	0.4	0.87	0.92	0.5	0.2	0.14	0.45	0.9
	e	1.03	0.34	0.06	0.04	0.05	0.25	0.34	0.22	0.49	0.8	0.92	0.52	0.21	0.17	0.44	0.79
	f	0.77	0.22	0.02	0.02	0.03	0.24	0.26	0.1	0.23	0.36	0.33	0.13	0.04	0.03	0.08	0.39
	g	0.42	0.12	0	0	0.01	0.12	0.15	0.04	0.07	0.11	0.09	0.03	0.01	0	0.02	0.16
7.15	a	0.12	0.16	0.04	0	0	0	0.02	0.01	0.05	0.28	0.56	0.41	0.11	0.04	0.09	0.09
	b	0.04	0.04	0.01	0	0	0	0.01	0	0.02	0.12	0.16	0.1	0.03	0.02	0.03	0.04
	c	0.03	0.03	0.01	0	0	0	0.01	0.01	0.01	0.1	0.16	0.09	0.03	0.01	0.03	0.04
	d	0.15	0.11	0.03	0.01	0.01	0.02	0.03	0.03	0.14	0.49	0.7	0.39	0.15	0.07	0.38	0.4
	e	0.14	0.07	0.04	0.02	0.01	0.01	0.03	0.02	0.09	0.32	0.56	0.25	0.09	0.05	0.26	0.28
	f	0.05	0.03	0.02	0.02	0	0	0	0	0.02	0.08	0.15	0.05	0.01	0	0.02	0.05
	g	0.03	0.02	0	0	0	0	0	0	0.02	0.04	0.06	0.01	0	0	0	0.01
9.8	a	0.01	0.03	0	0	0	0	0	0	0.01	0.09	0.17	0.15	0.07	0.01	0.03	0.02
	b	0.01	0.01	0	0	0	0	0	0	0.01	0.03	0.05	0.04	0.02	0	0.02	0.01
	c	0.01	0	0	0	0	0	0	0	0.01	0.02	0.04	0.04	0.01	0	0.01	0.01
	d	0.02	0.01	0.01	0	0	0	0	0	0.02	0.15	0.28	0.14	0.07	0.01	0.16	0.09
	e	0.02	0.03	0.02	0.01	0	0	0	0	0.01	0.09	0.24	0.05	0.02	0.01	0.08	0.04
	f	0	0	0	0	0	0	0	0	0	0.01	0.04	0	0	0	0	0
	g	0	0	0	0	0	0	0	0	0	0.01	0.02	0	0	0	0	0
12.7	a	0	0	0	0	0	0	0	0	0	0.01	0.04	0.03	0.02	0	0	0
	b	0	0	0	0	0	0	0	0	0	0	0.02	0.01	0	0	0	0
	c	0	0	0	0	0	0	0	0	0	0.01	0.02	0	0	0	0	0
	d	0.01	0.01	0	0	0	0	0	0	0.01	0.05	0.15	0.04	0.02	0.01	0.03	0.02
	e	0	0.01	0	0	0	0	0	0	0	0.04	0.12	0.01	0	0	0.01	0
	f	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0
	g	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0
15.6	a	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0
	b	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	c	0	0	0	0	0	0	0	0	0	0.01	0.01	0	0	0	0	0
	d	0	0	0	0	0	0	0	0	0	0.02	0.05	0.01	0.01	0	0	0
	e	0	0	0	0	0	0	0	0	0	0.01	0.03	0	0	0	0	0
	f	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	a	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	b	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	d	0	0	0	0	0	0	0	0	0	0.01	0.01	0	0	0	0	0
	e	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0
	f	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.1-11. Joint Frequency Distributions for the 300 Area 61 m Tower, 1983-1996 Data (Hoitink and Burk 1997).

Average Wind Speed	Atmospheric Stability Class	Percentage of Time Wind Blows from the 300 Area Toward the Direction Indicated															
		S	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE
0.89	a	0.08	0.07	0.07	0.09	0.1	0.11	0.13	0.11	0.09	0.05	0.05	0.04	0.04	0.03	0.05	0.06
	b	0.06	0.05	0.03	0.04	0.04	0.06	0.07	0.05	0.04	0.03	0.02	0.03	0.03	0.03	0.03	0.04
	c	0.04	0.04	0.04	0.03	0.05	0.05	0.05	0.06	0.04	0.03	0.02	0.02	0.02	0.03	0.03	0.04
	d	0.3	0.23	0.18	0.17	0.24	0.31	0.3	0.34	0.28	0.18	0.2	0.17	0.18	0.17	0.27	0.31
	e	0.3	0.22	0.17	0.15	0.2	0.25	0.3	0.34	0.35	0.27	0.23	0.19	0.2	0.22	0.25	0.31
	f	0.25	0.19	0.18	0.14	0.16	0.23	0.33	0.3	0.28	0.26	0.21	0.16	0.17	0.2	0.21	0.24
	g	0.1	0.08	0.06	0.04	0.07	0.1	0.15	0.13	0.14	0.11	0.1	0.08	0.1	0.1	0.12	0.14
2.65	a	0.25	0.27	0.36	0.39	0.52	0.54	0.49	0.29	0.19	0.23	0.22	0.13	0.06	0.04	0.06	0.15
	b	0.15	0.13	0.13	0.14	0.18	0.19	0.24	0.16	0.12	0.11	0.1	0.07	0.03	0.03	0.03	0.09
	c	0.14	0.12	0.1	0.11	0.16	0.19	0.22	0.14	0.1	0.11	0.09	0.06	0.02	0.02	0.03	0.09
	d	0.89	0.57	0.36	0.36	0.51	0.71	1.06	0.7	0.52	0.53	0.46	0.29	0.19	0.17	0.34	0.75
	e	0.83	0.44	0.15	0.1	0.22	0.45	0.86	0.81	0.78	0.7	0.62	0.43	0.34	0.36	0.4	0.64
	f	0.56	0.3	0.08	0.04	0.13	0.46	0.87	0.82	0.74	0.52	0.34	0.26	0.2	0.11	0.23	0.43
	g	0.28	0.11	0.03	0.01	0.03	0.23	0.46	0.34	0.27	0.16	0.1	0.07	0.06	0.06	0.1	0.23
4.7	a	0.25	0.56	0.37	0.12	0.11	0.21	0.34	0.17	0.2	0.44	0.57	0.25	0.08	0.04	0.07	0.11
	b	0.12	0.19	0.1	0.04	0.04	0.08	0.12	0.06	0.07	0.21	0.21	0.12	0.03	0.02	0.03	0.07
	c	0.12	0.17	0.11	0.04	0.02	0.07	0.11	0.06	0.07	0.16	0.19	0.08	0.02	0.01	0.04	0.07
	d	0.83	0.55	0.25	0.13	0.13	0.27	0.55	0.3	0.34	0.76	0.79	0.45	0.2	0.15	0.3	0.71
	e	1.01	0.35	0.08	0.07	0.08	0.27	0.59	0.42	0.6	0.93	0.87	0.6	0.35	0.27	0.43	0.85
	f	0.8	0.27	0.02	0.02	0.04	0.25	0.66	0.32	0.4	0.53	0.47	0.25	0.09	0.04	0.08	0.39
	g	0.41	0.13	0	0	0.01	0.12	0.34	0.12	0.14	0.16	0.12	0.05	0.02	0.01	0.02	0.17
7.15	a	0.16	0.27	0.07	0.01	0	0.01	0.03	0.02	0.04	0.32	0.61	0.45	0.11	0.05	0.07	0.08
	b	0.06	0.07	0.01	0	0	0.01	0.01	0.01	0.02	0.14	0.19	0.1	0.04	0.02	0.03	0.05
	c	0.04	0.05	0.01	0	0	0	0.02	0.01	0.02	0.11	0.17	0.1	0.02	0.01	0.02	0.04
	d	0.36	0.19	0.04	0.01	0.01	0.03	0.08	0.07	0.18	0.58	0.79	0.47	0.18	0.12	0.36	0.51
	e	0.6	0.17	0.05	0.02	0.02	0.08	0.18	0.11	0.18	0.5	0.97	0.65	0.25	0.16	0.44	0.63
	f	0.48	0.15	0.03	0.02	0.01	0.05	0.11	0.04	0.06	0.22	0.37	0.2	0.04	0.01	0.06	0.3
	g	0.31	0.07	0	0	0	0.01	0.03	0.01	0.02	0.06	0.1	0.04	0.01	0	0.02	0.14
9.8	a	0.04	0.05	0.01	0	0	0	0	0	0.01	0.11	0.22	0.25	0.1	0.02	0.05	0.03
	b	0.02	0.01	0	0	0	0	0	0	0.01	0.03	0.06	0.05	0.02	0.01	0.02	0.01
	c	0.01	0.01	0	0	0	0	0	0	0	0.03	0.06	0.05	0.02	0.01	0.02	0.01
	d	0.07	0.04	0.02	0.01	0	0.01	0.02	0.01	0.03	0.22	0.37	0.28	0.12	0.05	0.29	0.19
	e	0.08	0.05	0.04	0.01	0.01	0.01	0.01	0.02	0.03	0.17	0.5	0.25	0.09	0.04	0.29	0.19
	f	0.05	0.01	0.02	0.02	0	0	0	0	0.01	0.05	0.14	0.06	0.01	0	0.01	0.04
	g	0.02	0.01	0	0	0	0	0	0	0	0.02	0.05	0.02	0	0	0	0.01
12.7	a	0	0.02	0.01	0	0	0	0	0	0	0.03	0.09	0.07	0.06	0	0.01	0.01
	b	0	0.01	0	0	0	0	0	0	0	0.01	0.04	0.03	0.02	0	0.01	0
	c	0	0	0	0	0	0	0	0	0	0	0.04	0.03	0.01	0	0.01	0.01
	d	0.01	0.02	0.01	0	0	0	0	0	0.01	0.1	0.26	0.11	0.06	0.01	0.13	0.04
	e	0.01	0.02	0.02	0.01	0	0	0	0	0.01	0.07	0.24	0.06	0.02	0.02	0.09	0.02
	f	0	0	0.01	0.01	0	0	0	0	0	0.01	0.05	0.01	0	0	0	0
	g	0	0	0	0	0	0	0	0	0	0	0.03	0	0	0	0	0
15.6	a	0	0	0	0	0	0	0	0	0	0	0.02	0.01	0.01	0	0	0
	b	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0.01	0
	c	0	0	0	0	0	0	0	0	0	0	0.02	0.01	0	0	0	0
	d	0	0.01	0	0	0	0	0	0	0	0.02	0.13	0.02	0.01	0	0.01	0.01
	e	0	0.01	0.01	0	0	0	0	0	0	0.03	0.1	0.01	0	0	0.01	0
	f	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	g	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0
19	a	0	0	0	0	0	0	0	0	0	0	0.02	0	0	0	0	0
	b	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	c	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0
	d	0.01	0	0	0	0	0	0	0	0	0.01	0.09	0.01	0.01	0	0	0
	e	0	0.01	0.01	0	0	0	0	0	0	0.01	0.06	0	0	0	0	0
	f	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	g	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0

Table 4.1-12. Joint Frequency Distributions for the 400 Area 10 m Tower, 1983-1996 Data (Hoitink and Burk 1997).

Average Wind Speed	Atmospheric Stability Class	Percentage of Time Wind Blows from the 400 Area Toward the Direction Indicated															
		S	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE
0.89	a	0.1	0.12	0.1	0.12	0.12	0.15	0.12	0.09	0.11	0.09	0.08	0.06	0.05	0.06	0.07	0.1
	b	0.05	0.06	0.06	0.06	0.06	0.06	0.07	0.05	0.05	0.05	0.04	0.03	0.03	0.03	0.05	0.05
	c	0.04	0.05	0.06	0.05	0.05	0.06	0.07	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.04	0.06
	d	0.35	0.33	0.3	0.25	0.26	0.33	0.37	0.36	0.34	0.32	0.31	0.23	0.24	0.31	0.4	0.39
	e	0.29	0.25	0.22	0.17	0.22	0.24	0.26	0.27	0.35	0.38	0.38	0.32	0.32	0.34	0.39	0.38
	f	0.28	0.24	0.18	0.14	0.15	0.15	0.18	0.2	0.3	0.29	0.29	0.24	0.23	0.27	0.28	0.27
	g	0.15	0.11	0.07	0.06	0.06	0.07	0.08	0.09	0.12	0.13	0.11	0.09	0.11	0.11	0.14	0.12
2.65	a	0.35	0.41	0.4	0.3	0.3	0.39	0.46	0.42	0.5	0.39	0.2	0.13	0.15	0.16	0.19	0.23
	b	0.16	0.15	0.13	0.09	0.11	0.11	0.16	0.18	0.18	0.16	0.08	0.05	0.05	0.05	0.09	0.13
	c	0.14	0.13	0.12	0.07	0.08	0.09	0.14	0.16	0.17	0.12	0.06	0.04	0.05	0.06	0.1	0.13
	d	0.67	0.59	0.54	0.33	0.32	0.37	0.73	0.99	0.87	0.74	0.4	0.26	0.33	0.54	0.97	0.91
	e	0.6	0.49	0.36	0.2	0.17	0.25	0.62	1	1.12	1.11	0.68	0.46	0.54	0.72	1.1	0.84
	f	0.57	0.56	0.32	0.12	0.1	0.15	0.42	0.76	0.91	0.79	0.46	0.25	0.22	0.35	0.7	0.64
	g	0.31	0.29	0.14	0.05	0.04	0.05	0.14	0.31	0.34	0.26	0.16	0.08	0.08	0.16	0.33	0.31
4.7	a	0.35	0.39	0.21	0.07	0.07	0.07	0.13	0.18	0.53	0.68	0.29	0.18	0.17	0.17	0.24	0.23
	b	0.12	0.11	0.06	0.02	0.02	0.03	0.05	0.08	0.2	0.28	0.1	0.05	0.04	0.03	0.09	0.1
	c	0.09	0.11	0.06	0.01	0.02	0.02	0.05	0.07	0.16	0.22	0.08	0.04	0.04	0.04	0.09	0.1
	d	0.35	0.31	0.22	0.08	0.05	0.08	0.28	0.54	0.86	1.14	0.44	0.21	0.25	0.56	1.08	0.7
	e	0.22	0.2	0.1	0.03	0.02	0.03	0.29	0.9	0.98	1.13	0.55	0.25	0.31	0.8	1.54	0.68
	f	0.17	0.17	0.07	0.02	0	0.01	0.22	0.91	0.75	0.63	0.21	0.06	0.06	0.18	0.73	0.51
	g	0.08	0.08	0.02	0	0	0.01	0.1	0.46	0.29	0.2	0.06	0.01	0.01	0.05	0.32	0.22
7.15	a	0.08	0.1	0.07	0.01	0	0.01	0.01	0.02	0.13	0.59	0.41	0.21	0.16	0.12	0.19	0.11
	b	0.03	0.03	0.01	0	0	0	0.01	0.01	0.04	0.22	0.1	0.07	0.04	0.04	0.06	0.03
	c	0.02	0.02	0.01	0	0	0	0.01	0.01	0.04	0.19	0.1	0.05	0.03	0.04	0.05	0.03
	d	0.09	0.09	0.04	0.01	0	0.01	0.05	0.06	0.27	0.89	0.51	0.22	0.16	0.32	0.67	0.18
	e	0.03	0.06	0.03	0	0	0.01	0.02	0.08	0.2	0.67	0.45	0.16	0.09	0.3	0.6	0.13
	f	0.01	0.01	0.01	0	0	0	0.01	0.06	0.11	0.28	0.11	0.02	0.01	0.01	0.05	0.03
	g	0	0	0	0	0	0	0.01	0.05	0.06	0.11	0.04	0.01	0	0	0.02	0.01
9.8	a	0.01	0.03	0.02	0	0	0	0	0	0.01	0.11	0.18	0.13	0.07	0.04	0.06	0.01
	b	0	0.01	0	0	0	0	0	0	0.01	0.03	0.05	0.03	0.02	0.01	0.03	0
	c	0	0	0	0	0	0	0	0	0	0.02	0.04	0.02	0.01	0.01	0.03	0.01
	d	0.01	0.03	0.01	0.01	0	0	0	0	0.02	0.19	0.27	0.12	0.05	0.1	0.26	0.02
	e	0	0.04	0.01	0	0	0	0	0	0.01	0.16	0.21	0.05	0.02	0.05	0.11	0.01
	f	0	0	0	0	0	0	0	0	0	0.02	0.03	0	0	0	0	0
	g	0	0	0	0	0	0	0	0	0.01	0.02	0.02	0	0	0	0	0
12.7	a	0	0	0	0	0	0	0	0	0	0.01	0.05	0.03	0.01	0.01	0.01	0
	b	0	0	0	0	0	0	0	0	0	0.01	0.02	0	0	0	0	0
	c	0	0	0	0	0	0	0	0	0	0	0.02	0.01	0	0	0.01	0
	d	0	0.01	0	0	0	0	0	0	0	0.05	0.17	0.04	0.01	0.01	0.04	0
	e	0	0.01	0.01	0	0	0	0	0	0	0.05	0.07	0.01	0	0.01	0.02	0
	f	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0
	g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15.6	a	0	0	0	0	0	0	0	0	0	0	0.02	0	0	0	0	0
	b	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	c	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0
	d	0	0	0	0	0	0	0	0	0	0.01	0.04	0.01	0.01	0	0	0
	e	0	0	0.01	0	0	0	0	0	0	0.01	0.02	0	0	0	0	0
	f	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	a	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	b	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	d	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0
	e	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0
	f	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.1-13. Joint Frequency Distributions for the 400 Area 61 m Tower, 1983-1996 Data (Hoitink and Burk 1997).

Average Wind Speed	Atmospheric Stability Class	Percentage of Time Wind Blows from the 400 Area Toward the Direction Indicated															
		S	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE
0.89	a	0.08	0.09	0.1	0.09	0.1	0.12	0.1	0.09	0.09	0.07	0.06	0.05	0.06	0.04	0.07	0.07
	b	0.05	0.04	0.06	0.05	0.06	0.05	0.05	0.05	0.05	0.03	0.04	0.03	0.03	0.04	0.05	0.04
	c	0.04	0.03	0.05	0.04	0.05	0.06	0.05	0.04	0.03	0.04	0.03	0.02	0.02	0.03	0.04	0.05
	d	0.22	0.21	0.19	0.19	0.23	0.23	0.31	0.3	0.25	0.21	0.22	0.17	0.18	0.19	0.22	0.23
	e	0.18	0.17	0.14	0.13	0.15	0.16	0.22	0.22	0.25	0.21	0.22	0.21	0.19	0.17	0.18	0.2
	f	0.15	0.14	0.13	0.13	0.13	0.15	0.19	0.2	0.22	0.19	0.18	0.15	0.15	0.15	0.13	0.16
	g	0.07	0.06	0.06	0.06	0.06	0.06	0.07	0.09	0.09	0.06	0.06	0.05	0.07	0.05	0.06	0.06
2.65	a	0.27	0.31	0.32	0.23	0.24	0.29	0.36	0.33	0.35	0.28	0.17	0.11	0.11	0.13	0.15	0.2
	b	0.12	0.13	0.11	0.08	0.09	0.1	0.15	0.16	0.16	0.15	0.07	0.05	0.05	0.05	0.1	0.12
	c	0.11	0.11	0.12	0.07	0.07	0.09	0.12	0.14	0.16	0.11	0.06	0.05	0.05	0.06	0.08	0.11
	d	0.5	0.51	0.48	0.34	0.31	0.37	0.57	0.74	0.7	0.54	0.3	0.24	0.24	0.36	0.65	0.61
	e	0.41	0.35	0.29	0.2	0.21	0.2	0.36	0.54	0.65	0.54	0.48	0.4	0.43	0.47	0.57	0.52
	f	0.4	0.39	0.26	0.13	0.1	0.16	0.28	0.57	0.62	0.47	0.36	0.26	0.28	0.27	0.37	0.41
	g	0.2	0.18	0.11	0.05	0.03	0.05	0.13	0.28	0.29	0.19	0.12	0.08	0.09	0.09	0.15	0.18
4.7	a	0.34	0.4	0.25	0.09	0.06	0.06	0.14	0.2	0.47	0.61	0.23	0.14	0.12	0.17	0.2	0.21
	b	0.13	0.14	0.09	0.03	0.02	0.02	0.07	0.09	0.2	0.23	0.11	0.05	0.03	0.04	0.08	0.1
	c	0.09	0.12	0.09	0.02	0.02	0.03	0.06	0.09	0.17	0.21	0.07	0.03	0.03	0.04	0.08	0.1
	d	0.42	0.44	0.36	0.13	0.1	0.1	0.33	0.46	0.73	0.87	0.43	0.16	0.21	0.33	0.85	0.65
	e	0.34	0.3	0.21	0.09	0.06	0.07	0.35	0.61	0.79	0.8	0.68	0.33	0.35	0.61	1.04	0.63
	f	0.3	0.25	0.14	0.05	0.03	0.03	0.22	0.54	0.64	0.6	0.44	0.13	0.11	0.19	0.54	0.55
	g	0.18	0.15	0.07	0.01	0	0.01	0.1	0.29	0.27	0.22	0.13	0.03	0.03	0.06	0.24	0.33
7.15	a	0.14	0.16	0.09	0.01	0	0.01	0.03	0.03	0.13	0.59	0.39	0.17	0.13	0.11	0.19	0.13
	b	0.04	0.04	0.02	0.01	0	0	0.01	0.01	0.06	0.23	0.11	0.05	0.03	0.04	0.08	0.07
	c	0.04	0.04	0.02	0	0	0	0.02	0.02	0.06	0.19	0.09	0.04	0.03	0.04	0.06	0.04
	d	0.14	0.15	0.06	0.02	0.01	0.01	0.12	0.17	0.39	0.95	0.52	0.21	0.15	0.34	0.88	0.37
	e	0.14	0.11	0.07	0.01	0.01	0.01	0.17	0.28	0.44	1	0.79	0.23	0.19	0.74	1.52	0.48
	f	0.13	0.1	0.06	0.02	0.01	0	0.11	0.21	0.33	0.56	0.39	0.05	0.03	0.15	0.67	0.43
	g	0.05	0.03	0.01	0	0	0	0.03	0.07	0.15	0.2	0.11	0.02	0.01	0.05	0.27	0.21
9.8	a	0.02	0.06	0.04	0.01	0	0	0	0	0.02	0.16	0.25	0.16	0.08	0.06	0.1	0.04
	b	0.01	0.02	0.01	0	0	0	0.01	0.01	0.01	0.06	0.06	0.05	0.02	0.01	0.04	0.02
	c	0.01	0.01	0.01	0.01	0	0	0	0	0.01	0.06	0.05	0.03	0.02	0.02	0.04	0.02
	d	0.03	0.05	0.03	0.01	0.01	0.01	0.03	0.03	0.1	0.36	0.39	0.17	0.1	0.22	0.65	0.1
	e	0.04	0.06	0.05	0.01	0.01	0.01	0.02	0.04	0.11	0.44	0.46	0.15	0.08	0.5	1.06	0.11
	f	0.02	0.02	0.03	0.01	0.01	0.01	0.01	0.02	0.04	0.19	0.16	0.02	0.01	0.06	0.25	0.08
	g	0	0	0	0	0	0	0	0.01	0.02	0.1	0.06	0.01	0	0.03	0.11	0.03
12.7	a	0	0.02	0.02	0	0	0	0	0	0	0.04	0.08	0.09	0.04	0.01	0.04	0
	b	0	0.02	0	0	0	0	0	0	0	0.02	0.04	0.02	0.01	0.01	0.02	0
	c	0	0	0	0	0	0	0	0	0	0.02	0.03	0.02	0.01	0	0.02	0
	d	0.01	0.02	0.01	0.01	0	0	0.01	0.01	0.01	0.12	0.26	0.09	0.04	0.09	0.32	0.05
	e	0.01	0.03	0.01	0.01	0	0	0.01	0.02	0.02	0.16	0.27	0.08	0.02	0.08	0.28	0.03
	f	0	0.01	0	0	0	0	0	0.01	0.01	0.03	0.06	0.01	0.01	0	0.01	0.01
	g	0	0	0	0	0	0	0	0	0.01	0.02	0.02	0	0	0	0	0
15.6	a	0	0	0	0	0	0	0	0	0	0.01	0.02	0.02	0	0	0.01	0
	b	0	0	0	0	0	0	0	0	0	0	0.01	0.01	0	0	0.01	0
	c	0	0	0	0	0	0	0	0	0	0.01	0.02	0.01	0	0	0	0
	d	0	0	0.01	0	0	0	0	0	0	0.06	0.14	0.04	0.01	0.01	0.04	0.01
	e	0	0.01	0.01	0	0	0	0	0	0.01	0.06	0.1	0.03	0	0.01	0.05	0.02
	f	0	0	0	0	0	0	0	0	0	0.01	0.01	0	0	0	0	0
	g	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0
19	a	0	0	0	0	0	0	0	0	0	0.01	0.02	0	0	0	0	0
	b	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0
	c	0	0	0	0	0	0	0	0	0	0.01	0.01	0	0	0	0	0
	d	0	0	0	0	0	0	0	0	0	0.02	0.09	0.01	0.01	0	0	0
	e	0	0	0.01	0	0	0	0	0	0	0.04	0.05	0.01	0	0	0.01	0
	f	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.1-14. $\overline{X}$ /QρValues (sec m^{-3}) for Chronic Ground-Level Releases from 100-N Area Based on 1983 Through 1991 Meteorological Information (Schreckhise et al. 1993)

Distance (km)	S	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE	Distance (km)
	Sector (Wind from 100-N Towards Direction Indicated)																
0.1	2.3E-04	1.5E-04	1.6E-04	1.9E-04	3.6E-04	2.3E-04	1.9E-04	1.3E-04	1.7E-04	1.4E-04	2.0E-04	3.1E-04	5.1E-04	3.2E-04	2.4E-04	2.0E-04	0.1
0.2	6.3E-05	4.1E-05	4.3E-05	5.2E-05	1.0E-04	6.4E-05	5.2E-05	3.7E-05	4.7E-05	3.8E-05	5.5E-05	8.6E-05	1.4E-04	8.7E-05	6.5E-05	5.5E-05	0.2
0.3	3.0E-05	1.9E-05	2.1E-05	2.5E-05	4.8E-05	3.1E-05	2.5E-05	1.8E-05	2.2E-05	1.8E-05	2.6E-05	4.1E-05	6.8E-05	4.1E-05	3.1E-05	2.6E-05	0.3
0.4	1.8E-05	1.2E-05	1.2E-05	1.5E-05	2.9E-05	1.8E-05	1.5E-05	1.0E-05	1.3E-05	1.1E-05	1.6E-05	2.5E-05	4.0E-05	2.5E-05	1.8E-05	1.6E-05	0.4
0.5	1.2E-05	7.7E-06	8.2E-06	1.0E-05	1.9E-05	1.2E-05	1.0E-05	7.0E-06	8.9E-06	7.2E-06	1.1E-05	1.7E-05	2.7E-05	1.7E-05	1.2E-05	1.1E-05	0.5
0.6	8.6E-06	5.6E-06	5.9E-06	7.3E-06	1.4E-05	8.8E-06	7.2E-06	5.1E-06	6.4E-06	5.2E-06	7.6E-06	1.2E-05	2.0E-05	1.2E-05	8.9E-06	7.6E-06	0.6
0.7	6.5E-06	4.2E-06	4.5E-06	5.5E-06	1.1E-05	6.7E-06	5.5E-06	3.8E-06	4.9E-06	4.0E-06	5.8E-06	9.1E-06	1.5E-05	9.1E-06	6.8E-06	5.8E-06	0.7
0.8	5.1E-06	3.3E-06	3.5E-06	4.4E-06	8.4E-06	5.3E-06	4.3E-06	3.0E-06	3.9E-06	3.1E-06	4.5E-06	7.2E-06	1.2E-05	7.2E-06	5.3E-06	4.5E-06	0.8
0.9	4.2E-06	2.7E-06	2.9E-06	3.5E-06	6.8E-06	4.3E-06	3.5E-06	2.5E-06	3.1E-06	2.5E-06	3.7E-06	5.8E-06	9.5E-06	5.8E-06	4.3E-06	3.7E-06	0.9
1.0	3.5E-06	2.2E-06	2.4E-06	2.9E-06	5.6E-06	3.6E-06	2.9E-06	2.1E-06	2.6E-06	2.1E-06	3.1E-06	4.8E-06	7.9E-06	4.8E-06	3.6E-06	3.1E-06	1.0
2.4	8.0E-07	5.2E-07	5.5E-07	6.8E-07	1.3E-06	8.3E-07	6.7E-07	4.7E-07	6.0E-07	4.9E-07	7.1E-07	1.1E-06	1.8E-06	1.1E-06	8.3E-07	7.1E-07	2.4
4.0	3.6E-07	2.4E-07	2.5E-07	3.1E-07	6.0E-07	3.8E-07	3.1E-07	2.1E-07	2.7E-07	2.2E-07	3.2E-07	5.2E-07	8.4E-07	5.1E-07	3.8E-07	3.2E-07	4.0
5.6	2.2E-07	1.4E-07	1.5E-07	1.9E-07	3.6E-07	2.3E-07	1.9E-07	1.3E-07	1.7E-07	1.3E-07	2.0E-07	3.1E-07	5.1E-07	3.1E-07	2.3E-07	2.0E-07	5.6
7.2	1.5E-07	9.9E-08	1.1E-07	1.3E-07	2.5E-07	1.6E-07	1.3E-07	9.0E-08	1.1E-07	9.3E-08	1.4E-07	2.2E-07	3.6E-07	2.2E-07	1.6E-07	1.4E-07	7.2
12.1	7.4E-08	4.8E-08	5.2E-08	6.4E-08	1.2E-07	7.6E-08	6.2E-08	4.3E-08	5.5E-08	4.5E-08	6.6E-08	1.1E-07	1.7E-07	1.1E-07	7.8E-08	6.7E-08	12.1
24.1	2.9E-08	1.8E-08	2.0E-08	2.5E-08	4.7E-08	2.9E-08	2.4E-08	1.6E-08	2.1E-08	1.7E-08	2.5E-08	4.1E-08	6.7E-08	4.1E-08	3.0E-08	2.6E-08	24.1
40.3	1.4E-08	9.3E-09	1.0E-08	1.3E-08	2.4E-08	1.4E-08	1.2E-08	8.1E-09	1.0E-08	8.5E-09	1.3E-08	2.0E-08	3.4E-08	2.0E-08	1.5E-08	1.3E-08	40.3
56.3	9.2E-09	5.9E-09	6.4E-09	8.0E-09	1.5E-08	9.2E-09	7.5E-09	5.2E-09	6.6E-09	5.4E-09	8.0E-09	1.3E-08	2.2E-08	1.3E-08	9.7E-09	8.3E-09	56.3
72.4	6.6E-09	4.3E-09	4.6E-09	5.8E-09	1.1E-08	6.6E-09	5.3E-09	3.7E-09	4.7E-09	3.9E-09	5.8E-09	9.4E-09	1.5E-08	9.4E-09	7.0E-09	6.0E-09	72.4

Table 4.1-15. $\overline{X}$ /QρValues (sec m^{-3}) for Chronic 60 m Stack Releases from 100-N Area Based on 1983 Through 1991 Meteorological Information (Schreckhise et al. 1993)

Distance (km)	S	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE	Distance (km)
	Sector (Wind from 100-N Towards Direction Indicated)																
0.1	1.4E-09	7.9E-10	6.5E-10	4.3E-10	9.4E-10	6.8E-10	5.6E-10	3.8E-10	5.5E-10	4.0E-10	7.0E-10	9.4E-10	1.7E-09	1.4E-09	1.3E-09	1.1E-09	0.1
0.2	2.6E-07	1.5E-07	1.3E-07	8.3E-08	1.8E-07	1.4E-07	1.1E-07	7.8E-08	1.1E-07	7.8E-08	1.4E-07	1.8E-07	3.3E-07	2.7E-07	2.4E-07	2.1E-07	0.2
0.3	4.9E-07	2.9E-07	2.5E-07	1.6E-07	3.6E-07	2.7E-07	2.3E-07	1.6E-07	2.1E-07	1.5E-07	2.7E-07	3.5E-07	6.2E-07	5.0E-07	4.5E-07	3.9E-07	0.3
0.4	4.1E-07	2.5E-07	2.1E-07	1.5E-07	3.2E-07	2.4E-07	2.1E-07	1.5E-07	1.9E-07	1.3E-07	2.3E-07	3.0E-07	5.1E-07	4.2E-07	3.8E-07	3.2E-07	0.4
0.5	3.1E-07	1.9E-07	1.7E-07	1.2E-07	2.7E-07	2.0E-07	1.8E-07	1.3E-07	1.6E-07	1.1E-07	1.9E-07	2.4E-07	4.0E-07	3.2E-07	2.9E-07	2.5E-07	0.5
0.6	2.6E-07	1.6E-07	1.5E-07	1.1E-07	2.4E-07	1.9E-07	1.6E-07	1.2E-07	1.4E-07	1.0E-07	1.7E-07	2.1E-07	3.3E-07	2.7E-07	2.4E-07	2.0E-07	0.6
0.7	2.3E-07	1.5E-07	1.3E-07	1.1E-07	2.3E-07	1.8E-07	1.6E-07	1.2E-07	1.4E-07	1.0E-07	1.6E-07	1.9E-07	3.1E-07	2.4E-07	2.1E-07	1.8E-07	0.7
0.8	2.2E-07	1.4E-07	1.3E-07	1.1E-07	2.3E-07	1.9E-07	1.6E-07	1.2E-07	1.5E-07	1.0E-07	1.6E-07	1.9E-07	3.0E-07	2.3E-07	1.9E-07	1.7E-07	0.8
0.9	2.1E-07	1.4E-07	1.2E-07	1.1E-07	2.3E-07	1.9E-07	1.7E-07	1.2E-07	1.5E-07	1.1E-07	1.6E-07	1.9E-07	3.0E-07	2.2E-07	1.9E-07	1.6E-07	0.9
1.0	2.1E-07	1.4E-07	1.2E-07	1.2E-07	2.4E-07	2.0E-07	1.7E-07	1.3E-07	1.5E-07	1.1E-07	1.6E-07	2.0E-07	3.1E-07	2.2E-07	1.8E-07	1.6E-07	1.0
2.4	1.5E-07	1.0E-07	9.5E-08	1.1E-07	2.2E-07	1.7E-07	1.4E-07	1.0E-07	1.3E-07	9.5E-08	1.3E-07	1.7E-07	2.7E-07	1.8E-07	1.4E-07	1.2E-07	2.4
4.0	1.0E-07	6.7E-08	6.5E-08	7.6E-08	1.5E-07	1.1E-07	9.2E-08	6.7E-08	8.6E-08	6.4E-08	8.9E-08	1.2E-07	1.9E-07	1.2E-07	9.3E-08	8.0E-08	4.0
5.6	7.4E-08	4.8E-08	4.8E-08	5.7E-08	1.1E-07	8.0E-08	6.6E-08	4.8E-08	6.1E-08	4.7E-08	6.5E-08	9.0E-08	1.4E-07	9.0E-08	6.8E-08	5.9E-08	5.6
7.2	5.7E-08	3.7E-08	3.7E-08	4.5E-08	8.8E-08	6.2E-08	5.1E-08	3.7E-08	4.7E-08	3.6E-08	5.0E-08	7.1E-08	1.1E-07	7.1E-08	5.4E-08	4.6E-08	7.2
12.1	3.3E-08	2.2E-08	2.2E-08	2.7E-08	5.2E-08	3.5E-08	2.9E-08	2.1E-08	2.7E-08	2.1E-08	2.9E-08	4.2E-08	6.6E-08	4.2E-08	3.2E-08	2.7E-08	12.1
24.1	1.5E-08	9.9E-09	1.0E-08	1.3E-08	2.5E-08	1.6E-08	1.3E-08	9.1E-09	1.2E-08	9.3E-09	1.3E-08	2.0E-08	3.1E-08	2.0E-08	1.5E-08	1.3E-08	24.1
40.3	8.2E-09	5.5E-09	5.6E-09	7.3E-09	1.4E-08	8.5E-09	6.9E-09	4.9E-09	6.4E-09	5.1E-09	7.2E-09	1.1E-08	1.8E-08	1.1E-08	8.5E-09	7.2E-09	40.3
56.3	5.5E-09	3.7E-09	3.8E-09	5.0E-09	9.3E-09	5.7E-09	4.6E-09	3.3E-09	4.3E-09	3.4E-09	4.9E-09	7.4E-09	1.2E-08	7.4E-09	5.7E-09	4.9E-09	56.3
72.4	4.1E-09	2.7E-09	2.8E-09	3.7E-09	6.9E-09	4.2E-09	3.4E-09	2.4E-09	3.1E-09	2.5E-09	3.6E-09	5.5E-09	8.9E-09	5.5E-09	4.3E-09	3.7E-09	72.4

Table 4.1-16 $\overline{X}$/Qρ Values (sec m^{-3}) for Chronic Ground-Level Releases from 200 Areas Based on 1983 Through 1991 Meteorological Information (Schreckhise et al. 1993)

Distance	Sector (Wind from 100-N Towards Direction Indicated)																Distance
(km)	S	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE	(km)
0.1	1.7E-04	1.0E-04	9.9E-05	1.0E-04	1.7E-04	1.4E-04	1.6E-04	1.5E-04	1.6E-04	9.0E-05	1.1E-04	1.4E-04	3.8E-04	4.0E-04	2.5E-04	1.5E-04	0.1
0.2	4.6E-05	2.8E-05	2.7E-05	2.7E-05	4.7E-05	3.8E-05	4.3E-05	4.3E-05	4.5E-05	2.5E-05	3.0E-05	3.9E-05	1.1E-04	1.1E-04	6.9E-05	4.0E-05	0.2
0.3	2.2E-05	1.3E-05	1.3E-05	1.3E-05	2.2E-05	1.8E-05	2.1E-05	2.0E-05	2.1E-05	1.2E-05	1.4E-05	1.9E-05	5.0E-05	5.3E-05	3.3E-05	1.9E-05	0.3
0.4	1.3E-05	7.8E-06	7.5E-06	7.5E-06	1.3E-05	1.1E-05	1.2E-05	1.2E-05	1.3E-05	7.1E-06	8.4E-06	1.1E-05	3.0E-05	3.2E-05	2.0E-05	1.1E-05	0.4
0.5	8.4E-06	5.2E-06	5.0E-06	5.0E-06	8.7E-06	7.1E-06	8.2E-06	8.1E-06	8.6E-06	4.8E-06	5.7E-06	7.5E-06	2.0E-05	2.2E-05	1.3E-05	7.5E-06	0.5
0.6	6.1E-06	3.7E-06	3.6E-06	3.6E-06	6.3E-06	5.1E-06	5.9E-06	5.9E-06	6.2E-06	3.5E-06	4.1E-06	5.4E-06	1.5E-05	1.6E-05	9.5E-06	5.4E-06	0.6
0.7	4.6E-06	2.8E-06	2.7E-06	2.7E-06	4.8E-06	3.9E-06	4.5E-06	4.5E-06	4.7E-06	2.6E-06	3.1E-06	4.1E-06	1.1E-05	1.2E-05	7.2E-06	4.1E-06	0.7
0.8	3.6E-06	2.2E-06	2.1E-06	2.1E-06	3.8E-06	3.1E-06	3.5E-06	3.5E-06	3.7E-06	2.1E-06	2.5E-06	3.3E-06	8.8E-06	9.4E-06	5.7E-06	3.2E-06	0.8
0.9	2.9E-06	1.8E-06	1.7E-06	1.7E-06	3.1E-06	2.5E-06	2.9E-06	2.9E-06	3.0E-06	1.7E-06	2.0E-06	2.7E-06	7.2E-06	7.6E-06	4.6E-06	2.6E-06	0.9
1.0	2.4E-06	1.5E-06	1.4E-06	1.4E-06	2.5E-06	2.1E-06	2.4E-06	2.4E-06	2.5E-06	1.4E-06	1.7E-06	2.2E-06	6.0E-06	6.3E-06	3.9E-06	2.2E-06	1.0
2.4	5.5E-07	3.4E-07	3.3E-07	3.3E-07	5.8E-07	4.8E-07	5.5E-07	5.5E-07	5.8E-07	3.3E-07	3.9E-07	5.1E-07	1.4E-06	1.5E-06	8.9E-07	5.0E-07	2.4
4.0	2.5E-07	1.5E-07	1.5E-07	1.5E-07	2.6E-07	2.2E-07	2.5E-07	2.5E-07	2.7E-07	1.5E-07	1.8E-07	2.3E-07	6.4E-07	6.7E-07	4.1E-07	2.3E-07	4.0
5.6	1.5E-07	9.1E-08	8.9E-08	8.9E-08	1.6E-07	1.3E-07	1.5E-07	1.5E-07	1.6E-07	9.1E-08	1.1E-07	1.4E-07	3.9E-07	4.1E-07	2.5E-07	1.4E-07	5.6
7.2	1.0E-07	6.2E-08	6.1E-08	6.1E-08	1.1E-07	9.1E-08	1.1E-07	1.1E-07	1.1E-07	6.3E-08	7.5E-08	9.9E-08	2.7E-07	2.9E-07	1.7E-07	9.4E-08	7.2
12.1	4.9E-08	3.0E-08	2.9E-08	2.9E-08	5.3E-08	4.4E-08	5.1E-08	5.2E-08	5.5E-08	3.1E-08	3.6E-08	4.8E-08	1.3E-07	1.4E-07	8.2E-08	4.5E-08	12.1
24.1	1.9E-08	1.1E-08	1.1E-08	1.1E-08	2.0E-08	1.7E-08	2.0E-08	2.0E-08	2.1E-08	1.2E-08	1.4E-08	1.9E-08	5.1E-08	5.3E-08	3.1E-08	1.7E-08	24.1
40.3	9.2E-09	5.5E-09	5.5E-09	5.5E-09	1.0E-08	8.4E-09	9.8E-09	1.0E-08	1.1E-08	6.0E-09	7.0E-09	9.3E-09	2.6E-08	2.7E-08	1.6E-08	8.6E-09	40.3
56.3	5.9E-09	3.5E-09	3.5E-09	3.5E-09	6.4E-09	5.3E-09	6.3E-09	6.4E-09	6.9E-09	3.8E-09	4.5E-09	6.0E-09	1.7E-08	1.7E-08	1.0E-08	5.5E-09	56.3
72.4	4.2E-09	2.5E-09	2.5E-09	2.5E-09	4.6E-09	3.8E-09	4.5E-09	4.6E-09	5.0E-09	2.7E-09	3.2E-09	4.3E-09	1.2E-08	1.2E-08	7.1E-09	3.9E-09	72.4

Table 4.1-17. $\overline{X}$/Qρ Values (sec m^{-3}) for Chronic 60 m Stack Releases from 200 Areas Based on 1983 Through 1991 Meteorological Information (Schreckhise et al. 1993)

Distance	Sector (Wind from 100-N Towards Direction Indicated)																Distance
(km)	S	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE	(km)
0.1	1.5E-09	9.3E-10	7.9E-10	8.7E-10	1.4E-09	1.0E-09	8.2E-10	5.0E-10	4.9E-10	2.9E-10	3.6E-10	5.3E-10	6.6E-10	7.0E-10	9.1E-10	9.0E-10	0.1
0.2	3.0E-07	1.8E-07	1.5E-07	1.7E-07	2.8E-07	2.0E-07	1.6E-07	9.6E-08	9.5E-08	5.5E-08	6.8E-08	1.0E-07	1.3E-07	1.4E-07	1.8E-07	1.8E-07	0.2
0.3	5.6E-07	3.5E-07	2.9E-07	3.3E-07	5.3E-07	3.7E-07	3.0E-07	1.8E-07	1.9E-07	1.0E-07	1.3E-07	1.9E-07	2.4E-07	2.6E-07	3.5E-07	3.4E-07	0.3
0.4	4.7E-07	3.1E-07	2.5E-07	2.8E-07	4.4E-07	3.1E-07	2.6E-07	1.6E-07	1.6E-07	8.6E-08	1.0E-07	1.6E-07	2.0E-07	2.2E-07	3.0E-07	2.9E-07	0.4
0.5	3.6E-07	2.4E-07	1.9E-07	2.2E-07	3.4E-07	2.4E-07	2.0E-07	1.2E-07	1.3E-07	6.6E-08	7.8E-08	1.2E-07	1.6E-07	1.8E-07	2.5E-07	2.3E-07	0.5
0.6	3.0E-07	2.1E-07	1.6E-07	1.9E-07	2.8E-07	2.0E-07	1.7E-07	1.1E-07	1.1E-07	5.6E-08	6.6E-08	1.0E-07	1.4E-07	1.6E-07	2.2E-07	2.0E-07	0.6
0.7	2.7E-07	1.8E-07	1.5E-07	1.7E-07	2.5E-07	1.8E-07	1.6E-07	1.0E-07	9.6E-08	5.3E-08	6.2E-08	9.0E-08	1.3E-07	1.6E-07	2.1E-07	1.8E-07	0.7
0.8	2.6E-07	1.7E-07	1.4E-07	1.6E-07	2.3E-07	1.7E-07	1.5E-07	1.0E-07	9.3E-08	5.2E-08	6.3E-08	8.6E-08	1.4E-07	1.7E-07	2.1E-07	1.7E-07	0.8
0.9	2.5E-07	1.7E-07	1.3E-07	1.5E-07	2.2E-07	1.6E-07	1.5E-07	1.0E-07	9.2E-08	5.3E-08	6.5E-08	8.5E-08	1.4E-07	1.8E-07	2.1E-07	1.7E-07	0.9
1.0	2.4E-07	1.6E-07	1.3E-07	1.5E-07	2.2E-07	1.6E-07	1.5E-07	1.1E-07	9.3E-08	5.5E-08	6.7E-08	8.6E-08	1.5E-07	2.0E-07	2.1E-07	1.7E-07	1.0
2.4	1.5E-07	1.0E-07	8.6E-08	8.9E-08	1.4E-07	1.1E-07	1.1E-07	9.6E-08	8.7E-08	5.2E-08	6.3E-08	7.9E-08	1.7E-07	2.1E-07	1.7E-07	1.2E-07	2.4
4.0	9.3E-08	6.0E-08	5.2E-08	5.3E-08	8.9E-08	7.0E-08	7.4E-08	6.8E-08	6.4E-08	3.7E-08	4.5E-08	5.7E-08	1.3E-07	1.5E-07	1.1E-07	7.4E-08	4.0
5.6	6.4E-08	4.1E-08	3.6E-08	3.6E-08	6.2E-08	5.0E-08	5.4E-08	5.1E-08	4.9E-08	2.8E-08	3.3E-08	4.3E-08	9.8E-08	1.1E-07	8.2E-08	5.2E-08	5.6
7.2	4.8E-08	3.0E-08	2.7E-08	2.7E-08	4.7E-08	3.8E-08	4.2E-08	4.0E-08	3.9E-08	2.2E-08	2.6E-08	3.4E-08	7.8E-08	8.8E-08	6.3E-08	3.9E-08	7.2
12.1	2.6E-08	1.6E-08	1.4E-08	1.5E-08	2.6E-08	2.1E-08	2.4E-08	2.4E-08	2.4E-08	1.3E-08	1.5E-08	2.1E-08	4.8E-08	5.2E-08	3.6E-08	2.2E-08	12.1
24.1	1.1E-08	6.7E-09	6.1E-09	6.1E-09	1.1E-08	9.6E-09	1.1E-08	1.2E-08	1.2E-08	6.2E-09	7.2E-09	9.7E-09	2.4E-08	2.4E-08	1.6E-08	9.5E-09	24.1
40.3	5.7E-09	3.5E-09	3.2E-09	3.3E-09	6.1E-09	5.2E-09	6.2E-09	6.6E-09	6.6E-09	3.5E-09	4.0E-09	5.4E-09	1.3E-08	1.3E-08	8.8E-09	5.1E-09	40.3
56.3	3.7E-09	2.3E-09	2.1E-09	2.1E-09	4.1E-09	3.5E-09	4.2E-09	4.5E-09	4.5E-09	2.4E-09	2.7E-09	3.7E-09	9.2E-09	9.1E-09	5.9E-09	3.4E-09	56.3
72.4	2.7E-09	1.7E-09	1.6E-09	1.6E-09	3.0E-09	2.6E-09	3.1E-09	3.4E-09	3.4E-09	1.8E-09	2.0E-09	2.7E-09	6.9E-09	6.7E-09	4.3E-09	2.5E-09	72.4

Table 4.1-18. $\overline{X}/Q\rho$ Values (sec m^{-3}) for Chronic Ground-Level Releases from 300 Area Based on 1983 Through 1991 Meteorological Information (Schreckhise et al. 1993)

Distance (km)	S	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE	Distance (km)
	Sector (Wind from 100-N Towards Direction Indicated)																
0.1	2.9E-04	9.0E-05	5.1E-05	4.4E-05	1.2E-04	2.0E-04	2.8E-04	2.3E-04	3.0E-04	1.9E-04	1.9E-04	1.4E-04	1.7E-04	1.3E-04	1.8E-04	2.4E-04	0.1
0.2	7.8E-05	2.5E-05	1.4E-05	1.2E-05	3.2E-05	5.4E-05	7.6E-05	6.2E-05	8.3E-05	5.2E-05	5.3E-05	3.9E-05	4.6E-05	3.7E-05	4.8E-05	6.5E-05	0.2
0.3	3.8E-05	1.2E-05	6.5E-06	5.6E-06	1.5E-05	2.6E-05	3.7E-05	3.0E-05	4.0E-05	2.5E-05	2.5E-05	1.8E-05	2.2E-05	1.8E-05	2.3E-05	3.1E-05	0.3
0.4	2.2E-05	6.9E-06	3.8E-06	3.3E-06	8.8E-06	1.5E-05	2.2E-05	1.8E-05	2.4E-05	1.5E-05	1.5E-05	1.1E-05	1.3E-05	1.1E-05	1.4E-05	1.9E-05	0.4
0.5	1.5E-05	4.6E-06	2.5E-06	2.2E-06	5.9E-06	1.0E-05	1.5E-05	1.2E-05	1.6E-05	1.0E-05	1.0E-05	7.3E-06	8.8E-06	7.1E-06	9.3E-06	1.3E-05	0.5
0.6	1.1E-05	3.3E-06	1.8E-06	1.6E-06	4.2E-06	7.4E-06	1.1E-05	8.6E-06	1.2E-05	7.2E-06	7.3E-06	5.3E-06	6.4E-06	5.1E-06	6.7E-06	9.1E-06	0.6
0.7	8.3E-06	2.5E-06	1.4E-06	1.2E-06	3.2E-06	5.6E-06	8.1E-06	6.6E-06	8.8E-06	5.5E-06	5.5E-06	4.0E-06	4.9E-06	3.9E-06	5.1E-06	6.9E-06	0.7
0.8	6.5E-06	2.0E-06	1.1E-06	9.3E-07	2.5E-06	4.5E-06	6.4E-06	5.2E-06	6.9E-06	4.3E-06	4.4E-06	3.2E-06	3.9E-06	3.1E-06	4.1E-06	5.5E-06	0.8
0.9	5.3E-06	1.6E-06	8.7E-07	7.6E-07	2.1E-06	3.6E-06	5.2E-06	4.2E-06	5.6E-06	3.5E-06	3.6E-06	2.6E-06	3.1E-06	2.5E-06	3.3E-06	4.4E-06	0.9
1.0	4.4E-06	1.3E-06	7.2E-07	6.3E-07	1.7E-06	3.0E-06	4.3E-06	3.5E-06	4.7E-06	2.9E-06	3.0E-06	2.2E-06	2.6E-06	2.1E-06	2.7E-06	3.7E-06	1.0
2.4	1.0E-06	3.1E-07	1.7E-07	1.4E-07	3.9E-07	6.9E-07	1.0E-06	8.1E-07	1.1E-06	6.7E-07	6.8E-07	5.0E-07	6.0E-07	4.9E-07	6.4E-07	8.5E-07	2.4
4.0	4.7E-07	1.4E-07	7.5E-08	6.4E-08	1.8E-07	3.2E-07	4.6E-07	3.7E-07	5.0E-07	3.1E-07	3.1E-07	2.3E-07	2.8E-07	2.2E-07	2.9E-07	3.9E-07	4.0
5.6	2.8E-07	8.4E-08	4.5E-08	3.9E-08	1.1E-07	1.9E-07	2.8E-07	2.3E-07	3.0E-07	1.9E-07	1.9E-07	1.4E-07	1.7E-07	1.4E-07	1.8E-07	2.4E-07	5.6
7.2	2.0E-07	5.8E-08	3.1E-08	2.7E-08	7.4E-08	1.3E-07	2.0E-07	1.6E-07	2.1E-07	1.3E-07	1.3E-07	9.5E-08	1.2E-07	9.4E-08	1.2E-07	1.6E-07	7.2
12.1	9.6E-08	2.8E-08	1.5E-08	1.3E-08	3.6E-08	6.5E-08	9.5E-08	7.7E-08	1.0E-07	6.3E-08	6.3E-08	4.6E-08	5.6E-08	4.6E-08	6.0E-08	7.9E-08	12.1
24.1	3.7E-08	1.1E-08	5.7E-09	4.9E-09	1.4E-08	2.5E-08	3.7E-08	3.0E-08	3.9E-08	2.4E-08	2.4E-08	1.8E-08	2.2E-08	1.8E-08	2.3E-08	3.0E-08	24.1
40.3	1.8E-08	5.4E-09	2.9E-09	2.4E-09	6.9E-09	1.3E-08	1.8E-08	1.5E-08	2.0E-08	1.2E-08	1.2E-08	8.8E-09	1.1E-08	8.9E-09	1.1E-08	1.5E-08	40.3
56.3	1.2E-08	3.4E-09	1.8E-09	1.6E-09	4.4E-09	8.0E-09	1.2E-08	9.5E-09	1.3E-08	7.6E-09	7.7E-09	5.6E-09	6.9E-09	5.7E-09	7.3E-09	9.7E-09	56.3
72.4	8.4E-09	2.5E-09	1.3E-09	1.1E-09	3.2E-09	5.7E-09	8.5E-09	6.8E-09	9.0E-09	5.4E-09	5.5E-09	4.0E-09	4.9E-09	4.1E-09	5.2E-09	6.9E-09	72.4

Table 4.1-19. $\overline{X}/Q\rho$ Values (sec m^{-3}) for Chronic 60 m Stack Releases from 300 Area Based on 1983 Through 1991 Meteorological Information (Schreckhise et al. 1993)

Distance (km)	S	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE	Distance (km)
	Sector (Wind from 100-N Towards Direction Indicated)																
0.1	6.0E-10	5.6E-10	5.5E-10	4.7E-10	1.0E-09	6.2E-10	6.6E-10	5.4E-10	5.3E-10	5.5E-10	6.7E-10	5.2E-10	2.6E-10	1.2E-10	2.2E-10	3.2E-10	0.1
0.2	1.2E-07	1.1E-07	1.1E-07	9.1E-08	2.0E-07	1.2E-07	1.3E-07	1.1E-07	1.1E-07	1.1E-07	1.3E-07	1.0E-07	5.3E-08	2.6E-08	4.4E-08	6.5E-08	0.2
0.3	2.5E-07	2.1E-07	2.0E-07	1.8E-07	3.7E-07	2.3E-07	2.6E-07	2.1E-07	2.1E-07	2.1E-07	2.5E-07	2.0E-07	1.1E-07	5.5E-08	9.0E-08	1.4E-07	0.3
0.4	2.3E-07	1.9E-07	1.7E-07	1.5E-07	3.1E-07	2.0E-07	2.3E-07	1.8E-07	1.9E-07	1.9E-07	2.1E-07	1.7E-07	1.1E-07	5.4E-08	8.4E-08	1.4E-07	0.4
0.5	2.0E-07	1.5E-07	1.3E-07	1.2E-07	2.4E-07	1.6E-07	1.9E-07	1.5E-07	1.6E-07	1.6E-07	1.7E-07	1.3E-07	9.1E-08	4.9E-08	7.6E-08	1.2E-07	0.5
0.6	1.8E-07	1.3E-07	1.0E-07	9.9E-08	2.0E-07	1.4E-07	1.7E-07	1.3E-07	1.5E-07	1.4E-07	1.5E-07	1.1E-07	8.5E-08	4.8E-08	7.5E-08	1.2E-07	0.6
0.7	1.8E-07	1.1E-07	8.7E-08	8.7E-08	1.7E-07	1.4E-07	1.7E-07	1.3E-07	1.5E-07	1.4E-07	1.4E-07	1.1E-07	8.6E-08	5.0E-08	7.9E-08	1.3E-07	0.7
0.8	1.9E-07	1.1E-07	7.9E-08	8.0E-08	1.6E-07	1.4E-07	1.7E-07	1.3E-07	1.6E-07	1.4E-07	1.4E-07	1.1E-07	8.9E-08	5.3E-08	8.6E-08	1.4E-07	0.8
0.9	1.9E-07	1.1E-07	7.5E-08	7.5E-08	1.5E-07	1.4E-07	1.7E-07	1.3E-07	1.6E-07	1.4E-07	1.5E-07	1.1E-07	9.4E-08	5.7E-08	9.3E-08	1.5E-07	0.9
1.0	2.0E-07	1.0E-07	7.1E-08	7.2E-08	1.5E-07	1.4E-07	1.8E-07	1.4E-07	1.7E-07	1.5E-07	1.5E-07	1.1E-07	9.9E-08	6.1E-08	1.0E-07	1.5E-07	1.0
2.4	1.5E-07	6.0E-08	3.8E-08	3.6E-08	7.8E-08	1.0E-07	1.2E-07	1.0E-07	1.4E-07	1.1E-07	1.1E-07	8.3E-08	8.5E-08	5.9E-08	8.7E-08	1.2E-07	2.4
4.0	9.5E-08	3.7E-08	2.3E-08	2.1E-08	4.8E-08	6.7E-08	8.3E-08	7.0E-08	9.6E-08	7.2E-08	7.5E-08	5.4E-08	5.7E-08	4.1E-08	5.9E-08	8.2E-08	4.0
5.6	6.8E-08	2.5E-08	1.5E-08	1.4E-08	3.3E-08	4.8E-08	6.0E-08	5.0E-08	7.0E-08	5.1E-08	5.3E-08	3.9E-08	4.1E-08	3.0E-08	4.2E-08	5.9E-08	5.6
7.2	5.2E-08	1.9E-08	1.1E-08	1.1E-08	2.4E-08	3.6E-08	4.6E-08	3.9E-08	5.4E-08	3.9E-08	4.0E-08	2.9E-08	3.2E-08	2.3E-08	3.2E-08	4.5E-08	7.2
12.1	2.9E-08	1.0E-08	6.1E-09	5.5E-09	1.3E-08	2.0E-08	2.7E-08	2.2E-08	3.1E-08	2.1E-08	2.2E-08	1.6E-08	1.8E-08	1.3E-08	1.8E-08	2.5E-08	12.1
24.1	1.3E-08	4.4E-09	2.6E-09	2.3E-09	5.7E-09	9.0E-09	1.2E-08	1.0E-08	1.4E-08	9.2E-09	9.4E-09	6.9E-09	7.7E-09	5.9E-09	8.0E-09	1.1E-08	24.1
40.3	6.9E-09	2.3E-09	1.4E-09	1.2E-09	3.0E-09	4.8E-09	6.6E-09	5.4E-09	7.3E-09	4.9E-09	5.0E-09	3.7E-09	4.1E-09	3.2E-09	4.3E-09	5.8E-09	40.3
56.3	4.5E-09	1.5E-09	8.9E-10	7.9E-10	2.0E-09	3.2E-09	4.4E-09	3.6E-09	4.9E-09	3.2E-09	3.3E-09	2.4E-09	2.7E-09	2.1E-09	2.8E-09	3.8E-09	56.3
72.4	3.3E-09	1.1E-09	6.5E-10	5.8E-10	1.5E-09	2.3E-09	3.2E-09	2.7E-09	3.6E-09	2.3E-09	2.4E-09	1.8E-09	2.0E-09	1.6E-09	2.1E-09	2.8E-09	72.4

Table 4.1-20. $\overline{X}$/Qρ Values (sec m^{-3}) for Chronic Ground-Level Releases from 400 Area Based on 1983 Through 1991 Meteorological Information (Schreckhise et al. 1993)

Distance (km)	S	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE	Distance (km)
	Sector (Wind from 100-N Towards Direction Indicated)																
0.1	2.1E-04	1.4E-04	9.6E-05	6.9E-05	9.7E-05	8.5E-05	1.2E-04	1.9E-04	3.1E-04	2.2E-04	1.5E-04	9.9E-05	1.5E-04	1.5E-04	2.1E-04	1.7E-04	0.1
0.2	5.8E-05	3.9E-05	2.6E-05	1.9E-05	2.7E-05	2.3E-05	3.1E-05	5.1E-05	8.5E-05	6.0E-05	4.0E-05	2.7E-05	4.2E-05	4.2E-05	5.8E-05	4.8E-05	0.2
0.3	2.8E-05	1.8E-05	1.2E-05	8.9E-06	1.3E-05	1.1E-05	1.5E-05	2.5E-05	4.1E-05	2.9E-05	1.9E-05	1.3E-05	2.0E-05	2.0E-05	2.8E-05	2.3E-05	0.3
0.4	1.7E-05	1.1E-05	7.4E-06	5.3E-06	7.4E-06	6.5E-06	8.9E-06	1.5E-05	2.4E-05	1.7E-05	1.1E-05	7.7E-06	1.2E-05	1.2E-05	1.7E-05	1.4E-05	0.4
0.5	1.1E-05	7.3E-06	4.9E-06	3.5E-06	5.0E-06	4.3E-06	5.9E-06	9.8E-06	1.6E-05	1.2E-05	7.6E-06	5.2E-06	8.0E-06	8.0E-06	1.1E-05	9.1E-06	0.5
0.6	8.0E-06	5.3E-06	3.6E-06	2.5E-06	3.6E-06	3.1E-06	4.3E-06	7.1E-06	1.2E-05	8.3E-06	5.5E-06	3.8E-06	5.8E-06	5.8E-06	8.1E-06	6.6E-06	0.6
0.7	6.1E-06	4.0E-06	2.7E-06	1.9E-06	2.7E-06	2.4E-06	3.3E-06	5.4E-06	8.9E-06	6.3E-06	4.2E-06	2.9E-06	4.4E-06	4.4E-06	6.2E-06	5.0E-06	0.7
0.8	4.8E-06	3.2E-06	2.1E-06	1.5E-06	2.1E-06	1.9E-06	2.6E-06	4.3E-06	7.0E-06	5.0E-06	3.3E-06	2.3E-06	3.5E-06	3.5E-06	4.9E-06	4.0E-06	0.8
0.9	3.9E-06	2.6E-06	1.7E-06	1.2E-06	1.7E-06	1.5E-06	2.1E-06	3.5E-06	5.7E-06	4.0E-06	2.7E-06	1.8E-06	2.8E-06	2.8E-06	4.0E-06	3.2E-06	0.9
1.0	3.3E-06	2.1E-06	1.4E-06	1.0E-06	1.4E-06	1.3E-06	1.7E-06	2.9E-06	4.7E-06	3.4E-06	2.2E-06	1.5E-06	2.3E-06	2.3E-06	3.3E-06	2.7E-06	1.0
2.4	7.5E-07	4.9E-07	3.3E-07	2.3E-07	3.3E-07	2.9E-07	4.0E-07	6.7E-07	1.1E-06	7.8E-07	5.2E-07	3.5E-07	5.4E-07	5.4E-07	7.6E-07	6.2E-07	2.4
4.0	3.4E-07	2.2E-07	1.5E-07	1.1E-07	1.5E-07	1.3E-07	1.8E-07	3.1E-07	5.0E-07	3.5E-07	2.4E-07	1.6E-07	2.5E-07	2.5E-07	3.5E-07	2.8E-07	4.0
5.6	2.1E-07	1.4E-07	9.1E-08	6.4E-08	9.1E-08	8.0E-08	1.1E-07	1.9E-07	3.1E-07	2.2E-07	1.4E-07	9.8E-08	1.5E-07	1.5E-07	2.1E-07	1.7E-07	5.6
7.2	1.5E-07	9.5E-08	6.3E-08	4.4E-08	6.3E-08	5.5E-08	7.6E-08	1.3E-07	2.1E-07	1.5E-07	1.0E-07	6.8E-08	1.0E-07	1.0E-07	1.5E-07	1.2E-07	7.2
12.1	7.0E-08	4.6E-08	3.1E-08	2.1E-08	3.0E-08	2.7E-08	3.7E-08	6.2E-08	1.0E-07	7.2E-08	4.8E-08	3.3E-08	5.0E-08	5.0E-08	7.1E-08	5.8E-08	12.1
24.1	2.7E-08	1.8E-08	1.2E-08	8.2E-09	1.2E-08	1.0E-08	1.4E-08	2.4E-08	4.0E-08	2.8E-08	1.9E-08	1.3E-08	1.9E-08	1.9E-08	2.7E-08	2.2E-08	24.1
40.3	1.4E-08	8.9E-09	5.8E-09	4.1E-09	5.8E-09	5.1E-09	7.0E-09	1.2E-08	2.0E-08	1.4E-08	9.3E-09	6.3E-09	9.6E-09	9.5E-09	1.4E-08	1.1E-08	40.3
56.3	8.7E-09	5.7E-09	3.7E-09	2.6E-09	3.7E-09	3.2E-09	4.5E-09	7.6E-09	1.3E-08	8.8E-09	5.9E-09	4.0E-09	6.1E-09	6.0E-09	8.6E-09	7.0E-09	56.3
72.4	6.3E-09	4.1E-09	2.7E-09	1.9E-09	2.7E-09	2.3E-09	3.2E-09	5.5E-09	9.1E-09	6.3E-09	4.2E-09	2.9E-09	4.4E-09	4.3E-09	6.1E-09	5.0E-09	72.4

Table 4.1-21. $\overline{X}$/Qρ Values (sec m^{-3}) for Chronic 30 m Stack Releases from 400 Area Based on 1983 Through 1991 Meteorological Information (Schreckhise et al. 1993)

Distance (km)	S	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE	Distance (km)
	Sector (Wind from 100-N Towards Direction Indicated)																
0.1	6.3E-07	5.4E-07	4.3E-07	4.0E-07	5.3E-07	5.2E-07	4.6E-07	4.2E-07	9.4E-07	7.5E-07	3.9E-07	3.0E-07	4.0E-07	2.9E-07	3.3E-07	3.3E-07	0.1
0.2	1.1E-06	9.4E-07	7.4E-07	6.8E-07	9.1E-07	8.4E-07	7.9E-07	7.5E-07	1.6E-06	1.3E-06	6.8E-07	5.0E-07	6.8E-07	5.0E-07	6.1E-07	6.1E-07	0.2
0.3	9.7E-07	8.0E-07	6.3E-07	5.5E-07	7.5E-07	6.7E-07	7.0E-07	7.1E-07	1.3E-06	1.1E-06	6.1E-07	4.3E-07	6.1E-07	5.2E-07	6.7E-07	6.1E-07	0.3
0.4	9.3E-07	7.2E-07	5.7E-07	4.8E-07	6.5E-07	5.8E-07	6.5E-07	7.4E-07	1.3E-06	1.0E-06	6.1E-07	4.2E-07	6.2E-07	5.9E-07	7.8E-07	6.7E-07	0.4
0.5	9.0E-07	6.6E-07	5.3E-07	4.3E-07	6.0E-07	5.3E-07	6.2E-07	7.5E-07	1.3E-06	1.0E-06	6.1E-07	4.2E-07	6.4E-07	6.5E-07	8.6E-07	7.0E-07	0.5
0.6	8.6E-07	6.2E-07	4.9E-07	3.9E-07	5.4E-07	4.9E-07	5.8E-07	7.4E-07	1.2E-06	9.9E-07	6.1E-07	4.2E-07	6.4E-07	6.6E-07	8.8E-07	7.0E-07	0.6
0.7	8.1E-07	5.7E-07	4.6E-07	3.6E-07	5.0E-07	4.5E-07	5.4E-07	7.1E-07	1.2E-06	9.4E-07	5.9E-07	4.0E-07	6.2E-07	6.5E-07	8.6E-07	6.8E-07	0.7
0.8	7.6E-07	5.3E-07	4.2E-07	3.2E-07	4.5E-07	4.1E-07	5.0E-07	6.8E-07	1.1E-06	8.9E-07	5.6E-07	3.9E-07	5.9E-07	6.3E-07	8.2E-07	6.5E-07	0.8
0.9	7.1E-07	4.9E-07	3.9E-07	3.0E-07	4.1E-07	3.7E-07	4.7E-07	6.4E-07	1.0E-06	8.3E-07	5.3E-07	3.7E-07	5.6E-07	5.9E-07	7.8E-07	6.1E-07	0.9
1.0	6.6E-07	4.5E-07	3.6E-07	2.7E-07	3.8E-07	3.4E-07	4.3E-07	6.0E-07	9.8E-07	7.7E-07	5.0E-07	3.4E-07	5.2E-07	5.6E-07	7.3E-07	5.7E-07	1.0
2.4	2.9E-07	1.9E-07	1.4E-07	1.1E-07	1.5E-07	1.3E-07	1.8E-07	2.7E-07	4.4E-07	3.3E-07	2.2E-07	1.5E-07	2.3E-07	2.4E-07	3.2E-07	2.5E-07	2.4
4.0	1.6E-07	1.1E-07	7.6E-08	5.6E-08	7.9E-08	7.0E-08	9.3E-08	1.5E-07	2.4E-07	1.8E-07	1.2E-07	8.2E-08	1.2E-07	1.3E-07	1.7E-07	1.4E-07	4.0
5.6	1.0E-07	6.9E-08	4.9E-08	3.6E-08	5.1E-08	4.5E-08	6.0E-08	9.5E-08	1.6E-07	1.2E-07	7.7E-08	5.3E-08	8.0E-08	8.3E-08	1.1E-07	8.9E-08	5.6
7.2	7.6E-08	5.0E-08	3.6E-08	2.6E-08	3.6E-08	3.2E-08	4.3E-08	6.9E-08	1.2E-07	8.3E-08	5.6E-08	3.8E-08	5.8E-08	5.9E-08	8.1E-08	6.4E-08	7.2
12.1	3.9E-08	2.6E-08	1.8E-08	1.3E-08	1.8E-08	1.6E-08	2.2E-08	3.6E-08	5.9E-08	4.3E-08	2.9E-08	2.0E-08	3.0E-08	3.0E-08	4.1E-08	3.3E-08	12.1
24.1	1.6E-08	1.1E-08	7.3E-09	5.2E-09	7.4E-09	6.5E-09	8.8E-09	1.4E-08	2.4E-08	1.7E-08	1.2E-08	7.9E-09	1.2E-08	1.2E-08	1.7E-08	1.3E-08	24.1
40.3	8.3E-09	5.5E-09	3.7E-09	2.7E-09	3.8E-09	3.3E-09	4.5E-09	7.4E-09	1.2E-08	8.8E-09	5.9E-09	4.0E-09	6.1E-09	6.1E-09	8.4E-09	6.8E-09	40.3
56.3	5.4E-09	3.5E-09	2.4E-09	1.7E-09	2.4E-09	2.1E-09	2.9E-09	4.8E-09	8.0E-09	5.7E-09	3.8E-09	2.6E-09	3.9E-09	3.9E-09	5.4E-09	4.4E-09	56.3
72.4	3.9E-09	2.6E-09	1.7E-09	1.3E-09	1.8E-09	1.5E-09	2.1E-09	3.5E-09	5.8E-09	4.1E-09	2.7E-09	1.9E-09	2.8E-09	2.8E-09	3.9E-09	3.2E-09	72.4

Table 4.1-22. 95th Percentile E/Q Values (sec m^{-3}) for Acute Ground Level Releases from 100-N Area Based on 1983 Through 1991 Meteorological Information (Schreckhise et al. 1993)

Distance	Sector (Wind from 100-N Towards Direction Indicated)																Distance
(km)	S	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE	(km)
0.1	6.3E-02	5.1E-02	6.7E-02	7.3E-02	6.9E-02	5.8E-02	5.5E-02	5.3E-02	6.1E-02	5.8E-02	5.5E-02	5.6E-02	5.3E-02	5.7E-02	6.9E-02	7.5E-02	0.1
0.2	1.9E-02	1.5E-02	2.0E-02	2.2E-02	2.1E-02	1.8E-02	1.7E-02	1.6E-02	1.8E-02	1.8E-02	1.6E-02	1.7E-02	1.6E-02	1.7E-02	2.1E-02	2.3E-02	0.2
0.3	9.5E-03	7.7E-03	1.0E-02	1.1E-02	1.0E-02	8.8E-03	8.3E-03	8.0E-03	9.2E-03	8.8E-03	8.3E-03	8.5E-03	8.0E-03	8.6E-03	1.0E-02	1.1E-02	0.3
0.4	5.8E-03	4.8E-03	6.3E-03	6.8E-03	6.5E-03	5.4E-03	5.1E-03	4.9E-03	5.7E-03	5.4E-03	5.1E-03	5.2E-03	4.9E-03	5.3E-03	6.4E-03	7.0E-03	0.4
0.5	4.0E-03	3.3E-03	4.3E-03	4.7E-03	4.4E-03	3.7E-03	3.5E-03	3.4E-03	3.9E-03	3.7E-03	3.5E-03	3.6E-03	3.4E-03	3.6E-03	4.4E-03	4.8E-03	0.5
0.6	3.0E-03	2.4E-03	3.2E-03	3.4E-03	3.3E-03	2.8E-03	2.6E-03	2.5E-03	2.9E-03	2.8E-03	2.6E-03	2.6E-03	2.5E-03	2.7E-03	3.2E-03	3.5E-03	0.6
0.7	2.3E-03	1.9E-03	2.5E-03	2.7E-03	2.5E-03	2.1E-03	2.0E-03	1.9E-03	2.2E-03	2.1E-03	2.0E-03	2.0E-03	1.9E-03	2.1E-03	2.5E-03	2.7E-03	0.7
0.8	1.8E-03	1.5E-03	2.0E-03	2.1E-03	2.0E-03	1.7E-03	1.6E-03	1.5E-03	1.8E-03	1.7E-03	1.6E-03	1.6E-03	1.6E-03	1.7E-03	2.0E-03	2.2E-03	0.8
0.9	1.5E-03	1.2E-03	1.6E-03	1.8E-03	1.7E-03	1.4E-03	1.3E-03	1.3E-03	1.5E-03	1.4E-03	1.3E-03	1.3E-03	1.3E-03	1.4E-03	1.6E-03	1.8E-03	0.9
1.0	1.3E-03	1.0E-03	1.4E-03	1.5E-03	1.4E-03	1.2E-03	1.1E-03	1.1E-03	1.2E-03	1.2E-03	1.1E-03	1.1E-03	1.1E-03	1.1E-03	1.4E-03	1.5E-03	1.0
2.4	3.2E-04	2.6E-04	3.5E-04	3.8E-04	3.6E-04	3.0E-04	2.8E-04	2.7E-04	3.2E-04	3.0E-04	2.8E-04	2.9E-04	2.7E-04	2.9E-04	3.5E-04	3.9E-04	2.4
4.0	1.6E-04	1.3E-04	1.7E-04	1.8E-04	1.8E-04	1.5E-04	1.4E-04	1.3E-04	1.5E-04	1.5E-04	1.4E-04	1.4E-04	1.3E-04	1.4E-04	1.7E-04	1.9E-04	4.0
5.6	1.0E-04	8.2E-05	1.1E-04	1.2E-04	1.1E-04	9.4E-05	8.8E-05	8.5E-05	9.9E-05	9.4E-05	8.8E-05	9.0E-05	8.5E-05	9.2E-05	1.1E-04	1.2E-04	5.6
7.2	7.3E-05	5.9E-05	7.8E-05	8.5E-05	8.0E-05	6.8E-05	6.4E-05	6.1E-05	7.1E-05	6.8E-05	6.3E-05	6.5E-05	6.2E-05	6.6E-05	8.0E-05	8.7E-05	7.2
12.1	3.8E-05	3.1E-05	4.1E-05	4.4E-05	4.2E-05	3.5E-05	3.3E-05	3.2E-05	3.7E-05	3.5E-05	3.3E-05	3.4E-05	3.2E-05	3.4E-05	4.1E-05	4.5E-05	12.1
24.1	1.6E-05	1.3E-05	1.7E-05	1.9E-05	1.8E-05	1.5E-05	1.4E-05	1.3E-05	1.6E-05	1.5E-05	1.4E-05	1.4E-05	1.4E-05	1.5E-05	1.8E-05	1.9E-05	24.1
40.3	8.6E-06	7.0E-06	9.2E-06	1.0E-05	9.5E-06	8.0E-06	7.5E-06	7.2E-06	8.4E-06	8.0E-06	7.5E-06	7.7E-06	7.3E-06	7.8E-06	9.4E-06	1.0E-05	40.3
56.3	5.8E-06	4.7E-06	6.2E-06	6.7E-06	6.4E-06	5.4E-06	5.0E-06	4.8E-06	5.6E-06	5.4E-06	5.0E-06	5.1E-06	4.9E-06	5.2E-06	6.3E-06	6.9E-06	56.3
72.4	4.3E-06	3.5E-06	4.6E-06	5.0E-06	4.7E-06	4.0E-06	3.7E-06	3.6E-06	4.2E-06	4.0E-06	3.7E-06	3.8E-06	3.6E-06	3.9E-06	4.7E-06	5.1E-06	72.4

Table 4.1-23. 95th Percentile E/Q Values (sec m^{-3}) for Acute 60 m Stack Releases from 100-N Area Based on 1983 Through 1991 Meteorological Information (Schreckhise et al. 1993)

Distance	Sector (Wind from 100-N Towards Direction Indicated)																Distance
(km)	S	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE	(km)
0.1	1.3E-07	8.4E-08	9.0E-08	5.3E-08	7.4E-08	7.5E-08	5.4E-08	5.8E-08	8.4E-08	5.1E-08	5.0E-08	4.7E-08	4.7E-08	5.7E-08	1.2E-07	1.4E-07	0.1
0.2	2.5E-05	1.6E-05	1.8E-05	1.0E-05	1.5E-05	1.5E-05	1.1E-05	1.1E-05	1.7E-05	9.9E-06	9.7E-06	8.9E-06	8.8E-06	1.1E-05	2.3E-05	2.7E-05	0.2
0.3	4.1E-05	2.8E-05	3.1E-05	2.6E-05	3.1E-05	3.1E-05	2.7E-05	3.0E-05	3.5E-05	2.5E-05	2.2E-05	1.8E-05	1.8E-05	2.5E-05	4.1E-05	4.6E-05	0.3
0.4	3.7E-05	2.1E-05	2.9E-05	2.5E-05	3.0E-05	3.0E-05	2.5E-05	3.1E-05	3.5E-05	2.4E-05	1.6E-05	1.5E-05	1.5E-05	1.9E-05	3.7E-05	4.1E-05	0.4
0.5	3.0E-05	2.1E-05	2.6E-05	2.5E-05	2.6E-05	2.7E-05	2.6E-05	2.8E-05	3.0E-05	2.4E-05	1.5E-05	1.3E-05	1.2E-05	1.8E-05	2.8E-05	3.1E-05	0.5
0.6	2.8E-05	1.5E-05	1.8E-05	1.6E-05	1.8E-05	2.0E-05	1.7E-05	2.2E-05	2.9E-05	1.6E-05	1.4E-05	1.4E-05	1.3E-05	1.4E-05	2.3E-05	2.9E-05	0.6
0.7	1.4E-05	1.3E-05	1.4E-05	1.4E-05	1.4E-05	1.4E-05	1.4E-05	1.5E-05	1.5E-05	1.3E-05	1.3E-05	1.2E-05	1.2E-05	1.2E-05	1.3E-05	1.5E-05	0.7
0.8	2.4E-05	2.0E-05	2.2E-05	2.3E-05	2.4E-05	2.5E-05	2.5E-05	2.5E-05	2.6E-05	2.3E-05	2.0E-05	1.6E-05	1.5E-05	1.6E-05	2.2E-05	2.4E-05	0.8
0.9	2.3E-05	2.2E-05	2.2E-05	2.3E-05	2.3E-05	2.3E-05	2.3E-05	2.3E-05	2.3E-05	2.3E-05	2.2E-05	1.8E-05	1.6E-05	2.0E-05	2.2E-05	2.3E-05	0.9
1.0	2.8E-05	2.5E-05	2.5E-05	2.7E-05	2.8E-05	2.9E-05	2.8E-05	2.8E-05	3.0E-05	2.7E-05	2.5E-05	2.2E-05	2.0E-05	2.2E-05	2.5E-05	2.7E-05	1.0
2.4	2.3E-05	2.2E-05	2.3E-05	2.3E-05	2.3E-05	2.3E-05	2.3E-05	2.3E-05	2.3E-05	2.3E-05	2.3E-05	2.2E-05	2.1E-05	2.2E-05	2.3E-05	2.3E-05	2.4
4.0	1.7E-05	1.7E-05	1.8E-05	1.8E-05	1.8E-05	1.8E-05	1.8E-05	1.8E-05	1.9E-05	1.8E-05	1.7E-05	1.6E-05	1.4E-05	1.5E-05	1.7E-05	1.8E-05	4.0
5.6	1.4E-05	1.4E-05	1.5E-05	1.5E-05	1.5E-05	1.5E-05	1.4E-05	1.4E-05	1.5E-05	1.5E-05	1.4E-05	1.4E-05	1.4E-05	1.4E-05	1.4E-05	1.5E-05	5.6
7.2	1.3E-05	1.2E-05	1.3E-05	1.3E-05	1.3E-05	1.3E-05	1.3E-05	1.3E-05	1.3E-05	1.3E-05	1.2E-05	1.2E-05	1.1E-05	1.2E-05	1.3E-05	1.3E-05	7.2
12.1	8.5E-06	7.6E-06	8.7E-06	9.8E-06	9.6E-06	8.6E-06	8.4E-06	7.9E-06	8.8E-06	8.7E-06	7.7E-06	7.4E-06	6.6E-06	7.2E-06	8.7E-06	9.4E-06	12.1
24.1	5.6E-06	5.5E-06	5.7E-06	5.9E-06	5.8E-06	5.6E-06	5.6E-06	5.5E-06	5.7E-06	5.6E-06	5.5E-06	5.4E-06	5.2E-06	5.5E-06	5.7E-06	5.8E-06	24.1
40.3	3.6E-06	3.4E-06	3.8E-06	4.2E-06	4.1E-06	3.7E-06	3.6E-06	3.4E-06	3.8E-06	3.7E-06	3.4E-06	3.3E-06	3.1E-06	3.3E-06	3.9E-06	4.1E-06	40.3
56.3	2.7E-06	2.5E-06	2.8E-06	3.2E-06	3.1E-06	2.7E-06	2.6E-06	2.5E-06	2.8E-06	2.7E-06	2.4E-06	2.3E-06	2.2E-06	2.4E-06	2.9E-06	3.2E-06	56.3
72.4	2.1E-06	1.9E-06	2.2E-06	2.6E-06	2.5E-06	2.1E-06	2.0E-06	1.9E-06	2.2E-06	2.1E-06	1.9E-06	1.8E-06	1.7E-06	1.8E-06	2.3E-06	2.6E-06	72.4

Table 4.1-24. 95th Percentile E/Q Values (sec m^{-3}) for Acute Ground-Level Releases from 200 Areas Based on 1983 Through 1991 Meteorological Information (Schreckhise et al. 1993)

Distance (km)	S	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE	Distance (km)
						Sector (Wind from 100-N Towards Direction Indicated)											
0.1	3.0E-02	2.4E-02	3.4E-02	4.1E-02	4.5E-02	4.7E-02	4.3E-02	4.5E-02	5.9E-02	6.0E-02	3.9E-02	3.2E-02	3.2E-02	2.7E-02	3.0E-02	3.3E-02	0.1
0.2	9.1E-03	7.3E-03	1.0E-02	1.2E-02	1.4E-02	1.4E-02	1.3E-02	1.4E-02	1.8E-02	1.8E-02	1.2E-02	9.8E-03	9.7E-03	8.2E-03	9.0E-03	1.0E-02	0.2
0.3	4.6E-03	3.6E-03	5.1E-03	6.2E-03	6.8E-03	7.2E-03	6.5E-03	6.8E-03	9.0E-03	9.1E-03	5.9E-03	4.9E-03	4.9E-03	4.1E-03	4.5E-03	5.0E-03	0.3
0.4	2.8E-03	2.2E-03	3.2E-03	3.8E-03	4.2E-03	4.4E-03	4.0E-03	4.2E-03	5.5E-03	5.6E-03	3.7E-03	3.0E-03	3.0E-03	2.5E-03	2.8E-03	3.1E-03	0.4
0.5	1.9E-03	1.5E-03	2.2E-03	2.6E-03	2.9E-03	3.0E-03	2.8E-03	2.9E-03	3.8E-03	3.9E-03	2.5E-03	2.1E-03	2.1E-03	1.7E-03	1.9E-03	2.1E-03	0.5
0.6	1.4E-03	1.1E-03	1.6E-03	1.9E-03	2.1E-03	2.2E-03	2.0E-03	2.1E-03	2.8E-03	2.8E-03	1.9E-03	1.5E-03	1.5E-03	1.3E-03	1.4E-03	1.6E-03	0.6
0.7	1.1E-03	8.8E-04	1.2E-03	1.5E-03	1.6E-03	1.7E-03	1.6E-03	1.6E-03	2.2E-03	2.2E-03	1.4E-03	1.2E-03	1.2E-03	9.9E-04	1.1E-03	1.2E-03	0.7
0.8	8.8E-04	7.1E-04	9.9E-04	1.2E-03	1.3E-03	1.4E-03	1.3E-03	1.3E-03	1.7E-03	1.8E-03	1.1E-03	9.5E-04	9.4E-04	7.9E-04	8.8E-04	9.7E-04	0.8
0.9	7.3E-04	5.8E-04	8.2E-04	9.8E-04	1.1E-03	1.1E-03	1.0E-03	1.1E-03	1.4E-03	1.4E-03	9.4E-04	7.8E-04	7.8E-04	6.5E-04	7.2E-04	8.0E-04	0.9
1.0	6.1E-04	4.9E-04	6.8E-04	8.3E-04	9.1E-04	9.6E-04	8.7E-04	9.1E-04	1.2E-03	1.2E-03	7.9E-04	6.5E-04	6.5E-04	5.5E-04	6.0E-04	6.7E-04	1.0
2.4	1.6E-04	1.3E-04	1.7E-04	2.1E-04	2.3E-04	2.4E-04	2.2E-04	2.3E-04	3.1E-04	3.1E-04	2.0E-04	1.7E-04	1.7E-04	1.4E-04	1.5E-04	1.7E-04	2.4
4.0	7.6E-05	6.1E-05	8.5E-05	1.0E-04	1.1E-04	1.2E-04	1.1E-04	1.1E-04	1.5E-04	1.5E-04	9.9E-05	8.2E-05	8.1E-05	6.9E-05	7.6E-05	8.4E-05	4.0
5.6	4.9E-05	3.9E-05	5.4E-05	6.6E-05	7.2E-05	7.6E-05	6.9E-05	7.2E-05	9.6E-05	9.7E-05	6.3E-05	5.2E-05	5.2E-05	4.4E-05	4.8E-05	5.3E-05	5.6
7.2	3.5E-05	2.8E-05	3.9E-05	4.7E-05	5.2E-05	5.5E-05	5.0E-05	5.2E-05	6.9E-05	7.0E-05	4.5E-05	3.7E-05	3.7E-05	3.2E-05	3.5E-05	3.8E-05	7.2
12.1	1.8E-05	1.4E-05	2.0E-05	2.5E-05	2.7E-05	2.9E-05	2.6E-05	2.7E-05	3.6E-05	3.6E-05	2.4E-05	1.9E-05	1.9E-05	1.6E-05	1.8E-05	2.0E-05	12.1
24.1	7.7E-06	6.0E-06	8.6E-06	1.0E-05	1.1E-05	1.2E-05	1.1E-05	1.1E-05	1.5E-05	1.5E-05	1.0E-05	8.3E-06	8.2E-06	7.0E-06	7.7E-06	8.4E-06	24.1
40.3	4.1E-06	3.2E-06	4.6E-06	5.6E-06	6.1E-06	6.5E-06	5.9E-06	6.2E-06	8.2E-06	8.3E-06	5.4E-06	4.4E-06	4.4E-06	3.7E-06	4.1E-06	4.5E-06	40.3
56.3	2.8E-06	2.1E-06	3.1E-06	3.7E-06	4.1E-06	4.4E-06	3.9E-06	4.1E-06	5.5E-06	5.5E-06	3.6E-06	3.0E-06	3.0E-06	2.5E-06	2.8E-06	3.0E-06	56.3
72.4	2.1E-06	1.6E-06	2.3E-06	2.8E-06	3.1E-06	3.2E-06	2.9E-06	3.1E-06	4.0E-06	4.1E-06	2.7E-06	2.2E-06	2.2E-06	1.9E-06	2.0E-06	2.3E-06	72.4

Table 4.1-25. 95th Percentile E/Q Values (sec m^{-3}) for Acute 60 m Stack Releases from 200 Areas Based on 1983 Through 1991 Meteorological Information (Schreckhise et al. 1993)

Distance (km)	S	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE	Distance (km)
						Sector (Wind from 100-N Towards Direction Indicated)											
0.1	1.3E-07	1.1E-07	1.4E-07	1.6E-07	1.5E-07	1.4E-07	1.1E-07	5.2E-08	5.2E-08	5.2E-08	4.1E-08	3.3E-08	2.0E-08	1.5E-08	3.6E-08	1.1E-07	0.1
0.2	2.6E-05	2.2E-05	2.8E-05	3.1E-05	3.0E-05	2.7E-05	2.1E-05	1.0E-05	1.0E-05	1.0E-05	6.3E-06	6.1E-06	4.3E-06	3.2E-06	6.2E-06	2.1E-05	0.2
0.3	4.4E-05	3.6E-05	5.0E-05	5.5E-05	5.3E-05	4.5E-05	3.2E-05	2.0E-05	2.3E-05	2.1E-05	1.3E-05	1.1E-05	8.3E-06	6.8E-06	1.3E-05	3.3E-05	0.3
0.4	4.0E-05	3.7E-05	4.3E-05	4.5E-05	4.3E-05	4.1E-05	2.8E-05	1.6E-05	1.6E-05	1.6E-05	1.2E-05	9.2E-06	7.6E-06	7.0E-06	1.4E-05	3.1E-05	0.4
0.5	3.0E-05	3.0E-05	3.4E-05	3.8E-05	3.4E-05	3.1E-05	2.5E-05	1.4E-05	1.6E-05	1.4E-05	8.7E-06	8.6E-06	5.6E-06	5.0E-06	1.0E-05	2.7E-05	0.5
0.6	2.7E-05	2.6E-05	3.7E-05	4.1E-05	3.8E-05	3.1E-05	1.6E-05	1.4E-05	1.4E-05	1.4E-05	7.4E-06	6.8E-06	5.9E-06	5.5E-06	1.1E-05	1.9E-05	0.6
0.7	1.6E-05	1.7E-05	2.7E-05	3.6E-05	2.9E-05	2.3E-05	1.4E-05	1.2E-05	1.2E-05	1.2E-05	1.2E-05	8.5E-06	5.5E-06	4.4E-06	1.2E-05	1.4E-05	0.7
0.8	2.4E-05	2.5E-05	2.7E-05	3.1E-05	2.7E-05	2.6E-05	2.1E-05	1.7E-05	1.6E-05	1.7E-05	1.4E-05	7.6E-06	6.5E-06	6.0E-06	1.4E-05	2.3E-05	0.8
0.9	2.3E-05	2.3E-05	2.3E-05	2.7E-05	2.3E-05	2.3E-05	2.2E-05	2.0E-05	1.9E-05	2.1E-05	1.4E-05	7.4E-06	7.1E-06	7.1E-06	1.5E-05	2.2E-05	0.9
1.0	2.7E-05	2.7E-05	3.0E-05	3.1E-05	3.0E-05	2.8E-05	2.6E-05	2.3E-05	2.2E-05	2.3E-05	1.8E-05	8.3E-06	7.5E-06	7.3E-06	1.8E-05	2.6E-05	1.0
2.4	2.2E-05	2.2E-05	2.3E-05	2.3E-05	2.3E-05	2.3E-05	2.3E-05	2.3E-05	2.3E-05	2.3E-05	2.2E-05	1.1E-05	9.6E-06	8.6E-06	1.7E-05	2.3E-05	2.4
4.0	1.5E-05	1.4E-05	1.7E-05	1.7E-05	1.7E-05	1.8E-05	1.7E-05	1.7E-05	1.8E-05	1.7E-05	1.6E-05	1.4E-05	1.3E-05	9.4E-06	1.4E-05	1.6E-05	4.0
5.6	1.3E-05	1.3E-05	1.4E-05	1.4E-05	1.4E-05	1.4E-05	1.4E-05	1.5E-05	1.5E-05	1.5E-05	1.4E-05	1.4E-05	1.1E-05	6.6E-06	1.1E-05	1.4E-05	5.6
7.2	1.0E-05	1.0E-05	1.2E-05	1.2E-05	1.2E-05	1.3E-05	1.3E-05	1.3E-05	1.3E-05	1.3E-05	1.2E-05	1.1E-05	8.3E-06	4.9E-06	8.1E-06	1.1E-05	7.2
12.1	6.5E-06	5.7E-06	6.6E-06	6.6E-06	7.1E-06	8.0E-06	8.6E-06	9.0E-06	9.3E-06	8.7E-06	6.8E-06	6.6E-06	6.5E-06	3.5E-06	5.7E-06	6.6E-06	12.1
24.1	3.0E-06	2.7E-06	4.5E-06	4.8E-06	5.4E-06	5.6E-06	5.7E-06	5.8E-06	5.8E-06	5.7E-06	5.1E-06	4.1E-06	3.5E-06	2.0E-06	2.5E-06	4.2E-06	24.1
40.3	1.7E-06	1.6E-06	2.7E-06	2.9E-06	3.3E-06	3.5E-06	3.8E-06	4.0E-06	4.1E-06	3.8E-06	3.1E-06	2.4E-06	2.0E-06	1.4E-06	1.6E-06	2.5E-06	40.3
56.3	1.1E-06	1.0E-06	1.3E-06	1.8E-06	2.3E-06	2.5E-06	2.8E-06	3.1E-06	3.1E-06	2.9E-06	2.1E-06	1.6E-06	1.7E-06	9.7E-07	1.1E-06	1.4E-06	56.3
72.4	8.6E-07	7.6E-07	1.1E-06	1.4E-06	1.8E-06	2.0E-06	2.2E-06	2.5E-06	2.5E-06	2.3E-06	1.6E-06	1.3E-06	1.3E-06	7.2E-07	8.5E-07	1.1E-06	72.4

Table 4.1-26. 95th Percentile E/Q Values (sec m^{-3}) for Acute Ground-Level Releases from 300 Area Based on 1983 Through 1991 Meteorological Information (Schreckhise et al. 1993)

Distance (km)	S	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE	Distance (km)
	Sector (Wind from 100-N Towards Direction Indicated)																
0.1	3.0E-02	2.4E-02	3.0E-02	2.9E-02	3.4E-02	3.2E-02	3.3E-02	5.1E-02	4.9E-02	3.1E-02	3.0E-02	3.3E-02	6.3E-02	7.4E-02	5.6E-02	3.4E-02	0.1
0.2	9.2E-03	7.3E-03	9.2E-03	8.7E-03	1.0E-02	9.8E-03	1.0E-02	1.5E-02	1.5E-02	9.3E-03	9.0E-03	9.9E-03	1.9E-02	2.2E-02	1.7E-02	1.0E-02	0.2
0.3	4.6E-03	3.6E-03	4.6E-03	4.4E-03	5.1E-03	4.9E-03	5.1E-03	7.7E-03	7.5E-03	4.7E-03	4.5E-03	5.0E-03	9.5E-03	1.1E-02	8.4E-03	5.2E-03	0.3
0.4	2.8E-03	2.2E-03	2.8E-03	2.7E-03	3.2E-03	3.0E-03	3.1E-03	4.7E-03	4.6E-03	2.9E-03	2.8E-03	3.1E-03	5.9E-03	6.9E-03	5.2E-03	3.2E-03	0.4
0.5	2.0E-03	1.5E-03	2.0E-03	1.8E-03	2.2E-03	2.1E-03	2.1E-03	3.3E-03	3.2E-03	2.0E-03	1.9E-03	2.1E-03	4.0E-03	4.7E-03	3.6E-03	2.2E-03	0.5
0.6	1.4E-03	1.1E-03	1.4E-03	1.4E-03	1.6E-03	1.5E-03	1.6E-03	2.4E-03	2.3E-03	1.5E-03	1.4E-03	1.6E-03	3.0E-03	3.5E-03	2.6E-03	1.6E-03	0.6
0.7	1.1E-03	8.8E-04	1.1E-03	1.1E-03	1.2E-03	1.2E-03	1.2E-03	1.9E-03	1.8E-03	1.1E-03	1.1E-03	1.2E-03	2.3E-03	2.7E-03	2.0E-03	1.2E-03	0.7
0.8	8.9E-04	7.0E-04	8.9E-04	8.5E-04	9.9E-04	9.5E-04	9.8E-04	1.5E-03	1.4E-03	9.0E-04	8.7E-04	9.6E-04	1.8E-03	2.2E-03	1.6E-03	1.0E-03	0.8
0.9	7.3E-04	5.8E-04	7.3E-04	7.0E-04	8.2E-04	7.8E-04	8.1E-04	1.2E-03	1.2E-03	7.4E-04	7.2E-04	7.9E-04	1.5E-03	1.8E-03	1.3E-03	8.2E-04	0.9
1.0	6.2E-04	4.9E-04	6.2E-04	5.8E-04	6.9E-04	6.5E-04	6.8E-04	1.0E-03	1.0E-03	6.2E-04	6.0E-04	6.6E-04	1.3E-03	1.5E-03	1.1E-03	6.9E-04	1.0
2.4	1.6E-04	1.2E-04	1.6E-04	1.5E-04	1.7E-04	1.7E-04	1.7E-04	2.6E-04	2.5E-04	1.6E-04	1.5E-04	1.7E-04	3.3E-04	3.8E-04	2.9E-04	1.7E-04	2.4
4.0	7.7E-05	6.1E-05	7.7E-05	7.2E-05	8.5E-05	8.2E-05	8.4E-05	1.3E-04	1.3E-04	7.8E-05	7.6E-05	8.3E-05	1.6E-04	1.9E-04	1.4E-04	8.6E-05	4.0
5.6	4.9E-05	3.9E-05	4.9E-05	4.6E-05	5.4E-05	5.2E-05	5.4E-05	8.2E-05	8.0E-05	5.0E-05	4.8E-05	5.3E-05	1.0E-04	1.2E-04	9.0E-05	5.5E-05	5.6
7.2	3.5E-05	2.8E-05	3.5E-05	3.3E-05	3.9E-05	3.7E-05	3.9E-05	5.9E-05	5.7E-05	3.6E-05	3.5E-05	3.8E-05	7.3E-05	8.6E-05	6.5E-05	3.9E-05	7.2
12.1	1.8E-05	1.5E-05	1.8E-05	1.7E-05	2.0E-05	2.0E-05	2.0E-05	3.1E-05	3.0E-05	1.9E-05	1.8E-05	2.0E-05	3.8E-05	4.5E-05	3.4E-05	2.0E-05	12.1
24.1	7.8E-06	6.2E-06	7.8E-06	7.2E-06	8.6E-06	8.3E-06	8.5E-06	1.3E-05	1.3E-05	7.9E-06	7.6E-06	8.4E-06	1.6E-05	1.9E-05	1.4E-05	8.7E-06	24.1
40.3	4.2E-06	3.3E-06	4.2E-06	3.8E-06	4.6E-06	4.4E-06	4.6E-06	7.0E-06	6.8E-06	4.2E-06	4.1E-06	4.5E-06	8.7E-06	1.0E-05	7.7E-06	4.7E-06	40.3
56.3	2.8E-06	2.2E-06	2.8E-06	2.6E-06	3.1E-06	3.0E-06	3.1E-06	4.7E-06	4.5E-06	2.8E-06	2.7E-06	3.0E-06	5.8E-06	6.8E-06	5.1E-06	3.1E-06	56.3
72.4	2.1E-06	1.6E-06	2.1E-06	1.9E-06	2.3E-06	2.2E-06	2.3E-06	3.5E-06	3.4E-06	2.1E-06	2.0E-06	2.2E-06	4.3E-06	5.0E-06	3.8E-06	2.3E-06	72.4

Table 4.1-27. 95th Percentile E/Q Values (sec m^{-3}) for Acute 60 m Stack Releases from 300 Area Based on 1983 Through 1991 Meteorological Information (Schreckhise et al. 1993)

Distance (km)	S	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE	Distance (km)
	Sector (Wind from 100-N Towards Direction Indicated)																
0.1	2.5E-08	4.7E-08	1.0E-07	1.2E-07	1.2E-07	5.0E-08	4.2E-08	4.5E-08	2.9E-08	2.9E-08	3.0E-08	3.1E-08	2.5E-08	1.8E-08	1.4E-08	6.3E-09	0.1
0.2	5.4E-06	7.3E-06	2.1E-05	2.4E-05	2.5E-05	9.6E-06	7.4E-06	8.2E-06	6.0E-06	6.0E-06	6.0E-06	6.1E-06	5.6E-06	4.7E-06	3.1E-06	3.4E-06	0.2
0.3	1.1E-05	1.6E-05	3.0E-05	3.3E-05	3.3E-05	1.8E-05	1.6E-05	1.8E-05	1.1E-05	1.1E-05	1.1E-05	1.1E-05	1.1E-05	9.0E-06	6.7E-06	8.5E-06	0.3
0.4	1.0E-05	1.5E-05	2.1E-05	3.1E-05	2.9E-05	1.5E-05	1.5E-05	1.6E-05	1.2E-05	9.4E-06	8.7E-06	1.0E-05	1.1E-05	9.0E-06	7.5E-06	8.8E-06	0.4
0.5	8.8E-06	1.2E-05	2.1E-05	2.8E-05	2.5E-05	1.3E-05	1.2E-05	1.5E-05	8.8E-06	8.7E-06	8.2E-06	8.7E-06	8.8E-06	8.7E-06	6.7E-06	8.7E-06	0.5
0.6	7.7E-06	1.4E-05	1.5E-05	2.2E-05	1.6E-05	1.4E-05	1.4E-05	1.4E-05	7.7E-06	7.7E-06	7.3E-06	7.7E-06	7.7E-06	7.5E-06	7.4E-06	7.7E-06	0.6
0.7	1.2E-05	1.2E-05	1.3E-05	2.0E-05	1.4E-05	1.2E-05	1.2E-05	1.2E-05	1.2E-05	1.1E-05	1.1E-05	1.2E-05	1.2E-05	1.2E-05	1.2E-05	1.2E-05	0.7
0.8	1.2E-05	1.4E-05	1.6E-05	2.3E-05	2.0E-05	1.6E-05	1.5E-05	1.7E-05	1.5E-05	1.0E-05	8.4E-06	1.2E-05	1.7E-05	1.7E-05	1.5E-05	1.5E-05	0.8
0.9	1.1E-05	1.4E-05	2.0E-05	2.3E-05	2.2E-05	1.8E-05	1.7E-05	2.0E-05	1.7E-05	8.8E-06	7.8E-06	1.0E-05	2.0E-05	2.1E-05	1.7E-05	1.6E-05	0.9
1.0	1.1E-05	1.4E-05	2.1E-05	2.6E-05	2.4E-05	2.2E-05	2.0E-05	2.3E-05	2.1E-05	1.1E-05	9.9E-06	1.1E-05	2.3E-05	2.3E-05	2.1E-05	2.0E-05	1.0
2.4	1.2E-05	1.4E-05	1.6E-05	2.3E-05	2.0E-05	1.6E-05	1.5E-05	1.7E-05	1.5E-05	1.0E-05	8.3E-06	1.1E-05	1.7E-05	1.8E-05	1.5E-05	1.5E-05	2.4
4.0	1.2E-05	1.2E-05	2.2E-05	2.2E-05	2.2E-05	2.2E-05	2.2E-05	2.2E-05	2.2E-05	1.8E-05	1.5E-05	2.2E-05	2.3E-05	2.3E-05	2.2E-05	2.2E-05	4.0
5.6	1.3E-05	1.3E-05	1.4E-05	1.4E-05	1.6E-05	1.6E-05	1.6E-05	1.7E-05	1.6E-05	1.4E-05	1.4E-05	1.5E-05	1.8E-05	1.8E-05	1.6E-05	1.5E-05	5.6
7.2	9.8E-06	9.6E-06	1.2E-05	1.3E-05	1.4E-05	1.4E-05	1.4E-05	1.4E-05	1.4E-05	1.3E-05	1.1E-05	1.4E-05	1.4E-05	1.5E-05	1.4E-05	1.4E-05	7.2
12.1	7.3E-06	7.1E-06	9.5E-06	1.0E-05	1.1E-05	1.2E-05	1.2E-05	1.3E-05	1.2E-05	9.9E-06	8.7E-06	1.1E-05	1.3E-05	1.3E-05	1.2E-05	1.1E-05	12.1
24.1	5.7E-06	5.0E-06	6.4E-06	6.5E-06	6.6E-06	7.6E-06	7.7E-06	8.5E-06	7.8E-06	6.5E-06	6.5E-06	6.5E-06	8.2E-06	9.1E-06	7.6E-06	6.6E-06	24.1
40.3	2.6E-06	2.3E-06	2.9E-06	3.2E-06	4.5E-06	5.5E-06	5.6E-06	5.7E-06	5.6E-06	3.6E-06	2.9E-06	3.9E-06	5.7E-06	5.8E-06	5.5E-06	4.4E-06	40.3
56.3	1.6E-06	1.6E-06	1.6E-06	1.8E-06	2.7E-06	3.4E-06	3.5E-06	3.8E-06	3.6E-06	2.1E-06	1.6E-06	2.2E-06	3.8E-06	3.9E-06	3.4E-06	2.6E-06	56.3
72.4	1.1E-06	1.0E-06	1.1E-06	1.1E-06	1.6E-06	2.4E-06	2.6E-06	2.8E-06	2.6E-06	1.2E-06	1.1E-06	1.2E-06	2.8E-06	3.0E-06	2.4E-06	1.8E-06	72.4

Table 4.1-28. 95th Percentile E/Q Values (sec m^{-3}) for Acute Ground-Level Releases from 400 Area Based on 1983 Through 1991 Meteorological Information (Schreckhise et al. 1993)

Distance (km)	S	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE	Distance (km)
	Sector (Wind from 100-N Towards Direction Indicated)																
0.1	3.4E-02	3.2E-02	3.3E-02	3.7E-02	4.6E-02	3.6E-02	3.2E-02	2.9E-02	2.9E-02	1.9E-02	3.1E-02	3.3E-02	3.4E-02	3.0E-02	2.7E-02	3.2E-02	0.1
0.2	1.0E-02	9.7E-03	9.9E-03	1.1E-02	1.4E-02	1.1E-02	9.7E-03	8.6E-03	8.9E-03	5.9E-03	9.2E-03	1.0E-02	1.0E-02	9.0E-03	8.2E-03	9.5E-03	0.2
0.3	5.1E-03	4.9E-03	5.0E-03	5.6E-03	7.0E-03	5.4E-03	4.9E-03	4.3E-03	4.5E-03	2.9E-03	4.6E-03	5.0E-03	5.2E-03	4.5E-03	4.1E-03	4.8E-03	0.3
0.4	3.2E-03	3.0E-03	3.1E-03	3.4E-03	4.3E-03	3.3E-03	3.0E-03	2.7E-03	2.7E-03	1.8E-03	2.8E-03	3.1E-03	3.2E-03	2.8E-03	2.5E-03	3.0E-03	0.4
0.5	2.2E-03	2.1E-03	2.1E-03	2.4E-03	3.0E-03	2.3E-03	2.1E-03	1.8E-03	1.9E-03	1.2E-03	2.0E-03	2.1E-03	2.2E-03	1.9E-03	1.7E-03	2.0E-03	0.5
0.6	1.6E-03	1.5E-03	1.6E-03	1.7E-03	2.2E-03	1.7E-03	1.5E-03	1.3E-03	1.4E-03	9.2E-04	1.4E-03	1.6E-03	1.6E-03	1.4E-03	1.3E-03	1.5E-03	0.6
0.7	1.2E-03	1.2E-03	1.2E-03	1.3E-03	1.7E-03	1.3E-03	1.2E-03	1.0E-03	1.1E-03	7.1E-04	1.1E-03	1.2E-03	1.3E-03	1.1E-03	9.9E-04	1.2E-03	0.7
0.8	9.9E-04	9.4E-04	9.6E-04	1.1E-03	1.4E-03	1.0E-03	9.4E-04	8.3E-04	8.6E-04	5.7E-04	8.9E-04	9.7E-04	1.0E-03	8.8E-04	7.9E-04	9.3E-04	0.8
0.9	8.2E-04	7.7E-04	7.9E-04	8.8E-04	1.1E-03	8.6E-04	7.7E-04	6.9E-04	7.1E-04	4.7E-04	7.3E-04	7.9E-04	8.3E-04	7.2E-04	6.5E-04	7.6E-04	0.9
1.0	6.9E-04	6.5E-04	6.7E-04	7.4E-04	9.4E-04	7.2E-04	6.5E-04	5.8E-04	5.9E-04	3.9E-04	6.2E-04	6.7E-04	6.9E-04	6.0E-04	5.5E-04	6.4E-04	1.0
2.4	1.7E-04	1.6E-04	1.7E-04	1.9E-04	2.4E-04	1.8E-04	1.7E-04	1.5E-04	1.5E-04	1.0E-04	1.6E-04	1.7E-04	1.8E-04	1.5E-04	1.4E-04	1.6E-04	2.4
4.0	8.5E-05	8.1E-05	8.3E-05	9.2E-05	1.2E-04	9.0E-05	8.1E-05	7.2E-05	7.5E-05	4.9E-05	7.7E-05	8.3E-05	8.6E-05	7.6E-05	6.9E-05	8.0E-05	4.0
5.6	5.4E-05	5.2E-05	5.3E-05	5.9E-05	7.5E-05	5.7E-05	5.2E-05	4.6E-05	4.8E-05	3.1E-05	4.9E-05	5.3E-05	5.5E-05	4.8E-05	4.4E-05	5.1E-05	5.6
7.2	3.9E-05	3.7E-05	3.8E-05	4.2E-05	5.4E-05	4.1E-05	3.7E-05	3.3E-05	3.4E-05	2.3E-05	3.5E-05	3.8E-05	4.0E-05	3.5E-05	3.2E-05	3.7E-05	7.2
12.1	2.0E-05	1.9E-05	2.0E-05	2.2E-05	2.8E-05	2.1E-05	1.9E-05	1.7E-05	1.8E-05	1.2E-05	1.8E-05	2.0E-05	2.1E-05	1.8E-05	1.6E-05	1.9E-05	12.1
24.1	8.6E-06	8.2E-06	8.4E-06	9.3E-06	1.2E-05	9.1E-06	8.2E-06	7.3E-06	7.5E-06	5.0E-06	7.8E-06	8.4E-06	8.7E-06	7.7E-06	7.0E-06	8.1E-06	24.1
40.3	4.6E-06	4.4E-06	4.5E-06	5.0E-06	6.4E-06	4.9E-06	4.4E-06	3.9E-06	4.1E-06	2.7E-06	4.2E-06	4.5E-06	4.7E-06	4.1E-06	3.7E-06	4.3E-06	40.3
56.3	3.1E-06	2.9E-06	3.0E-06	3.4E-06	4.3E-06	3.3E-06	2.9E-06	2.6E-06	2.7E-06	1.8E-06	2.8E-06	3.0E-06	3.1E-06	2.8E-06	2.5E-06	2.9E-06	56.3
72.4	2.3E-06	2.2E-06	2.2E-06	2.5E-06	3.2E-06	2.4E-06	2.2E-06	1.9E-06	2.0E-06	1.3E-06	2.1E-06	2.2E-06	2.3E-06	2.0E-06	1.9E-06	2.2E-06	72.4

Table 4.1-29. 95th Percentile E/Q Values (sec m^{-3}) for Acute 30 m Stack Releases from 400 Area Based on 1983 Through 1991 Meteorological Information (Schreckhise et al. 1993)

Distance (km)	S	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE	Distance (km)
	Sector (Wind from 100-N Towards Direction Indicated)																
0.1	3.6E-05	3.7E-05	3.7E-05	5.9E-05	5.9E-05	6.8E-05	3.7E-05	3.2E-05	3.3E-05	2.7E-05	2.3E-05	3.0E-05	3.2E-05	2.1E-05	1.6E-05	2.6E-05	0.1
0.2	5.3E-05	5.4E-05	8.3E-05	1.5E-04	1.5E-04	1.5E-04	8.1E-05	5.2E-05	5.1E-05	4.0E-05	3.6E-05	5.1E-05	5.2E-05	3.6E-05	3.1E-05	5.0E-05	0.2
0.3	4.9E-05	4.9E-05	6.9E-05	1.1E-04	1.2E-04	1.1E-04	7.0E-05	4.8E-05	4.7E-05	4.6E-05	4.7E-05	4.8E-05	4.8E-05	4.7E-05	4.6E-05	4.8E-05	0.3
0.4	8.5E-05	8.1E-05	9.2E-05	9.6E-05	9.7E-05	9.5E-05	9.2E-05	6.3E-05	4.5E-05	3.5E-05	4.8E-05	6.7E-05	7.7E-05	5.3E-05	4.5E-05	7.4E-05	0.4
0.5	9.5E-05	8.8E-05	1.1E-04	1.1E-04	1.1E-04	1.1E-04	1.1E-04	7.1E-05	5.5E-05	4.5E-05	6.6E-05	8.1E-05	8.9E-05	6.8E-05	5.8E-05	8.6E-05	0.5
0.6	9.9E-05	9.4E-05	1.1E-04	1.1E-04	1.1E-04	1.1E-04	1.0E-04	8.5E-05	7.0E-05	5.9E-05	8.2E-05	9.3E-05	9.6E-05	8.4E-05	7.4E-05	9.5E-05	0.6
0.7	9.6E-05	9.0E-05	1.0E-04	1.0E-04	1.0E-04	1.0E-04	9.9E-05	8.6E-05	8.0E-05	7.6E-05	8.6E-05	9.5E-05	9.6E-05	8.8E-05	8.1E-05	9.5E-05	0.7
0.8	9.3E-05	9.1E-05	9.6E-05	9.7E-05	9.7E-05	9.7E-05	9.5E-05	8.9E-05	8.4E-05	6.7E-05	8.9E-05	9.3E-05	9.3E-05	9.0E-05	8.6E-05	9.3E-05	0.8
0.9	8.8E-05	8.8E-05	8.9E-05	8.9E-05	8.9E-05	8.9E-05	8.9E-05	8.8E-05	8.5E-05	6.0E-05	8.8E-05	8.8E-05	8.8E-05	8.8E-05	8.8E-05	8.8E-05	0.9
1.0	8.4E-05	8.2E-05	8.5E-05	8.6E-05	8.7E-05	8.7E-05	8.4E-05	8.1E-05	8.1E-05	6.3E-05	8.2E-05	8.6E-05	8.5E-05	8.3E-05	7.7E-05	8.4E-05	1.0
2.4	4.7E-05	4.4E-05	4.8E-05	5.1E-05	5.2E-05	5.0E-05	4.6E-05	3.6E-05	3.9E-05	3.1E-05	4.5E-05	4.9E-05	4.9E-05	4.4E-05	3.4E-05	4.5E-05	2.4
4.0	3.4E-05	3.1E-05	3.4E-05	3.5E-05	3.5E-05	3.5E-05	3.4E-05	2.3E-05	2.5E-05	2.0E-05	3.1E-05	3.5E-05	3.5E-05	2.9E-05	2.2E-05	3.1E-05	4.0
5.6	2.5E-05	2.1E-05	2.3E-05	2.6E-05	2.6E-05	2.6E-05	2.2E-05	1.5E-05	1.7E-05	1.3E-05	2.0E-05	2.4E-05	2.5E-05	2.0E-05	1.5E-05	2.1E-05	5.6
7.2	1.9E-05	1.6E-05	1.8E-05	2.0E-05	2.1E-05	2.0E-05	1.7E-05	1.1E-05	1.2E-05	1.0E-05	1.5E-05	1.8E-05	1.9E-05	1.5E-05	1.1E-05	1.6E-05	7.2
12.1	1.1E-05	8.6E-06	1.0E-05	1.1E-05	1.2E-05	1.1E-05	9.5E-06	5.8E-06	6.4E-06	5.8E-06	8.5E-06	1.0E-05	1.1E-05	8.0E-06	5.8E-06	8.8E-06	12.1
24.1	4.8E-06	4.1E-06	4.5E-06	5.2E-06	5.9E-06	5.1E-06	4.2E-06	2.9E-06	3.2E-06	2.6E-06	3.6E-06	4.5E-06	5.0E-06	3.4E-06	2.8E-06	4.0E-06	24.1
40.3	2.7E-06	2.3E-06	2.5E-06	2.9E-06	3.3E-06	2.8E-06	2.4E-06	1.7E-06	1.8E-06	1.5E-06	2.1E-06	2.5E-06	2.8E-06	1.9E-06	1.6E-06	2.3E-06	40.3
56.3	1.8E-06	1.6E-06	1.7E-06	2.0E-06	2.3E-06	1.9E-06	1.6E-06	1.2E-06	1.3E-06	9.9E-07	1.4E-06	1.7E-06	1.9E-06	1.3E-06	1.1E-06	1.6E-06	56.3
72.4	1.4E-06	1.2E-06	1.3E-06	1.5E-06	1.7E-06	1.4E-06	1.2E-06	9.0E-07	9.7E-07	7.4E-07	1.1E-06	1.3E-06	1.4E-06	1.0E-06	8.7E-07	1.2E-06	72.4

4.1.7 Special Meteorological Considerations on the Hanford Site

Winds exhibit significant variation across the Hanford Site because of its large size and varying terrain. Stations near the Columbia River tend to exhibit wind patterns that are strongly influenced by the topography of the river and the surrounding terrain. For example, in the 100 Area, the river runs southwest to northeast at 100-N and northwest to southeast at 100-F. The wind direction frequency for 100-N shows a high frequency of winds from the west-southwest and southwest, while 100-F shows a high frequency of winds from the southeast and south-southeast (Figure 4.1-2). The 60-m (197-ft) tower at the 100-N Area provides additional data to define the wind up to 60 m (197 ft) above ground level. Winds aloft are less influenced by surface features than winds near the surface, as shown by the much smaller frequency of winds from the west-southwest and southwest at 60 m (197 ft) at 100-N (Figure 4.1-3).

Prevailing winds in the 200 Areas (i.e., HMS) tend to come from the west through the northwest, the direction of summer drainage winds; sites further south (i.e., FFTF) show prevailing winds that come from the south through the southwest (Figure 4.1-2). Even stations close together can exhibit significant differences. For example, the stations at Rattlesnake Springs and the 200 West Area are separated by about 5 km (3 mi), yet the wind patterns at the two stations are very different (see Figure 4.1-2). Thus, care should be taken when assessing the appropriateness of the wind data used in estimating environmental impacts. When possible, wind data from the closest representative station should be used for assessing local dispersion conditions. For elevated releases, the most representative data may come from the closest representative 60-m (197-ft) tower rather than the nearest 9.1-m (30-ft) tower.

4.1.8 Nonradiological Air Quality

Ambient Air Quality Standards have been set by the U.S. Environmental Protection Agency (EPA) and by the State of Washington (see Section 6.2.1). Ambient air is that portion of the atmosphere, external to buildings, to which the general public has access (40 CFR 50). The standards define levels of air quality that are necessary, with an adequate margin of safety, to protect the public health (primary standards) and the public welfare (secondary standards). Standards exist for sulfur oxides (measured as sulfur dioxide), nitrogen dioxide, carbon monoxide, total suspended particulates (TSP), fine particulates (PM_{10}), lead, and ozone. The standards specify the maximum pollutant concentrations and frequencies of occurrence that are allowed for specific averaging periods. The averaging periods vary from 1 hour to 1 year, depending on the pollutant.

For areas meeting ambient air standards, the EPA has established the Prevention of Significant Deterioration (PSD) program to protect existing ambient air quality while at the same time allowing a margin for future growth. The Hanford Site operates under a PSD permit issued by the EPA in 1980. The permit provides specific limits for emissions of oxides of nitrogen from the Plutonium-Uranium Extraction (PUREX) and Uranium Trioxide (UO_3) Plants.

State and local governments have the authority to impose standards for ambient air quality that are stricter than the national standards. Washington State has established more stringent standards for sulfur dioxide and TSP. In addition, Washington State has established standards for other pollutants, such as fluoride, that are not covered by national standards. The state standards for carbon monoxide, nitrogen dioxide, ozone, PM_{10}, and lead are identical to the national standards. Table 4.1-30 summarizes the relevant air quality standards (federal and

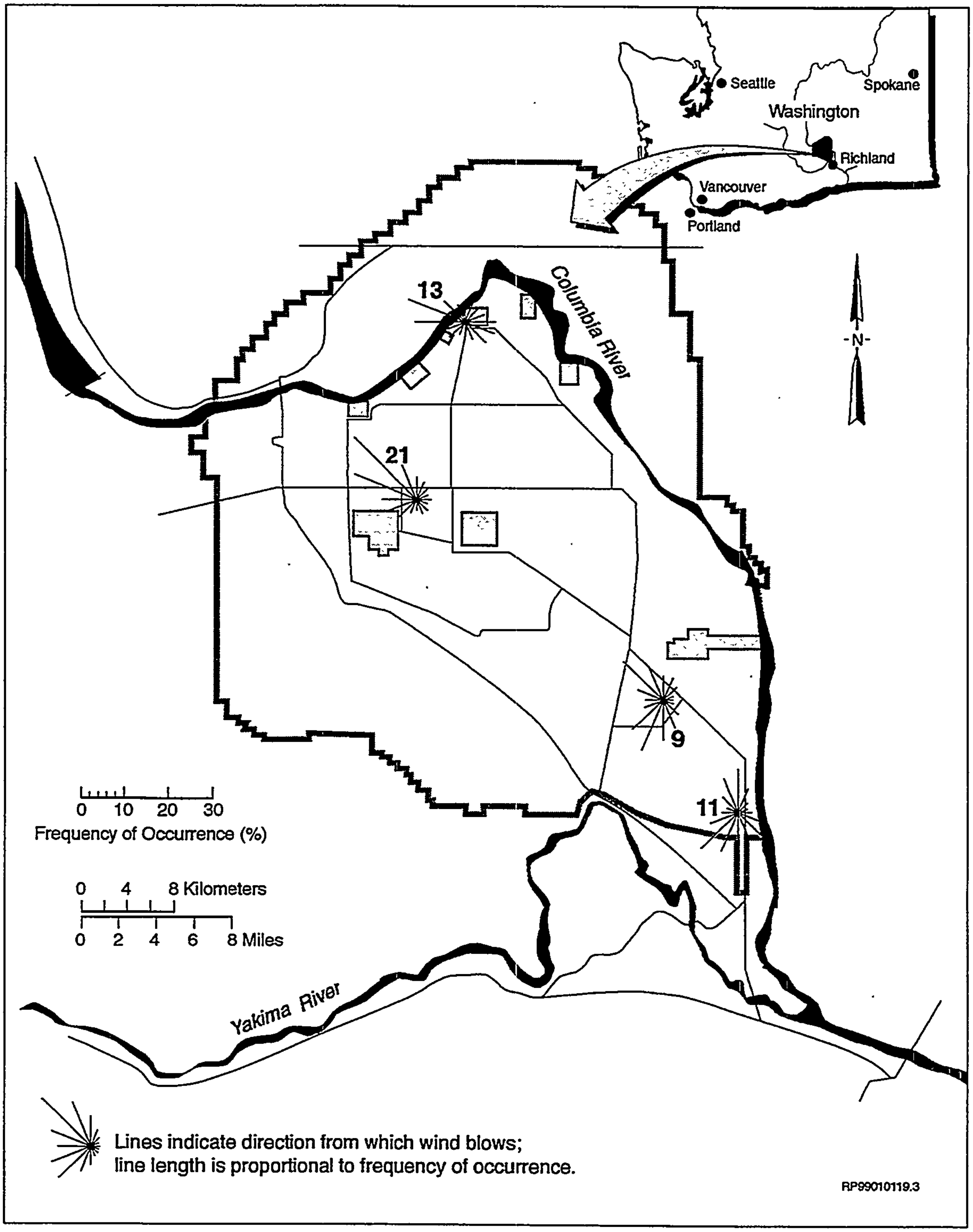


Figure 4.1-3. Wind Roses at the 60-m (200-ft) Level of the Hanford Meteorological Monitoring Network, 1986 to 1998.

Table 4.1-30. National and Washington State Ambient Air Quality Standards. [(a)]

Pollutant	National Primary	National Secondary	Washington State
Total Suspended Particulates			
Annual geometric mean	NS[(b)]	NS	60 μg/m^3
24-h average	NS	NS	150 μg/m^3
PM-10 (fine particulates)			
Annual arithmetic mean	50 μg/m^3	50 μg/m^3	50 μg/m^3
24-h average	150 μg/m^3	150 μg/m^3	150 μg/m^3
Sulfur Dioxide			
Annual average	0.03 ppm (≅80 μg/m^3)	NS	0.02 ppm (≅50 μg/m^3)
24-h average	0.14 ppm (≅370μg/m^3)	NS	0.10 ppm (≅260 μg/m^3)
3-h average	NS	0.50 ppm (≅1.3 mg/m^3)	NS
1-h average	NS	NS	0.40 ppm (≅1.0 mg/m^3)[(c)]
Carbon Monoxide			
8-h average	9 ppm (≅10 mg/m^3)	9 ppm (≅10 mg/m^3)	9 ppm (≅10 mg/m^3)
1-h average	35 ppm (≅40 mg/m^3)	35 ppm (≅40 mg/m^3)	35 ppm (≅40 mg/m^3)
Ozone			
1-h average	0.12 ppm (≅230 μg/m^3)	0.12 ppm (≅230 μg/m^3)	0.12 ppm (≅230 μg/m^3)
Nitrogen Dioxide			
Annual average	0.05 ppm (≅100 μg/m^3)	0.05 ppm (≅100 μg/m^3)	0.05 ppm (≅100 μg/m^3)
Lead			
Quarterly average	1.5 μg/m^3	1.5 μg/m^3	1.5 μg/m^3

(a) Source: Ecology (1997). Annual standards are never to be exceeded; short-term standards are not to be exceeded more than once per year unless otherwise noted. Particulate pollutants are in microgram per cubic meter. Gaseous pollutants are in parts per million and equivalent microgram (or milligram) per cubic meter.

Abbreviations: ppm = parts per million; μg/m^3 = micrograms per cubic meter; mg/m^3 = milligrams per cubic meter.

(b) NS = no standard.

(c) 0.25 ppm not to be exceeded more than twice in any 7 consecutive days.

supplemental state standards).

On July 18, 1997 the EPA issued new air quality standards for particulate matter and ozone (Ecology 1997). These new standards include a standard for fine particulate matter with a diameter of 2.5 µm or less ($PM_{2.5}$). Decisions on violations of the new particulate matter and ozone standard will be delayed for 5 to 8 years to give states time to set up monitoring networks and obtain 3 years of data. Table 4.1-31 shows the new and revised standards for particulate matter and ozone.

4.1.8.1 Prevention of Significant Deterioration

Nitrogen oxide emissions from the PUREX and UO_3 Plants are permitted under the PSD program. These facilities were not operated in 1997, and no PSD permit violations occurred. Neither the PUREX nor the $U0_3$ plants are expected to operate again.

4.1.8.2 Emissions of Nonradiological Pollutants

Nonradiological pollutants are mainly emitted from power-generating and chemical-processing facilities located on the Hanford Site. Table 4.1-32 summarizes the 1997 emission rates of nonradiological constituents from these facilities. The 100, 400 and 600 Areas have no nonradioactive emission sources of concern (Dirkes and Hanf 1998).

Table 4.1-31. New and Revised Standards for Particulate Matter (PM) and Ozone. [a]

Standard	Level	Form
Annual PM_{10}	50 $\mu g/m^3$	3-year average of annual mean
24-Hour PM_{10}	150 $\mu g/m^3$	3-year average of 99^{th} percentile monitored concentration
Annual $PM_{2.5}$	15 $\mu g/m^3$	3-year average of annual mean
24-Hour $PM_{2.5}$	65 $\mu g/m^3$	3-year average of 98^{th} percentile monitored concentration
8-Hour Ozone	0.08 ppm	3-year average of 4^{th} highest monitored daily concentration

[a] Source: Ecology (1997); Particulate Concentrations are in microgram per cubic meter; Ozone concentration is in parts per million.

Table 4.1-32. Non-radioactive Constituents Discharged to the Atmosphere, 1997[a] (Dirkes and Hanf 1998).

Constituent	Release, kg 200-East Area	200-West Area	300 Area
Particulate matter	1.41×10^3	5.62×10^1	1.07×10^4
Nitrogen oxides	1.61×10^5	1.65×10^4	3.80×10^4
Sulfur oxides	2.35×10^5	1.97×10^2	1.44×10^5
Carbon monoxide	5.33×10^4	1.78×10^2	3.46×10^3
Lead	1.40×10^2	3.46×10^{-2}	2.05×10^1
Volatile organic compounds[b]	1.15×10^3	1.81×10^2	1.94×10^2
Ammonia[c]	3.60×10^3	2.79×10^3	NM[d]
Arsenic	1.50×10^2	1.16×10^{-2}	1.20×10^1
Beryllium	2.02×10^1	6.92×10^{-3}	4.44×10^{-1}
Cadmium	1.19×10^1	3.05×10^{-2}	2.23×10^1
Carbon tetrachloride	NE[d]	2.27×10^{-1}[e]	NE
Chromium	4.34×10^2	1.32×10^{-1}	1.35×10^1
Cobalt	NE	NE	1.28×10^1
Copper	2.73×10^2	7.75×10^{-1}	2.94×10^1
Formaldehyde	6.12×10^1	1.12×10^0	4.28×10^1
Manganese	6.01×10^2	3.88×10^{-2}	7.82×10^0
Mercury	4.43×10^0	8.31×10^{-3}	3.38×10^0
Nickel	3.57×10^2	4.98×10^{-2}	2.46×10^2
Polycyclic organic matter	NE	4.35×10^2	5.80×10^3
Selenium	5.42×10^1	6.50×10^{-2}	4.01×10^0
Vanadium	3.74×10^1	1.93×10^{-1}	3.19×10^2

(a) The estimate of volatile organic compound emissions does not include emissions from certain laboratory operations.

(b) Produced from burning fossil fuels for steam generation and electrical generators.

(c) Ammonia releases are from the 200-East Area tank farms, 200-West Area tank farms, and operation of the 242-A Evaporator.

(d) NE = no emissions; NM = not measured

(e) This is an estimated value because over 99% of the measured values are below the 1-ppmv (parts per million-volume) detection limit.

4.1.8.3 Offsite Monitoring

The Washington State Department of Ecology in 1996 conducted the only offsite monitoring near the Hanford Site for PM_{10} (Ecology 1998). PM_{10} was monitored at one location in Benton County, at Columbia Center Mall, located approximately 17 km (10.5 mi) south-southwest of the 300 Area, in Kennewick. During 1996, the 24-hr PM_{10} standard established by the state of Washington, 150 μg/m³, was not exceeded. The Site did not exceed the annual primary standard, 50 μg/m³, during 1996. The arithmetic mean for 1996 was 21 μg/m³ at Columbia Center (Ecology 1998).

4.1.8.4 Background Monitoring

During the last 10 years, carbon monoxide, sulfur dioxide, and nitrogen dioxide have been monitored periodically in communities and commercial areas southeast of Hanford. These urban measurements are typically used to estimate the maximum background pollutant concentrations for the Hanford Site because of the lack of specific onsite monitoring.

Particulate concentrations can reach relatively high levels in eastern Washington State because of exceptional natural events (i.e., dust storms, volcanic eruptions, and large brushfires) that occur in the region. Washington State ambient air quality standards have not considered "rural fugitive dust" from exceptional natural events when estimating the maximum background concentrations of particulates in the area east of the Cascade Mountain crest. In June 1996, EPA adopted the policy that allows dust storms to be treated as uncontrollable natural events. This means that the EPA may not designate areas affected by dust storms as nonattainment. However, controls will be developed for human activities that contribute to exceedances during such events (Ecology 1997).

Areas that require more strict controls on air quality impacts are nonattainment areas (areas that have exceeded the National Ambient Air Quality Standards) and certain national parks and wilderness areas called Federal Class I areas. Actions on the Hanford Site may not produce air quality impacts that significantly affect these areas. The nearest nonattainment areas are the Wallula area (located approximately 30 km [20 mi] southeast of the site) which is in nonattainment for PM_{10} and the Yakima area (located about 53 km [33 mi] west of the site) which is in nonattainment for PM_{10} and carbon monoxide. The major source of PM_{10} in the Wallula area is from windblown dust and to a lesser extent, nearby industry. For the Yakima area, the EPA has determined that the PM_{10} standards have been met, and the area will soon be designated as in attainment (Ecology 1998). Yakima exceeded the carbon monoxide standard back in the 1980s, but has not exceeded the standard since that time. The nearest federal Class I areas to the Hanford Site are Mount Rainer National Park, located 160 km (100 mi) west of the site; Goat Rocks Wilderness Area, located approximately 145 km (90 mi) west of the site; Mount Adams Wilderness Area, located approximately 150 km (95 mi) southwest of the site; and Alpine Lakes Wilderness Area, located approximately 175 km (110 mi) northwest of the site.

4.1.9 Radiological Air Quality

Airborne effluents that may contain radioactive constituents are continually monitored at the Hanford Site. Samples are analyzed for gross alpha and gross beta activity as well as selected radionuclides.

Radioactive emissions during 1997 originated in the 100, 200, 300, and 400 Areas. 100 Area emissions originated from the deactivation of N reactor, K Basins (irradiated fuel found in 2 water-filled storage basins), a re-circulation facility designed to filter radioactive water from the N Reactor basin, and a radiochemistry laboratory. 200 Area emissions originated from the PUREX Plant, Plutonium Finishing Plant, T Plant, 222-S Laboratory, underground storage tanks, and waste evaporators. 300 Area emissions originated from the 324 Waste Technology Engineering Laboratory, 325 Applied Chemistry Laboratory, 327 Post-Irradiation Laboratory, and 340 Vault and Tanks. 400 Area emissions originated at the FFTF and Maintenance and Storage Facility (Dirkes and Hanf 1998). A summary of radiological air emissions is provided in Table 4.1-33.

Table 4.1-33. Radionuclides Discharged to the Atmosphere at the Hanford Site, 1997 (Dirkes and Hanf 1998).

Radionuclide	Half-Life	Release, Ci[a]				
		100 Areas	200-East Area	200-West Area	300 Area	400 Area
Tritium (as HTO)[b]	12.3 yr	NM[a]	NM	NM	1.5×10^{0}	7.9×10^{0}
Tritium (as HT)[b]	12.3 yr	NM	NM	NM	2.1×10^{1}	NM
Cobalt-60	5.3 yr	ND[a]	ND	ND	8.3×10^{-10}	NM
Zinc-65	244.4 d	ND	ND	ND	ND	NM
Strontium-90	29.1 yr	2.1×10^{-5}	2.5×10^{-4}[c]	3.0×10^{-4}[c]	1.5×10^{-5}[c]	NM
Zirconium-95	64.02 d	ND	ND	ND	ND	NM
Ruthenium-106	368 d	ND	ND	NM	ND	NM
Tin-113	115.1 d	ND	ND	NM	ND	NM
Antimony-125	2.77 yr	3.7×10^{-9}	ND	NM	ND	NM
Iodine-129	1.6×10^{7} yr	NM	1.4×10^{-3}	NM	ND	NM
Iodine-131	8.040 d	NM	ND	NM	ND	ND
Cesium-134	2.1 yr	ND	ND	ND	ND	NM
Cesium-137	30 yr	5.5×10^{-5}	9.1×10^{-4}	7.7×10^{-9}	7.9×10^{-7}	4.6×10^{-6}[d]
Europium-152	13.6 yr	ND	ND	ND	ND	NM
Europium-154	8.8 yr	ND	ND	ND	ND	NM
Europium-155	5 yr	ND	ND	ND	ND	NM
Radon-220	56 s	NM	NM	NM	5.0×10^{1}	NM
Radon-222	3.8 d	NM	NM	NM	1.6×10^{0}	NM
Plutonium-238	87.7 yr	5.8×10^{-7}	1.8×10^{-7}	2.2×10^{-6}	9.5×10^{-10}	NM
Plutonium-238/240	2.4×10^{4} yr	3.9×10^{-6}[e]	6.3×10^{-6}[e]	1.1×10^{-4}[e]	1.1×10^{-6}[e]	3.8×10^{-7}[e]
Plutonium-241	14.4 yr	4.0×10^{-5}	6.4×10^{-6}	4.6×10^{-5}	NM	NM
Americium-241	432 yr	2.5×10^{-6}	4.8×10^{-6}	2.0×10^{-5}	6.5×10^{-9}	NM

(a) 1 Ci = 3.7×10^{10} Bq; NM = not measured; ND = not detected.
(b) HTO = tritiated water vapor; HT = elemental tritium.
(c) This value includes gross beta release data. Gross beta and unspecified beta results assumed to be strontium-90 for dose calculations.
(d) The 400 Area's cesium-137 value is derived fully from gross beta measurements
(e) This value includes gross alpha release data. Gross alpha and unspecified alpha results assumed to be plutonium-239/240 for dose calculations.

4.2 Geology

S. M. Goodwin and A. C. Rohay

Geologic considerations for the Hanford Site include physiography, stratigraphy, structural geology, soil characteristics, and seismicity.

4.2.1 Physiography

The Hanford Site lies within the Columbia Basin subprovince of the Columbia Intermontane Province (Figure 4.2-1). The Columbia Intermontane Province is the product of Miocene flood basalt volcanism and regional deformation that occurred over the last 17 million years. The

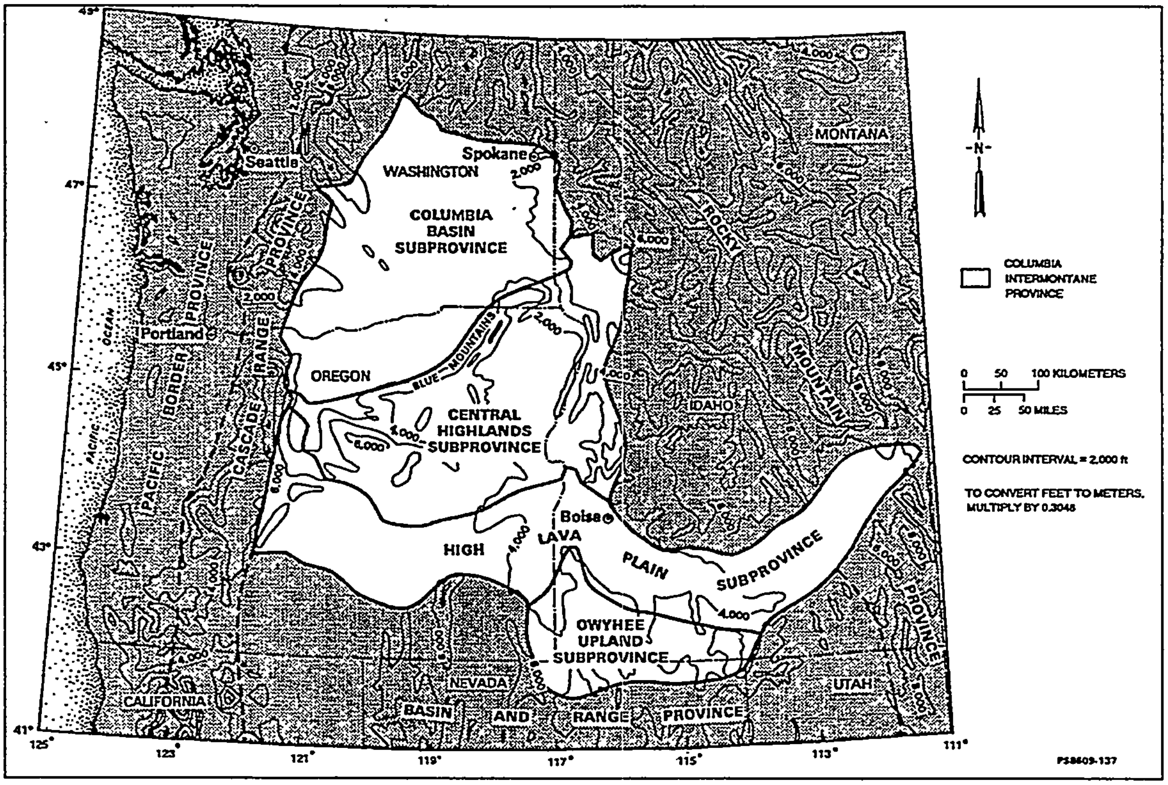


Figure 4.2-1. Physiographic Provinces of the Pacific Northwest, with Columbia Intermontane Province Shown in White (DOE 1988).

Columbia Plateau is that portion of the Columbia Intermontane Province that is underlain by the Columbia River Basalt Group (Thornbury 1965).

The low-relief plains of the Central Plains subprovince and anticlinal ridges of the Yakima Folds physiographic section dominate the physiography of the Hanford Site (DOE 1988). The surface topography has been modified within the past several million years by several geomorphic processes: 1) Pleistocene cataclysmic flooding, 2) Holocene eolian activity, and 3) landsliding. Cataclysmic flooding occurred when ice dams in western Montana and northern Idaho were breached, allowing large volumes of water to spill across eastern and central Washington forming the channeled scablands and depositing sediments in the Pasco Basin. The last major flood occurred about 13,000 years ago, during the late Pleistocene Epoch. Anastomosing flood channels, giant current ripples, bergmounds, and giant flood bars are among the landforms created by the floods. Waste management facilities in the 200 Area are located on one prominent flood bar, the Cold Creek bar (Figure 4.2-2) (DOE 1988).

Since the end of the Pleistocene, winds have locally reworked the flood sediments, depositing dune sands in the lower elevations and loess (windblown silt) around the margins of the Pasco Basin. Many sand dunes have been stabilized by anchoring vegetation except where they have been reactivated by human activity disturbing the vegetation.

Landslides occur along the north limbs of some Yakima Folds and along steep river embankments such as White Bluffs. Landslides on the Yakima Folds occur along contacts between basalt flows or sedimentary units intercalated with the basalt, whereas active landslides

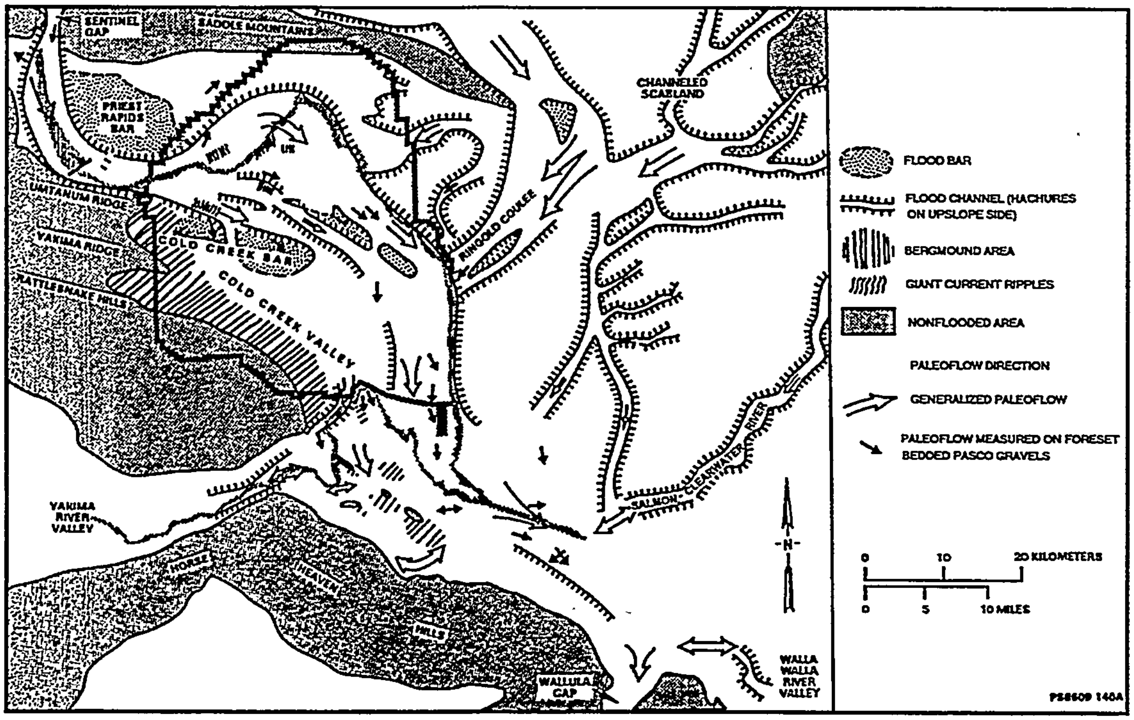


Figure 4.2-2. Paleoflow Directions and Landforms Associated with Cataclysmic Flooding in the Central Columbia Plateau (DOE 1988).

at White Bluffs occur in suprabasalt sediments. The active landslides at White Bluffs are principally the result of irrigation activity east of the Columbia River.

4.2.2 Stratigraphy

The stratigraphy of the Hanford Site consists of Miocene-age and younger rocks. Older Cenozoic sedimentary and volcaniclastic rock underlie the Miocene and younger rocks but are not exposed at the surface. The Hanford Site stratigraphy is summarized in Figure 4.2-3 and described in the following subsections. A more detailed discussion of the Hanford Site stratigraphy is given by DOE 1988; Delaney et al. 1991; Reidel et al. 1992.

4.2.2.1 Columbia River Basalt Group

The Columbia River Basalt Group (Figure 4.2-3) consists of an assemblage of tholeiitic, continental flood basalts of Miocene age. These flows cover an area of more than 163,170 km^2 (63,000 mi^2) in Washington, Oregon, and Idaho and have an estimated volume of about 174,000 km^3 (67,200 mi^3) (Tolan et al. 1987). Isotopic age determinations suggest flows of the Columbia River Basalt Group were erupted during a period from approximately 17 to 6 million years ago, with more than 98% by volume being erupted in a 2.5-million-year period (17 to 14.5 million years ago).

Columbia River basalt flows were erupted from north-northwest-trending fissures or linear vent systems in north-central and northeastern Oregon, eastern Washington, and western Idaho (Swanson et al. 1979a,b; Waters 1961). The Columbia River Basalt Group is formally divided

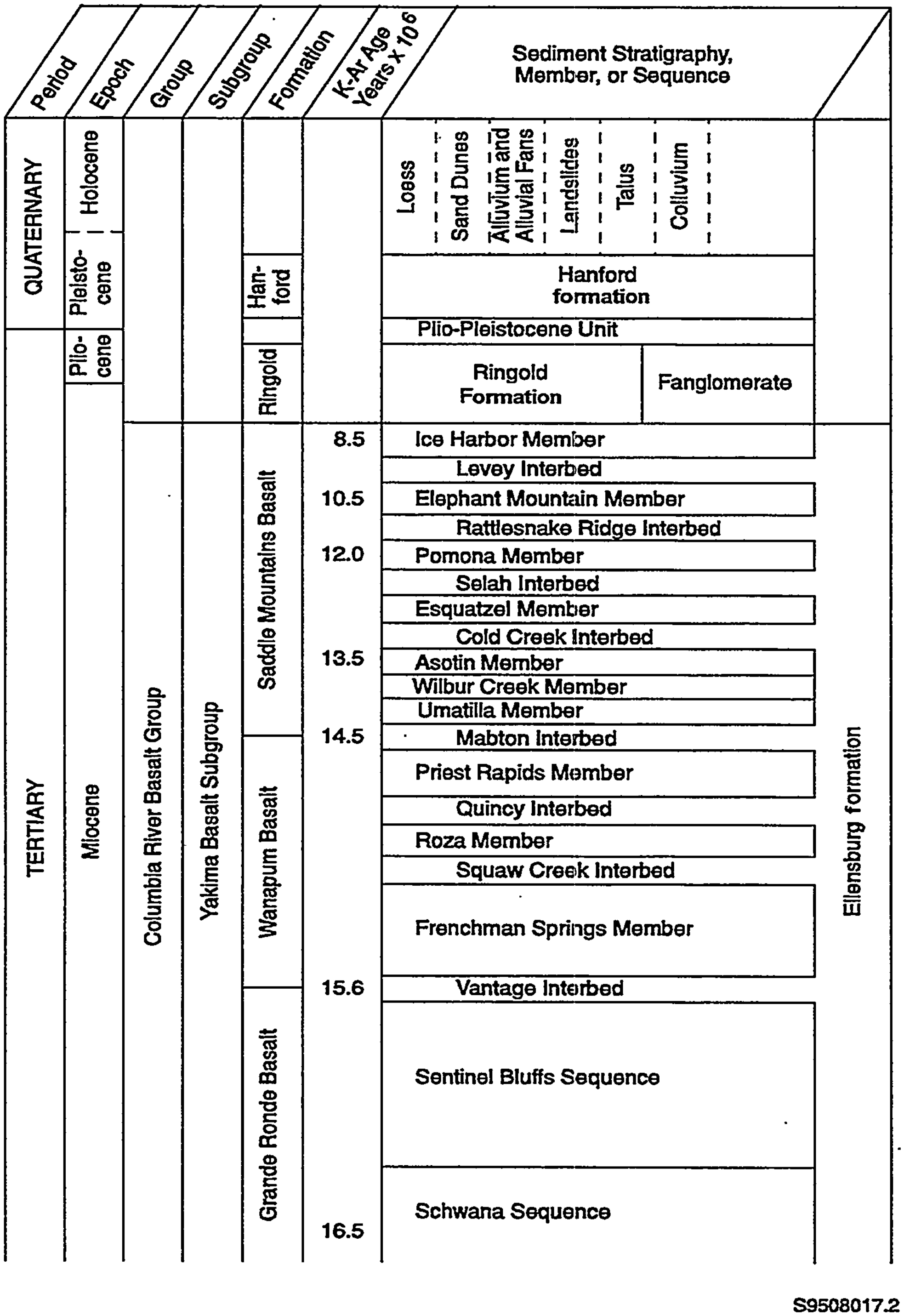


Figure 4.2-3. Stratigraphic Column for the Pasco Basin.

into five formations, from oldest to youngest: Imnaha Basalt, Picture Gorge Basalt, Grande Ronde Basalt, Wanapum Basalt, and Saddle Mountains Basalt. Of these, only the Grande Ronde, Wanapum, and Saddle Mountains Basalts are known to be present in the Pasco Basin.

The Saddle Mountains Basalt forms the uppermost basalt unit in the Pasco Basin except along some of the bounding ridges where Wanapum and Grande Ronde Basalt flows are exposed.

4.2.2.2 Ellensburg Formation

The Ellensburg Formation (Figure 4.2-3) includes epiclastic and volcaniclastic sedimentary rocks interbedded with the Columbia River Basalt Group in the central and western part of the Columbia Plateau (Schmincke 1964; Smith 1988; Swanson et al. 1979a,b). The age of the Ellensburg Formation is principally Miocene, although locally it may be equivalent to early Pliocene. The thickest accumulations of the Ellensburg Formation lie along the western margin of the Columbia Plateau where Cascade Range volcanic and volcaniclastic materials interfinger with the Columbia River Basalt Group. Within the Pasco Basin, individual interbeds, primarily in the Wanapum and Saddle Mountains Basalts, have been named (i.e., Mabton, Selah, and Cold Creek). The lateral extent and thickness of interbedded sediments generally increase upward in the section (Reidel and Fecht 1981). Two major facies, volcaniclastic and fluvial, are present either as distinct or mixed deposits. Deposition along the western margin of the plateau was primarily by volcanic debris flows (lahars) and related stream and sheet floods. Some airfall and pyroclastic-flow deposits are present. Airfall tuff is the dominant volcaniclastic material at the Hanford Site (Reidel et al. 1992).

4.2.2.3 Suprabasalt Sediments

The suprabasalt sediments within and adjacent to the Hanford Site (Figure 4.2-3) are dominated by the fluvial-lacustrine Ringold Formation and glaciofluvial Hanford formation, with minor eolian and colluvium deposits (Baker et al. 1991; DOE 1988; Tallman et al. 1981).

Ringold Formation. Late Miocene to Pliocene deposits younger than the Columbia River Basalt Group are represented by the Ringold Formation within the Pasco Basin (Grolier and Bingham 1978; Gustafson 1973; Newcomb et al. 1972; Rigby and Othberg 1979; Lindsey 1996). The fluvial-lacustrine Ringold Formation was deposited in generally east-west trending valleys by the ancestral Columbia River and its tributaries in response to development of the Yakima Fold Belt. While exposures of the Ringold Formation are limited to White Bluffs within the central Pasco Basin and to Smyrna and Taunton Benches north of the Pasco Basin, extensive data on the Ringold Formation are available from boreholes.

Newcomb (1958) used well logs to extend the Ringold Formation to include subsurface sediments down to the underlying basalt bedrock based on lithologic similarity and continuity of strata exposed at the surface. Newcomb was the first to divide the Ringold Formation into lithostratigraphic units, a lower "blue clay" unit composed of silt, clay, sand, and gravel; a middle gravel and sand unit known as the "conglomerate member" and an upper unit composed of silt, sand, clay, volcanic ash, and gravel. Continued studies of the Ringold Formation at the Hanford Site expanded the number of lithostratigraphic units (Myers et al. 1979; Tallman et al. 1979; Bjornstad 1984, 1985; DOE 1988). Other studies divided the Ringold into lithofacies (Grolier and Bingham 1978; Grolier 1978; Tallman et al. 1981) and a series of fining-upward sequences

(PSPL 1982). These studies have proven to be of limited use in that they either overgeneralized the stratigraphic variation in the Ringold Formation for widespread use or are valid only within specific study areas on the Hanford Site.

Recent investigations (Lindsey and Gaylord 1990; Lindsey 1991a, 1996) indicate that Ringold strata are best described and interpreted on the basis of facies associations. These studies demonstrate that the Ringold Formation can be divided into several stratigraphic packages defined on the basis of dominant facies associations. Facies associations are each defined on the basis of lithology, stratification, and facies architecture. The following facies are defined for the Ringold Formation on the basis of sediment characteristics and depositional environments. A more detailed description of the Ringold facies associations and their characteristics can be found in Lindsey 1996. Stratigraphic columns for the Hanford Site showing geologic correlations among various authors are exhibited in Figure 4.2-4.

Facies Association I: Clast- and matrix-supported pebble-to-cobble gravel fine to coarse sand matrix. Intercalated lenticular sand and silt lenses may also be present. Cementation varies throughout the facies from none to well developed. Primary cements include calcium carbonate, iron oxides, and silica. Clast composition is variable with basalt, quartzite, porphyritic volcanics, and greenstone the most common rock types. Less typical are silicic plutonic rocks, gneisses, and volcanic breccias. Matrix sands are predominantly quartzo-feldspathic with a subordinate basalt lithic fraction. Stratification includes crudely defined massive bedding and low angle trough cross-bedding. Planar cross beds may be well developed locally. Deposition of facies association I was characterized by alternating periods of high and low flow in a gravely fluvial braidplain with wide, shallow, shifting channels (Reidel et al. 1992; Lindsey 1996).

Facies Association II: Fine to coarse quartzo-feldspathic sand similar in composition to sand in facies association I. Sands are typically light tan to buff, but may include brown, red-brown, and yellow-brown, or salt-and-pepper colors. Intercalated silt and pebble beds may be present. Stratification primarily is composed of planar and trough cross-bedded sand lenses overlying scoured bases (Lindsey 1996). Facies association II is interpreted to have been bedload deposition in low sinuosity braided channels.

Facies Association III: Laminated to massive silt, silty fine-grained sand, and paleosols displaying medium to strongly developed blocky beds. Colors range from light gray to brown, green and black. Red-brown, massive, sand may be found intercalated with the silts and clays as thin interbeds. Calcium carbonate and silica precipitates are present throughout the unit, commonly as stringers, nodules, and concretions. Also present are filamentous, branching root and burrow casts. Silcrete may be found locally. Facies association III formed as overbank, levee, and crevasse splay deposits in a floodplain environment where pedogenic alteration occurred (Lindsey 1996).

Facies Association IV: Plane laminated to massive clay with thin silt and silty sand interbeds dominate this facies. Colors range from gray, tan, and brown in outcrop to gray and blue-gray in the subsurface (Lindsey 1996). Thin calcium carbonate and iron oxide cemented intervals are found in outcrop along with evidence of soft sediment deformation. Facies association IV was deposited in a lake under standing water to deltaic conditions (Reidel et al. 1992). A laterally continuous, white diatomaceous clay present within the association records a period of deposition into a clear body of water relatively distant from fluvial distributaries (Lindsey 1996).

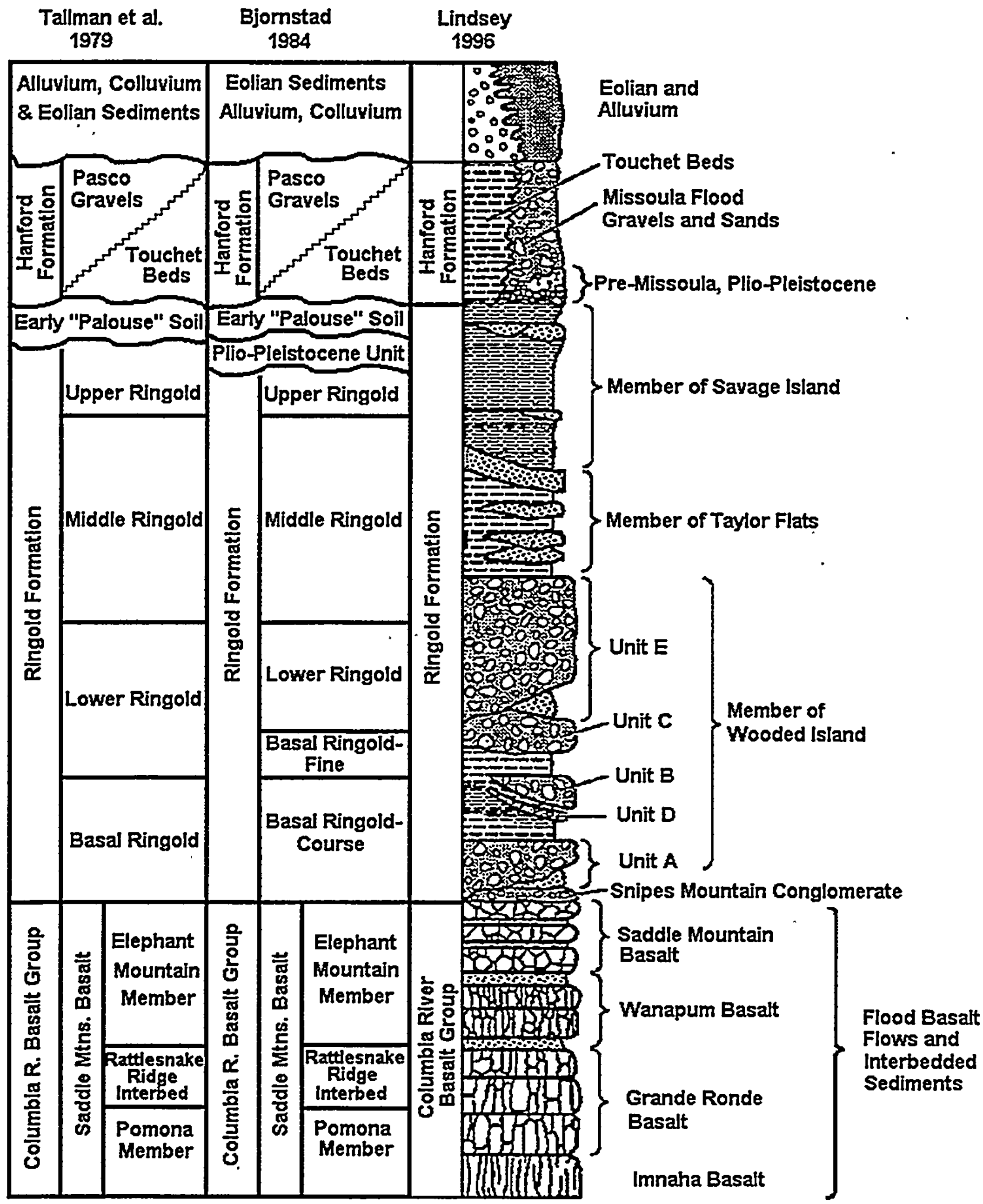


Figure 4.2-4. Stratigraphic Column for the Hanford Site Showing Correlations Among Various Authors.

Facies Association V: Massive, matrix supported basaltic gravels forming sheetlike tabular bodies dominate facies association V (Lindsey 1992). These deposits are generally found around the periphery of the basin and record alluvial fan debris flows and sidestreams draining into the Pasco Basin (Reidel et al. 1992).

Ringold Formation Facies Association Distribution. The Ringold Formation is divided into three informal members that are designated as the member of Wooded Island, the member of Taylor Flats, and the member of Savage Island. Each member contains characteristic facies associations. The member of Wooded Island is dominated by fluvial gravel (facies association I) and forms most of the lower half of the Ringold Formation. The member of Taylor Flats forms the middle part of the Ringold Formation and is dominated by fluvial sands (facies association II) and overbank-paleosol deposits (facies association III). The member of Taylor Flats interfingers with the member of Wooded Island in the northern portion of Pasco Basin where fluvial gravels pinch out. Lacustrine deposits (facies association IV) dominate the upper member, the member of Savage Island (Lindsey 1996). The following is a brief description of each informal member as defined by Lindsey. The reader should refer to Lindsey 1996 for a more detailed description of Ringold stratigraphy.

Informal member of Wooded Island. The lower half of the Ringold Formation is designated as the informal member of Wooded Island and is characterized by five separate stratigraphic gravel-rich intervals. These gravels are designated units A, B, C, D, and E, and are separated by deposits typical of facies associations III and IV (laminated to massive silts, clays, and paleosols). Unit A is the lowermost gravel unit in the Ringold Formation. Unit A was deposited in a Columbia River braidplain from Sentinel Gap southeast into the Cold Creek syncline and marks the initial deposition of the Ringold Formation within Pasco Basin. Overlying unit A is a relatively extensive fine-grained deposit known as the lower mud unit. The lower mud unit was deposited in a lake that filled most of the Pasco Basin. Overlying the lower mud unit are two fluvial gravel-dominated units, B and D. Associated with units B and D are intercalated overbank-paleosol deposits. As the ancestral Columbia River and its tributaries traveled back and forth across the Pasco Basin, unit B was deposited in the eastern to east-central Pasco Basin and unit D was deposited in southwestern Pasco Basin. Where units B and D are absent, overbank and paleosols of facies association III overlie the lower mud unit. Units B and D are differentiated from overlying units C and E by a locally thick (>10 m) paleosol sequence typical of facies association III referred to as the sub C+E interval. Where the sub C+E interval is absent, units B and D are not differentiated from overlying gravel units C and E.

Uppermost gravel units C and E are separated in the eastern Pasco Basin by an unnamed but widespread paleosol sequence similar in character to the paleosol sequence overlying units B and D and referred to as the sub E interval. In the western Pasco Basin, the sub E interval is absent and units C and E are not differentiated. Combined, units C and E form a northwest-to-southeast-oriented linear body as much as 100 m thick stretching from Sentinel Gap to Wallula Gap in the subsurface. Units C and E interfinger with muddy paleosols around the fringe of the Pasco Basin, especially to the north where units C and E pinch out.

Informal member of Taylor Flats. Approximately 90 m of interbedded fluvial sand (facies association II) and overbank fines (facies association III) form the member of Taylor Flats. Outcrops of the member extend the length of the White Bluffs. In the central to western portion of the Pasco Basin, most of this member has been removed by post-Ringold erosion and only a thin, discontinuous section remains. This thin erosional remnant has previously been referred to as the Upper Ringold Unit (Myers et al. 1979; Tallman et al. 1979, 1981; Lindsey et al. 1992).

Although the member is now absent from much of the Pasco Basin, the distribution of erosional remnants indicates the member once extended across the entire basin.

Informal member of Savage Island. Lacustrine deposits (facies association IV) dominate the uppermost Ringold Formation, the 90-m thick member of Savage Island. Three successive lake-fill sequences are present in the member in the east central Pasco Basin. Each of the sequences has a basal diatomaceous interval that grades upward into interstratified silt and sand. The member has been almost completely removed by post-Ringold erosion from the central and western Pasco Basin. Small outcrops remain locally in shallow ravines along the northwest base of Rattlesnake Mountain.

Deposition of the Ringold Formation was followed by a period of regional incision in the late Pliocene to early Pleistocene. Within the Pasco Basin, this is reflected by the abrupt termination and eroded nature of the top of the Ringold Formation (Bjornstad 1985; Brown 1960; Newcomb et al. 1972). The exact timing and duration of incision are unknown; however, the incision probably occurred between 1 and 3.4 million years ago.

Plio-Pleistocene Unit. Pedogenic carbonates overlie and truncate the Ringold Formation member of Savage Island along the length of the White Bluffs. These carbonates are interpreted to be correlative to calcium carbonate- and silt-rich strata referred to locally as the Plio-Pleistocene unit and to multilithologic gravels referred to as the pre-Missoula gravel (Lindsey 1996). Unconformably overlying the Ringold Formation in the vicinity of 200 West is the laterally discontinuous Plio-Pleistocene unit (Reidel et al. 1992). Distribution of the Pliocene-Pleistocene unit depends in part on erosion of the underlying Ringold Formation and post-depositional erosion by catastrophic Missoula floods (Slate 1996). The unit can informally be divided into two subunits: a coarse-grained facies consisting of weathered and unweathered basaltic gravels deposited as locally derived slope wash, colluvium, and sidestream alluvium, and fine-grained pedogenic carbonate horizons that were originally deposited as overbank sediments (Reidel et al. 1992; Slate 1996; Bjornstad 1984, 1985). Thickness of the Plio-Pleistocene deposits ranges from 0 to 20 m. The finer and more massive carbonate horizons influence contaminant migration by slowing its rate of downward movement and potentially diverting contaminants laterally (Slate 1996).

Eolian Deposits. Eolian deposits at the Hanford Site include five loess units informally referred to as units L1 though L5. Loess units are differentiated on the basis of position relative to other stratigraphic units, color, soil development, and paleomagnetic polarity (Reidel et al. 1992). The oldest unit is L1, a very compact reddish yellow loess capped by silcrete. The chemical nature and stratigraphic position of the silcrete suggest that its age is late Pliocene to early Pleistocene (Reidel et al. 1992). The youngest loess unit in the Pasco Basin is unit L5. It includes loess deposited since late Wisconsin time (about 20 ka). More specific information can be found on the various loess units in Reidel et al. (1992).

The main eolian unit in the subsurface at the Hanford Site is the early "Palouse" soil (Reidel et al. 1992). The Palouse soil overlies the Plio-Pleistocene unit in the Cold Creek syncline area and is composed of up to 20 m of massive, loess-like silt and minor fine-grained sand (Tallman et al. 1979, 1981; DOE 1988). The early Palouse soil differs from the overlying Hanford formation slackwater flood deposits by a greater calcium-carbonate content, massive structure in core samples, and a high natural gamma response in geophysical logs (DOE 1988). The upper contact of the unit is poorly defined, and may grade into the overlying silty slackwater deposits of the Hanford formation. Based on a predominantly reversed polarity, the unit is inferred to be early Pleistocene in age (Reidel et al. 1992).

Pre-Missoula Gravels. Sand and gravel river sediments, referred to informally as the pre-Missoula gravels (PSPL 1982), were deposited after incision of the Ringold and before deposition of the cataclysmic flood deposits. The pre-Missoula gravels are up to 25 m thick, contain less basalt than the underlying Ringold gravels and overlying Hanford deposits, and have a distinctive white or bleached color (Reidel et al. 1992). Composition of the unit is a quartzose and gneissic clast-supported pebble-to-cobble gravel with a matix of quartzo-feldspathic sand (Reidel et al. 1992). These sediments appear to occur in a swath that runs from the Old Hanford townsite on the eastern side of the Hanford Site across the Site toward Horn Rapids on the Yakima River. Magnetic polarity data indicate that the pre-Missoula gravel unit is no younger than early Pleistocene in age (> 1 Ma) (Reidel et al. 1992).

Hanford formation. Cataclysmic floods inundated the Pasco Basin a number of times during the Pleistocene, beginning as early as 1 million years ago (Bjornstad and Fecht 1989); the last major flood sequence is dated at about 13,000 years ago by the presence of Mount St. Helens "S" tephra (Mullineaux et al. 1978) interbedded with the flood deposits. The number and timing of cataclysmic floods continues to be debated. Baker et al. (1991) document as many as 10 flood events during the last ice age. The largest and most frequent floods came from glacial Lake Missoula in northwestern Montana; however, smaller floods may have escaped down-valley from glacial Lakes Clark and Columbia along the northern margin of the Columbia Plateau (Waitt 1980), or down the Snake River from glacial Lake Bonneville (Malde 1968). The flood deposits informally called the Hanford formation, blanket low-lying areas over most of the central Pasco Basin.

Cataclysmic floodwaters entering the Pasco Basin quickly became impounded behind Wallula Gap, which was too restrictive for the volume of water involved. Floodwaters formed temporary lakes with a shoreline up to 381 m (1250 ft) in elevation, which lasted only a few weeks or less (Baker 1978). The Hanford formation is thickest in the vicinity of the 200 Areas where it is up to 65 m (Reidel et al. 1992).

The Hanford formation is divided into three facies: (1) gravel-dominated, (2) sand-dominated, and (3) silty (Reidel et al. 1992). These facies are referred to as coarse-grained deposits, plane-laminated sands facies, and rhythmite facies in Baker et al. (1991). Locally, the gravel-dominated facies is commonly referred to as the "Pasco Gravels" and the silty facies is often designated as "Touchet Beds."

The gravel-dominated facies generally consist of coarse-grained basaltic sand and granule-to-boulder gravel. Deposits display massive bedding, plane to low-angle bedding, and large-scale planar cross-bedding in outcrop. The gravels usually are matrix-poor and display an open-framework texture. Lenticular sand and silt beds are intercalated throughout the facies. Gravel clasts are generally dominated by basalt (50 to 80%). The gravel-dominated facies was deposited by high-energy floodwaters in or immediately adjacent to the main channel cataclysmic floodways (Reidel et al. 1992).

The sand-dominated facies consists of fine-to coarse-grained sand and granule gravel displaying plane lamination and bedding and less commonly plane bedding and channel-fill sequences. Silt content is variable, and sands may contain small pebbles and rip-up clasts. The sands are typically basaltic and are commonly referred to as "salt and pepper" in appearance. The laminated sand facies was deposited adjacent to main flood channelways during the waning stages of flooding and is transitional between the gravel-dominated and silty facies (Reidel et al. 1992).

The silty facies consists of thinly bedded, plane-laminated and ripple cross-laminated silt and fine- to coarse-grained sand (Reidel et al. 1992). This facies commonly displays normally graded rhythimites a few centimeters to several tens of centimeters thick (Bjornstad et al 1987; DOE 1988). These sediments were deposited under slackwater conditions and in back-flooded areas (DOE 1998a).

Clastic dikes are commonly associated with, but not restricted to, cataclysmic flood deposits on the Columbia Plateau. While there is general agreement that clastic dikes formed during cataclysmic flooding, a primary mechanism to satisfactorily explain the formation of all dikes has not been identified (Supply System 1981). Among the more probable explanations are fracturing initiated by hydrostatic loading and hydraulic injection associated with receding floodwaters. These dikes may provide vertical pathways for downward migration of water through the vadose zone.

Alluvium is present, not only as a surficial deposit along major river and stream courses (Figure 4.2-5), but also in the subsurface, where it is found underlying, and interbedded with, proglacial flood deposits. Two types of alluvium are recognized in the Pasco Basin: quartzitic mainstream and basalt-rich sidestream alluvium. Colluvium (talus and slopewash) is a common Holocene deposit in moderate-to-high relief areas. Colluvium, like the dune sand that is found locally in the Pasco Basin, is not commonly preserved in the stratigraphic record. Varying thicknesses of loess or sand mantle much of the Columbia Plateau. Active and stabilized sand dunes are widespread over the Pasco Basin (Figure 4.2-5).

Landslide deposits in the Pasco Basin are of variable age and genesis. Most occur within the basalt outcrops along the ridges, such as on the north side of Rattlesnake Mountain, or steep river embankments such as White Bluffs, where the Ringold Formation member of Savage Island crops out in the Pasco Basin (Figure 4.2-5).

4.2.2.4 100 Areas Stratigraphy

The 100 Areas are spread out along the Columbia River in the northern portion of the Pasco Basin (Figure 4.0-1). All of the 100 Areas, except the 100-B/C Area, lie on the north limb of the Wahluke syncline. The 100-B/C Area lies over the axis of the syncline. The top of basalt in the 100 Areas ranges in elevation from 46 m (150 ft) near the 100-H Area to -64 m (-210 ft) below sea level near the 100-B/C Area. The Ringold Formation and Hanford formation occur throughout this area; the pre-Missoula gravels may be present near the 100-B/C and 100-K Areas but are not readily distinguished from Ringold and Hanford sediments. The Plio-Pleistocene unit and early "Palouse" soil have not been recognized in the 100 Areas.

The Ringold Formation shows a marked west-to-east variation in the 100 Areas (Lindsey 1992). The main channel of the ancestral Columbia River flowed along the front of Umtanum Ridge and through the 100-B/C and 100-K Areas, before turning south to flow along the front of Gable Mountain and/or through the Gable Mountain-Gable Butte gap. This main channel deposited coarse-grained sand and gravel facies of the Ringold Formation (Units A, B, C, and E). Farther to the north and east, however, the Ringold sediments gradually become dominated by the lacustrine and overbank deposits and associated paleosols (Ringold Lower Mud Unit of the member of Wooded Island), with the 100-H Area showing almost none of the gravel facies. In the 100 Areas, the Hanford formation consists primarily of the gravel-dominated facies, with local occurrences of the sand-dominated or silty facies. Hydrogeologic reports providing specific information have been written for each of the 100 Areas. These are as follows: 100-B/C Area - Lindberg (1993a); 100-D Area - Lindsey and Jaeger (1993); 100-F Area - Lindsey (1992); 100-H

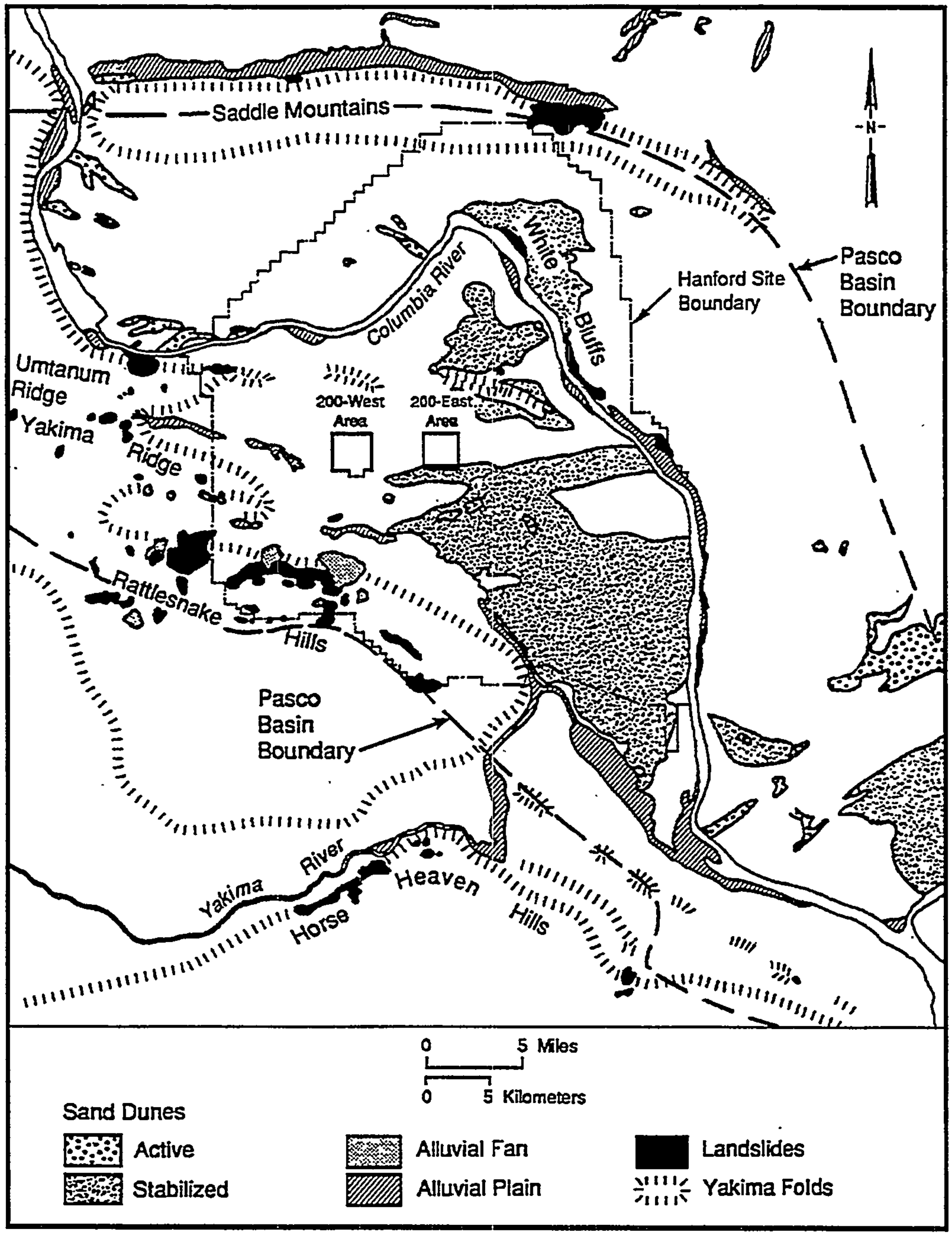


Figure 4.2-5. Location of Surficial Features (DOE 1988).

Area - Lindsey and Jaeger (1993); 100-K Area - Lindberg (1993b); and 100-N Area - Hartman and Lindsey (1993).

4.2.2.5 200 Areas Stratigraphy

The geology in the 200 West and 200 East Areas is surprisingly different, although they are separated by a distance of only 6 km (4 mi) (Figure 4.0-1). One of the most complete suprabasalt stratigraphic sections on the Hanford Site, with most of Lindsey's (1996) Ringold units, as well as the Plio-Pleistocene unit, early "Palouse" soil, and the Hanford formation, is found in the 200 West Area. There are numerous reports on the geology of the 200 West Area, including Connelly et al. (1992a), Lindsey (1991b), Lindsey et al. 1994), and Reidel et al. (1992).

In the 200 East Area, most of the Ringold Formation units are present in the southern part but have been eroded in a complex pattern to the north. On the north side of the 200 East Area, the Hanford formation rests directly on the basalt, and there are no Ringold sediments present. Erosion by the ancestral Columbia River and catastrophic flooding are believed to have removed the Ringold Formation from this area. Neither the Plio-Pleistocene unit nor the early "Palouse" soil have been identified in the 200 East Area. Reports on the geology of the 200 East Area include Connelly et al. (1992b), Lindsey et al. (1992, 1994), and Tallman et al. (1979).

4.2.2.6 300 Area Stratigraphy

The 300 Area is located in the southeastern portion of the Hanford Site (Figure 4.0-1). The 300 Area lies above a gentle syncline formed by the intersection of the Palouse Slope and the western side of the Pasco Basin. Over most of the Hanford Site, the uppermost basalt flows belong to the Elephant Mountain Member, but near the 300 Area, even younger flows belonging to the Ice Harbor Member are found, causing a relative high in the top of basalt surface (Schalla et al. 1988). (The Elephant Mountain and Ice Harbor Members are the top two members of the Saddle Mountains Basalt.) Both Ringold Formation and Hanford formation sediments are found in the 300 Area; Swanson (1992) describes the geology in more detail.

4.2.3 Structural Geology of the Region

The Hanford Site is located near the junction of the Yakima Fold Belt and the Palouse structural subprovinces (DOE 1988). These structural subprovinces are defined on the basis of their structural fabric, unlike the physiographic provinces that are defined on the basis of landforms. The Palouse subprovince is primarily a regional paleoslope that dips gently toward the central Columbia Basin and exhibits only relatively mild structural deformation. The Palouse Slope is underlain by a wedge of Columbia River basalt that overlies the Paleozoic North American craton and thins gradually toward the east and north and laps onto the adjacent highlands.

The principal characteristics of the Yakima Fold Belt are a series of segmented, narrow, asymmetric anticlines that have wavelengths between 5 and 31 km (3 and 19 mi) and amplitudes commonly <1 km (0.6 mi) (Reidel 1984; Reidel et al.1989, 1994). These anticlinal ridges are separated by broad synclines or basins that, in many cases, contain thick accumulations of Neogene- to Quaternary-age sediments. The deformation of the Yakima Folds occurred under north-south compression. The fold belt was growing during the eruption of the Columbia River Basalt Group and continued to grow into the Pleistocene and probably into the present (Reidel

1984; Reidel et al.1994).

Thrust or high-angle reverse faults with fault planes that strike parallel or subparallel to the axial trends are principally found along the limbs of the anticlines (Bentley et al. 1980; Hagood 1985; Reidel 1984; Reidel et al. 1994; Reidel and Fecht 1994a,b; Swanson et al. 1979a, 1979b, 1981). The amount of vertical stratigraphic offset associated with these faults varies but commonly exceeds hundreds of meters.

The Saddle Mountains uplift is a segmented anticlinal ridge extending from near Ellensburg to the western edge of the Palouse Slope. This ridge forms the northern boundary of the Pasco Basin and the Wahluke syncline (Figure 4.2-6). It is generally steepest on the north, with a gently dipping southern limb. A major thrust or high-angle reverse fault occurs on the north side (Reidel 1984; Reidel et al. 1994).

The Umtanum Ridge-Gable Mountain uplift is a segmented, asymmetrical anticlinal ridge extending 137 km (85 mi) in an east-west direction and passing north of the 200 Areas (Figure 4.2-6), forming the northern boundary of the Cold Creek syncline and the southern boundary of the Wahluke syncline. Three of this structure's segments are located on or adjacent to the Hanford Site. From the west, Umtanum Ridge plunges eastward toward the Pasco Basin and merges with the Gable Mountain-Gable Butte segment. The latter segment then merges with the Southeast anticline, which trends southeast before dying out near the Columbia River eastern boundary of the Gable Mountain-Gable Butte segment.

There is a major thrust to high-angle reverse fault on the north side of the Umtanum Ridge structure (PSPL 1982; Reidel and Fecht 1994b) that dies out as it plunges eastward past the Gable Mountain-Gable Butte segment. Gable Mountain and Gable Butte are two topographically isolated, anticlinal ridges composed of a series of northwest-trending, doubly plunging, echelon anticlines, synclines, and associated faults. The potential for present-day faulting has been identified on Gable Mountain (PSPL 1982).

The Yakima Ridge uplift extends from west of Yakima to the center of the Pasco Basin, where it forms the southern boundary of the Cold Creek syncline (DOE 1988; Reidel and Fecht 1994a) (Figure 4.2-6). The Yakima Ridge anticline plunges eastward into the Pasco Basin, where it continues on a southeastern trend mostly buried beneath sediments. A thrust to high-angle reverse fault is thought to be present on the north side of the anticline, dying out as the fold extends to the east.

Rattlesnake Mountain is an asymmetrical anticline with a steeply dipping and faulted northern unit that forms the southern boundary of the Pasco Basin (Figure 4.2-6). It extends from the structurally complex Snively Basin area southeast to the Yakima River, where the uplift continues as a series of doubly plunging anticlines (Fecht et al. 1984; Reidel and Fecht 1994a). At Snively Basin, the Rattlesnake Mountain structure intersects the Rattlesnake Hills anticline, which extends beyond Yakima and has an east-west trend.

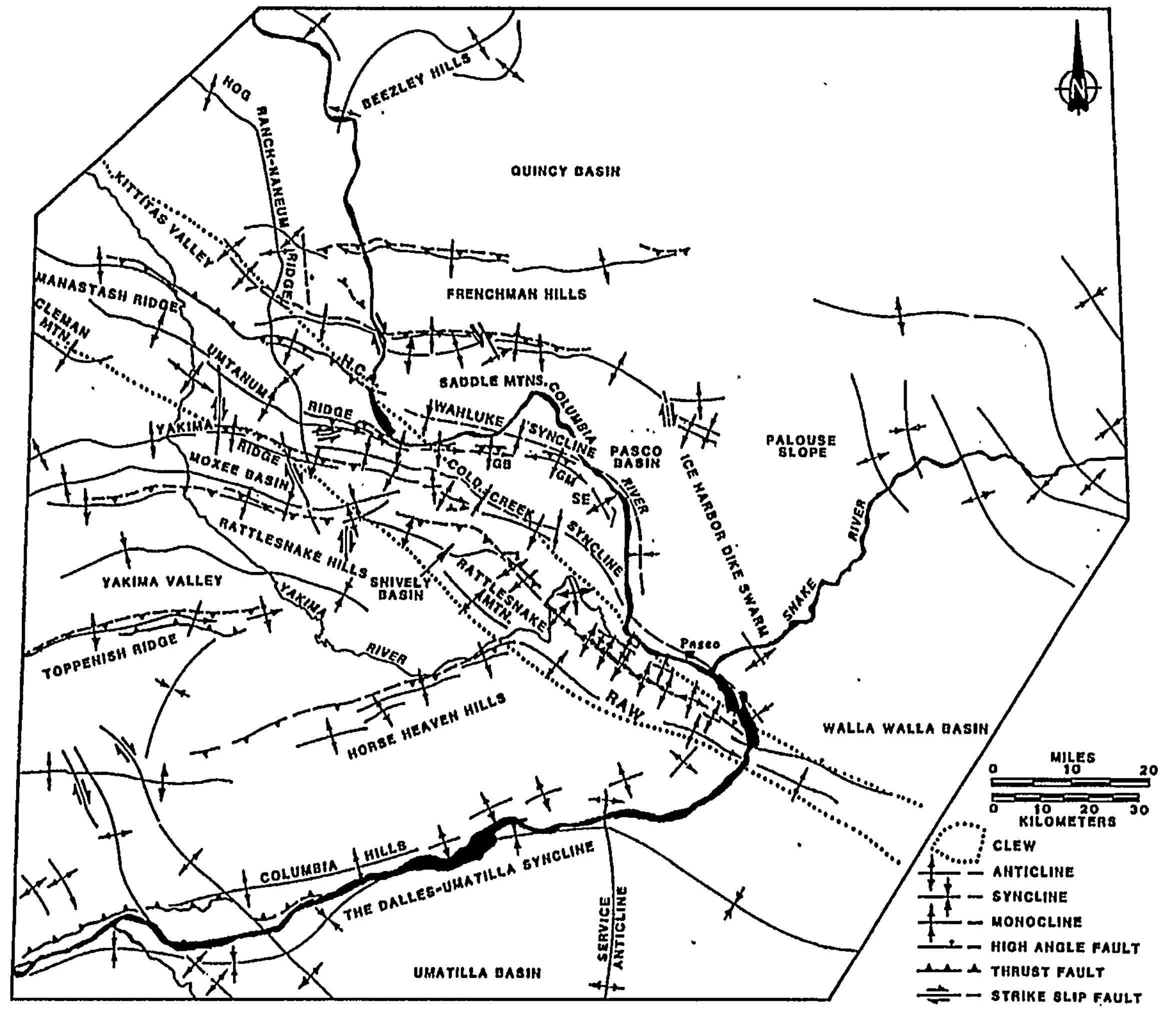


Figure 4.2-6. Location of Structural Features (Reidel et al. 1989)

The Cold Creek syncline (Figure 4.2-6) lies between the Umtanum Ridge-Gable Mountain uplift and the Yakima Ridge uplift. The Cold Creek syncline is an asymmetric and relatively flat-bottomed structure (DOE 1988; Reidel and Fecht 1994a). The Wahluke syncline lies between the Saddle Mountains and the Umtanum Ridge-Gable Mountain uplifts. It too is asymmetric and relatively flat-bottomed, and it is broader than the Cold Creek syncline (Myers et al. 1979; Reidel and Fecht 1994b).

The Cold Creek Fault (Reidel and Fecht 1994a) occurs on the west end of the Cold Creek syncline and coincides with a west-to-east change in hydraulic gradient (Figure 4.2-6). The data suggest that this feature is a high-angle fault that has faulted the basalts and, at least, the older Ringold units (Johnson et al. 1993). This fault apparently has not affected younger Ringold units or the Hanford formation.

Another fault, informally called the May Junction fault (Reidel and Fecht 1994a), is located nearly 4.5 km (3 mi) east of the 200 East Area. Like the Cold Creek fault, this fault is thought to be a high-angle fault that has offset the basalts and the older Ringold units. It does not appear to have affected the younger Ringold units or the Hanford formation.

4.2.4 Soils

Hajek (1966) describes 15 different soil types on the Hanford Site, varying from sand to silty and sandy loam. These are shown in Figure 4.2-7 and briefly described in Table 4.2-1. Various classifications, including land use, are also given in Hajek (1966). The soil classifications given in Hajek (1966) have not been updated to reflect current reinterpretations of soil classifications. Until soils on the Hanford Site are resurveyed, the descriptions presented in Hajek (1966) will continue to be used.

4.2.5 Seismicity

The historic record of earthquakes in the Pacific Northwest dates from about 1840. The early part of this record is based on newspaper reports of human perception of the shaking and structural damage as classified by the Modified Mercalli Intensity (MMI) scale, and is probably incomplete because the region was sparsely populated. The historical record appears to be complete since 1905 for MMI V and since 1890 for MMI VI (Rohay 1989). Seismograph networks did not start providing earthquake locations and magnitudes of earthquakes in the Pacific Northwest until about 1960. A comprehensive network of seismic stations that provides accurate locating information for most earthquakes of magnitude >2.5 was installed in eastern Washington in 1969. DOE (1988) provides a summary of the seismicity of the Pacific Northwest, a detailed review of the seismicity in the Columbia Plateau region and the Hanford Site, and a description of the seismic networks used to collect the data.

Large earthquakes (Richter magnitude >7) in the Pacific Northwest have occurred near Puget Sound, Washington, and near the Rocky Mountains in eastern Idaho and western Montana. One of these events occurred near Vancouver Island in 1946, and produced a maximum MMI of VIII and a Richter magnitude of 7.3. Another large event occurred near Olympia, Washington, in 1949 that had a maximum intensity of MMI VIII and a Richter magnitude of 7.1. The two largest events near the Rocky Mountains were the 1959 Hebgen Lake earthquake in western Montana, which had a Richter magnitude of 7.5 and an MMI X, and the 1983 Borah Peak earthquake in eastern Idaho, which had a Richter magnitude of 7.3 and an MMI IX.

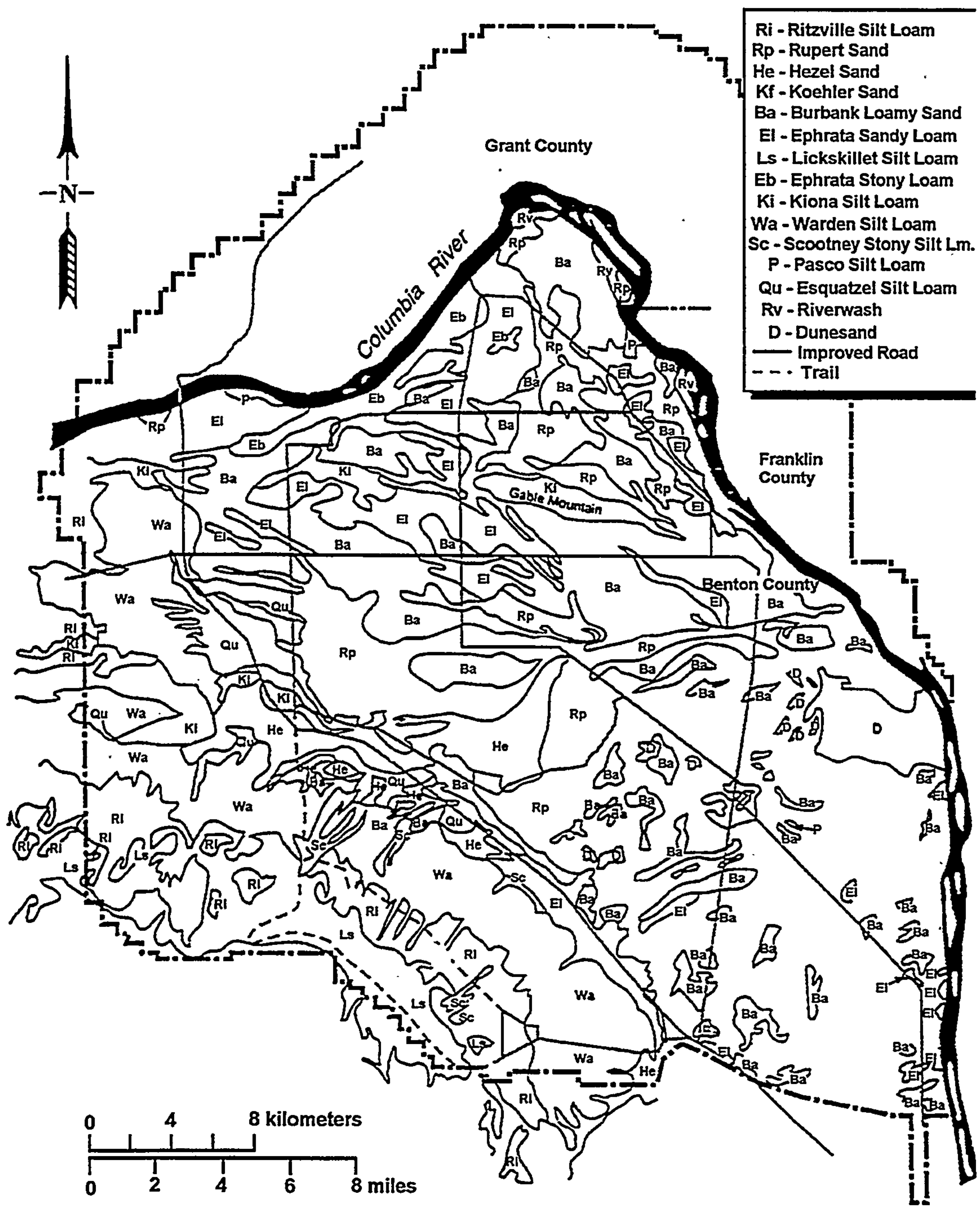


Figure 4.2-7. Soil Map of the Hanford Site (Hajak 1966).

Table 4.2-1. Soil Types on the Hanford Site (Hajek 1966)

Name (symbol)	Description
Ritzville Silt Loam (Ri)	Dark-colored silt loam soils midway up the slopes of the Rattlesnake Hills. Developed under bunch grass from silty wind-laid deposits mixed with small amounts of volcanic ash. Characteristically >150 cm (60 in.) deep, but bedrock may occur between 75 and 150 cm (30 and 60 in.).
Rupert Sand (Rp)	One of the most extensive soils on the Hanford Site. Brown-to-grayish-brown coarse sand grading to dark grayish-brown at 90 cm (35 in.). Developed under grass, sagebrush, and hopsage in coarse sandy alluvial deposits that were mantled by wind-blown sand. Hummocky terraces and dune-like ridges.
Hezel Sand (He)	Similar to Rupert sands; however, a laminated grayish-brown strongly calcareous silt loam subsoil is usually encountered within 100 cm (39 in.) of the surface. Surface soil is very dark brown and was formed in wind-blown sands that mantled lake-laid sediments.
Koehler Sand (Kf)	Similar to other sandy soils on the Hanford Site. Developed in a wind-blown sand mantle. Differs from other sands in that the sand mantles a lime-silica cemented "Hardpan" layer. Very dark grayish-brown surface layer is somewhat darker than Rupert Sands. Calcareous subsoil is usually dark grayish-brown at about 45 cm (18 in.).
Burbank Loamy Sand (Ba)	Dark-colored, coarse-textured soil underlain by gravel. Surface soil is usually about 40 cm (16 in.) thick but can be 75 cm (30 in.) thick. Gravel content of subsoil ranges from 20% to 80%.
Ephrata Sandy Loam (El)	Surface is dark colored and subsoil is dark grayish-brown medium-textured soil underlain by gravelly material, which may continue for many feet. Level topography.
Lickskillet Silt Loam (Ls)	Occupies ridge slopes of Rattlesnake Hills and slopes >765 m (2509 ft) elevation. Similar to Kiona series except surface soils are darker. Shallow over basalt bedrock, with numerous basalt fragments throughout the profile.
Ephrata Stony Loam (Eb)	Similar to Ephrata sandy loam. Differs in that many large hummocky ridges are made up of debris released from melting glaciers. Areas between hummocks contain many boulders several feet in diameter.

Name (symbol)	Description
Kiona Silt Loam (Ki)	Occupies steep slopes and ridges. Surface soil is very dark grayish-brown and about 10 cm (4 in.) thick. Dark-brown subsoil contains basalt fragments 30 cm (12 in.) and larger in diameter. Many basalt fragments found in surface layer. Basalt rock outcrops present. A shallow stony soil normally occurring in association with Ritzville and Warden soils.
Warden Silt Loam (Wa)	Dark grayish-brown soil with a surface layer usually 23 cm (9 in.) thick. Silt loam subsoil becomes strongly calcareous at about 50 cm (20 in.) and becomes lighter colored. Granitic boulders are found in many areas. Usually >150 cm (60 in.) deep.
Scootney Stony Silt Loam (Sc)	Developed along the north slope of Rattlesnake Hills; usually confined to floors of narrow draws or small fan-shaped areas where draws open onto plains. Severely eroded with numerous basaltic boulders and fragments exposed. Surface soil is usually dark grayish-brown grading to grayish-brown in the subsoil..
Pasco Silt Loam (P)	Poorly drained very dark grayish-brown soil formed in recent alluvial material. Subsoil is variable, consisting of stratified layers. Only small areas found on the Hanford Site, located in low areas adjacent to the Columbia River.
Esquatzel Silt Loam (Qu)	Deep dark-brown soil formed in recent alluvium derived from loess and lake sediments. Subsoil grades to dark grayish-brown in many areas, but color and texture of the subsoil are variable because of the stratified nature of the alluvial deposits.
Riverwash (Rv)	Wet, periodically flooded areas of sand, gravel, and boulder deposits that make up overflowed islands in the Columbia River and adjacent land.
Dune Sand (D)	Miscellaneous land type that consists of hills or ridges of sand-sized particles drifted and piled up by wind and are either actively shifted or so recently fixed or stabilized that no soil horizons have developed.

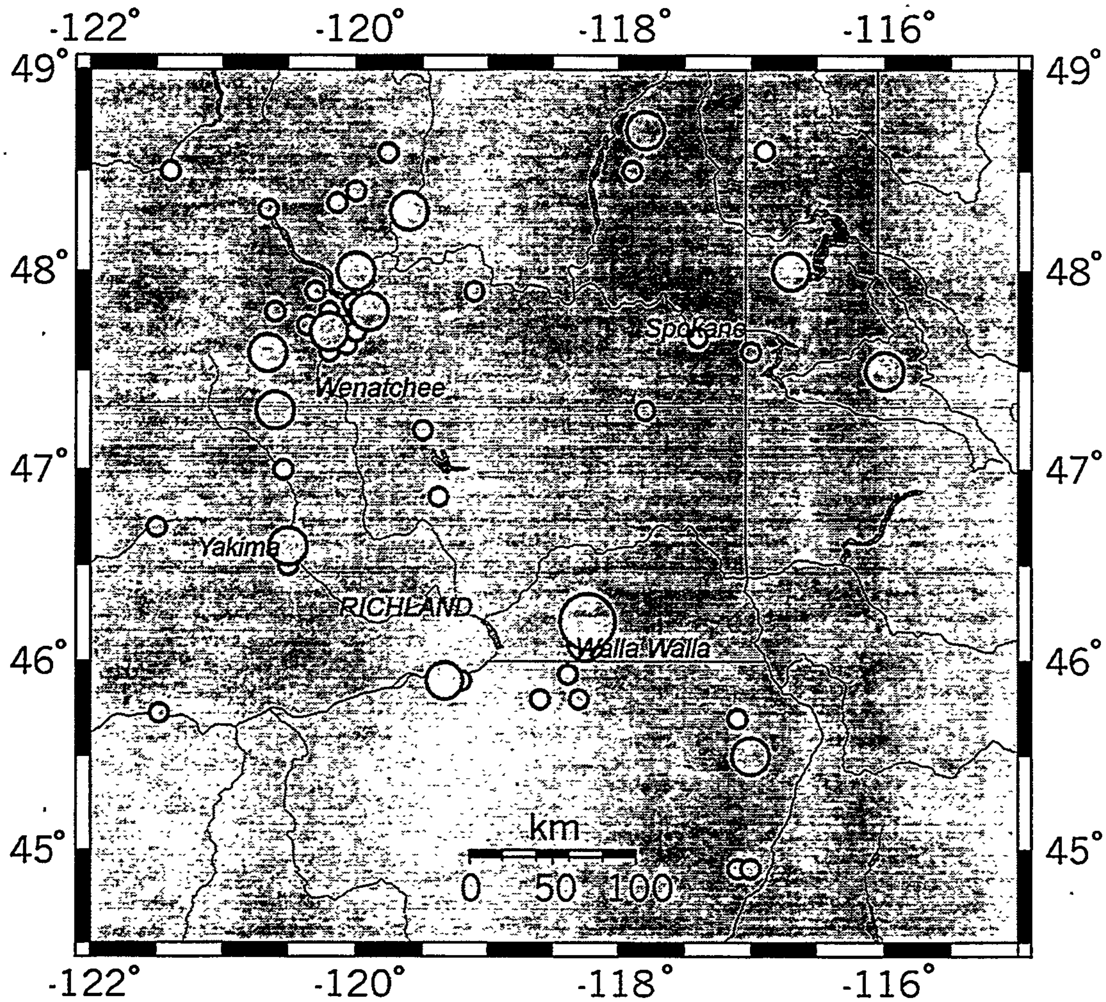
A larger earthquake of uncertain location occurred in north-central Washington in 1872. This event had an estimated maximum MMI ranging from VIII to IX and an estimated Richter magnitude of approximately 7. The distribution of intensities suggests a location within a broad region between Lake Chelan, Washington, and the British Columbia border.

Seismicity of the Columbia Plateau, as determined by the rate of earthquakes per area and the historical magnitude of these events, is relatively low when compared with other regions of the Pacific Northwest, the Puget Sound area, and western Montana/eastern Idaho. Figure 4.2-8 shows the locations of all earthquakes that occurred in the Columbia Plateau before 1969 with an MMI of ≥IV and at Richter magnitude ≥4, and Figure 4.2-9 shows the locations of all earthquakes that occurred from 1969 to 1998 at Richter magnitudes ≥3. The largest known earthquake in the Columbia Plateau occurred in 1936 near Milton-Freewater, Oregon. This earthquake had a Richter magnitude of 5.75 and a maximum MMI of VII, and was followed by a number of aftershocks that indicate a northeast-trending fault plane. Other earthquakes with Richter magnitudes ≥5 an/or MMIs of VI occurred along the boundaries of the Columbia Plateau in a cluster near Lake Chelan extending into the northern Cascade Range, in northern Idaho and Washington, and along the boundary between the western Columbia Plateau and the Cascade Range. Three MMI VI earthquakes have occurred within the Columbia Plateau, including one event in the Milton-Freewater, Oregon, region in 1921; one near Yakima, Washington, in 1892; and one near Umatilla, Oregon, in 1893. In the central portion of the Columbia Plateau, the largest earthquakes near the Hanford Site are two earthquakes that occurred in 1918 and 1973. These two events were magnitude 4.4 and intensity V, and were located north of the Hanford Site near Othello.

Earthquakes often occur in spatial and temporal clusters in the central Columbia Plateau, and are termed "earthquake swarms." The region north and east of the Hanford Site is a region of concentrated earthquake swarm activity, but earthquake swarms have also occurred in several locations within the Hanford Site. The frequency of earthquakes in a swarm tends to gradually increase and decay with no one outstanding large event within the sequence. Roughly 90% of the earthquakes in swarms have Richter magnitudes of 2 or less. These earthquake swarms generally occur at shallow depths, with 75% of the events located at depths <4 km. Each earthquake swarm typically lasts several weeks to months, consists of several to 100 or more earthquakes, and the locations are clustered in an area 5 to 10 km in lateral dimension. Often, the longest dimension of the swarm area is elongated in an east-west direction. However, detailed locations of swarm earthquakes indicate that the events occur on fault planes of variable orientation, and not on a single, throughgoing fault plane.

Earthquakes in the central Columbia Plateau also occur to depths of about 30 km. These deeper earthquakes are less clustered and occur more often as single, isolated events. Based on seismic refraction surveys in the region, the shallow earthquake swarms are occurring in the Columbia River Basalts, and the deeper earthquakes are occurring in crustal layers below the basalts.

The spatial pattern of seismicity in the central Columbia Plateau suggests an association of the shallow swarm activity with the east-west oriented Saddle Mountains anticline. However, this association is complex, and the earthquakes do not delineate a throughgoing fault plane that would be consistent with the faulting observed on this structure.



	MMI	Equivalent Richter Magnitude (Calculated)
○ (small)	V	4.0 - 4.7
○ (medium)	VI	4.7 - 5.3
○ (large)	VII	5.3 - 6.3

Figure 4.2-8. Historical Seismicity of the Columbia Plateau and Surrounding Areas. All earthquakes between 1850 and March 20, 1969, with a Modified Mercalli Intensity of V or larger or a Richter magnitude of 4 or larger are shown (Rohay 1989).

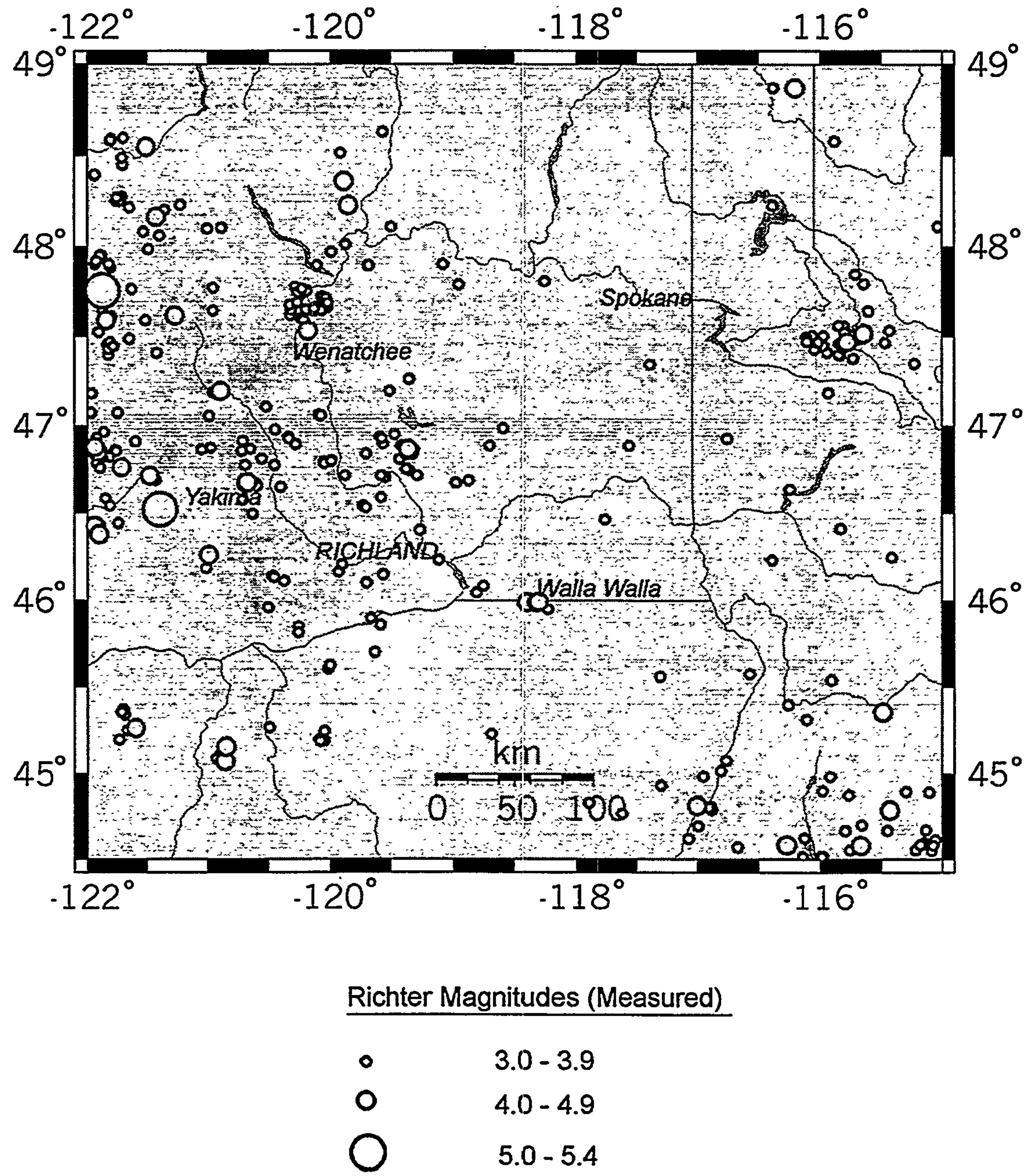


Figure 4.2-9. Seismicity of the Columbia Plateau and Surrounding Areas as Measured by Seismographs. All earthquakes from 3/20/1969 to 12/31/1997 with Richter magnitude 3 or larger are shown. Data sources UWGP (1999) and CNSS (1999).

Earthquake focal mechanisms in the central Columbia Plateau generally indicate reverse faulting on east-west planes, consistent with a north-south-directed maximum compressive stress and with the formation of the east-west-oriented anticlinal folds of the Yakima Fold Belt (Rohay 1987). However, earthquake focal mechanisms indicate faulting on a variety of fault plane orientations.

Earthquake focal mechanisms along the western margin of the Columbia Plateau also indicate north-south compression, but here the minimum compressive stress is oriented east to west, resulting in strike-slip faulting (Rohay 1987). Geologic studies indicate an increased component of strike-slip faulting in the western portion of the Yakima Fold Belt. Earthquake focal mechanisms in the Milton-Freewater region to the southeast indicate a different stress field, one with maximum compression directed east-west instead of north-south.

Estimates for the earthquake potential of structures and zones in the central Columbia Plateau have been developed during the licensing of nuclear power plants at the Hanford Site. In reviewing the operating license application for the Washington Public Power Supply System (now Energy Northwest) Project WNP-2, the U.S. Nuclear Regulatory Commission (NRC 1982) concluded that four earthquake sources should be considered for seismic design: the Rattlesnake-Wallula alignment, Gable Mountain, a floating earthquake in the tectonic province, and a swarm area.

For the Rattlesnake-Wallula alignment, which passes along the southwest boundary of the Hanford Site, the NRC estimated a maximum Richter magnitude of 6.5, and for Gable Mountain, an east-west structure that passes through the northern portion of the Hanford Site, a maximum Richter magnitude of 5.0. These estimates were based upon the inferred sense of slip, the fault length, and/or the fault area. The floating earthquake for the tectonic province was developed from the largest event located in the Columbia Plateau, the Richter magnitude 5.75 Milton-Freewater earthquake. The maximum swarm earthquake for the purpose of WNP-2 seismic design was a Richter magnitude 4.0 event, based on the maximum swarm earthquake in 1973. (The NRC concluded that the actual magnitude of this event was smaller than estimated previously.)

Probabilistic seismic hazard analyses have been used to determine the seismic ground motions expected from multiple earthquake sources, and these are used to design or evaluate facilities on the Hanford Site. The most recent site-specific hazard analysis (Geomatrix 1994, 1996) estimated that 0.10 g (1 g is the acceleration of gravity) horizontal acceleration would be experienced on average every 500 yr (or with a 10% chance every 50 yr). This study also estimated that 0.2 g would be experienced on average every 2500 yr (or with a 2% chance in 50 yr). These estimates are in approximate agreement with the results of national seismic hazard maps produced by the U.S. Geological Survey (USGS 1996).

4.3 Hydrology

P. D. Thorne

Hydrology considerations at the Hanford Site include surface water and groundwater.

4.3.1 Surface Water

Surface water at Hanford includes the Columbia River, Columbia riverbank seepage, springs, and ponds. In addition, the Yakima River flows along a short section of the southern boundary of the Site (Figure 4.3-1), and there is surface water associated with irrigation east and north of the Hanford Site.

4.3.1.1 Columbia River

The Columbia River is the second largest river in the contiguous United States in terms of total flow and is the dominant surface-water body on the Hanford Site. The original selection of the Hanford Site for plutonium production and processing was based, in part, on the abundant water provided by the Columbia River. The existence of the Hanford Site has precluded development of this section of river for irrigation and power, and the Hanford Reach of the Columbia River is currently under consideration for designation as a National Wild and Scenic River as a result of congressional action in 1988 (see Section 6.2.6).

Originating in the mountains of eastern British Columbia, Canada, the Columbia River drains a total area of approximately 680,000 km^2 (262,480 mi^2) en route to the Pacific Ocean. Flow of the Columbia River is regulated by 11 dams within the United States, 7 upstream and 4 downstream of the Site. Priest Rapids is the nearest upstream dam, and McNary is the nearest downstream dam. Lake Wallula, the impoundment created by McNary Dam, extends up near Richland, Washington. Except for the Columbia River estuary, the only unimpounded stretch of the river in the United States is the Hanford Reach, which extends from Priest Rapids Dam to the head of Lake Wallula.

Flows through the Hanford Reach fluctuate significantly and are controlled primarily by releases from Priest Rapids Dam. Annual flows near Priest Rapids during the 68 years prior to 1985 averaged nearly 3360 m^3/s (120,000 ft^3/s) (McGavock et al. 1987). Daily average flows during this period ranged from 1000 to 7000 m^3/s (36,000 to 250,000 ft^3/s). During the last 10 years, the average daily flow was also about 3360 m^3/s (120,000 ft^3/s). However, larger than normal snowpacks resulted in exceptionally high spring runoff during 1996 and 1997. The peak flow rate during 1997 was nearly 11,750 m^3/s (415,000 ft^3/s) (DART 1999). Average daily flows from 1989 through August 1999 are plotted in Figure 4.3-2. Flows typically peak from April through June during spring runoff from snowmelt, and are lowest from September through October. As a result of daily fluctuations in discharges from Priest Rapids Dam, the depth of the river varies significantly over a short time period. Vertical fluctuations of 1.5 m (>5 ft) during a 24-hr period are not uncommon along the Hanford Reach (Dirkes 1993). The width of the river varies from approximately 300 m (1000 ft) to 1000 m (3300 ft) within the Hanford Site.

The primary uses of the Columbia River include the production of hydroelectric power, irrigation of cropland in the Columbia Basin, and transportation of materials by barge. The Hanford Reach is the upstream limit of barge traffic on the mainstem Columbia River. Barges are used to transport reactor vessels from decommissioned nuclear submarines to Hanford for disposal. Several communities located on the Columbia River rely on the river as their source of drinking water. The Columbia River is also used as a source of both drinking water and industrial water for several Hanford Site facilities (Dirkes 1993). In addition, the Columbia River is used extensively for recreation, which includes fishing, hunting, boating, sailboarding, water-skiing, diving, and swimming.

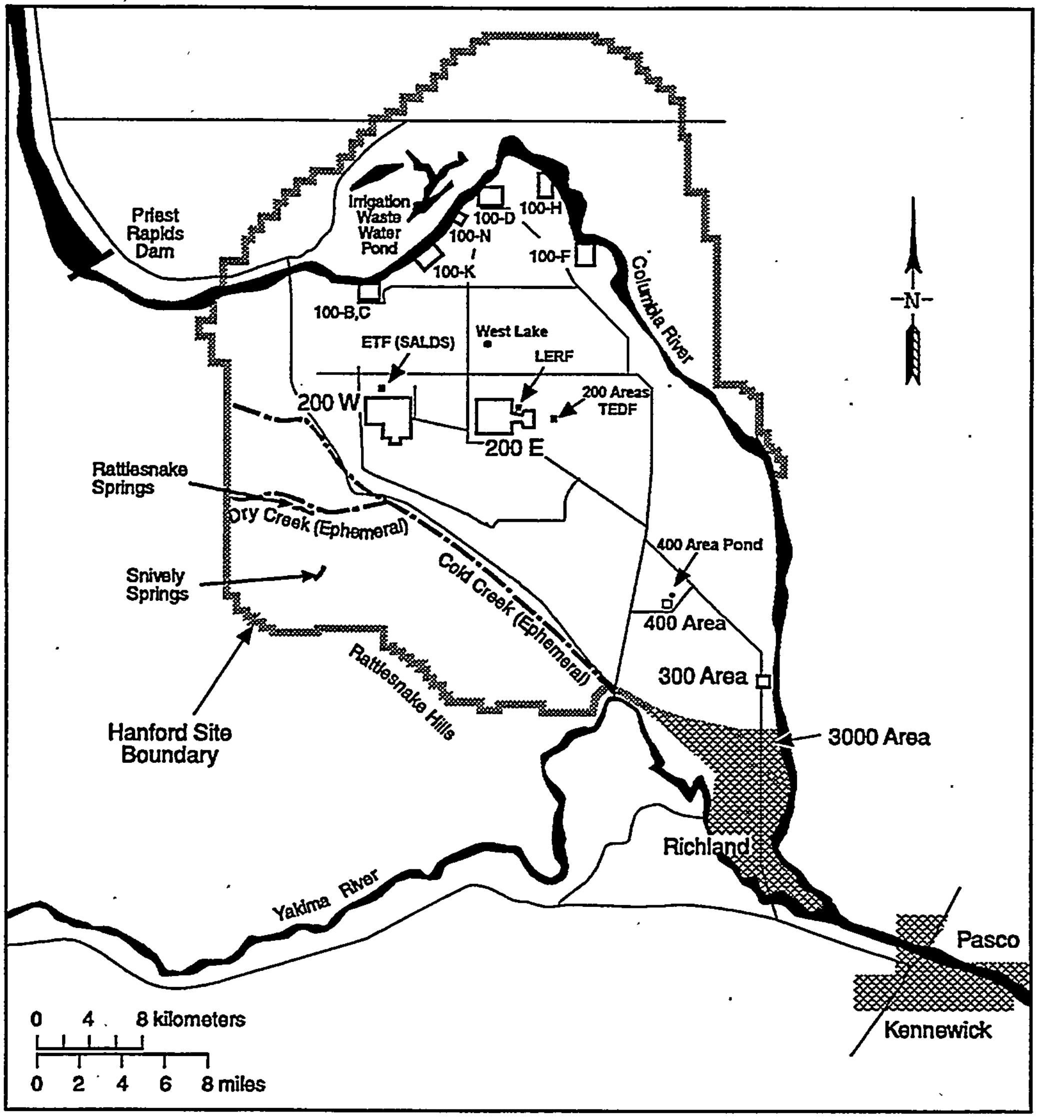


Figure 4.3-1. Surface Water Features Including Rivers, Ponds, Major Springs, and Ephemeral Streams on the Hanford Site.

4.3.1.2 Yakima River

The Yakima River, which follows a small length of the southern boundary of the Hanford Site, has much lower flow than the Columbia River. The average flow, based on nearly 60 years of records, is about 104 m^3/s (3712 ft^3/s), with an average monthly maximum of 490 m^3/s (17,500 ft^3/s) and minimum of 4.6 m^3/s (165 ft^3/s). Exceptionally high flows were observed during 1996 and 1997. The peak average daily flow rate during 1997 was nearly 1300 m^3/s (45,900 ft^3/s). Average daily flows from 1989 through May 1999 are plotted in Figure 4.3-3. Approximately one-third of the Hanford Site is drained by the Yakima River System.

4.3.1.3 Springs and Streams

Several springs are found on the slopes of the Rattlesnake Hills, along the western edge of the Hanford Site (DOE 1988). An alkaline spring at the east end of Umtanum Ridge was also documented by The Nature Conservancy in their Biodiversity Inventory and Analysis of the Hanford Site - 1997 Annual Report (Hall 1998). Rattlesnake and Snively springs form small surface streams. Water discharged from Rattlesnake Springs flows down Dry Creek for about 3 km (1.6 mi) before disappearing into the ground (Figure 4.3-1). Cold Creek and its tributary, Dry Creek, are ephemeral streams within the Yakima River drainage system in the southwestern portion of the Hanford Site. These streams drain areas to the west of the Hanford Site and cross the southwestern part of the Site toward the Yakima River. Surface flow, when it occurs, infiltrates rapidly and disappears into the surface sediments in the western part of the Site. The ecological characteristics of these systems are described in Section 4.4.2.2.

4.3.1.4 Runoff

Total estimated precipitation over the Pasco Basin is about 9×10^8 m^3 (3.2×10^{10} ft^3) annually, averaging <20 cm/yr (approximately 8 in./yr). Mean annual runoff from the Pasco Basin is estimated at <3.1×10^7 m^3/yr (1.1 x 10 ft^3/yr), or approximately 3% of the total precipitation. The basin-wide runoff coefficient is zero for all practical purposes. The remaining precipitation is assumed to be lost through evapotranspiration, with <1% recharging the groundwater system (DOE 1988). However, studies described by Gee et al. (1992) suggest that precipitation may contribute recharge to the groundwater in areas where soils are coarse-textured and bare of vegetation. Studies by Fayer and Walters (1995), Gee and Kirkham (1984), and Gee and Heller (1985) provide information concerning natural recharge rates and evapotranspiration at selected locations on the Hanford Site.

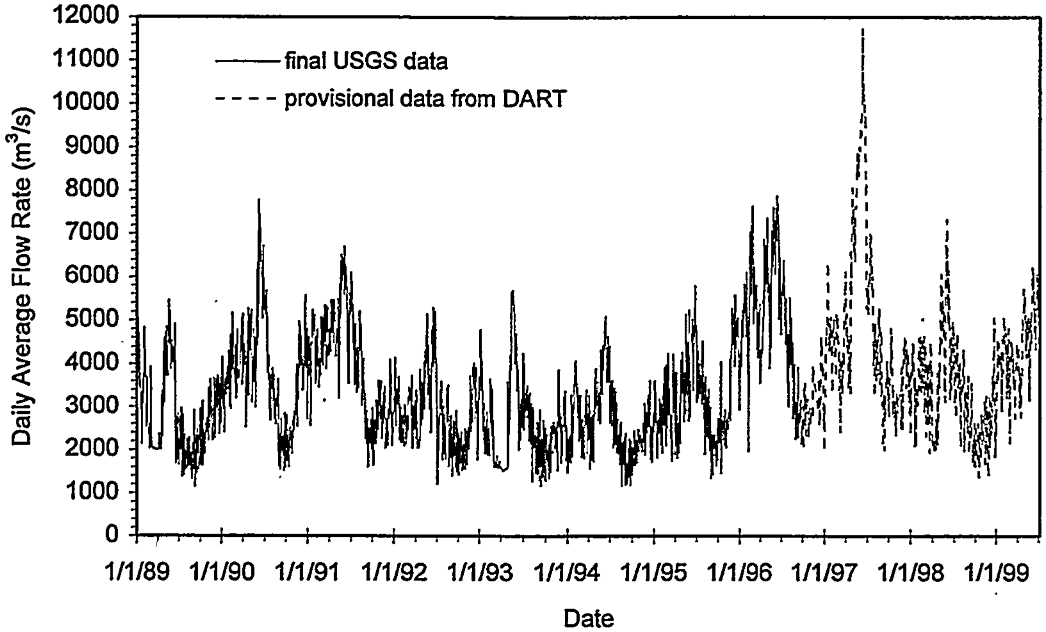


Figure 4.3-2. Average daily flow for the Columbia River below Priest Rapids Dam from 1989 through August 1999 (data from USGS 1999a and DART 1999).

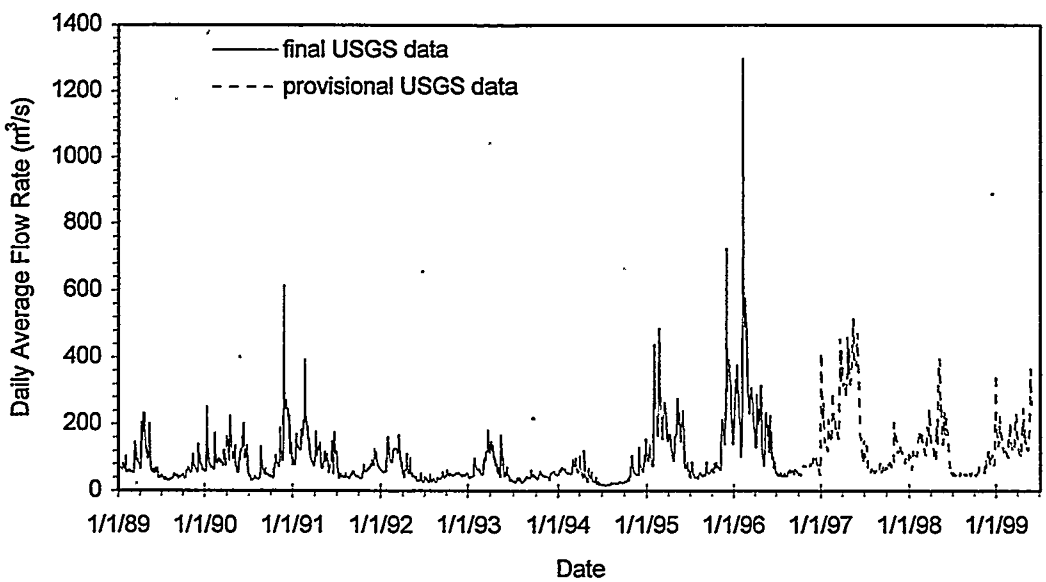


Figure 4.3-3. Average daily flow for the Yakima River from 1989 through May 1999 (data from USGS 1999a and USGS 1999b).

4.3.1.5 Flooding

Large Columbia River floods have occurred in the past (DOE 1987), but the likelihood of recurrence of large-scale flooding has been reduced by the construction of several flood control/water-storage dams upstream of the Site. 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, with a peak discharge at the Hanford Site of 21,000 m^3/s (742,000 ft^3/s). The floodplain associated with the 1894 flood is shown in Figure 4.3-4. The largest recent flood took place in 1948 with an observed peak discharge of 20,000 m^3/s (700,000 ft^3/s) at the Hanford Site. The probability of flooding at the magnitude of the 1894 and 1948 floods has been greatly reduced because of upstream regulation by dams (Figure 4.3-5). The exceptionally high runoff during the spring of 1996 resulted in a maximum discharge of nearly 11,750 m^3/s (415,000 ft^3/s) (DART 1999).

There are no Federal Emergency Management Agency (FEMA) floodplain maps for the Hanford Reach of the Columbia River. FEMA only maps developing areas, and the Hanford Reach has been specifically excluded because the adjacent land is primarily under federal control.

There have been fewer than 20 major floods on the Yakima River since 1862 (DOE 1986). The most severe occurred in November 1906, December 1933, May 1948, and February 1996; discharge magnitudes at Kiona, Washington, were 1870, 1900, 1050, and 1300 m^3/s (66,000, 67,000, 37,000, and 45,900 ft^3/s), respectively. (Average flow is 104 m^3/s (165 ft^3/s), and the average monthly maximum is 490 m^3/s (17,500 ft^3/s)). The recurrence intervals for the 1933 and 1948 floods are estimated at 170 and 33 years, respectively. The development of irrigation reservoirs within the Yakima River Basin has considerably reduced the flood potential of the river. The southern border of the Hanford Site could be susceptible to a 100-year flood on the Yakima River (Figure 4.3-6).

Evaluation of flood potential is conducted in part through 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, such as antecedent moisture conditions, snowmelt, and tributary conditions, that could result in maximum runoff. The probable maximum flood for the Columbia River downstream of Priest Rapids Dam has been calculated to be 40,000 m^3/s (1.4 million ft^3/s) and is greater than the 500-year flood. The floodplain associated with the probable maximum flood is shown in Figure 4.3-7. This flood would inundate parts of the 100 Areas located adjacent to the Columbia River, but the central portion of the Hanford Site would remain unaffected (DOE 1986).

The U.S. Army Corps of Engineers (Corps) (1989) has derived the Standard Project Flood with both regulated and unregulated peak discharges given for the Columbia River downstream of Priest Rapids Dam. Frequency curves for both natural (unregulated) and regulated peak discharges are also given for the same portion of the Columbia River. The regulated Standard Project Flood for this part of the river is given as 15,200 m^3/s (54,000 ft^3/s) and the 100-year regulated flood as 12,400 m^3/s (440,000 ft^3/s). No maps for the flooded areas are available.

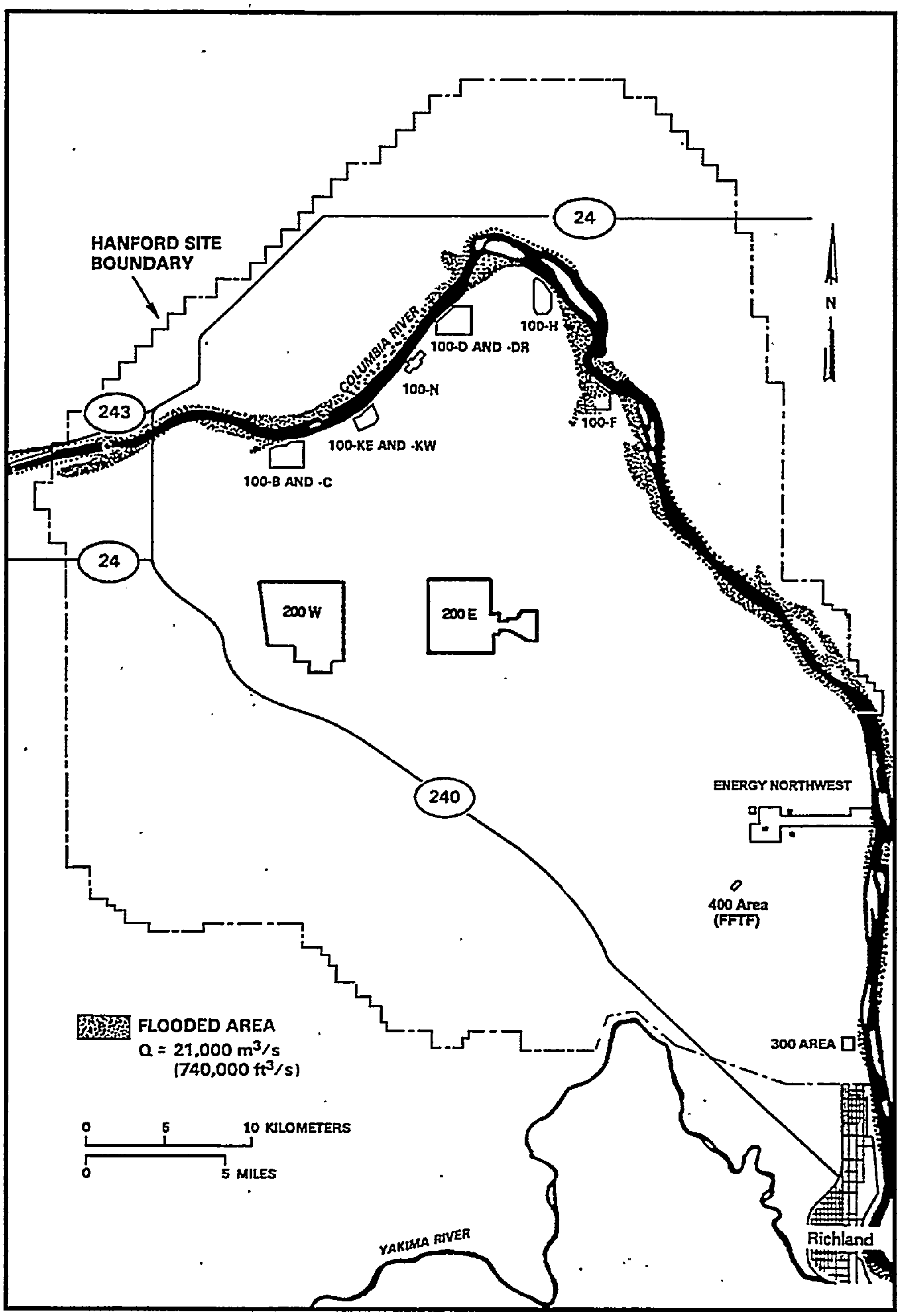


Figure 4.3-4. Flood Area During the 1894 Flood (DOE 1986).

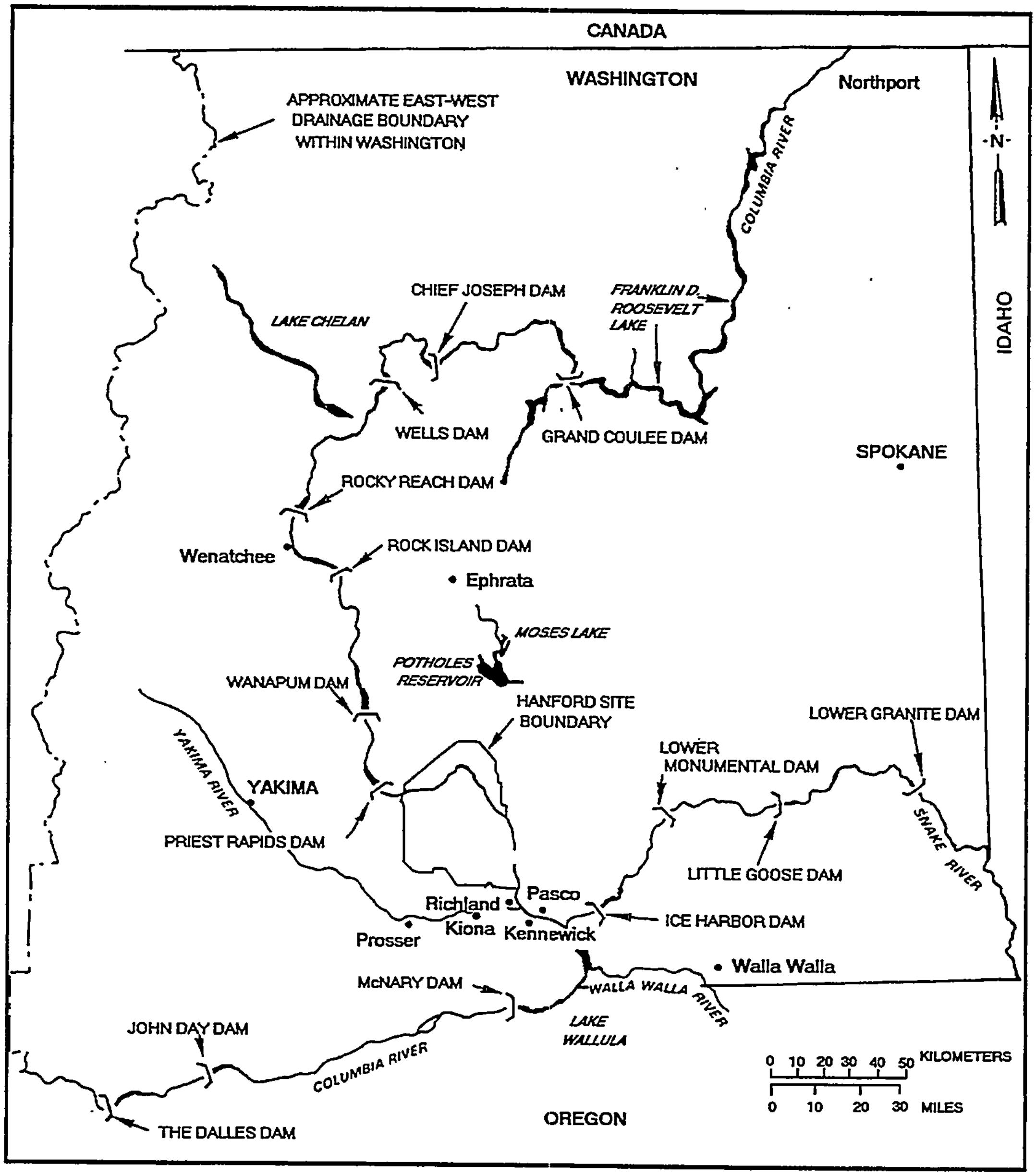


Figure 4.3-5. Locations of Principal Dams Within the Columbia Plateau (DOE 1988).

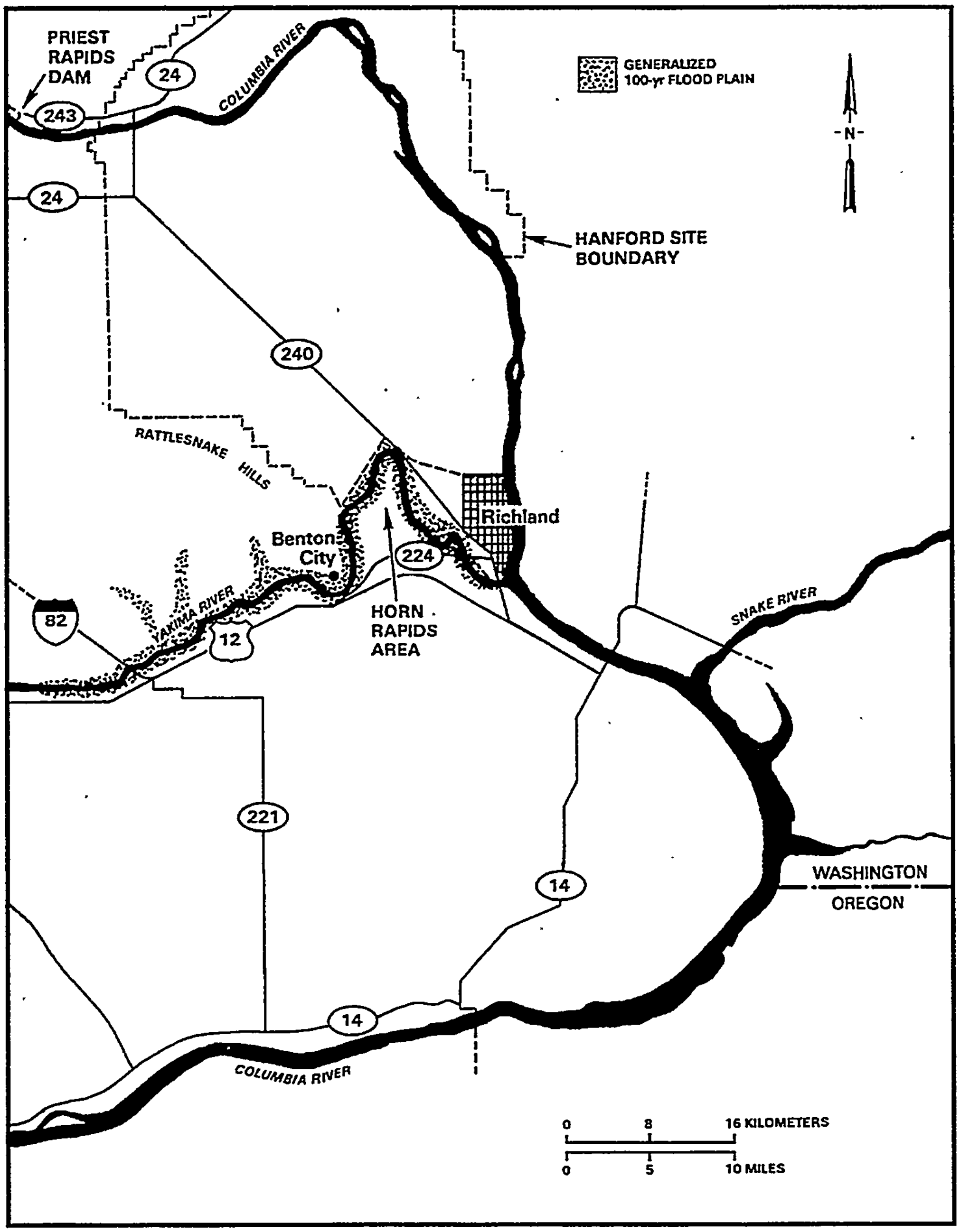


Figure 4.3-6. Flood Area from a 100-Year Flood of the Yakima River near the Hanford Site (DOE 1986).

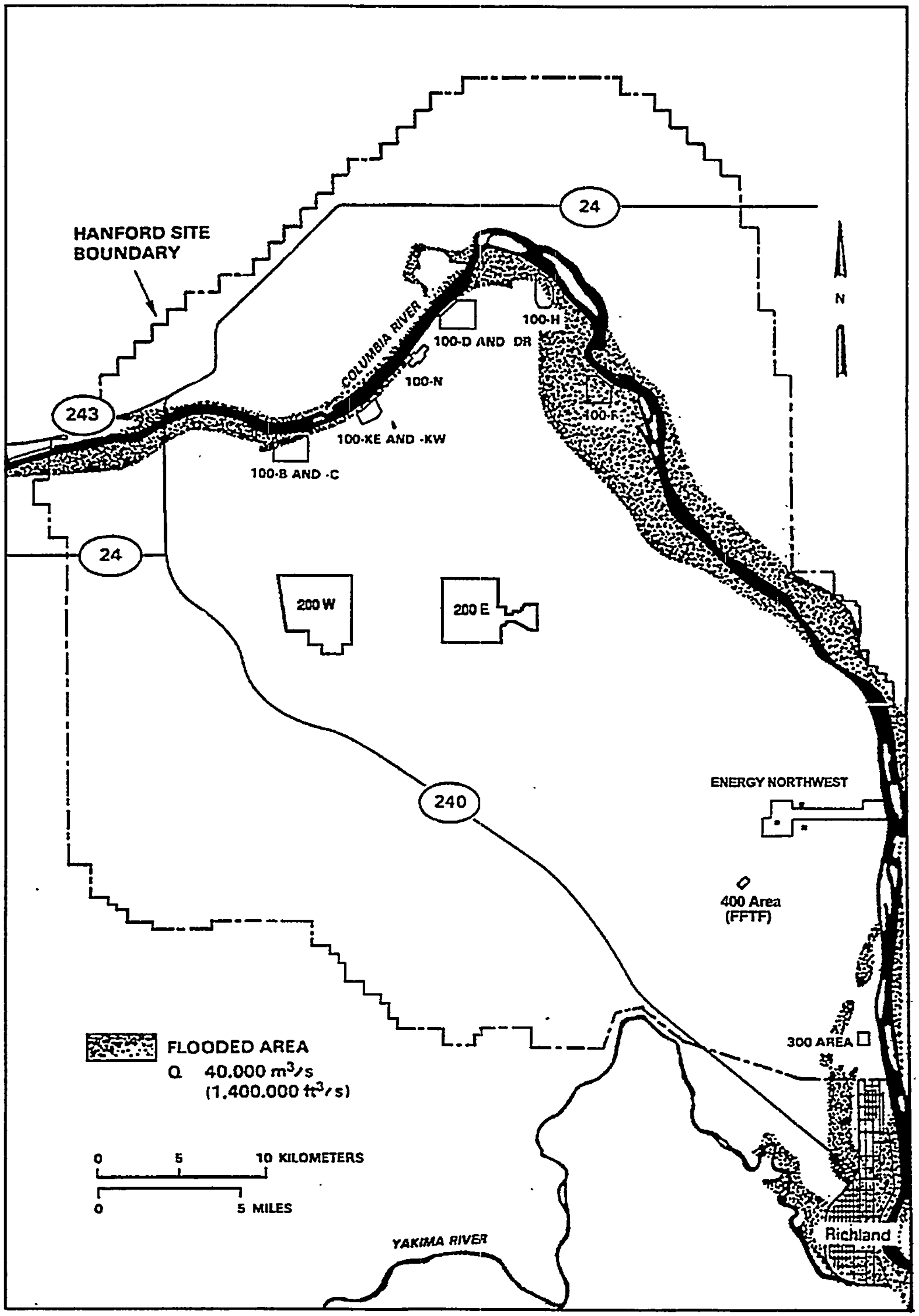


Figure 4.3-7. Flood Area for the Probable Maximum Flood (DOE 1986).

Potential dam failures on the Columbia River have been evaluated. Upstream failures could arise from a number of causes, with the magnitude of the resulting flood depending on the degree of breaching at the dam. The Corps evaluated a number of scenarios on the effects of failures of Grand Coulee Dam, assuming flow conditions of 11,000 m^3/s (400,000 ft^3/s). For emergency planning, they hypothesized that 25% and 50% breaches, the "instantaneous" disappearance of 25% or 50% of the center section of the dam, would result from the detonation of nuclear explosives in sabotage or war. The discharge or floodwave resulting from such an instantaneous 50% breach at the outfall of the Grand Coulee Dam was determined to be 600,000 m^3/s (21 million ft^3/s). In addition to the areas inundated by the probable maximum flood (Figure 4.3-7), the remainder of the 100 Areas, the 300 Area, and nearly all of Richland, Washington, would be flooded (DOE 1986; see also ERDA 1976). No determinations were made for failures of dams upstream, for associated failures downstream of Grand Coulee, or for breaches >50% of Grand Coulee, for two principal reasons:

1. The 50% scenario was believed to represent the largest realistically conceivable flow resulting from either a natural or human-induced breach (DOE 1986), i.e., it was hard to imagine that a structure as large as Grand Coulee Dam would be 100% destroyed instantaneously.

2. It was also assumed that a scenario such as the 50% breach would occur only as the result of direct explosive detonation, and not because of a natural event such as an earthquake, and that even a 50% breach under these conditions would indicate an emergency situation in which there might be other overriding major concerns.

The possibility of a landslide resulting in river blockage and flooding along the Columbia River has also been examined for an area bordering the east side of the river upstream of the city of Richland. The possible landslide area considered was the 75 m- (250 ft-) high bluff generally known as White Bluffs. Calculations were made for an 8×10^5 m^3 (1×10^6 yd^3) landslide volume with a concurrent flood flow of 17,000 m^3/s (600,000 ft^3/s) (a 200-year flood), resulting in a floodwave crest elevation of 122 m (400 ft) above mean sea level. Areas inundated upstream of such a landslide event would be similar to those shown in Figure 4.3-7 (DOE 1986).

A flood risk analysis of Cold Creek was conducted in 1980 as part of the characterization of a basaltic geologic repository for high-level radioactive waste. Such design work is usually done according to the criteria of Standard Project Flood or probable maximum flood, rather than the worst-case or 100-year flood scenario. Therefore, in lieu of 100- and 500-year flood plain studies, a probable maximum flood evaluation was made for a reference repository location directly west of the 200 East Area and encompassing the 200 West Area (Skaggs and Walters 1981). Schematic mapping indicates that access to the reference repository would be unimpaired but that State Route (SR) 240 along the southwestern and western areas would not be usable (Figure 4.3-8).

4.3.1.6 Columbia Riverbank Seepage

The seepage of groundwater into the Columbia River has been known to occur for many years. Riverbank seeps were documented along the Hanford Reach long before Hanford operations began during the Second World War (Jenkins 1922). Seepage occurs both below the river surface and on the exposed riverbank, particularly at low river stage. The seeps flow intermittently, apparently influenced primarily by changes in river level. Riverbank seeps are

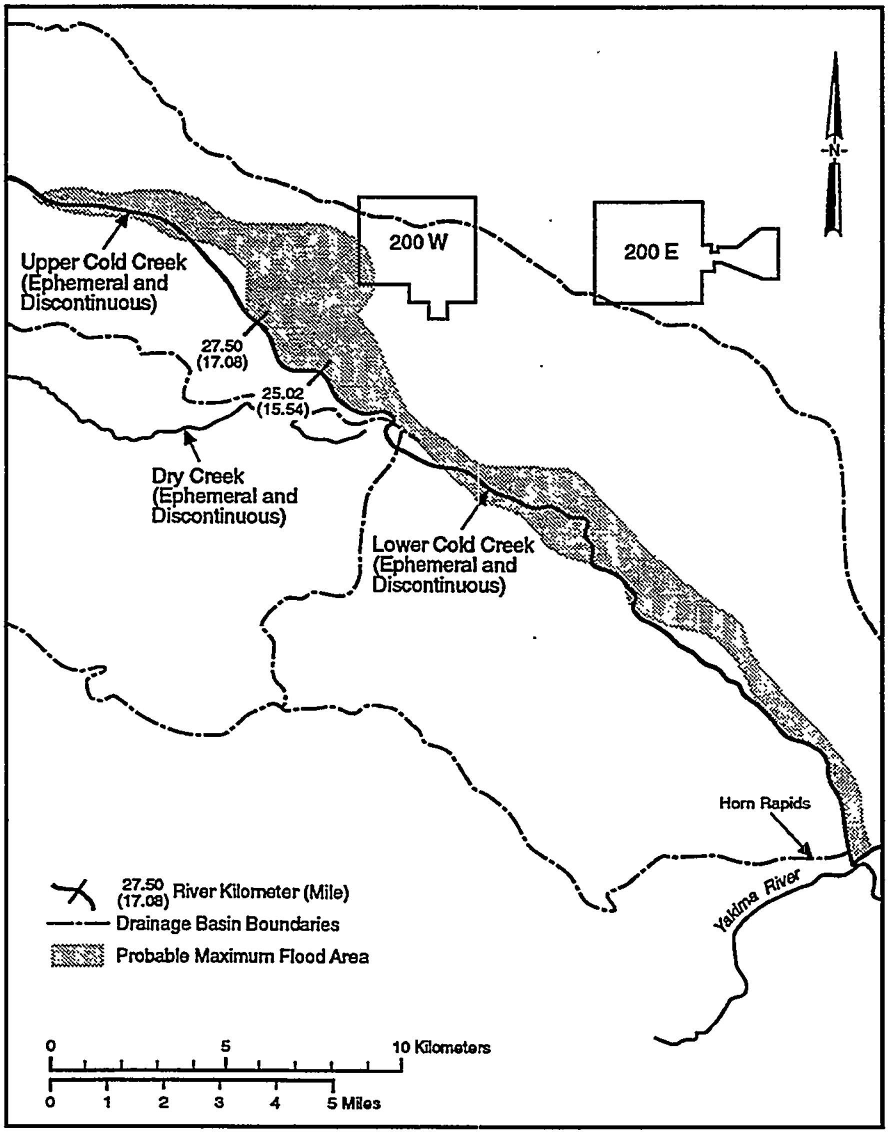


Figure 4.3-8. Extent of Probable Maximum Flood in Cold Creek Area (Skaggs and Waters 1981).

monitored for radionuclides at the 100-N Area, the Old Hanford townsite, and the 300 Area. Hanford-origin contaminants have been documented in some of these groundwater discharges along the Hanford Reach (Dirkes 1990; DOE 1992a,b; McCormack and Carlile 1984; Peterson and Johnson 1992).

4.3.1.7 Onsite Ponds and Ditches

Currently active ponds on the Hanford site are shown in Figure 4.3-1. There are no currently active ditches on the Site. Ponds include West Lake, the 200 Areas Treated Effluent Disposal Facility (TEDF) disposal ponds, the Liquid Effluent Retention Facility (LERF), and a 400 Area Pond. West Lake is north of the 200 East Area and is a natural feature recharged from groundwater (Gephardt et al. 1976). West Lake has not received direct effluent discharges from Site facilities; rather, its existence is caused by the intersection of the elevated water table with the land surface in the topographically low area. The two TEDF disposal ponds are each 2 ha (5-acres) in size and receive non-RCRA-permitted wastewater that meets discharge requirements. The wastewater percolates into the ground from the disposal ponds. The LERF is a wastewater holding facility consisting of three RCRA compliant surface impoundments with a total capacity of 24.6 million L (6.5 million gal). These ponds are equipped with double liners, a leak detection system, and floating covers (Dirkes and Hanf 1997). The 400 Area Pond is located near the 400 Area and is used for the disposal of process water (primarily cooling tower water) (Dirkes and Hanf 1998). In addition to these ponds, water storage facilities at the former 100-K Area fuel production site have been filled with water from the Columbia River and used for fish production (see Section 4.4.2.1).

The ponds are not accessible to the public and did not constitute a direct offsite environmental impact during 1993 (Dirkes et al. 1994). However, the ponds are accessible to migratory waterfowl, creating a potential pathway for the dispersion of contaminants. Periodic sampling provides an independent check on effluent control and monitoring systems (Woodruff et al. 1993).

The Nature Conservancy (Hall 1998), documented the existence of several naturally occurring vernal ponds near Gable Mountain and Gable Butte. These ponds appear to occur where a depression is present in a relatively shallow buried basalt surface. Water collects within the depression over the winter resulting in a shallow pond that dries during the summer months. The formation of these ponds in any particular year depends on the amount and temporal distribution of precipitation and snowmelt events. The vernal ponds range in size from about 20 ft x 20 ft to 150 ft x 100 ft. They were found in three clusters. Approximately 10 were documented at the eastern end of Umtanum Ridge, 6 or 7 were observed in the central part of Gable Butte, and 3 were found at the eastern end of Gable Mountain.

4.3.1.8 Offsite Surface Water

Other than rivers and springs, there are no naturally occurring bodies of surface water adjacent to the Hanford Site. However, there are artificial wetlands, caused by irrigation, on the east and west sides of the Wahluke Slope portion of the Hanford Site, which lies north of the Columbia River. Hatcheries and irrigation canals constitute the only other artificial surface water expressions in the area. The Ringold Hatchery, just south of the Hanford Site boundary on the east side of the Columbia River, is the only local hatchery.

4.3.2 Groundwater

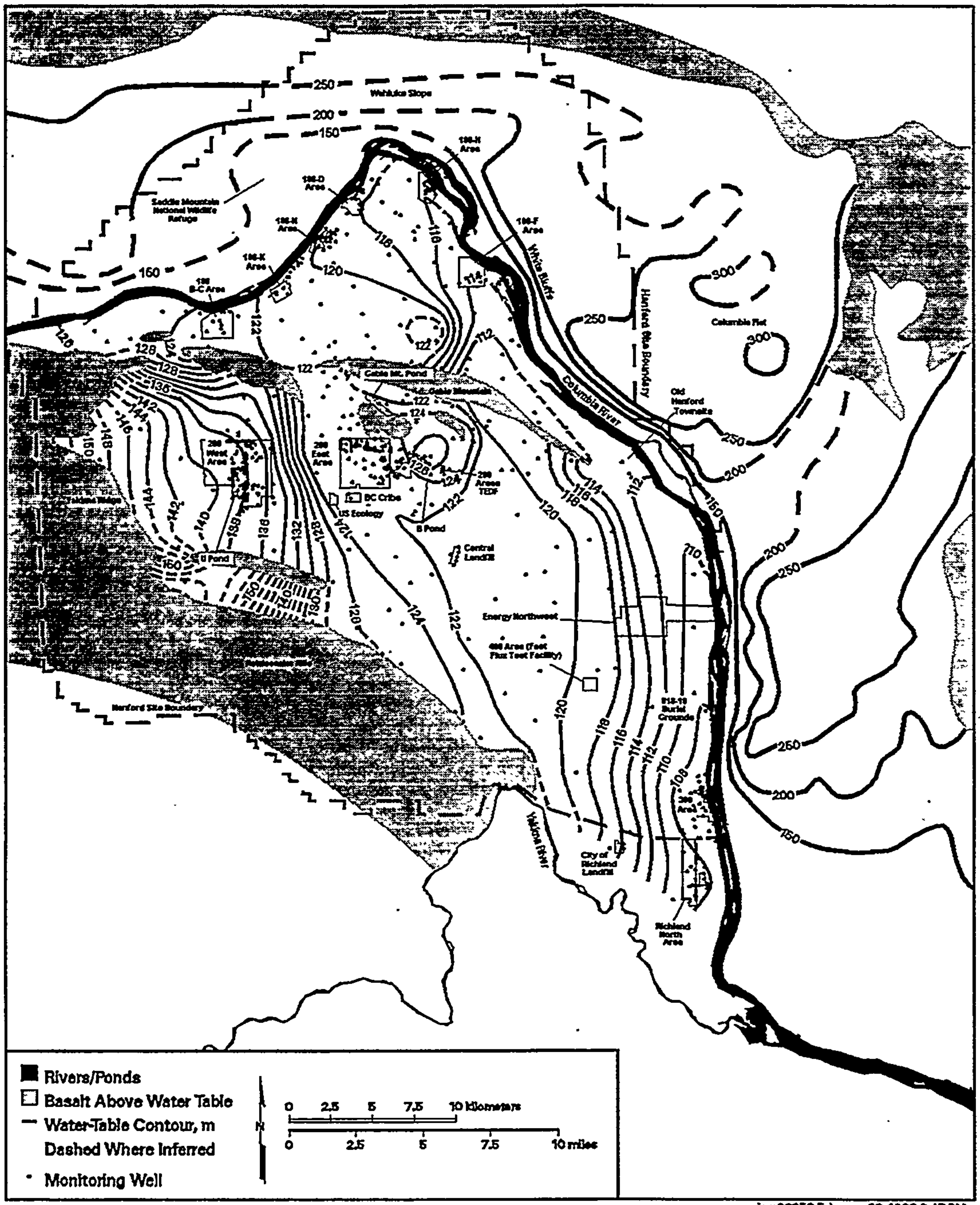
Groundwater is but one of the many interconnected stages of the hydrologic cycle. Essentially all groundwater, including Hanford's, originated as surface water either from natural recharge such as rain, streams, and lakes, or from artificial recharge such as reservoirs, excess irrigation, canal seepage, deliberate augmentation, industrial processing, and wastewater disposal.

4.3.2.1 Hanford Site Aquifer System

Groundwater beneath the Hanford Site is found in both an upper unconfined aquifer system and deeper basalt-confined aquifers. The unconfined aquifer system is also referred to as the suprabasalt aquifer system. Portions of the suprabasalt aquifer system are locally confined or semiconfined. However, because the entire suprabasalt aquifer system is interconnected on a Sitewide scale, it is referred to as the Hanford unconfined aquifer system in this report.

Basalt Confined Aquifer System. Confined aquifers within the Columbia River Basalts are formed by relatively permeable sedimentary interbeds and the more porous tops and bottoms of basalt flows. The horizontal hydraulic conductivities of most of these aquifers fall in the range of 10^{-10} to 10^{-4} m/s (3 x 10^{-10} to 3 x 10^{-4} ft/s). Saturated but relatively impermeable dense interior sections of the basalt flows have horizontal hydraulic conductivities ranging from 10^{-15} to 10^{-9} m/s (3 x 10^{-15} to 3 x 10^{-9} ft/s), about five orders of magnitude lower than those of the confined aquifers (DOE 1988). Hydraulic-head information indicates that groundwater in the basalt confined aquifers generally flows towards the Columbia River and, in some places, towards areas of enhanced vertical communication with the unconfined aquifer system (Bauer et al. 1985; DOE 1988; Spane 1987). The basalt confined aquifer system is important because there is a potential for significant groundwater movement between the two systems. Head relationships presented in previous reports (DOE 1988) demonstrate the potential for such communication. In addition, limited water chemistry data indicate that interaquifer leakage has taken place in an area of increased vertical communication near the Gable Mountain anticlinal structure, north of the 200 East Area (Graham et al. 1984; Jensen 1987; Johnson et al. 1993).

Unconfined Aquifer System. Groundwater in the unconfined aquifer at Hanford generally flows from recharge areas in the elevated region near the western boundary of the Hanford Site toward the Columbia River on the eastern and northern boundaries. The Columbia River is the primary discharge area for the unconfined aquifer. A map showing water table elevations for the Hanford Site and adjacent areas across the Columbia River is shown in Figure 4.3-9. The Yakima River borders the Hanford Site on the southwest and is generally regarded as a source of recharge. Along the Columbia River shoreline, daily river level fluctuations may result in water table elevation changes of up to 3 m (10 ft). During the high river stage periods of 1996 and 1997, some wells near the Columbia River showed water level changes of more than 3 m (10 ft). As the river stage rises, a pressure wave is transmitted inland through the groundwater. The longer the duration of the higher river stage, the farther inland the effect is propagated. The pressure wave is observed farther inland than the water actually moves. For the river water to flow inland, the river level must be higher than the groundwater surface and must remain high long enough for the water to flow through the sediments. Typically, this inland flow of river water is restricted to within several hundred feet of the shoreline (McMahon and Peterson 1992).



jpm98053 February 20, 1998 3:47 PM

Figure 4.3-9. Water Table Elevations for the Unconfined Aquifer at Hanford, June 1997 (Hartman and Dresel 1998).

Natural areal recharge from precipitation across the entire Hanford Site is thought to range from about 0 to 10 cm/yr (0 to 4 in./yr) but is probably <2.5 cm/yr (1 in./yr) over most of the Site (Gee and Heller 1985; Bauer and Vaccaro 1990; Fayer and Walters 1995). Since 1944, the artificial recharge from Hanford wastewater disposal has been significantly greater than the natural recharge. An estimated 1.68 x 10^{12} L (4.44 x 10^{11} gal) of liquid was discharged to disposal ponds, trenches, and cribs from 1944 to the present.

Horizontal hydraulic conductivities of sand and gravel facies within the Ringold Formation generally range from about 10^{-5} to 10^{-4} m/s (0.9 to 9 ft/d), compared to 10^{-2} to 10^{-3} m/s (1,000 to 10,000 ft/d) for the Hanford formation (DOE 1988). Because the Ringold sediments are more consolidated and partially cemented, they are about 10 to 100 times less permeable than the sediments of the overlying Hanford formation. Before wastewater disposal operations at the Hanford Site, the uppermost aquifer was mainly within the Ringold Formation and the water table extended into the Hanford formation at only a few locations (Newcomb et al. 1972). However, wastewater discharges have raised the water table elevation across the Site and created groundwater mounds under the two main wastewater disposal areas in the 200 Areas. Because of the general increase in groundwater elevation, the unconfined aquifer now extends upward into the Hanford formation. This change has resulted in an increase in groundwater velocity not only because of the greater volume of groundwater but also because the newly saturated Hanford sediments are highly permeable.

After the beginning of Hanford operations in 1943, the water table rose about 27 m (89 ft) under the U Pond disposal area in the 200 West Area and about 9 m (30 ft) under disposal ponds near the 200 East Area. The volume of water that has been discharged to the ground at the 200 West Area is actually less than that discharged at the 200 East Area. However, the lower conductivity of the aquifer near the 200 West Area has inhibited groundwater movement in this area and resulted in a higher groundwater mound.

The presence of the groundwater mounds has locally affected the direction of groundwater movement, causing radial flow from the discharge areas. Zimmerman et al. (1986) documented changes in water table elevation between 1950 and 1980. They showed that the edge of the mounds migrated outward from the sources over time until about 1980. Water levels have declined over most of the Hanford Site since 1984 because of decreased wastewater discharges (Hartman and Dresel 1998).

Limitations of Hydrogeologic Information. The sedimentary architecture of the unconfined aquifer is very complex because of repeated deposition and erosion. Although hundreds of wells have been drilled on the Hanford Site, many penetrate only a small percentage of the total unconfined aquifer thickness, and there is a limited number of useful wells for defining the deeper sediment facies. A number of relatively deep wells were drilled in the early 1980s as part of a study for a proposed nuclear power plant (PSPL 1982), and these data are helpful in defining facies architecture. For most of the thinner and less extensive sedimentary units, correlation between wells is either not possible or uncertain. Coarse-grained units of the Ringold Formation (e.g., Units A, B, C, D, and E) are more permeable than are the fine-grained units, which generally act as aquitards that locally confine groundwater in deeper permeable sediments.

A limited amount of hydraulic property data is available from testing of wells. Hydraulic test results from wells on the Hanford Site have been compiled for the Hanford Ground-Water

Project and for environmental restoration efforts (Connelly et al. 1992a,b; Kipp and Mudd 1973; Thorne and Newcomer 1992; Thorne et al. 1993; Thorne et al. 1994). Depths of the tested intervals have been correlated with the top of the unconfined aquifer as defined by the water-table elevations presented in Newcomer et al. (1991). Most hydraulic tests were done within the upper 15 m (49 ft) of the aquifer, and many were open to more than one geologic unit. In some cases, changes in water table elevation may have significantly changed the unconfined aquifer transmissivity at a well since the time of the hydraulic test. Few hydraulic tests within the Hanford Site unconfined aquifer system have yielded reliable estimates of aquifer-specific yield.

Groundwater Residence Times. Tritium and carbon-14 measurements indicate that residence or recharge time (length of time required to replace the groundwater) takes tens to hundreds of years for spring waters, from hundreds to thousands of years for the unconfined aquifer, and more than 10,000 years for groundwater in the shallow confined aquifer (Johnson et al. 1992). Chlorine-36 and noble gas isotope data suggest ages greater than 100,000 years for groundwater in the deeper confined systems (Johnson et al. 1992). These relatively long residence times are consistent with semiarid-site recharge conditions and point to the need for conservation. For example, in the western Pasco Basin, extensive agricultural groundwater use of the Priest Rapids Member confined aquifer (recharge time >10,000 years) has lowered the potentiometric surface >10 m (33 ft) over several square miles to the west of the Hanford Site. Continued excessive withdrawals along the western edge of the Pasco Basin could eventually impact the confined aquifer flow directions beneath the Hanford Site (Johnson et al. 1992).

Hydrology East and North of the Columbia River. The Hanford Site boundary extends east and north of the Columbia River to provide a buffer zone for non-Hanford activities such as recreation and agriculture. Hanford Site activities in these areas have not impacted the groundwater. However, the groundwater in this area is impacted by high artificial recharge from irrigation and canal leakage. Areas east and north of the Columbia River are irrigated by the South Columbia Basin Irrigation District. Artificial recharge has increased water table elevations in large areas of the Pasco Basin, in some places by as much as 92 m (300 ft) (Drost et al. 1989).

There are two general hydrologic areas that impinge upon the Hanford Site boundaries to the east and north of the river. The eastern area extends from north to south between the lower slope of the Saddle Mountains and the Esquatzel Diversion canal and includes the Ringold Coulee, White Bluffs area, and Esquatzel Coulee. The water table occurs in the Pasco gravels of the Hanford formation in both Ringold and Esquatzel Coulees. Brown (1979) reported that runoff from spring discharge at the mouth of Ringold Coulee is >37,850 L/min (10,000 gal/min). Elsewhere in this area, the unconfined aquifer is in the less-transmissive Ringold Formation. Irrigation has also created perched aquifers and resulted in a series of springs issuing from perched water along the White Bluffs. The increased hydraulic pressure in these sediments has caused subsequent slumping and landslides (Brown 1979; Newcomer et al. 1991).

The other principal irrigated area is the northern part of the Pasco Basin on the Wahluke Slope, which lies between the Columbia River and the Saddle Mountain anticline. Irrigation on Wahluke Slope has created ponds and seeps in the Saddle Mountain Wildlife Refuge. The direction of unconfined groundwater flow is southward from the basalt ridges towards the Columbia River. Bauer et al. (1985) reported that lateral water table gradients are essentially equal to or slightly less than the structural gradients on the flanks of the anticlinal fold mountains where the basalt dips steeply.

4.3.3 Groundwater Quality

4.3.3.1 Natural Groundwater Quality

The natural quality of groundwater at the Hanford Site varies depending on the aquifer system and depth, which generally is related to residence time in the aquifer. The background water quality (i.e., unaffected by Hanford discharges) for the unconfined aquifer are discussed in DOE (1992b). Background water quality for the unconfined aquifer was later investigated and documented in DOE (1997b). This study involved the examination of historical data as well as collection of new data from wells in areas that have not been affected by Hanford Site contaminants. Groundwater chemistry in the basalt confined aquifers displays a range depending on depth and residence time. The chemical type varies from a calcium and magnesium-carbonate water to a sodium- and chloride-carbonate water. Some of the shallower basalt confined aquifers in the region (e.g., the Wanapum basalt aquifer) have exceptionally good water-quality characteristics: <300 mg/L dissolved solids; <0.1 mg/L iron and magnesium; <20 mg/L sodium, sulfate, and chloride; and <10 ppb heavy metals (Johnson et al. 1992).

4.3.3.2 Groundwater Contamination

Groundwater beneath large areas of the Hanford Site has been impacted by radiological and chemical contaminants resulting from past Hanford Site operations. These contaminants were primarily introduced through wastewater discharged to cribs, ditches, trenches and ponds (Kincaid et al. 1998). Contaminants from spills, injection wells, and leaking waste tanks have also impacted groundwater in some areas. Groundwater contamination is being actively remediated in several areas through pump and treat operations. These are summarized in Hartman and Dresel (1998).

In addition to contaminants within the aquifer, there are contaminants within the vadose zone beneath waste sites, which have a potential to move downward into the aquifer (Kincaid et al. 1998). The rate of movement of contamination through the vadose zone depends on contaminant and soil chemistry, stratigraphy, and infiltration of recharge. Characterization and monitoring of the vadose zone is performed and consists primarily of in situ borehole spectral gamma logging, soil-gas sampling, and soil sampling and analysis during borehole drilling. Vadose zone contamination is being remediated in selected areas through excavation and disposal of shallow contaminated sediments in the 100 areas and vapor extraction for carbon tetrachloride found in the 200 West Area (Hartman and Dresel 1998).

4.3.3.3 Groundwater Monitoring

Monitoring of radiological and chemical constituents in groundwater at the Hanford Site is performed to characterize physical and chemical trends in the flow system, establish groundwater quality baselines, assess groundwater remediation, and identify new or existing groundwater problems. Groundwater monitoring is also performed to verify compliance with applicable environmental laws and regulations. Samples were collected from approximately 800 wells in 1997 to determine the distributions of radiological and chemical constituents in Hanford Site groundwater. Results of Hanford Site groundwater monitoring for fiscal year (FY) 1997 are presented in Hartman and Dresel (1998).

To assess the quality of groundwater, concentrations measured in samples were compared with EPA's Drinking Water Standards and DOE's Derived Concentration Guides. Radiological constituents including cesium-137, cobalt-60, iodine-129, strontium-90, technetium-99, total alpha, total beta, tritium, uranium, and plutonium were detected at levels greater than the Drinking Water Standards in one or more onsite wells. Concentrations of strontium-90, tritium, uranium and plutonium were detected at levels greater than DOE's Derived Concentration Guides. Certain nonradioactive chemicals regulated by the EPA and the State of Washington were also present in Hanford Site groundwater. These were nitrate, fluoride, chromium, cyanide, carbon tetrachloride, chloroform, trichloroethylene, and tetrachloroethylene. Figure 4.3-10 shows the extent of radiological contamination in Hanford Site groundwater above the applicable Drinking Water Standards and Figure 4.3-11 shows the extent of chemical constituents above the applicable Drinking Water Standards.

4.3.4 Water Quality of the Columbia River

The State of Washington has classified the stretch of the Columbia River from Grand Coulee to the Washington-Oregon border, which includes the Hanford Reach, as Class A, Excellent (Ecology 1992). Class A waters are to be suitable for essentially all uses, including raw drinking water, recreation, and wildlife habitat. State and federal Drinking Water Standards apply to the Columbia River and are currently being met (see Section 6.2.2).

During 1996, water samples were collected quarterly from the Columbia River along transects established at the Vernita Bridge (upstream of the Hanford Site) and the Richland pumphouse (downstream of the Hanford Site), and annually along transects at 100-N, 100-F, the Hanford townsite, and the 300 Area (Figure 4.3-12) (Dirkes and Hanf 1997). The current major source of heat to the Columbia River in the Hanford Reach is solar radiation (Dauble et al. 1987). The average pH values ranged from 7.7 to 8.1 for all samples from the Vernita Bridge and Richland pumphouse single-point sampling locations. Mean specific conductance values for the same sampling locations range from 130 to 141 :S/cm. There is no apparent difference between the two locations.

Radionuclides consistently detected in the river during 1996 were tritium, strontium-90, iodine-129, plutonium-239/240, uranium-234, and uranium-238. Total alpha and beta measurements are useful indicators of the general radiological quality of the river that provide an early indication of changes in radioactive contamination levels because results are obtained quickly. Total alpha and beta measurements for 1996 were similar to the previous year, and were approximately 5% or less of the applicable Drinking Water Standards of 15 and 50 pCi/L, respectively. Tritium measured at the Richland Pumphouse was significantly higher than at Vernita Bridge, but continued to be well below the state and federal Drinking Water Standards (Dirkes and Hanf 1997). The presence of a tritium concentration gradient at the Richland pumphouse supports previous conclusions made by Backman (1962) and Dirkes (1993) that contaminants in the 200 Area groundwater plume entering the river at and upstream of the 300 Area are not completely mixed by the time the river reaches the Richland pumphouse.

All nonradiological water quality standards were met for Class A-designated water (Dirkes and Hanf 1995).

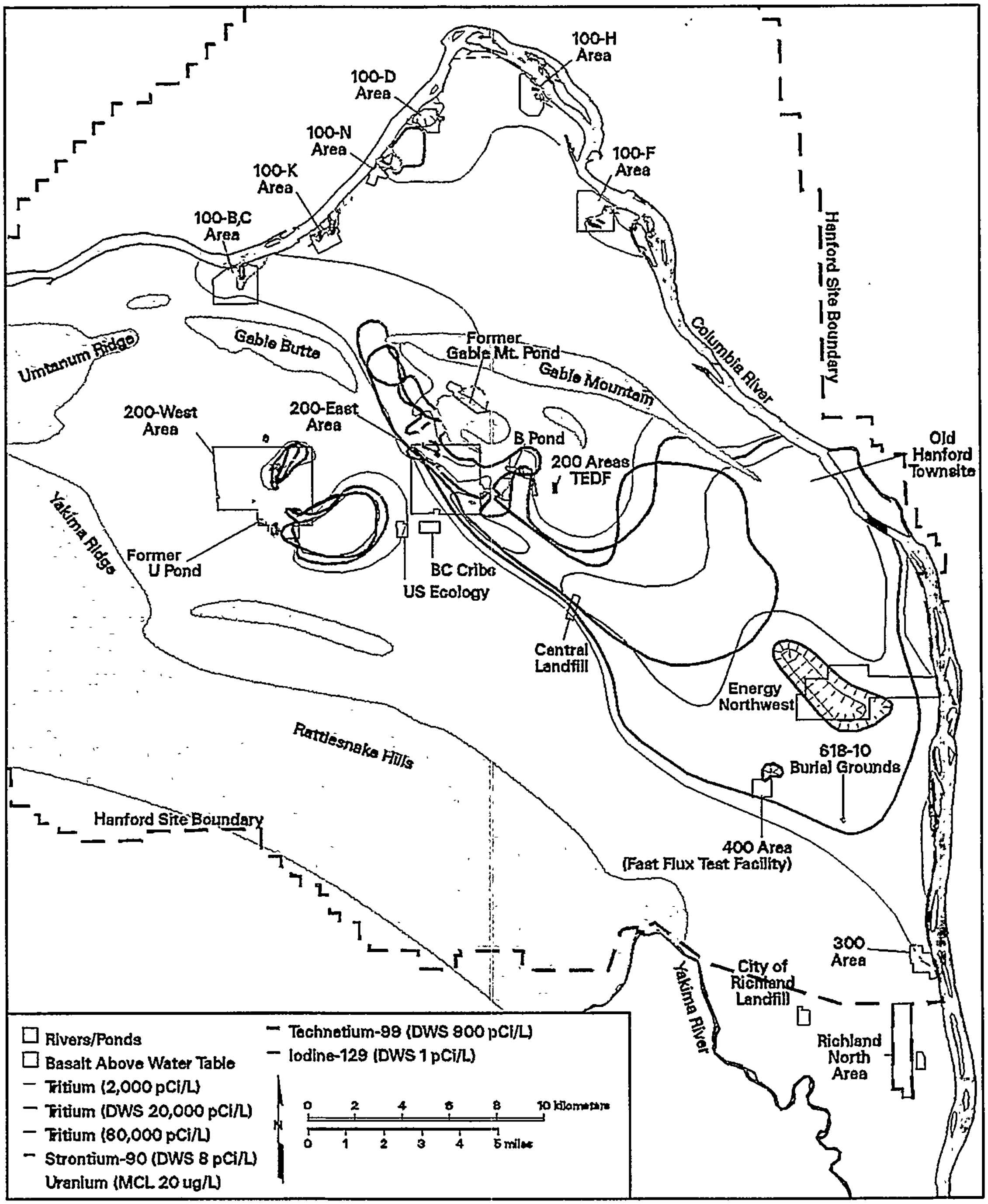


Figure 4.3-10. Distribution of Major Radionuclides in Groundwater at Concentrations Above the Drinking Water Standard (DWS) During Fiscal Year 1997.

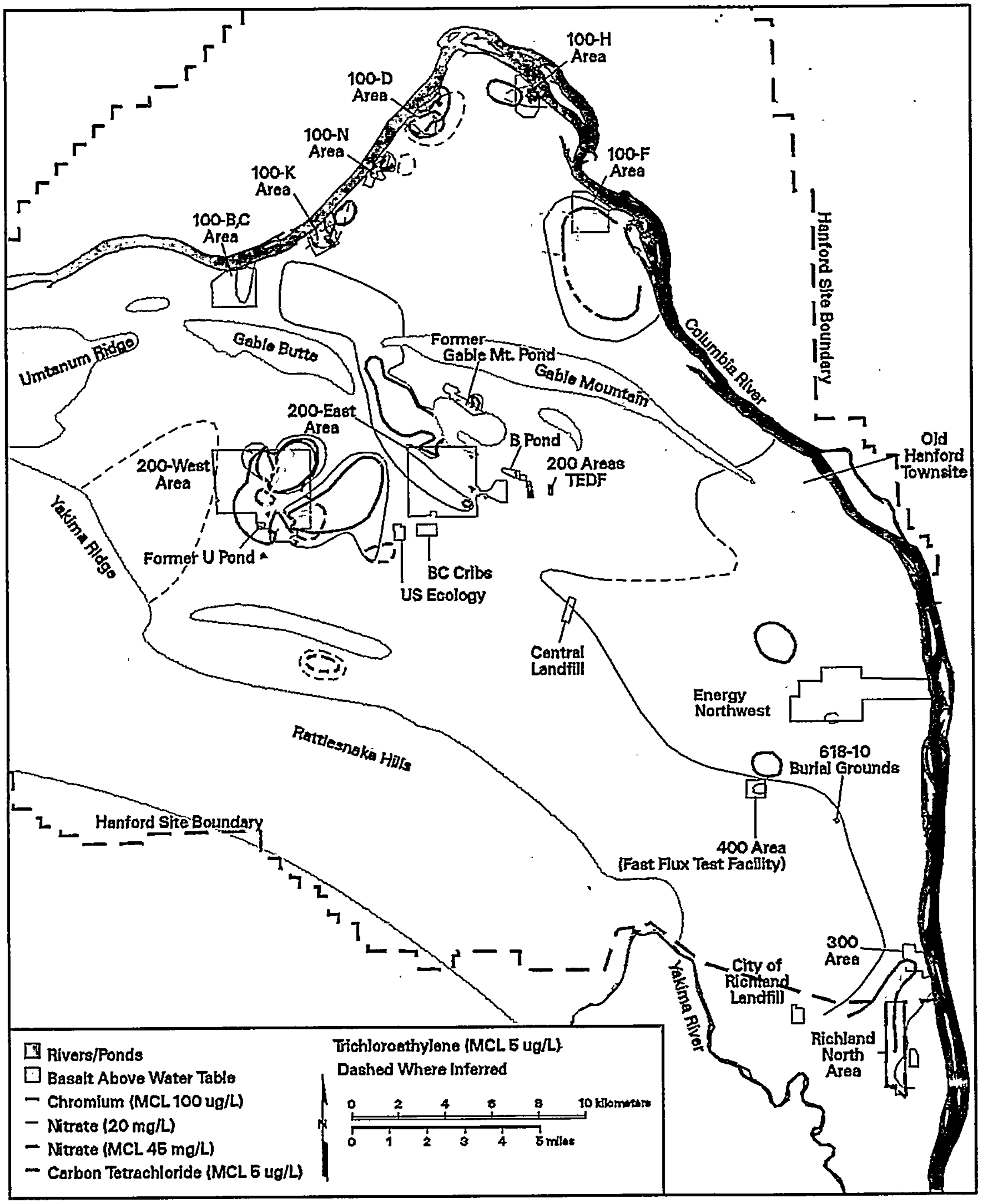


Figure 4.3-11. Distribution of Major Hazardous Chemicals in Groundwater at Concentrations Above the Drinking Water Standard (DWS) During Fiscal Year 1997.

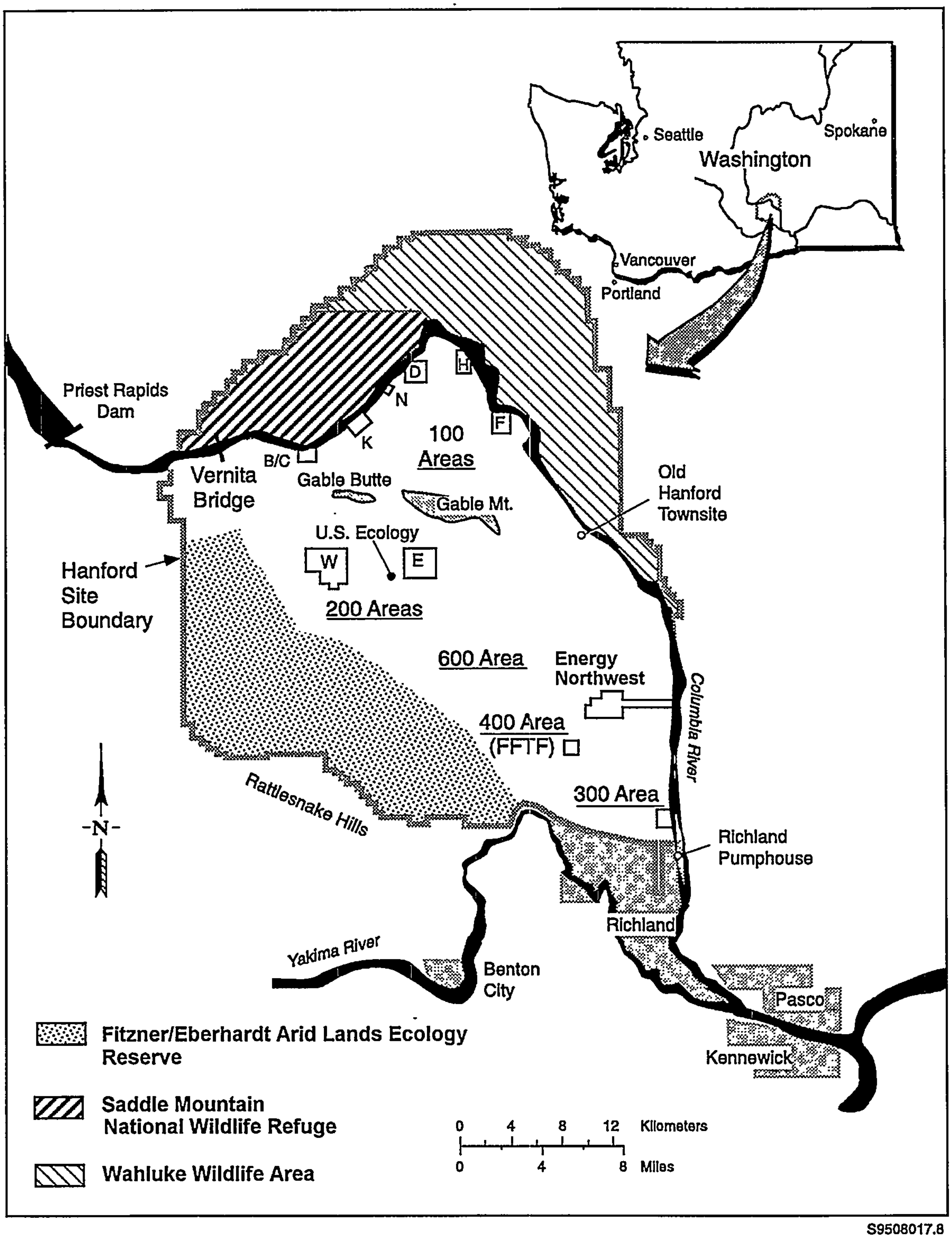


Figure 4.3-12. Sites of Columbia River Monitoring (Dirkes and Hanf 1997).

4.3.5 100 Areas Hydrology

The hydrology of the 100 Areas is unique because of their location adjacent to the Columbia River. The water table ranges in depth from near 0 m at the river edge to 30 m (107 ft). The groundwater flow direction is generally toward the river. However, during high river stage, the flow direction may reverse immediately adjacent to the river. The unconfined aquifer in the 100 Areas is composed of either the Ringold Unit E gravels or a combination of the Unit E gravels and the Hanford formation. As shown in Figure 4.3-13, there are two large areas where the water table is within the Ringold Formation (Lindsey 1992) and the Hanford formation is unsaturated. In the 100-H and 100-F Areas, the Ringold Unit E gravels are missing, and the Hanford formation lies directly over the fine-grained Ringold lower-mud unit. In most of the 100 Areas, the lower Ringold mud forms an aquitard, and the Ringold gravels below the mud are locally confined. Additional information on the hydrology of the 100 Areas is available in Hartman and Peterson (1992) and Peterson et al. (1996). A number of studies of various sites in the 100 Areas present specific hydrologic information. These include: 100-B/C Area - Lindberg (1993a); 100-D Area - Lindsey and Jaeger (1993); 100-F Area - Lindsey (1992), Petersen (1992); 100-H Area - Liikala et al. (1988), Lindsey and Jaeger (1993); 100-K Area - Lindberg (1993b); and 100-N Area - Gilmore et al. (1992), Hartman and Lindsey (1993).

4.3.6 200 Areas Hydrology

In the 200 West Area, the water table occurs almost entirely in the Ringold Unit E gravels, while in the 200 East Area, it occurs primarily in the Hanford formation and in the Ringold Unit A gravels. Along the southern edge of the 200 East Area, the water table is in the Ringold Unit E gravels. The upper Ringold facies were eroded in most of the 200 East Area by the Missoula floods which subsequently deposited Hanford gravels and sands on what was left of the Ringold Formation. Because the Hanford formation sand and gravel deposits are much more permeable than the Ringold gravels, the water table is relatively flat in the 200 East Area, but groundwater flow velocities are higher. On the north side of the 200 East Area, there is evidence of erosional channels that may allow communication between the unconfined and uppermost basalt confined aquifer (Graham et al. 1984; Jensen 1987).

The hydrology of the 200 Areas has been strongly influenced by the discharge of large quantities of wastewater to the ground over a 50-yr period. Those discharges have caused elevated water levels across much of the Hanford Site resulting in a large groundwater mound beneath the former U Pond in the 200 West Area and a smaller mound beneath the former B Pond, east of the 200 East Area. Water table changes beneath 200 West Area have been greatest because of the lower transmissivity of the aquifer in this area. Discharges of water to the ground have been greatly reduced, and corresponding decreases in the elevation of the water table have been measured. The decline in part of the 200 West Area has been more than 7 m (23 ft) (Hartman and Dresel 1998). Water levels are expected to continue to decrease as the unconfined groundwater system reaches equilibrium with the new level of artificial recharge (Wurstner and Freshley 1994).

A number of reports dealing with the hydrogeology of the 200 Areas have been released including the following: Graham et al. (1981), Last et al. (1989), and Connelly et al. (1992a,b).

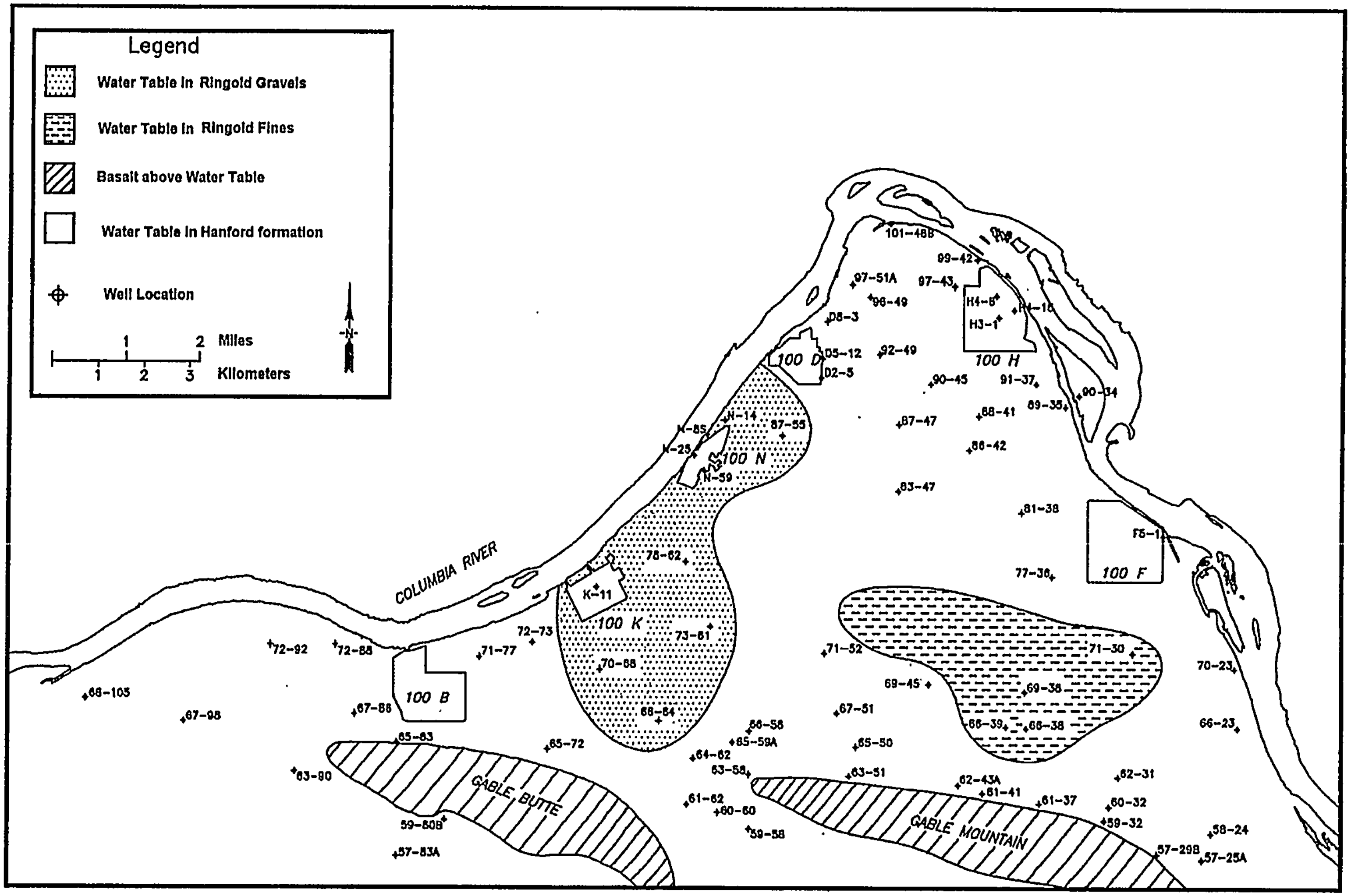


Figure 4.3-13. Geologic Units Intersected by the Water Table in the 100 Areas (modified from Lindsey 1992)

4.3.7 300 Area Hydrology

The unconfined aquifer water table in the 300 Area is generally found in the Ringold Formation at a depth of 9 to 19 m (30 to 62 ft) below ground surface. Fluctuations in the river level strongly affect the groundwater levels and flow in the 300 Area, just as they do in the 100 Areas. Groundwater flows from the northwest, west, and even the southwest to discharge into the Columbia River near the 300 Area. Schalla et al. (1988) and Swanson (1992) have provided more detailed information on the hydrogeology of the 300 Area.

4.3.8 1100 and Richland North Areas Hydrology

Land ownership of the former 1100 Area was transferred from the DOE to the Port of Benton on October 1, 1998. The groundwater in the southeastern portion of the Hanford Site is less impacted by Hanford Site operations than by other activities. In addition to natural recharge, artificial recharge is associated with the North Richland recharge basins (used to store Columbia River water for Richland water use) south of the former 1100 Area, and irrigated farming near the Richland North Area and west and southwest of the former 1100 Area. Although pumping to obtain water also occurs from the unconfined aquifer in these areas, there is a mound in the water table beneath the Richland City system of recharge basins. The Richland City recharge basins are used primarily as a backup system between January and March each year when the filtration plant is closed for maintenance, and during the summer months to augment the city's river-water supply. The water level also rose from December 1990 and December 1991 in the area of the Lamb-Weston Potato-Processing Plant, which uses large amounts of water and, except for plant maintenance during July, operates year-round. The water table in the former 1100 Area seems to reflect irrigation cycles connected with agriculture (Newcomer et al. 1991).

4.4 Ecology

T. M. Poston

The Hanford Site encompasses about 1450 km^2 (about 560 mi^2) of shrub-steppe habitat that is adapted to the region's mid-latitude semiarid climate (Critchfield 1974). The Site encompasses undeveloped land interspersed with industrial development along the western shoreline of the Columbia River and at several locations in the interior of the Site. This land, with restricted public access, provides a buffer for the smaller areas currently used for storage of nuclear materials, waste storage, and waste disposal; only about 6% of the land area has been developed for DOE facilities.

The Hanford Site is characterized as a shrub-steppe ecosystem (Daubenmire 1970). Such ecosystems are typically dominated by a shrub overstory with a grass understory. In the early 1800s, the dominant plants in the area were big sagebrush underlain by perennial Sandberg's bluegrass and bluebunch wheatgrass. With the advent of settlement, livestock grazing and agricultural production contributed to colonization by nonnative plant species that currently dominate the landscape. Although agriculture and livestock production were the primary subsistence activities at the turn of the century, these activities ceased when the Hanford Site was designated in 1943. Remnants of past agricultural practices are still evident. Large areas of the Site have experienced range fires that have greatly influenced the vegetation canopy and distribution of wildlife.

The Columbia River borders the Hanford Site to the east. Operation of Priest Rapids Dam upstream of the Hanford Site accommodates maintenance of intakes at the Site and contributes to management of anadromous fish populations. The Columbia River and associated riparian zones provide habitat for numerous wildlife and plant species.

Several areas on the Site, totaling 668 km^2 (258 mi^2), have been designated for research or as wildlife refuges (see Figure 4.0-1). These include the Fitzner/Eberhardt Arid Lands Ecology (ALE) Reserve (304 km^2 [117 mi^2]) and the Saddle Mountain National Wildlife Refuge (130 km^2 [50 mi^2]) that are managed by the U.S. Fish and Wildlife Service. The Washington State Department of Fish and Wildlife manages the Wahluke Slope Wildlife Area (235 km^2 [91 mi^2]). Under an agreement made in April 1999, the Wahluke Slope Wildlife Area will be combined with the Saddle Mountain National Wildlife Refuge and managed as a unit by the U. S. Fish and Wildlife Service. The Saddle Mountain National Wildlife Refuge and the Wahluke Slope Wildlife Area are generally referred to as the Wahluke (or North) Slope. The National Park Service, in a record of decision issued on July 16, 1996, proposed that the Hanford Reach be designated as a recreational river in the national wild and scenic rivers system. The Nature Conservancy has conducted biodiversity surveys of these areas on the Hanford Site and has tentatively identified 45 taxa new to science (Hall 1998).

Other descriptions of the ecology of the Hanford Site can be found in Cadwell (1994), Downs et al. (1993), ERDA (1975), Jamison (1982), Landeen (1996), Rogers and Rickard (1977), Sackschewsky et al. (1992), Watson et al. (1984), and Weiss and Mitchell (1992).

4.4.1 Terrestrial Ecology

4.4.1.1 Vegetation

Natural plant communities have been altered by Euro-American human activities that have resulted in the proliferation of nonnative species. Of the 590 species of vascular plants recorded for the Hanford Site, approximately 20% of all species are considered nonnative (Sackschewsky et al. 1992). Cheatgrass is the dominant nonnative species. It is an aggressive colonizer and has become well established across the site (Rickard and Rogers 1983). Plants at the Hanford Site are adapted to low annual precipitation (16 cm [6.3 in.]), low water-holding capacity of the rooting substrate (sand), dry summers, and cold winters. Range fires that historically burned through the area during the dry summers eliminate fire intolerant species (e.g., big sagebrush) and allow more opportunistic and fire-resistant species a chance to become established.

The Nature Conservancy of Washington (Hall 1998) conducted plant surveys on ALE, the Wahluke Slope, and riparian communities along the Columbia River shoreline from 1994 through 1997. These surveys tentatively identified 16 terrestrial "potential" plant communities. Designation as a potential community indicates the type of community that would exist in an area if it were free of disturbance. In addition to characterizing potential plant communities, the Conservancy found 112 populations/occurrences of 28 rare plant taxa on the Hanford Site (Hall 1998).

Existing vegetation and land use areas that occur on the Hanford Site are illustrated in Figure 4.4-1. The Nature Conservancy also prepared plant community maps for ALE, the North Slope, and central Hanford (Pabst 1995; Hall 1998). These maps are based on plant species that, through the course of time, are expected to dominate the community at climax stage and may not represent existing cover. A list of common plant species in shrub-steppe and riparian areas are presented in Table 4.4-1. A much broader definition of these types including shrublands, grasslands, tree zones, riparian, and unique habitat follows.

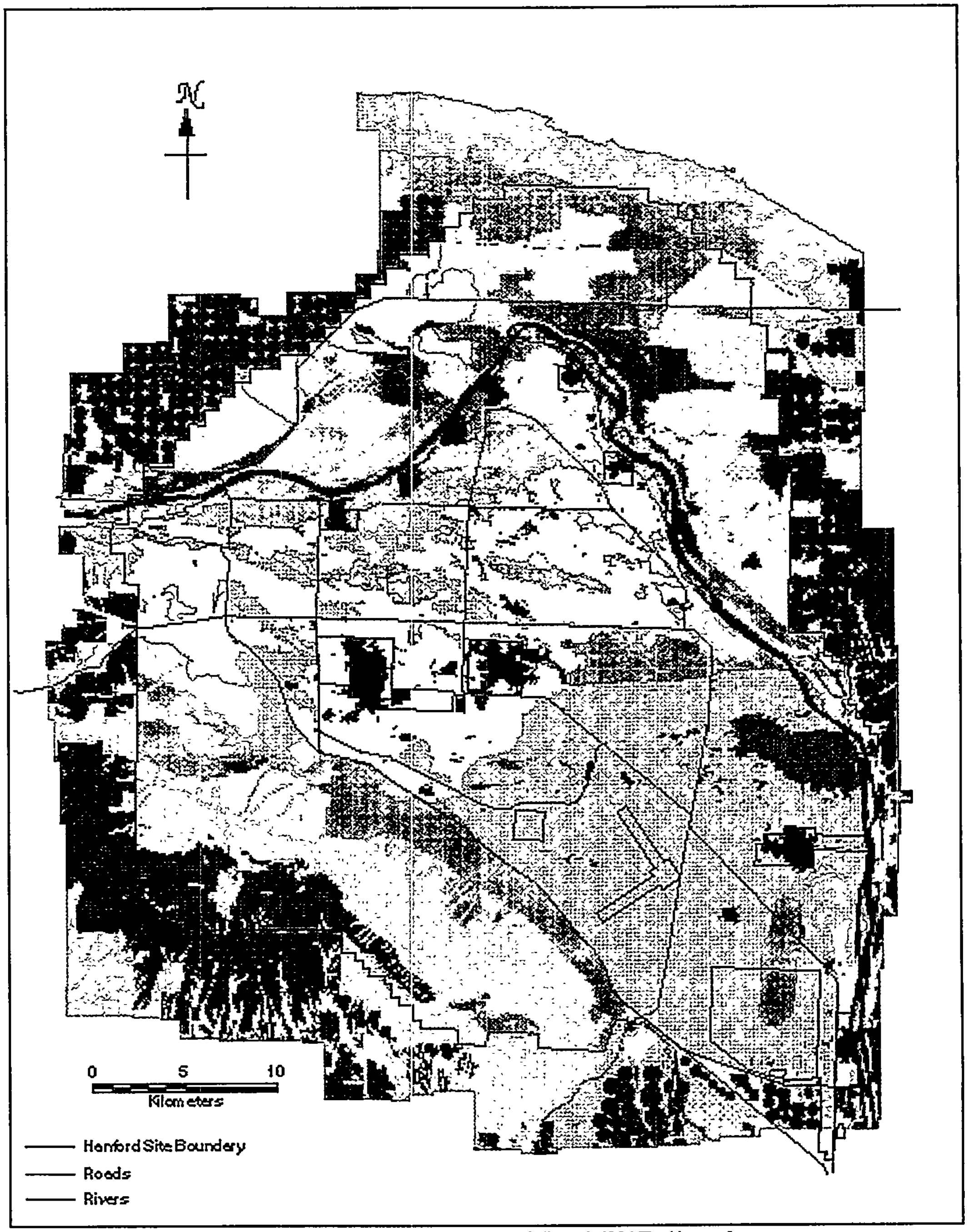
Shrublands. Shrublands occupy the largest area in terms of acreage and comprise seven of the nine major plant communities on the Hanford Site (Sackschewsky et al. 1992). Of the shrubland types, sagebrush-dominated communities are the predominant type, with other shrub communities varying with changes in soil and elevation.

The areas botanically characterized as shrub-steppe include remnant native big sagebrush, threetip sagebrush, bitterbrush, gray rabbitbrush, and spiny hopsage. Remnant bluebunch wheatgrass, Sandberg's bluegrass, needle-and-thread grass, Indian ricegrass, and prairie junegrass also occur in this vegetation type. Heterogeneity of species composition varies with soil, slope, and elevation. Of the vegetation types depicted in Figure 4.4-1, those with a shrub component (i.e., big sagebrush, threetip sagebrush, bitterbrush, spiney hopsage, rabbitbrush, winterfat, and snow-buckwheat) are considered shrub-steppe. Vegetation types with a significant cheatgrass component are generally of lower habitat quality than those with bunchgrass understories. Postfire shrub-steppe on the Columbia River Plain refers to areas impacted by wildfire that are in the process of redeveloping shrub-steppe characteristics.

Grasslands. Most grasses occur as understory in shrub-dominated plant communities. Cheatgrass has replaced many native perennial grass species and is well established in many low-elevation (<244 m [800 ft]) and/or disturbed areas (Rickard and Rogers 1983). Of the native grasses that occur on the Site, bluebunch wheatgrass occurs at higher elevations. Sandberg's bluegrass is more widely distributed and occurs within several plant communities. Needle-and-thread grass, Indian ricegrass, and thickspike wheatgrass occur in sandy soils and dune habitats. Species preferring more moist locations include bentgrass, meadow foxtail, lovegrasses, and reed canarygrass (DOE 1996a).

Trees. Before settlement, the Hanford Site landscape lacked trees, and the Columbia River shoreline supported a few scattered cottonwood or willows. Homesteaders planted trees in association with agricultural areas. Shade and ornamental trees were also planted around former military installations and industrial areas on the site. Currently, approximately 23 species of trees occur on the Site. The most commonly occurring species are black locust, Russian olive, cottonwood, mulberry, sycamore, and poplar. Many of these nonnative species are aggressive colonizers and have become established along the Columbia River (e.g., mulberry, cottonwood, poplar, Russian olive), serving as a functional component of the riparian zone (DOE 1996a). Trees provide nesting habitat and thermal cover for many species of mammals and birds.

Riparian (wetland) Areas. Riparian habitat includes sloughs, backwaters, shorelines, islands, and palustrine areas associated with the Columbia River floodplain. Vegetation that occurs along the river shoreline includes water smartweed, pondweed, sedges, reed canarygrass, and bulbous bluegrass. Trees include willow, mulberry, and Siberian elm. Other riparian vegetation occurs in association with perennial springs and seeps. Rattlesnake and Snively springs are highly diverse biologic communities (Cushing and Wolf 1984) that support bulrush,



Data Collected: 1994/The Nature Conservancy
1987, 1991/Pacific Northwest National Laboratory
Map Created: December 1995/Pacific Northwest National Laboratory

Figure 4.4-1. Distribution of Vegetation Types and Land Use Areas on the Hanford Site.

LEGEND

- Post-Fire Shrub-Steppe on the Columbia River Plain
- Rabbitbrush/Bunchgrasses
- Rabbitbrush/Cheatgrass
- Big Sagebrush/Bunchgrasses-Cheatgrass
- Big Sagebrush-Spiny Hopsage/Bunchgrasses-Cheatgrass
- Threetip Sagebrush/Bunchgrasses
- Spiny Hopsage/Bunchgrasses
- Spiny Hopsage/Cheatgrass
- Black Greasewood/Sandberg's Bluegrass
- Winterfat/Bunchgrasses
- Winterfat/Cheatgrass
- Snow Buckwheat/Indian Ricegrass
- Bunchgrasses
- Cheatgrass-Sandberg's Bluegrass
- Planted Non-Native Grass
- Bitterbrush/Bunchgrasses Sand Dune Complex
- Bitterbrush/Cheatgrass
- Alkali Saltgrass-Cheatgrass
- Riparian
- Basalt Outcrops
- Agricultural Areas
- Buildings/Parking Lots/Gravel Pits/Disturbed Areas
- Abandoned Old Fields
- Riverine Wetlands and Associated Deepwater Habitats
- Cliffs (White Bluffs)
- Non-Riverine Wetlands and Associated Deepwater Habitats

Figure 4.4-1. (cont'd)

Table 4.4-1. Common Vascular Plants on the Hanford Site (Taxonomy follows Hitchcock and Cronquist 1973).

A. Shrub-Steppe Species	Scientific Name
Shrub	
Big sagebrush	*Artemisia tridentata*
Bitterbrush	*Purshia tridentata*
Gray rabbitbrush	*Chrysothamnus nauseosus*
Green rabbitbrush	*Chrysothamnus viscidiflorus*
Snow buckwheat	*Eriogonum niveum*
Spiny hopsage	*Grayia (Atriplex) spinosa*
Threetip sagebrush	*Artemisia tripartita*
Perennial Grasses	
Bluebunch wheatgrass	*Agropyron spicatum*
Bottlebrush squirreltail	*Sitanion hystrix*
Crested wheatgrass	*Agropyron desertorum (cristatum)*[a]
Indian ricegrass	*Oryzopsis hymenoides*
Needle-and-thread grass	*Stipa comata*
Prairie junegrass	*Koeleria cristata*
Sand dropseed	*Sporobolus cryptandrus*
Sandberg's bluegrass	*Poa sandbergii (secunda)*
Thickspike wheatgrass	*Agropyron dasytachyum*
Perennial Forbs	
Bastard toad flax	*Comandra umbellata*
Buckwheat milkvetch	*Astragalus caricinus*
Carey's balsamroot	*Balsamorhiza careyana*
Cusick's sunflower	*Helianthus cusickii*
Cutleaf ladysfoot mustard	*Thelypodium laciniatum*
Douglas' clusterlily	*Brodiaea douglasii*
Dune scurfpea	*Psoralea lanceolata*
Franklin's sandwort	*Arenaria franklinii*
Gray's desertparsley	*Lomatium grayi*
Hoary aster	*Machaeranthera canescens*
Hoary falseyarrow	*Chaenactis douglasii*
Longleaf phlox	*Phlox longifolia*
Munro's globemallow	*Sphaeralcea munroana*
Pale eveningprimrose	*Oenothera pallida*
Sand beardtongue	*Penstemon acuminatus*
Stalked-pod milkvetch	*Astragalus sclerocarpus*
Threadleaf fleabane	*Erigeron filifolius*

A. Shrub-Steppe Species (cont'd.)	Scientific Name
Turpentine spring parsley	*Cymopteris terebinthinus*
Winged dock	*Rumex venosus*
Yarrow	*Achillea millefolium*
Yellow bell	*Fritillaria pudica*
Annual Forbs	
Annual Jacob's ladder	*Polemonium micranthum*
Blue mustard	*Chorispora tenella*[(a)]
Bur ragweed	*Ambrosia acanthicarpa*
Clasping pepperweed	*Lepidium perfoliatum*
Indian wheat	*Plantago patagonica*
Jagged chickweed	*Holosteum umbellatum*[(a)]
Jim Hill's tumblemustard	*Sisymbrium altissimum*[(a)]
Matted cryptantha	*Cryptantha circumscissa*
Pink microsteris	*Microsteris gracilis*
Prickly lettuce	*Lactuca serriola*[(a)]
Rough wallflower	*Erysimum asperum*
Russian thistle (tumbleweed)	*Salsola kali*[(a)]
Slender hawksbeard	*Crepis atrabarba*
Spring whitlowgrass	*Draba verna*[(a)]
Storksbill	*Erodium cicutarium*[(a)]
Tall willowherb	*Epilobium paniculatum*
Tarweed fiddleneck	*Amsinckia lycopsoides*
Threadleaf scorpion weed	*Phacelia linearis*
Western tansymustard	*Descurainia pinnata*
White cupseed	*Plectritis macrocera*
Whitestem stickleaf	*Mentzelia albicaulis*
Winged cryptantha	*Cryptantha pterocarya*
Yellow salsify	*Tragopogon dubius*[(a)]
Annual Grasses	
Cheatgrass	*Bromus tectorum*[(a)]
Slender sixweeks	*Festuca octoflora*
Small sixweeks	*Festuca microstachys*

B. Riparian Species	Scientific Name
Trees and Shrubs	
Black cottonwood	*Populus trichocarpa*
Black locust	*Robinia pseudo-acacia*
Coyote willow	*Salix exigua*
Dogbane	*Apocynum cannabinum*
Peach, apricot, cherry	*Prunus* spp.
Peachleaf willow	*Salix amygdaloides*
Willow	*Salix* spp.
White mulberry	*Morus alba*[a]
Perennial Grasses and Forbs	
Bentgrass	*Agrostis* spp. [b]
Blanket flower	*Gaillardia aristata*
Bulrushes	*Scirpus* spp.[b]
Cattail	*Typha latifolia*[b]
Columbia River gumweed	*Grindelia columbiana*
Hairy golden aster	*Heterotheca villosa*
Heartweed	*Polygonum persicaria*
Horsetails	*Equisetum* spp.
Horseweed tickseed	*Coreopsis atkinsoniana*
Lovegrass	*Eragrostis* spp. [b]
Lupine	*Lupinus* spp.
Meadow foxtail	*Alopecurus aequalis* [b]
Pacific sage	*Artemisia campestris*
Prairie sagebrush	*Artemisia ludoviciana*
Reed canary grass	*Phalaris arundinacea*[b]
Rushes	*Juncus* spp.
Russian knapweed	*Centaurea repens*[a]
Sedge	*Carex* spp.[b]
Water speedwell	*Veronica anagallis-aquatica*
Western goldenrod	*Solidago occidentalis*
Wild onion	*Allium* spp.
Wiregrass spikerush	*Eleocharis* spp.[b]
Aquatic Vascular	
Canadian waterweed	*Elodea canadensis*
Columbia yellowcress	*Rorippa columbiae*
Duckweed	*Lemna minor*

B. Riparian Species	Scientific Name
Aquatic Vascular (cont'd.)	
Pondweed	*Potamogeton* spp.
Spiked water milfoil	*Myriophyllum spicatum*
Watercress	*Rorippa nasturtium-aquaticum*

[a] Introduced
[b] Perennial grasses and graminoids.

spike rush, and cattail. Watercress, which persists at these sites, is also abundant for a large portion of the year. Most wastewater ponds and ditches on the Hanford Site have been decommissioned and no longer support riparian vegetation. On the North Slope, there are several irrigation return ponds that support riparian vegetation.

Riparian habitat that occurs in association with the Columbia River includes riffles, gravel bars, backwater sloughs, and cobble shorelines. These emergent habitats occur infrequently along the Hanford Reach and have acquired greater significance because of the net loss of wetland habitat elsewhere within the region. From surveys conducted in 1994 and 1995, The Nature Conservancy identified 13 rare plant species (out of 19 total on the Hanford Site) residing along the Hanford Reach (Soll and Soper 1996). Four new species previously not listed at Hanford (Sackschewsky et al. 1992) were found in the 31 wetland areas surveyed by The Nature Conservancy (Hall 1998). Noxious weeds are also becoming established along the riparian zones of the Hanford Reach. Purple loosestrife, yellow nutsedge, reed canarygrass, and yellow star thistle are some of the more common species found near or on wetlands. Common emergent species include reed canarygrass, common witchgrass, and large barnyard grass. Rushes and sedges occur along the shorelines of the Columbia River and at several sloughs along the Hanford Reach at White Bluffs, below the 100-H Area, downstream of the 100-F Area, and the Hanford Slough.

Unique Habitats. Unique habitats on the Hanford Site include bluffs, dunes, and islands (DOE 1996a). The White Bluffs, Umtanum Ridge, and Gable Mountain on the Hanford Site include rock outcrops that occur infrequently on the Site. Basalt outcrops are most often occupied by plant communities dominated by buckwheat and Sandberg's bluegrass.

The terrain of the dune habitat rises and falls between 3 and 5 m (10 and 16 ft) above ground level, creating areas that range from 2.5 to several hundred acres in size (U.S. Department of the Army 1990). The dunes are vegetated by bitterbrush, scurfpea, and thickspike wheatgrass.

Island habitat accounts for approximately 474 ha (1170 acres) (Hanson and Browning 1959) and 64.3 km (39.9 mi) of river shoreline within the main channel of the Hanford Reach. However, DOE owns and administers the upland portions of Locke Island (River mile [RM] 371-373.5) and Wooded Island (RM 348-351), and all of Island # 7 (RM 367). The Washington State Department of Natural Resources oversees the shorelines of Locke and Wooded islands. Shoreline riparian vegetation that characterizes the islands includes willow, poplar, Russian olive, and mulberry. Prior to regulation of river flows by dams, trees were not found along river shoreline habitat. Species occurring on the island interior include buckwheat, lupine, mugwort, thickspike wheatgrass, giant wildrye, yarrow, and cheatgrass (Warren 1980). Management of these islands is the responsibility of the island owners that include DOE, the U.S. Fish and Wildlife Service, and the U.S. Bureau of Land Management. Recent landslides that were caused by rotational slumping in the White Bluffs area have resulted in accelerated erosion of Locke Island by the Columbia River.

West Lake and its immediate basin represent a unique habitat that is characterized by highly saline conditions (Poston et al. 1991). These conditions occurred most likely from disposal of sewage at the site during the Manhattan Project in the 1940s. West Lake is classified as a waste site under CERCLA. Water levels of the pond fluctuate with wastewater discharge levels in the 200 Areas. Predominant plants include salt grass, plantain, and rattle box. Three-spine bulrush grows along the shoreline; however, the water in the pond is too saline to support aquatic macrophytes.

Operable Units. The Hanford Site encompasses numerous waste management units and groundwater contamination plumes that have been grouped into operable units under CERCLA. Each unit has complementary characteristics of such parameters as geography, waste content, type of facility, and relationship of contaminant plumes. In general, the operable units are typified by nonnative or invasive plants. Cheatgrass, Russian thistle, and tumble mustard are invasive species that have colonized many of the disturbed portions of these sites. The 100 Area operable units are characterized by a narrow band of riparian vegetation along the shoreline of the Columbia River, with much of the area shoreward consisting of old agricultural fields, dominated by cheatgrass and tumble mustard. Scattered big sagebrush and gray rabbitbrush also occur throughout the 100 Areas (Landeen et al. 1993). An area of natural big sagebrush habitat near the100-D area has experienced significant and apparently natural decline in recent years (Cardenas et al. 1997). A total area encompassing 1780 hectares (ha) is in decline, and a central core area of 280 ha has experienced more than 80% mortality. State threatened, endangered, or sensitive species that occur within the 100 Area operable units include Columbia yellowcress, southern mudwort, false pimpernel, shining flatsedge, gray cryptantha, and possibly dense sedge (Landeen et al. 1993; Soll and Soper 1996).

Waste management areas, reactors, and crib sites are generally either barren or vegetated by invasive species, including Russian thistle, tumble mustard, and cheatgrass. Russian thistle and gray rabbitbrush that occur in these areas are deep rooted and have the potential to accumulate radionuclides and other buried contaminants, functioning as a pathway to other parts of the ecosystem (Landeen et al. 1993). The undisturbed portions of the 200 Areas are characterized as sagebrush/cheatgrass or Sandberg's bluegrass communities of the 200 Area Plateau. The dominant plants on the 200 Area Plateau are big sagebrush, rabbitbrush, cheatgrass, and Sandberg's bluegrass. Cheatgrass provides half of the total plant cover. Most of the waste disposal and storage sites are covered by nonnative vegetation or are kept in a vegetation-free condition.

Vegetation surveys were conducted at the 300-FF-5 Operable Unit during 1992. The shrub-steppe vegetation community in the unit is characterized as antelope bitterbrush/Sandberg's bluegrass with an overstory of bitterbrush and big sagebrush and an understory of cheatgrass and Sandberg's bluegrass (Brandt et al. 1993). Dominant riparian vegetation in the unit included white mulberry and shrub willow, reed canarygrass, bulbous bluegrass, sedges, and horsetail. Columbia yellowcress, an endangered state species, was identified at 18 locations near this operable unit.

4.4.1.2 Wildlife

Approximately 300 species of terrestrial vertebrates have been observed on the Hanford Site. The species list includes approximately 40 species of mammals, 246 species of birds, 4 species of amphibians, and 9 species of reptiles (Soll and Soper 1996; Brandt et al. 1993). From 1991 to 1993, surveys for birds, mammals, insects, and vegetation were conducted at several of the 100 and 300 Area operable units and the results documented in topical reports (Brandt et al. 1993; Landeen et al. 1993). The Nature Conservancy (Hall 1998) recently summarized its findings for birds and mammal surveys. These surveys fall short of the number of species that have been documented on the Site historically. For example, 178 species were observed in the bird surveys in 1997. This number falls short of the 246 species identified historically. Specific surveys were not conducted for mammals, but encounters were documented and compared to historic lists.

Shrubland and Grassland Wildlife. The shrub and grassland habitat of the Hanford Site supports many groups of terrestrial wildlife. Species include large game animals like Rocky Mountain elk and mule deer; predators such as coyote, bobcat, and badger; and herbivores like deer mice, harvest mice, grasshopper mice, ground squirrels, voles, and black-tailed jackrabbits. The most abundant mammal on the Hanford Site is the Great Basin pocket mouse.

Mule deer are reliant on shoreline vegetation and bitterbrush shrubs for browse (Tiller et al. 1997). Elk, which are more dependent on open grasslands for forage, seek the cover of sagebrush and other shrub species during the summer months. Elk first appeared on the Hanford Site in 1972 (Fitzner and Gray 1991), and have increased from approximately 8 animals in 1975 to approximately 900 in 1999. The herd of elk that inhabits the Hanford Site primarily occupies ALE and private lands that adjoin the reserve to the north and west, are occasionally seen on the 200 Area plateau, and have been sighted at the White Bluffs boat launch on the Hanford Site. The herd tends to congregate on ALE in the winter and disperses during the summer months to higher elevations on ALE, private land to the west of ALE, and the Yakima Training Center.

Shrubland and grasslands provide nesting and foraging habitat for many passerine bird species. Surveys conducted during 1993 (Cadwell 1994) reported the occurrence of western meadowlarks and horned larks more frequently in shrubland habitats than in other habitats on the Site. Long-billed curlews and vesper sparrows were also noted as commonly occurring species in shrubland habitat. Species that are dependent on undisturbed shrub habitat include sage sparrow, sage thrasher, and loggerhead shrike. Both the sage sparrow and loggerhead shrike tend to roost and nest in sagebrush or bitterbrush that occurs at lower elevations (DOE 1996a). Ground-nesting species that occur in grass-covered uplands include long-billed curlews, western meadowlark, and burrowing owls.

Common upland gamebird species that occur in shrub and grassland habitat include chukar partridge, California quail, and Chinese ring-necked pheasant. Chukars are most numerous in the Rattlesnake Hills, Yakima Ridge, Umtanum Ridge, Saddle Mountains, and Gable Mountain areas of the Hanford Site. Less common species include western sage grouse, Hungarian partridge, and scaled quail. Western sage grouse were historically abundant on the Hanford Site; however, populations have declined since the early 1800s because of the conversion of sagebrush-steppe habitat. Surveys conducted by the Washington Department of Fish and Wildlife and PNNL during late winter and early spring 1993, and biodiversity inventories conducted by The Nature Conservancy in 1997, did not observe western sage grouse in sagebrush-steppe habitat at ALE. However, they have been observed on ALE in 1999[b]

Among the more common raptor species that use shrub and grassland habitat are ferruginous hawks, Swainson's hawk, and red-tailed hawk. Northern harriers, sharp-shinned hawks, rough-legged hawks, and golden eagles also occur in these habitats, although infrequently. In 1994, nesting by red-tailed, Swainson's, and ferruginous hawks included 41 nests located across the Hanford Site on high voltage transmission towers, trees, cliffs, and basalt outcrops. In recent years, the number of nesting ferruginous hawks (a Washington State threatened species) on the Hanford Site has increased, as a result, in part, to their acceptance of steel powerline towers in the open grass and shrubland habitats.

Many species of insects occur throughout all habitats on the Hanford Site. Butterflies, grasshoppers, and darkling beetles are among the more conspicuous of the approximately 1500 species of insects that have been identified from specimens collected on the Hanford Site (Hall 1998). The actual number of insect species occurring on the Hanford Site may reach as high as 15,000. Recent surveys performed by The Nature Conservancy included the collection of 30,000 specimens and have resulted in the identification of 42 new taxa and 172 new findings in the State of Washington (Hall 1998). Insects are more readily observed during the warmer months of the year.

The side-blotched lizard is the most abundant reptile species that occurs on the Hanford Site. Short-horned and sagebrush lizards are reported for the Hanford Site, but occur infrequently. The most common snake species include gopher snake, yellow-bellied racer, and Pacific rattlesnake. The Great Basin spadefoot toad, Woodhouse's toad, Pacific tree frog, and bullfrogs are the only amphibians found on the Site (Soll and Soper 1996; Brandt et al. 1993).

Riparian Wildlife. Riparian areas provide nesting and foraging habitat and escape cover for many species of birds and mammals. Shoreline riparian communities are seasonally important for a variety of species. Willows trap food for waterfowl (e.g., Canada geese) and birds that use shoreline habitat (e.g., Forster's tern) and provide nesting habitat for passerines (e.g., mourning doves). Terrestrial and aquatic insects are abundant in emergent grasses and provide forage for fish, waterfowl, and shorebirds. Riparian areas provide nesting and foraging habitat and cover for many species of birds and mammals.

Mammals that occur primarily in riparian areas include rodents, bats, furbearers (e.g., mink and weasels), porcupine, raccoon, skunk, and mule deer. Beavers rely on shoreline habitat for dens and foraging. River otters have been observed infrequently in the Hanford Reach. During the summer months, mule deer rely on riparian vegetation for foraging. Mule deer also use Columbia River islands for fawning and nursery areas. Beaver and muskrat rely on shoreline habitat for dens and foraging. The Columbia River and Rattlesnake Springs provide foraging habitat for most species of bats including myotis, small-footed myotis, silver-haired bats, and pallid bats that feed on emergent aquatic insects (Becker 1993).

Common bird species that occur in riparian habitats include American robin, black-billed magpie, song sparrow, and dark-eyed junco (Cadwell 1994). Upland gamebirds that use this habitat include ring-necked pheasants and California quail. Predatory birds include common barn owl and great horned owl. Species known or expected to nest in riparian habitat are Brewer's blackbird, mourning dove, black-billed magpie, northern oriole, lazuli bunting, eastern and western kingbird, and western wood peewee. Bald eagles have wintered on the

---

[b] Source: Personal communication with B.L. Tiller, PNNL, August 1999.

Hanford Site since 1960. Great blue herons and black crowned night herons are associated with trees in riparian habitat along the Columbia River and use groves or individual trees for perching and nesting.

The Hanford Site is located in the Pacific Flyway, and the Hanford Reach serves as a resting area for neotropical migrant birds, migratory waterfowl, and shorebirds (Soll and Soper 1996). During the fall and winter months, ducks (primarily mallards) and Canada geese rest on the shorelines and islands along the Hanford Reach. The area between the Old Hanford townsite and Vernita Bridge is closed to recreational hunting, and large numbers of migratory waterfowl find refuge in this portion of the river. Other species observed during this period include white pelicans, egrets, double-crested cormorants, coots, and common loons.

Wildlife Occurring in Unique Habitat. Bluffs provide perching, nesting, and escape habitat for several bird species on the Hanford Site. The White Bluffs and Umtanum Ridge provide nesting habitat for prairie falcons, red-tailed hawks, cliff swallows, bank swallows, and rough-winged swallows. In the past, Canada geese used the lower elevations of the White Bluffs for nesting and brooding. Bald eagles use the White Bluffs for roosting. Bluff areas provide habitat for sensitive species (i.e., Hoover's desert parsley and peregrine falcon) that otherwise may be subject to impact from frequent or repeated disturbance. The White Bluffs bladderpod is a newly discovered Washington State endangered species that grows on the White Bluffs. Trees that do not normally occur in arid steppe habitat-provide nesting, perching, and roosting sites for many birds. Consequently, raptors, like ferruginous and Swainson's hawks, can use trees for breeding in areas that previously did not support breeding populations. Ferruginous hawks also nest on electrical transmission line towers.

Dune habitat is unique in its association with the surrounding shrub-steppe vegetation type. The uniqueness of the dunes is noted in its vegetation component as well as the geologic formation. The terrain of the Hanford dunes provides habitat for mule deer, burrowing owls, and coyotes as well as many transient species.

Islands afford a unique arrangement of upland and shoreline habitat for avian and terrestrial species. Islands vary in soil type and vegetation and range from narrow cobble benches to extensive dune habitats. Except for several plant species, the islands accommodate many of the same species that occur in mainland habitats. Operation of Priest Rapids Dam upstream of the Hanford Reach creates daily and seasonal fluctuations in river levels, which may limit community structure and overall shoreline species viability along the shoreline interface.

Islands provide resting, nesting, and escape habitat for waterfowl and shorebirds. Use of islands for nesting by Canada geese has been monitored since 1950. The suitability of habitat for nesting Canada geese is attributed to restricted human use of islands during the nesting season, suitable substrate, and adequate forage and cover for broods (Eberhardt et al. 1989). The nesting population fluctuates annually. In recent years, geese have more frequently used the downstream islands in the Reach for nesting as a result of coyote predation in the upper Reach islands. Islands also accommodate colonial nesting species including California gulls, ring-billed gulls, and Forster's terns. Island areas ranging from 12 to 20 ha (30 to 50 acres) accommodate colonial nesting species that may range in population size of upwards of 2000 individuals.

With the cessation of nuclear materials production activities at the Hanford Site, the amount of water discharged to the ground in the 200 Area Plateau has significantly decreased. West Lake has shrunk and currently is a group of small isolated pools and mud flats. Avocets and sandpipers still use the lake, but it does not support coots or other nesting waterfowl. The water is too saline for consumption by mammals.

4.4.2 Aquatic Ecology

There are two types of natural aquatic habitats on the Hanford Site: the Columbia River which flows along the northern and eastern edges of the Hanford Site, and small spring-streams and seeps located mainly on ALE (Figure 4.4-2) in the Rattlesnake Hills. West Pond is created by a rise in the water table in the 200 Areas and is not fed by surface flow. Disposal of sewage during the early years created highly saline and alkaline conditions that greatly restricted complement of biota (Poston et al. 1991).

4.4.2.1 Columbia River

The Columbia River is the dominant aquatic ecosystem on the Hanford Site and supports a large and diverse community of plankton, benthic invertebrates, fish, and other communities. It has a drainage area of about 680,000 km^2 (262,480 mi^2), an estimated average annual discharge of 6600 m^3/s (71,016 ft/s), and a total length of about 2000 km (about 1240 mi) from its origin in British Columbia to its mouth at the Pacific Ocean. The Columbia has been dammed both upstream and downstream from the Hanford Site, and the reach flowing through the area is the last free-flowing, but regulated, reach of the Columbia River in the United States above Bonneville Dam. Plankton populations in the Hanford Reach are influenced by communities that develop in the reservoirs of upstream dams, particularly Priest Rapids Reservoir and by manipulation of water levels below by dam operations in upstream and downstream reservoirs. Phytoplankton and zooplankton populations at the Hanford Site are largely transient, flowing from one reservoir to another. There is generally insufficient time for characteristic endemic groups of phytoplankton and zooplankton to develop in the Hanford Reach. No tributaries enter the Columbia during its passage through the Hanford Site; however, there are several irrigation water return canals that discharge into the Columbia River along the Franklin County shoreline.

Public Law 100-605, passed by Congress in 1988, authorized the study of the Hanford Reach for possible designation as a wild and scenic river. (This law expired and was renewed as Public Law 104-333 in 1996.) In 1994, based on the results of this study, the National Park Service (NPS) (DOI 1994) recommended creation of a 41,310-ha (102,000-acre) National Wildlife Refuge containing the river and its corridor. The Secretary of the Interior further recommended that the Reach and its corridor be designated as a recreational river in the national wild and scenic rivers system. The NPS issued a Record of Decision (ROD) on July 16, 1996. The U.S. Fish and Wildlife Service would administer the refuge and river. Before the plan can be implemented, it must be enacted by Congress. If enacted, the designation would not preclude existing landuse and recreational use of the river for boating, hunting, and fishing but would preclude expansion of agriculture and other non-compatible development within the refuge and river corridor (DOI 1994). Establishing the lands adjacent to the river as a National Wildlife Refuge would increase protection to all habitat types within and along the Reach.

The Columbia River is a very complex ecosystem because of its size, the number of alterations, the biotic diversity, and size and diversity of its drainage basin. Streams in general, especially smaller ones, usually depend on organic matter from outside sources (e.g., terrestrial plant debris) to provide energy for the ecosystem. Large rivers, particularly the Columbia River with its series of large reservoirs, contain significant populations of primary energy producers (e.g., algae and plants) that contribute to the basic energy requirements of the biota.

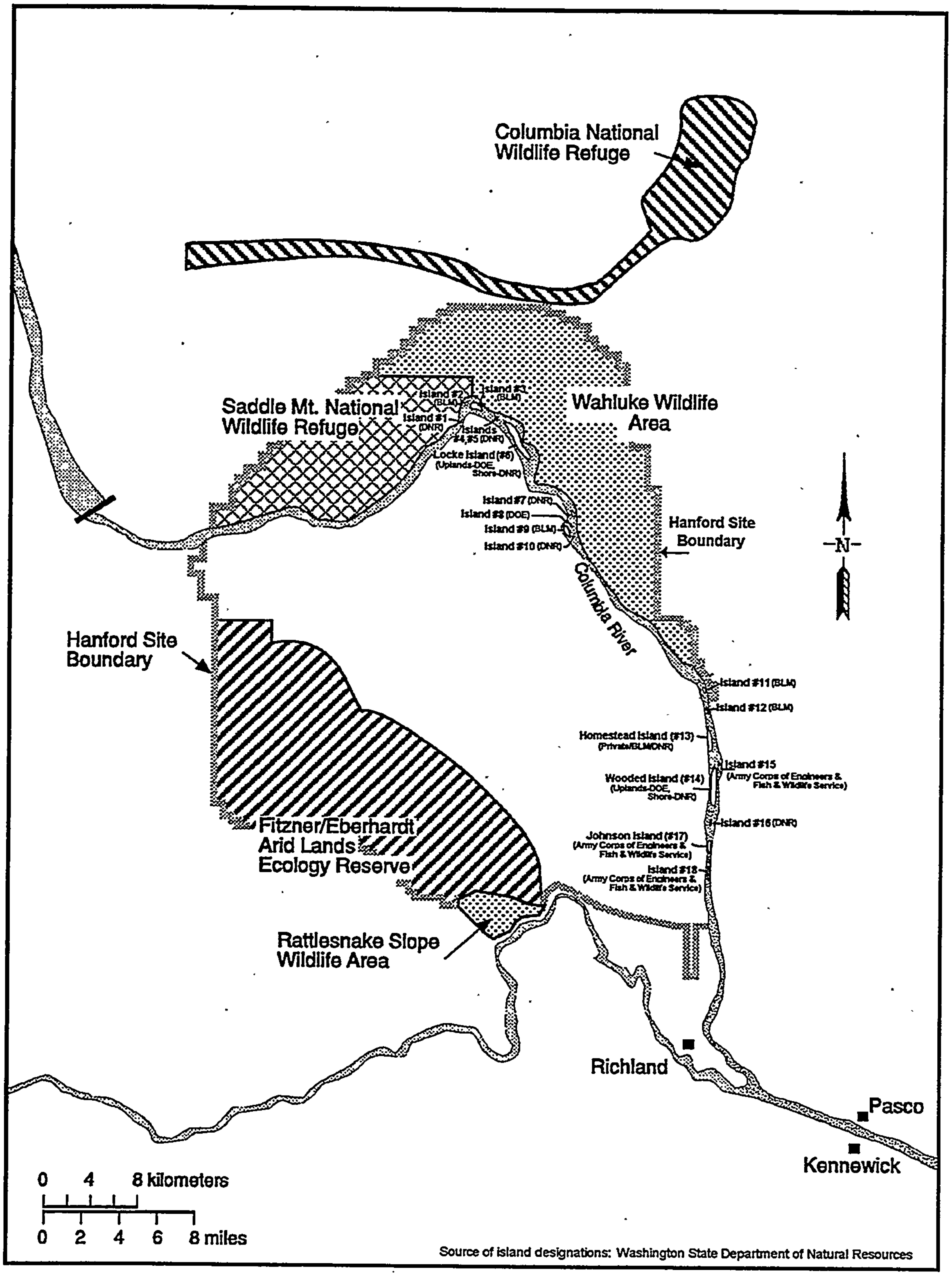


Figure 4.4-2. National and State Wildlife Refuges on and near the Hanford Site.

Phytoplankton (free-floating algae) and periphyton (sessile algae) are abundant in the Columbia River and provide food for herbivores such as immature insects, which in turn are consumed by predaceous species.

Phytoplankton. Phytoplankton species identified from the Hanford Reach include diatoms, golden or yellow-brown algae, green algae, blue-green algae, red algae, and dinoflagellates. Studies show diatoms are the dominant algae in the Columbia River phytoplankton, usually representing more than 90% of the populations. The main genera included *Asterionella, Cyclotella, Fragilaria, Melosira, Stephanodiscus*, and *Synedra* (Neitzel et al. 1982a). These are typical of those forms found in lakes and ponds and originated in the upstream reservoirs. A number of algae found as free-floating species in the Hanford Reach of the Columbia River are actually derived from the periphyton; they were detached and suspended by current and frequent fluctuations of the water level.

Cushing (1967a) found the peak concentration of phytoplankton occurred in April and May, with a secondary peak in late summer/early autumn. The spring pulse in phytoplankton density was probably related to increasing light and water temperature rather than to availability of nutrients, because phosphate and nitrate nutrient concentrations are never limiting. Minimum numbers were present in December and January. Green algae (*Chlorophyta*) and blue-green algae (*Cyanophyta*) occur in the phytoplankton community during warmer months but in substantially fewer numbers than diatoms. Diversity indices, carbon uptake, and chlorophyll-a concentrations for the phytoplankton at various times and locations can be found in Beak Consultants Inc. (1980), Neitzel et al. (1982a), and Wolf et al. (1976).

Periphyton. Communities of periphytic species ("benthic microflora") develop on suitable solid substrata wherever there is sufficient light for photosynthesis. Cushing (1967b) observed peaks of production to occur in spring and late summer. Dominant genera are the diatoms *Achnanthes, Asterionella, Cocconeis, Fragilaria, Gomphonema, Melosira, Nitzchia, Stephanodiscus*, and *Synedra* (Beak Consultants Inc. 1980; Neitzel et al. 1982a; Page and Neitzel 1978; Page et al. 1979).

Macrophytes. Macrophytes are sparse in the Columbia River because of strong currents, rocky bottom, and frequently fluctuating water levels. Rushes (*Juncus* spp.) and sedges (*Carex* spp.) occur along shorelines of the slack-water areas such as White Bluffs Slough below the 100-H Area, the slough area downstream of the 100-F Area, and Hanford Slough. Macrophytes are also present along gently sloping shorelines that are subject to flooding during the spring freshet and daily fluctuating river levels (below Coyote Rapids and the 100-D Area). Commonly found plants include *Lemna, Potamogeton, Elodea*, and *Myriophyllum*. Where they exist, macrophytes have considerable ecological value. They provide food and shelter for juvenile fish and spawning areas for some species of warm water game fish. Exotic macrophytes (milfoil) have increased to nuisance levels, and may encourage increased sedimentation of fine particulate matter. These changes could have a significant impact on trophic relationships of the Columbia River.

Zooplankton. The zooplankton populations in the Hanford Reach of the Columbia River are generally sparse. Studies by Neitzel et al. (1982b) indicate crustacean zooplankters were dominant in the open-water regions. Dominant genera were *Bosmina, Diaptomus*, and *Cyclops*. Densities were lowest in winter and highest in the summer, with summer peaks dominated by *Bosmina*, ranging up to 160,650 organisms/m^3 (4500 organisms/ft^3). Winter densities were generally <1785 organisms/m^3 (<50 organisms/ft^3). *Diaptomus* and *Cyclops* dominated in winter and spring, respectively.

Benthic Organisms. Benthic organisms are found either attached to or closely associated with the substratum. All major freshwater benthic taxa are represented in the Columbia River. Insect larvae such as caddisflies (*Trichoptera*), midge flies (*Chironomidae*), and black flies (*Simuliidae*) are dominant. Dominant caddisfly species are *Hydropsyche cockerelli, Cheumatopsyche campyla*, and *C. enonis*. Other benthic organisms include limpets, snails, sponges, and crayfish. Peak larval insect densities are found in late fall and winter, and the major emergence is in spring and summer (Wolf 1976). Stomach contents of fish collected in the Hanford Reach from June 1973 through March 1980 revealed that benthic invertebrates were important food items for nearly all juvenile and adult fish. There was a close relationship between food organisms in the stomach contents and those in the benthic and invertebrate drift communities.

Fish. Gray and Dauble (1977) listed 43 species of fish in the Hanford Reach of the Columbia River. The brown bullhead (*Ictalurus nebulosus*) has been collected since 1977, bringing the total number of fish species identified in the Hanford Reach to 44 (Table 4.4-2). Of these species, chinook salmon, sockeye salmon, coho salmon, and steelhead trout use the river as a migration route to and from upstream spawning areas and are of the greatest economic importance. Additionally, fall chinook salmon and steelhead trout also spawn in the Hanford Reach. The relative contribution of upper-river bright stocks to fall chinook salmon runs in the Columbia River increased from about 24% of the total in the early 1980s, to 50% to 60% of the total by 1988 (Dauble and Watson 1990). Inundation of other mainstream Columbia spawning grounds by dams has increased the relative importance of the Hanford Reach to fall chinook salmon production in the Columbia and Snake rivers (Watson 1970, 1973).

The steelhead fishery in the Hanford Reach (Highway 395 Bridge to Priest Rapids Dam) consists almost exclusively of summer run fish. The estimated sport catch for the 1996-97 season was 2855 fish. The majority of these fish (97%) were marked hatchery fish. About 80% of this harvest occurred from June through September (WDFW 1999).

American shad, another anadromous species, may also spawn in the Hanford Reach. The upstream range of the shad has been increasing since 1956 when <10 adult shad ascended McNary Dam. Since then, the number of shad ascending Priest Rapids Dam has risen to many thousands each year, and young-of-the-year have been collected in the Hanford Reach. The shad is not dependent on the same conditions that are required by the salmonids for spawning and apparently has found favorable conditions for reproduction throughout much of the Columbia and Snake rivers.

Studies were initiated in the spring of 1993 to evaluate the potential for use of water storage facilities at the former 100-K Area fuel production site for fish production. Pilot studies at the facility indicated that juvenile fall chinook salmon could be transported to the 100-K facility and successfully held prior to planting in the Columbia River (Dauble et al. 1993).[c]

Other fisheries studies at the 100-K water treatment facility include the Yakama Nation's (YN) expansion of fall chinook salmon rearing activities to include raising 500,000 salmon in 14 net pens. Several other species of fish including sturgeon, channel catfish, and walleye have been raised at the facility. However, there are no fish rearing programs currently operating at K Basin.

---

[c] Dauble, D. D., G. A. Martenson, D. F. Herborn, and B. N. Anderson. 1994. *K Basin Fisheries Investigations: FY 94 Summary of Activities*. Letter Report. Pacific Northwest Laboratory, Richland, Washington.

Table 4.4-2. Fish Species in the Hanford Reach of the Columbia River.

Common Name	Scientific Name
American shad	*Alosa sapidissima*
Black bullhead	*Ameiurus melas*
Black crappie	*Pomoxis nigromaculatus*
Bluegill	*Lepomis macrochirus*
Bridgelip sucker	*Catostomus columbianus*
Brown bullhead	*Ictalurus nebulosus*
Burbot	*Lota lota*
Carp	*Cyprinus carpio*
Channel catfish	*Ictalurus punctatus*
Chinook salmon	*Oncorhynchus tshawytscha*
Chiselmouth	*Acrocheilus alutaceus*
Coho salmon	*Oncorhynchus kisutch*
Cutthroat trout	*Oncorhynchus clarki*
Dolly Varden	*Salvelinus malma*
Lake whitefish	*Coregonus clupeaformis*
Largemouth bass	*Micropterus salmoides*
Largescale sucker	*Catostomus macrocheilus*
Leopard dace	*Rhinichthys falcatus*
Longnose dace	*Rhinichthys cataractae*
Mottled sculpin	*Cottus bairdi*
Mountain sucker	*Catostomus platyrhynchus*
Mountain whitefish	*Prosopium williamsoni*
Northern pikeminnow (aka squawfish)	*Ptychocheilus oregonensis*
Pacific lamprey	*Entosphenus tridentatus*
Peamouth	*Mylocheilus caurinus*
Piute sculpin	*Cottus beldingi*
Prickley sculpin	*Cottus asper*
Pumpkinseed	*Lepomis gibbosus*
Rainbow trout (steelhead)	*Oncorhynchus mykiss*
Redside shiner	*Richardsonius balteatus*
Reticulate sculpin	*Cottus perplexus*
River lamprey	*Lampetra ayresi*
Sand roller	*Percopsis transmontana*
Smallmouth bass	*Micropterus dolomieui*
Sockeye salmon	*Oncorhynchus nerka*
Speckled dace	*Rhinichthys osculus*
Tench	*Tinca tinca*
Threespine stickleback	*Gasterosteus aculeatus*
Torrent sculpin	*Cottus rotheus*
Walleye	*Stizostedion vitreum vitreum*
White crappie	*Pomoxis annularis*
White sturgeon	*Acipenser transmontanus*
Yellow perch	*Perca flavescens*
Yellow bullhead	*Ictalurus natalis*

Other fish of importance to sport fishermen are mountain whitefish, white sturgeon, smallmouth bass, crappie, catfish, walleye, and yellow perch. Large populations of rough fish are also present, including carp, redside shiner, suckers, and northern pikeminnow (formerly known as "squawfish").

4.4.2.2 Spring Streams

Small interrupted streams, such as Rattlesnake and Snively Springs, contain diverse biotic communities and are extremely productive (Cushing and Wolf 1984). Dense blooms of watercress occur that are not lost until one of the major flash floods occurs. Aquatic insect production is fairly high as compared with mountain streams (Gaines 1987). The macrobenthic biota varies from site to site and is related to the proximity of colonizing insects and other factors.

Rattlesnake Springs, on the western side of the Hanford Site, forms a small surface stream that flows for about 2.5 km (1.6 mi) before disappearing into the ground as a result of seepage and evapotranspiration. Base flow of this stream is about 0.01 m^3/s (0.4 ft^3/s) (Cushing and Wolf 1982). Water temperature ranges from 2° to 22°C (36° to 72°F). Mean annual total alkalinities (as $CaCO_3$), nitrate nitrogen, phosphate phosphorus, and total dissolved solids are 127, 0.3, 0.18, and 217 mg/L, respectively (Cushing and Wolf 1982; Cushing et al. 1980). The sodium content of the spring water is about 7 ppm (Brown 1970). Rattlesnake Springs is of ecological importance because it provides a source of water to terrestrial animals in an otherwise arid part of the Site. Snively Springs, located farther west and at a higher elevation than Rattlesnake Springs, is also another source of drinking water for terrestrial animals. The major rooted aquatic plant, which in places may cover the entire width of the stream, is watercress (*Rorippa nasturtium-aquaticum*). Isolated patches of bulrush (*Scirpus* sp.), spike rush (*Eleocharis* sp.), and cattail (*Typha latifolia*) occupy <5% of the stream bed.

Primary productivity at Rattlesnake Springs is greatest during the spring and coincident with the maximum periphyton standing crop. Net primary productivity averaged 0.9 $g/cm^2/d$ organic matter during 1969 and 1970; the spring maximum was 2.2 $g/cm^2/d$. Seasonal productivity and respiration rates are within the ranges reported for arid region streams. Although Rattlesnake Springs is a net exporter of organic matter during much of the growing season, it is subject to flash floods and severe scouring and denuding of the streambed during winter and early spring, making it an importer of organic materials on an annual basis (Cushing and Wolf 1984).

Secondary production is dominated by detritus-feeding collector-gatherer insects (mostly *Chironomidae* and *Simuliidae*) that have multiple cohorts and short generation times (Gaines et al. 1992). Overall production is not high and is likely related to the low diversity found in these systems related to the winter spates that scour the spring-streams. Total secondary production in Rattlesnake and Snively springs is 16,356 and 14,154 g/dry weight m^2/yr, respectively. There is an indication that insects in these spring-streams depend on both autochthonous (originating within the stream) and allochthonous (originating outside the stream) primary production as an energy source, despite significant shading of these spring-streams that would appear to preclude significant autochthonous production (Mize 1993).

An inventory of the many springs occurring on the Rattlesnake Hills has been published by Schwab et al. (1979). Limited physical and chemical data are included for each site.

4.4.2.3 Wetlands

Several habitats on the Hanford Site could be considered wetlands. The largest wetland habitat is the riparian zone bordering the Columbia River. The extent of this zone varies but includes extensive stands of willows, grasses, various aquatic macrophytes, and other plants. The zone is extensively impacted by both seasonal water-level fluctuations and daily variations related to power generation at Priest Rapids Dam immediately upstream of the Site.

Other wetlands can be found within the Saddle Mountain National Wildlife Refuge and the Wahluke Wildlife Area; these two areas encompass all the lands extending from the north bank of the Columbia River northward to the Site boundary and east of the Columbia River down to Ringold Springs. Wetland habitat in these areas consists of fairly large pond habitat resulting from irrigation runoff (see Figure 4.3-1). These ponds have extensive stands of cattails (*Typha* sp.) and other emergent aquatic vegetation surrounding the open-water regions. They are extensively used as resting sites by waterfowl.

Some wetland habitat exists in the riparian zones of some of the larger spring streams on the Fitzner/Eberhardt ALE Reserve of the Hanford Site (see earlier description). These are not extensive and usually amount to less than a hectare in size, although the riparian zone along Rattlesnake Springs is probably about 2 km (1.2 mi) in length and consists of peachleaf willows, cattails, and other plants.

The U.S. Fish and Wildlife Service has published a series of 1:24,000 maps that show the locations of wetlands. An accompanying booklet describes how to use these maps. Four sets of these maps, covering the Hanford Site, and the instructional booklet for their use are available from 1) D. A. Neitzel, Sigma 5 Building/Room 2216 (PNNL); 2) the Consolidated Information Center, Washington State University Tri-Cities Campus; 3) the office of the DOE Richland NEPA Compliance Officer; and 4) the environmental restoration contractor.

4.4.2.4 Temporary Water Bodies

Several artificial water bodies, both ponds and ditches, were formed as a result of wastewater disposal practices associated with operation of the reactors and separation facilities. The majority of these have been taken out of service and have been backfilled with the cessation of activities (except West Pond). When present, however, they form established aquatic ecosystems complete with representative flora and fauna (Emery and McShane 1980). The temporary wastewater ponds and ditches existed for as long as two decades. Rickard et al. (1981) discusses the ecology of Gable Mountain Pond, one of the former major lentic sites. Emery and McShane (1980) present ecological characteristics of all the temporary water bodies. The ponds develop luxuriant riparian communities and become quite attractive to autumn and spring migrating birds. Several species nest near the ponds. Section 4.3.1.7 describes those water bodies still active.

4.4.3 Threatened and Endangered Species

Threatened and endangered plants and animals identified on the Hanford Site, as listed by the federal government (50 CFR 17) and Washington State (Washington Natural Heritage Program 1997), are shown in Table 4.4-3. No plants or mammals on the federal list of threatened and endangered wildlife and plants (50 CFR 17) are known to occur on the Hanford

Table 4.4-3. Federally or Washington State Listed Threatened (T) and Endangered (E) Species Occurring or Potentially Occurring on the Hanford Site.

Common Name	Scientific Name	Federal	State
Plants			
Columbia milk-vetch	*Astragalus columbianus*		T
Columbia yellowcress	*Rorippa columbiae*		T
Dwarf evening primrose	*Camissonia (=Oenothera) pygmaea*		T
Hoover's desert parsley	*Lomatium tuberosum*		T
Loeflingia	*Loeflingia squarrosa* var. *squarrosa*		T
Northern wormwood[(a)]	*Artemisia campestris borealis* var. *wormskioldii*		E
Umtanum desert buckwheat	*Eriogonum codium*		E
White Bluffs bladderpod	*Lesquerella tuplashensis*		E
White eatonella	*Eatonella nivea*		T
Birds			
Aleutian Canada goose[(b)]	*Branta canadensis leucopareia*	T	T
American white pelican	*Pelecanus erythrorhychos*		E
Bald eagle	*Haliaeetus leucocephalus*	T	T
Ferruginous hawk	*Buteo regalis*		T
Peregrine falcon[(b)]	*Falco peregrinus*	E	E
Sandhill crane[(b)]	*Grus canadensis*		E
Western sage grouse	*Centrocercus urophasianus phaios*		T
Mammals			
Pygmy rabbit[(a)]	*Brachylagus idahoensis*		E
Fish			
Steelhead	*Oncorhynchus mykiss*	E/T[(c)]	
Spring-run chinook salmon[(d)]	*Oncorhynchus tshawytscha*	E	

(a) Likely not currently occurring on the site.
(b) Incidental occurrence.
(c) Mid-Columbia Evolutionary Significant Unit (ESU) is threatened, upper Columbia River ESU is endangered.
(d) Upper and mid-Columbia River spring-run ESUs migrate through the Hanford Site.

Site. There are, however, three species of birds (Aleutian Canada goose, bald eagle, and peregrine falcon) and two species of fish (steelhead and spring-run chinook salmon) on the federal list of threatened and endangered species. Several species of both plants and animals are under consideration for formal listing by the federal government and Washington State (refer to Figure 4.4-1 for locations of species discussed in this section). The U.S. Fish and Wildlife Service reviews the status of candidate species for listing under the Endangered Species Act on an annual basis. The results of these reviews are posted on the U.S. Fish and Wildlife's homepage (http://www.fws.gov). Anadramous fish are reviewed and listed by the National Marine Fisheries Service (http://www.nwr.noaa.gov).

Pristine shrub-steppe habitat is considered priority habitat by Washington State because of its relative scarcity in the state, and because of its requirement as nesting/breeding habitat by several state and federal species of concern. Several recent publications describing the distribution of threatened and endangered species on the Hanford Site have been prepared by Becker (1993), Cadwell (1994), Downs et al. (1993), Fitzner et al. (1994), Frest and Johannes (1993), Pabst (1995), and Hall (1998).

4.4.3.1 Plants

Nine species of Hanford Site plants are included in the Washington State listing as threatened or endangered (Washington Natural Heritage Program 1997). Columbia milk-vetch (*Astragalus columbianus*), Dwarf evening primrose (*Oenothera pygmaea*), loeflingia (*Loeflingia squarrosa*), white eatonella (*Eatonella nivea*), Columbia yellowcress (*Rorippa columbiae*), and Hoover's desert parsley (*Lomatium tuberosum*) are listed as threatened. Northern wormwood (*Artemisia campestris* ssp. *borealis* var. *wormskioldii*), Umtanum desert buckwheat (*Eriogonum codium*), and White Bluffs bladderpod (*Lesquerella tuplashensis*) are designated endangered. Columbia milk-vetch occurs on dry-land benches along the Columbia River near Priest Rapids Dam, Midway, and Vernita; it also has been found atop Umtanum Ridge and in Cold Creek Valley near the present vineyards and on Yakima Ridge (on ALE). Dwarf evening primrose has been found north of Gable Mountain, near the Vernita Bridge, Ringold, and on mechanically disturbed areas (e.g., the gravel pit near the Wye Barricade). Hoover's desert parsley grows on steep talus slopes near Priest Rapids Dam, Midway, and Vernita. Yellowcress occurs in the wetted zone of the water's edge along the Hanford Reach. Northern wormwood is known to occur near Beverly and could inhabit the northern shoreline of the Columbia River across from the 100 Areas. Umtanum desert buckwheat and White Bluffs bladderpod occur only on the Hanford Site and no where else in the world.

4.4.3.2 Animals

The federal government lists the Aleutian Canada goose (*Branta canadensis leucopareia*), Mid-Columbia River steelhead (*Oncorhynchus mykiss),* and the bald eagle (*Haliaeetus leucocephalus*) as threatened and the peregrine falcon (*Falco peregrinus*), upper Columbia River spring chinook salmon (*Oncorhynchus tshawyscha*) and upper Columbia River steelhead (*Oncorhynchus mykiss*) as endangered. Washington State lists the peregrine falcon, the Aleutian Canada goose, white pelican (*Pelecanus erythrorhynchos*), sandhill crane (*Grus canadensis*), and pygmy rabbit (*Brachylagus idahoensis*), as endangered, and lists the ferruginous hawk (*Buteo regalis*), western sage grouse (*Centrocercus urophasianus phaios*), and the bald eagle as threatened. The peregrine falcon is a casual migrant to the Hanford Site and does not nest here. The bald eagle is a regular winter resident and forages on dead salmon and waterfowl along the Columbia River; it does not nest on the Hanford Site, although it has attempted to nest for the last several years. Sage grouse were sited on ALE in 1999.

Access controls are in place along the river at certain times of the year to prevent the disturbance of eagles. Washington State Bald Eagle Protection Rules were issued in 1986 (Washington Administrative Code [WAC]-232-12-292). DOE has prepared a site management plan (Fitzner and Weiss 1994) to mitigate eagle disturbance. This document constitutes a biological assessment for those activities implemented in accordance with the plan and, unless there are extenuating circumstances associated with a given project, the document fulfills the requirements of Section 7(a)(2) of the Endangered Species Act for bald eagles and peregrine falcons. Section 7(a) of the Endangered Species Act also requires consultation with the U.S. Department of the Interior and Washington State when any action is taken that may destroy, adversely modify, or jeopardize the existence of bald eagle or other endangered species' habitat. An increased use of power poles for nesting sites by the ferruginous hawk on the Hanford Site has been noted.

Steelhead and salmon are regulated as Evolutionary Significant Units (ESU) by the National Marine Fisheries Service (NMFS) based on their historical geographic spawning areas. The upper Columbia River ESU steelhead was listed as endangered in August 1997. The upper Columbia River ESU spring-run chinook salmon was listed as endangered in March 1999. These adult steelhead and chinook salmon migrate upstream through the Hanford Reach to spawn in upriver tributaries and juveniles pass through the Hanford Reach on their outward migration to the sea. A steelhead management plan is presently being developed with DOE and the NMFS.

Table 4.4-4 lists designated candidate species under consideration for possible addition to the threatened or endangered list by Washington State. Table 4.4-5 lists Washington State plant species that are of concern and are currently listed as sensitive or are in one of three monitored groups (Hall 1998).

4.4.4 Special Ecological Considerations in the 100 Areas

In the 100 Areas, cheatgrass is prevalent because of the extensive perturbation of soils in these areas. The characteristic communities found are cheatgrass-tumble mustard, sagebrush/cheatgrass, or Sandberg's bluegrass, sagebrush-bitterbrush/cheatgrass, and willow-riparian vegetation near the Columbia River shoreline. California quail and Chinese ring-necked pheasants are more likely to be found near the Columbia River, and several mammals, such as raccoons, beavers, and porcupines, are more likely to be present near the Columbia River.

Table 4.4-4. Washington State Candidate Species Found or Potentially Found on the Hanford Site.

Common Name	Scientific Name
Molluscs	
Columbia pebble snail	*Fluminicola (= Lithoglyphus)* columbiana
Shortfaced lanx	*Fisherola* (= *Lanx*) *nuttalli*
Insects	
Columbia River tiger beetle[a]	*Cicindela columbica*
Juniper hairstreak	*Mitoura siva*
Silver-bordered bog fritillary	*Boloria selene atrocastalis*
Birds	
Burrowing owl	*Athene cunicularia*
Common loon	*Gavia immer*
Flammulated owl[b]	*Otus flammeolus*
Golden eagle	*Aquila chrysaetos*
Lewis' woodpecker[b]	*Melanerpes lewis*
Loggerhead shrike	*Lanius ludovicianus*
Northern goshawk[b]	*Accipter gentilis*
Sage sparrow	*Amphispiza belli*
Sage thrasher	*Oreoscoptes montanus*
Merlin	*Falco columbarius*
Reptiles	
Striped whipsnake	*Masticophis taeniatus*
Mammals	
Merriam's shrew	*Sorex merriami*
Townsend's big-eared bat[a]	*Corynorhinus townsendii*[c]
Washington ground squirrel[b]	*Spermophilus washingtoni*

(a) Probable, but not observed, on the Hanford Site.
(b) Reported, but seldom observed on the Hanford Site.
(c) Also known as *Plecotus townsendii*.

Table 4.4-5. Washington State Plant Species of Concern Occurring on the Hanford Site.

Common Name	Scientific Name	State Listing[a]
Annual paintbrush	*Castilleja exilis*	R1
Awned half chaff sedge	*Lipocarpha (= Hemicarpha) aristulata*	R1
Basalt milk-vetch	*Astragalus conjunctus var. rikardii*	R1
Bristly combseed	*Pectocarya setosa*	W
Brittle prickly-pear	*Opuntia fragilis*	R1
Canadian St. John's wort	*Hypericum majus*	S
Chaffweed	*Centunculus minimus*	R1
Columbia River mugwort	*Artemesia lindleyana*	W
Crouching milkvetch	*Astragalus succumbens*	W
Desert dodder	*Cuscuta denticulata*	S
Desert evening-primrose	*Oenothera cespitosa*	S
False pimpernel	*Lindernia dubia anagallidea*	R2
Fuzzytongue penstemon	*Penstemon eriantherus whitedii*	R1
Geyer's milkvetch	*Astragalus geyeri*	S
Grand redstem	*Ammannia robusta*	R1
Gray cryptantha	*Cryptantha leucophaea*	S
Great Basin gilia	*Gilia leptomeria*	R1
Hedge hog cactus	*Pediocactus simpsonii var. robustio nigrispinus*	R1
Kittitas larkspur	*Delphinium multiplex*	W
Miner's candle	*Cryptantha scoparia*	R1
Palouse thistle	*Cirsium brevifolium*	W
Piper's daisy	*Erigeron piperianus*	S
Robinson's onion	*Allium robinsonii*	W
Rosy balsamroot	*Balsamorhiza rosea*	W
Rosy pussypaws	*Calyptridium roseum*	S
Scilla onion	*Allium scilloides*	W
Shining flatsedge	*Cyperus bipartitus (rivularis)*	S
Small-flowered evening-primrose	*Camissonia (= Oenothera) minor*	R1
Small-flowered nama	*Nama densum var. parviflorum*	R1
Smooth cliffbrake	*Pellaea glabella simplex*	W
Snake River cryptantha	*Cryptantha spiculifera (= C. interrupta)*	S
Southern mudwort	*Limosella acaulis*	W
Stalked-pod milkvetch	*Astragalus sclerocarpus*	W
Suksdorf's monkey flower	*Mimulus suksdorfii*	S
Toothcup	*Rotala ramosior*	R1
Winged combseed	*Pectocarya linearis*	R1

The following species have been reported as occurring on the Hanford Site, but the known collections are questionable in terms of location or identification, and have not been recently collected on the Hanford Site.

Coyote tobacco	*Nicotiana attenuata*	S
Dense sedge	*Carex densa*	S
Few-flowered collinsia	*Collinsia sparsiflora var. bruciae*	S
Medic milkvetch	*Astragalus speirocarpus*	W
Palouse milkvetch	*Astragalus arrectus*	S
Thompson's sandwort	*Arenaria franklinii thompsonii*	R2

[a] S = Sensitive (i.e., taxa vulnerable or declining) and could become endangered or threatened without active management or removal of threats.
R1 = Taxa for which there are insufficient data to support listing as threatened, endangered, or sensitive (formerly monitor group 1).
R2 = Taxa with unresolved taxanomic questions (formerly monitor group 2).
W = Taxa that are more abundant and/or less threatened than previously assumed (formerly monitor group 3).

4.5 Cultural, Archaeological, and Historical Resources

M. K. Wright and D. W. Harvey

The Hanford Reach is one of the richest cultural resource areas in the western Columbia Plateau. It contains numerous well-preserved archaeological sites representing prehistoric, contact, and historic periods. Period resources and traditional cultural places include sites, buildings, and structures and landscapes from the pre-Hanford Site, Manhattan Project, and Cold War eras. Sitewide management of Hanford's cultural resources follows the *Hanford Cultural Resources Management Plan* (Chatters 1989).

The Hanford Cultural Resources Laboratory (HCRL) holds records for approximately 930 cultural resource sites and isolated finds as well as 495 buildings and structures that have been recorded on Washington State Historic Property Inventory forms. Of the 930 recorded cultural resource sites, 117 have been evaluated for listing in the National Register of Historic Places (National Register); approximately 813 cultural resource sites and isolated finds have not been evaluated.

Evaluated cultural resource sites include 49 of which are listed in the National Register (1 reactor building, 4 single archaeological sites, and 44 archaeological sites in 6 archaeological districts) (Table 4.5-1).

Table 4.5-1. Historic Buildings, Archaeological Sites and Districts Listed in the National Register of Historic Places.

Property Name	Date Listed by Keeper
Districts:	
Hanford North Archaeological District	August 28, 1976
Locke Island Archaeological District	August 28, 1976
Ryegrass Archaeological District	January 31, 1976
Savage Island Archaeological District	August 28, 1976
Snively Canyon Archaeological District	August 28, 1976
Wooded Island Archaeological District	July 19, 1976
Sites:	
Hanford Island Archaeological Site	August 28, 1976
Paris Archaeological Site	September 20, 1978
Rattlesnake Springs Sites (2)	May 4, 1976
Building:	
105-B Reactor	April 3, 1992

Ten individual archaeological sites and 58 cultural resource sites and 527 buildings/structures in three historic districts have been determined to be eligible for listing in the National Register (Table 4.5-2). In addition to the National Register sites and districts just described, 47 of Hanford's cultural resource sites (46 in three districts and one site) are listed in Washington State's Washington Heritage Register (Table 4.5-3). More information on sites eligible for listing in the National Register and the Washington Heritage Register may be found by contacting the DOE Richland Operations Cultural Resources Program manager.

The DOE identified a National Register-eligible Hanford Site Manhattan Project and Cold War Era Historic District which serves to organize and delineate the evaluation and mitigation of Hanford's built environment (Table 4.5-2). Standards for evaluating and mitigating the built environment were established in accordance with National Register criteria, as well as historic contexts and themes associated with nuclear technology for national defense and non-military purposes, energy production, and human health and environmental protection. A programmatic agreement (DOE 1996b) that addresses management of the built environment (buildings and structures) constructed during the Manhattan Project and Cold War periods was completed by the Department of Energy. The Advisory Council on Historic Preservation and Washington State Historic Preservation Officer accepted this programmatic agreement in 1996 (DOE 1996b).

Establishment of the Hanford Site Manhattan Project and Cold War Era Historic District resulted in the selection of 190 buildings, structures, and complexes as contributing properties within the historic district recommended for mitigation. Certain property types, such as mobile trailers, modular buildings, storage tanks, towers, wells and structures with minimal or no visible surface manifestations, were exempt from the identification and evaluation requirement.

Approximately 900 buildings and structures were identified as either contributing properties with no individual documentation requirement (not selected for mitigation) or as non-contributing exempt properties, and will be documented in a database DOE maintains (Marceau 1998).

Cultural resource reviews are conducted of Hanford Site projects that entail disturbing ground and/or altering or demolishing existing structures. These reviews ensure that prehistoric and historic sites, traditional use areas, and existing structures eligible for the National Register are considered before impacts by proposed projects. (For Manhattan Project/Cold War era properties, refer to Appendix A, Table A.5, Hanford Site Manhattan Project and Cold War Historic District Treatment Plan for the list of buildings/structures eligible for the National Register as contributing properties within the Historic District recommended for mitigation (Marceau 1998)).

Table 4.5-2. Archaeological Sites and Historic Districts Determined Eligible for Listing in the National Register of Historic Places.

Property Name	Date Determined Eligible for Listing in the National Register of Historic Places
Districts:	
Gable Mountain Cultural District	February 12, 1990
Hanford Site Manhattan Project and Cold War Era Historic District	August 21, 1996
McGee Ranch/Cold Creek Valley District	December 23, 1994
Archaeological Sites:	
HT-95-050 (Fry and Conforth Farm)	May 1, 1998
3-121 (White Bluffs Road)	January 6, 1994
45BN423	May 17, 1994
45BN434	May 31, 1995
45BN446	May 17, 1994
HT94-028	December 6, 1994
HT94-029	December 6, 1994
HT94-030	December 6, 1994
HT94-031	December 6, 1994
HT94-032	December 6, 1994

Table 4.5-3. Archaeological Sites and Districts Listed in the Washington Heritage Register.

Property Name	Date Listed by State Historic Preservation Officer
Districts:	
Coyote Rapids Archaeological District	May 23, 1975
Hanford South Archaeological District	August 26, 1983
Wahluke Archaeological District	May 23, 1975
Site:	
Gable Mountain Archaeological Site	November 15, 1974

4.5.1 Native American Cultural Resources

In prehistoric and early historic times, the Hanford Reach of the Columbia River was populated by Native Americans of various tribal affiliations. The Wanapum and the Chamnapum lived along the Columbia River from south of Richland upstream to Vantage (Relander 1956; Spier 1936). Some of their descendants still live nearby at Priest Rapids (Wanapum); others live on the Yakama and Umatilla Reservations. Palus people, who lived on the lower Snake River, joined the Wanapum and Chamnapum to fish the Hanford Reach of the Columbia River, and some inhabited the river's east bank (Relander 1956; Trafzer and Scheuerman 1986). Many descendants of the Palus now live on the Colville Reservation. The Nez Perce, Walla Walla, and Umatilla people also made periodic visits to fish in the area. Their descendants retain traditional secular and religious ties to the region and many have knowledge of the ceremonies and lifeways of their ancestral culture.

The Hanford Reach and the greater Hanford Site, a geographic center for American Indian religious belief, is central to the practice of Indian religion of the region, and many believe the creator made the first people here (DOI 1994). Indian religious leaders such as *Smoholla* began their teachings here. Native plant and animal foods, some of which can be found on the Hanford Site, are used in the ceremonies performed by tribal members. Certain landforms, especially Rattlesnake Mountain, Gable Mountain, Gable Butte, and various sites along and including the Columbia River, remain sacred to them.

A historic context for the Ethnographic/Contact Period of the Hanford Site has been prepared as part of a National Register Multiple Property Documentation form to assist with the evaluation of the National Register eligibility of Native American ethnographic resources (DOE 1997a).

4.5.2 Archaeological Resources

People have inhabited the Middle Columbia River region since the end of the glacial period. More than 8000 years of prehistoric human activity in this largely arid environment have left extensive archaeological deposits along the river shores (Chatters 1989; Greengo 1982; Leonhardy and Rice 1970). Well-watered areas inland from the river show evidence of concentrated human activity (Chatters 1982, 1989; Daugherty 1952; Greene 1975; Leonhardy and Rice 1970; Rice 1980a), and recent surveys have indicated extensive, although dispersed, use of arid lowlands for hunting. Throughout most of the region, hydroelectric development, agricultural activities, and domestic and industrial construction have destroyed or covered the majority of these deposits. Amateur artifact collectors have had an immeasurable impact on what remains. By virtue of their inclusion in the Hanford Site from which the public is restricted, archaeological deposits found in the Hanford Reach of the Columbia River and on adjacent plateaus and mountains have been spared some of the disturbances that have befallen other sites. The Hanford Site is thus a *de facto* reserve of archaeological information of the kind and quality that have been lost elsewhere in the region.

About 365 archaeological sites and isolated finds associated with the prehistoric period have been recorded on Hanford; of these, almost 50 contain prehistoric and historic components. Prehistoric period sites common to the Hanford Site include remains of numerous pit house villages, various types of open campsites, spirit quest monuments (rock cairns), hunting camps, game drive complexes, and quarries in nearby mountains and rocky bluffs (Rice 1968a,b; Rice 1980a); hunting/kill sites in lowland stabilized dunes; and small temporary camps near perennial sources of water located away from the river (Rice 1968b).

Many recorded sites were found during four archaeological reconnaissance projects conducted between 1926 and 1968 (Drucker 1948; Krieger 1928; Rice 1968a,b). Much of this early archaeological survey and reconnaissance activity concentrated on islands and on a strip of land approximately 400 m (1312 ft) wide on either side of the river (Rice 1980a). Reconnaissance of several project-specific areas and other selected locations conducted through the mid-1980s added to the recorded site inventories. Systematic archaeological surveys conducted from the middle 1980s through 1998 are responsible for much of the remainder (Chatters 1989; Chatters and Cadoret 1990; Chatters and Gard 1992; Chatters et al. 1990, 1991, 1992; Last et al. 1993; Andrefsky et al. 1996).

During his reconnaissance of the Hanford Site in 1968, Rice inspected portions of Gable Mountain, Gable Butte, Snively Canyon, Rattlesnake Mountain, and Rattlesnake Springs (Rice 1968b). Rice also inspected additional portions of Gable Mountain and part of Gable Butte in the late 1980s (Rice 1987). Some reconnaissance of the BWIP Reference Repository Location (Rice 1984), a proposed land exchange in T. 22 N., R. 27 E., Section 33 (Rice 1981), and three narrow transportation and utility corridors (ERTEC 1982; Morgan 1981; Smith et al. 1977) were also conducted. Other large-scale survey areas have been completed in recent years, including the 100 Areas from 1991 through 1993 (Chatters et al. 1992; Wright 1993), McGee Ranch (Gard and Poet 1992), the Laser Interferometer Gravitational Wave Observatory Project, the North Slope Waste Sites Project, the Environmental Restoration Disposal Facility, the 1995 WSU Archaeological Block Survey of the Hanford 600 Area (Andrefsky et al. 1996) and the Section 110 Vernita Survey (Bard and McClinttock 1998[d]; Hale and McClintock 1998[e]). To date, approximately 11% of the Hanford Site has been surveyed.

A historic context for the Prehistoric Period of the Hanford Site has been prepared as part of a National Register Multiple Property Documentation form to assist with the evaluation of the National Register eligibility of prehistoric archaeological resources (DOE 1997a).

4.5.3 Traditional Cultural Places and Traditional Use Areas

In 1990, the National Park Service developed the concept of traditional cultural property or traditional cultural place (TCP) as a means to identify and protect cultural landscapes, places, and objects that have special cultural significance to American Indians and other ethnic groups (Bard 1997). A significant TCP is associated with "cultural practices or beliefs of a living community that (a) are rooted in that community's history, and (b) are important in maintaining the continuing cultural identity of the community" (Parker and King 1990).

(d) Unpublished report: Hale, L. L., and R. McClintock. 1998. *Cultural Resources Report Narrative #98-0600-029, Vernita Block Survey*. Report on file at the Hanford Cultural Resources Laboratory, Pacific Northwest National Laboratory, Richland, Washington.

(e) Unpublished report: Bard, J., and R. McClintock. August 16, 1998. Memorandum to Darby Stapp, PNNL. Block Survey Report: ca 8.26 sq. km (ca 2040 acres/3.19 sq miles) in the Hanford 600 Area near Vernita Bridge – Project 98-600-029. Copy on file at the Hanford Cultural Resources Laboratory, Pacific Northwest National Laboratory, Richland, Washington.

Native American traditional cultural places within the Hanford Site include but are not limited to a wide variety of places and landscapes: archaeological sites, cemeteries, trails and pathways, campsites and villages, fisheries, hunting grounds, plant gathering areas, holy lands, landmarks, and important places in Indian history and culture, places of persistence and resistance, and landscapes of the heart (Bard 1997). Traditional cultural places of importance to Native Americans are determined through methods that are mutually satisfying to DOE and the Native American community.

Euro-American traditional cultural places found on the Hanford Site include structures and places that are important to descendents of pre-1943 settlers in the former White Bluffs, Hanford, Allard, and Cold Springs areas. These places are deeply rooted in the memories of local residents and include but are not limited to a former cemetery, numerous former homesites and townsites, orchards, fields, and places of former community activities, e.g., Hanford Grange Hall, churches, and schools.

A historic context for the Native American Ethnographic/Contact Period and the Euro-American Resettlement Period (pre-Hanford era) has been prepared as part of a National Register Multiple Property Documentation form to assist with the evaluation of the National Register eligibility of traditional cultural places and traditional use areas (DOE 1997a).

4.5.4 Historic Archaeological Resources

Some of the first Euro-Americans who traveled nearest the Hanford Site were Lewis and Clark, who traveled along the Columbia and Snake rivers during their 1803 to 1806 exploration of the Louisiana Territory. Other visitors included fur trappers, military units, and miners who passed through the Hanford Site on their way to lands up and down the Columbia River and across the Columbia Basin. It was not until the 1860s that merchants set up stores, a freight depot, and the White Bluffs Ferry on the Hanford Reach. Chinese miners began to work the gravel bars for gold. Cattle ranches were established in the 1880s, and farmers soon followed. Agricultural development, irrigation districts, and roads soon dotted the landscape, particularly in the eastern potion of the central Hanford Site. Several small thriving towns, including Hanford, White Bluffs, Richland, and Ringold, grew up along the riverbanks in the early 20th century. The communities' accessibility to outside markets grew with the arrival of the Chicago, Milwaukee, St. Paul Railroad branch line (Priest Rapids-Hanford Line) from Beverly, Washington. Other ferries were established at Hanford, Wahluke, and Richmond. The towns and nearly all other structures were razed after the U.S. Government acquired the land for the Hanford Engineer Works in 1943 (Chatters 1989; ERTEC 1981; Rice 1980a).

About 517 historic archaeological sites associated with the pre-Hanford Site era and the Cold War era, including an assortment of farmsteads, corrals, dumps, and military sites, have been recorded by the HCRL since 1987. Forty-eight of these sites contain both historic and prehistoric components. Resources from the pre-Hanford Site period are scattered over the entire Hanford Site and include numerous areas of gold mine tailings along the riverbanks of the Columbia and remains of homesteads, agricultural fields, ranches, and irrigation features. Properties from this period include former semi-subterranean structures near McGee Ranch; the Hanford Irrigation Ditch; the former Hanford townsite; Wahluke Ferry; the White Bluffs townsite and bank; the Richmond Ferry; Arrowsmith townsite; the White Bluffs road; and the Chicago, Milwaukee, St. Paul Railroad (Priest Rapids-Hanford Line) and associated whistle stops.

Historic archaeological military sites associated with the Cold War era are scattered throughout the Site's 600 Area. These archaeological resources are mainly located within the former Camp Hanford forward positions, the 16 antiaircraft artillery sites that encircled the 100 and 200 Areas, and the three Nike missile installations on Wahluke Slope. (A fourth Nike position, in relatively intact condition, is located at the base of Rattlesnake Mountain in the Fitzner/Eberhardt ALE Reserve.) The Nike position in ALE has been determined eligible for inclusion in the National Register as a contributing property within the Hanford Site Manhattan Project and Cold War Era Historic District. Five of the 16 antiaircraft artillery sites have also been determined eligible for the National Register. The antiaircraft artillery and Nike sites were strategic components in Camp Hanford's military defense of the Site's plutonium production facilities during the 1950s. Potential archeological resources at these sites include former gun emplacements, launch and radar sites, concrete foundations and pads, pathways/sidewalks, and associated dump sites, small arms firing ranges, and ammunition caches.

A historic context for the Euro-American Resettlement Period (pre-Hanford Site era) has been prepared as part of a National Register Multiple Property Documentation form to assist with the evaluation of the National Register eligibility of historic archaeological resources (DOE 1997a).

4.5.5 Historic Built Environment

A number of buildings associated with the pre-Hanford Site era have been documented. They include the Hanford Irrigation and Power Company's pumping plant at Coyote Rapids, the high school and the electrical substation at the Hanford townsite, the White Bluffs bank, the Bruggeman's fruit warehouse, and the cabin at the East White Bluffs ferry landing.

Historic built resources documented from the Manhattan Project and Cold War eras include buildings and structures found in the 100, 200, 300, 400, 600, 700, and former 1100 Areas. The most important of these are the plutonium production and test reactors, chemical separation and plutonium finishing buildings, and fuel fabrication/manufacturing facilities. The first reactors, 100-B, 100-D, and 100-F, were constructed during the Manhattan Project. Plutonium for the first atomic explosion and the bomb that destroyed Nagasaki to end World War II was produced at the Hanford Site. Additional reactors and processing facilities were constructed after World War II during the Cold War period. All reactor containment buildings still stand, although many ancillary structures have been removed.

DOE-RL will give consideration to the retention of Register-eligible buildings and structures that may qualify for adaptive reuse as interpretive centers, museums, industrial, or manufacturing facilities.

Historic contexts were completed for the Manhattan Project and Cold War eras as part of a National Register Multiple Property Documentation Form prepared for the Hanford Site to assist with the evaluation of National Register eligibility of buildings and structures sitewide (DOE 1997a). 527 Manhattan Project and Cold War buildings/structures and complexes have been determined eligible for the National Register as contributing properties within the Historic District. Of that number, 190 were recommended for mitigation. DOE/RL is in the process of undertaking an assessment of the contents of the contributing buildings and structures to locate and identify any Manhattan and Cold War era artifacts which may have interpretive or educational value for museum exhibit purposes (see Appendix A, Table A.5, *Hanford Site Manhattan Project and Cold War Era Historic Treatment Plan*) (Marceau 1998).

4.5.6 Site Areas

Cultural resources are found in each of several areas on the Hanford Site including the 100, 200, 300, 400, 600, 700, former 1100, and North Richland Areas. A brief synopsis of known resources found in these areas is presented in the following sections.

4.5.6.1 100 Areas

Intensive field surveys were completed in the 100 Areas from 1991 to 1995 (Andrefsky et al. 1996; Chatters et al. 1992; Wright 1993). Much of the surface area within the 100 Area operable units has been disturbed by the industrial activities that have taken place during the past 50 years. However, numerous prehistoric and historic archaeological sites have been encountered, and many are potentially eligible for the National Register. As remediation continues in the 100 Areas of the Hanford Site the potential exists for inadvertent discoveries of either prehistoric or historic cultural resources. To understand impacts to cultural resources and to reduce the need to perform extensive reviews on highly disturbed areas, disturbance maps and reports have been completed for 100 B/C, 100 D/DR, and 100 F Areas. Contact the DOE, Richland Operations Office Cultural Resource Program manager for further information.

The 100 Areas were the locations of nine plutonium production reactors and their ancillary and support facilities. The production reactors functioned to irradiate uranium fuel elements, the essential second step in the plutonium production process. A complete inventory of 100 Area buildings and structures was completed during FY 1995, and a National Register evaluation for each was finalized during 1996. To date, 146 buildings/structures have been inventoried in the 100 Areas. Of that number, 55 have been determined eligible for the National Register as contributing properties within the Historic District recommended for mitigation (Marceau 1998).

100-B/C Area. Three archaeological sites can be identified from area literature (Rice 1968a; Rice 1980a,b); all lie partially within the 100-B/C Area. Thirty-five sites and isolated finds were recorded in the B/C Area during archaeological surveys competed in 1995. The remains of Haven Station, a small stop on the former Chicago, Milwaukee, and St. Paul Railroad, is located to the west of the reactor compound. One archaeological site and the remains of the small community of Haven lie on the opposite bank of the Columbia River. Many sites related to hunting and religious activities are located at the west-end of Gable Butte, due south of the 100 B/C Area. These sites are part of the proposed Gable Mountain/Gable Butte Cultural District nomination.

Two archaeological sites located in the general area near 100 B/C have been investigated. Test excavations conducted in 1991 at one hunting site revealed large quantities of deer and mountain sheep bone and projectile points dating from 500 to 1500 years old. A second archaeological site is considered to be eligible for listing in the National Register, in part, because it may contain new information about the Frenchman Springs and Cayuse Phases of prehistory.

Located east of the B/C Area is the former Hanford Irrigation and Power Company pumping plant built near Coyote Rapids in 1908. The Hanford Irrigation Ditch, which carried water from the pumping plant to the former Hanford and White Bluffs townsites, is located adjacent and south of the plant.

The 105-B Reactor was the world's first full-scale plutonium production reactor and is designated as a National Historic Mechanical Engineering Landmark. It is also listed in the National Register, was recently named as a National Civil Engineering Landmark, and was given the Nuclear Historic Landmark Award. Historic American Engineering Record documentation of B Reactor will be completed in FY99. DOE is planning to convert the former reactor into a publicly accessible museum. A total of 14 buildings and structures within the reactor compound have been recorded on historic property inventory forms. Of that number, 10 properties have been determined eligible for the National Register as contributing properties within the Historic District recommended for mitigation. These include 105-B Reactor, 181-B River Pumphouse, 104-B-1 Tritium Vault, 104-B-2 Tritium Laboratory, 105-B-Rod Tip Cave, 116-B Reactor Exhaust Stack, 117-B Exhaust Air Filter Building, 118-B-1 Solid Waste Burial Trench, and 182-B Reservoir and Pump House (Marceau 1998).

100-D/DR Area. One hundred and six known archaeological sites lie within 2 km (1.2 mi) of the 100-D/DR Reactor compound, three on the northern bank and the remainder on the southern bank. The Wahluke Archaeological District is located north of the reactor compound area. Twenty-seven sites located south of the reactor compound may potentially be eligible for the National Register because of their association with a traditional cultural property. Most remaining sites represent early Euro-American settlement activities. The former community of Wahluke, which was at the landing of a ferry of the same name, is situated on the river's north bank.

All the buildings and structures in the 100-D/DR Area were built during the Manhattan Project and Cold War eras. Twenty buildings/structures have been inventoried, including the 105 D and DR Reactor buildings. Both reactors were determined eligible for the National Register as contributing properties within the Historic District, but were not recommended for mitigation. An assessment of the contents of 105-DR was conducted to locate and identify any Manhattan Project/Cold War era artifacts that may have interpretive or educational value in potential museum exhibits. A radiological worker procedure poster and an instrument ladder in the control room were identified and tagged. The 185/189-D buildings and adjoining facilities, all part of the 190-D complex, have been determined eligible for the National Register and were documented to Historic American Engineering Record standards (Marceau 1998).

100-F Area. The 100-F Area is situated on a segment of the Columbia River that contains many cultural sites. According to Relander (1956), camps and villages of the Wanapum extended from the Old Hanford townsite upstream to the former White Bluffs townsite. Eighty-one archaeological sites have been recorded near the 100-F Area. Sites of particular importance include a cemetery, a National Register site, and a site that appears to contain artifact deposits dating to at least 6000 years ago.

The principal historic site in the vicinity is the East White Bluffs ferry landing and former townsite. This location was the upriver terminus of shipping during the early- and mid-19th century. It was at this point that supplies for trappers, traders, and miners were off-loaded, and commodities from the interior were transferred from pack trains and wagons to riverboats. The first store and ferry of the Mid-Columbia region were located at the ferry landing (ERTEC 1981). A log cabin, thought by some to have been a blacksmith shop in the mid-19th century, still stands there. Test excavations conducted at the cabin by the University of Idaho revealed historic and prehistoric elements. The structure has been recorded according to standards of the Historic American Buildings Survey (Rice 1976). The only remaining structure associated with the White Bluffs townsite (near the railroad) is the White Bluffs Bank.

Three Manhattan Project/Cold War era buildings/structures have been inventoried in this area, including the 105-F Reactor building. The 108-F Biology Laboratory, originally a chemical pump house, has been determined eligible for the National Register as a contributing property within the Historic District recommended for mitigation (Marceau 1998). An assessment of the contents of 105-F was conducted to identify any artifacts that may have value as potential museum exhibits. A fuel scale, two signs and an elevator control panel were identified and tagged.

100-H Area. As of 1995, there have been 40 archaeological sites recorded within 2 km (1.2 mi) of the area. Included in this group are two historic Wanapum cemeteries, six camps (one with an associated cemetery), and three housepit villages. The largest village contains approximately 100 housepits and numerous storage caches. It appears to have been occupied from 2500 years ago to historic times (Rice 1968a). The cemeteries, camps, and villages are included in the Locke Island Archaeological District.

Historic sites in the vicinity recorded during 1992, 1993, and 1995 include 20th century farmsteads, household dumps, and military encampments. None have yet been evaluated for eligibility to the National Register.

Four Cold War era buildings/structures were inventoried in the 100-H Area. Of that number, only the 105-H Reactor was determined eligible for the National Register as a contributing property within the Historic District. The reactor, however, was not recommended for mitigation (Marceau 1998).

100-K Area. Events took place at this locality in the mid-19th century that were of great significance to Native American people in the interior Northwest (Relander 1956). In this general area, the origins of the Seven Drums or Dreamer religion began, then spread to many neighboring tribes, and is now practiced in some form by members of the Colville, Nez Perce, Umatilla, Wanapum, Warm Springs, and Yakama Tribes.

An archaeological survey of the 100-K Area in 1991 revealed five previously unrecorded archaeological sites. Archaeological surveys conducted during 1995 of areas not surveyed in 1991 resulted in documentation of 31 additional prehistoric and historic sites. Two sites are believed to date to the Cascade Phase (9000 to 4000 years ago). More importantly, a group of pithouses with associated long house and sweat lodge were identified that may have been the site of Smohalla's first *Washat* dance. Coyote Rapids, which is a short distance upstream, was called *Moon*, or Water Swirl Place. Two National Register Districts are located near the 100-K Area, the Coyote Rapids Archaeological District and the Ryegrass Archaeological District. Two individual archaeological sites have been determined to be eligible for listing in the National Register.

Historic farmstead sites are widely scattered throughout the nearby area. Two important linear features, the Hanford Irrigation Ditch and the former Chicago, Milwaukee, and St. Paul Railroad, are also present in the 100-K Area. Remnants of the Allard community and the Allard Pumphouse at Coyote Rapids are located west of the K Reactor compound.

Thirty-eight buildings/structures have been inventoried in the 100-K Reactor Area, including the 105-KE and KW Reactor buildings. Of that number, 13 have been determined eligible for the National Register as contributing properties within the Historic District recommended for mitigation. These include the 105-KW Reactor, 190-KW Main Pumphouse, 107-KW Retention Basin, 183-KW Filter Plant, and 181-KW River Pump House (Marceau

1998).

100-N Area. Thirty-one archaeological sites have been recorded within 2 km (1.2 mi) of the 100-N Area perimeter. Four of these sites are either listed, or considered eligible for listing, on the National Register. Three sites (two housepit villages and one cemetery) comprise the Ryegrass Archaeological District. Site 45BN179, once considered for a National Register nomination as the Hanford Generating Plant Site, has been found to be part of 45BN149, which is already listed in the National Register (Chatters et al. 1990). Extant knowledge about the archaeology of the 100-N Area is based largely on reconnaissance-level archaeological surveys conducted during the late 1960s to late 1970s (Rice 1968b; see also Rice 1980a,b), which do not purport to produce complete inventories of the areas covered. Intensive surveys of areas surrounding 100-N were conducted during 1991 and 1995.

Three areas near the 100-N Area are known to have been of some importance to the Wanapum. The knobs and kettles surrounding the area are called *Mooli Mooli*, which means Little Stacked Hills. Gable Mountain (called *Nookshai* or Otter) and Gable Butte, which lie to the south of the river, are sacred mountains where youths would go on overnight vigils seeking guardian spirits (Relander 1956). Sites of religious importance may also exist near the 100-N compound.

The most common evidence of pre-Hanford Site era activities now found near the 100-N Area consists of historic archaeological sites where farmhouses once stood and agricultural fields remain. The historic Hanford Ditch is adjacent to and south of the 100-N compound.

Sixty-six Cold War era buildings and structures have been inventoried in the 100-N Area (Marceau 1998). The 100-N Reactor, completed in 1963, was the last of the plutonium production, graphite-moderated reactors. The design of N Reactor differed from the previous eight reactors in several ways to afford greater safety and to enable co-generation of electricity. Thirty 100-N Area buildings/structures have been determined eligible for the National Register as contributing properties within the Historic District recommended for mitigation. These include the 105-N Reactor, 109-N Heat Exchanger Building, 181-N River Water Pump House, 183-N Water Filter Plant, 184-N Plant Service Power House, 185-N Export Powerhouse, and the 1112-N Guard Station (DOE 1997c).

4.5.6.2 200 Areas

The HCRL conducted a comprehensive archaeological resources review for the fenced portions of the 200 Areas in 1987 and 1988. This review incorporated both an examination of the existing literature as well as "an intensive pedestrian survey of all undisturbed portions of the 200 East Area and a stratified random survey [of the undisturbed portions] of the 200 West Area" (Chatters and Cadoret 1990).

Two historic-archaeological sites (i.e., can and glass scatters), four isolated historic artifacts, one isolated cryptocrystalline flake, and an extensive linear feature (i.e., the White Bluffs Road) were the only materials greater than 50 years old discovered during the field survey. Only the White Bluffs Road, in its entirety, was determined eligible for listing in the National Register of Historic Places. This road, which passes diagonally southwest to northeast through the 200 West Area, originated as a Native American trail. It played a role in Euro-American immigration, development, agriculture, and Hanford Site operations. Segments of the White Bluffs Road that are located in the 200 West Area have been determined to be non-contributing.

The 200 Areas were the locations of the chemical separations (processing) plants and their ancillary and support facilities. The plants functioned to dissolve the irradiated fuel elements to separate out the plutonium, the essential third step in plutonium production. Historic property inventory forms have been completed for 72 buildings/structures in the 200 Area. Of that number, 58 have been determined eligible for the National Register as contributing properties within the Historic District recommended for mitigation. These include the 202-A Purex Plant, 212-N Lag Storage Facility, 221-T Plant, 222-S Redox Plant, 225-B Encapsulation Building, 231-Z Plutonium Metallurgical Laboratory, 234-5Z Plutonium Finishing Plant, 236-Z Plutonium Reclamation Facility, 242-Z Water Treatment Facility, 282-E Pumphouse and Reservoir Building, 283-E Water Filtration Plant, and the 284-W Power House and Steam Plant. The 232-Z Waste Incinerator Facility and the 233-S Plutonium Concentration Building, determined eligible for the National Register, have been documented to Historic American Engineering Record standards (Marceau 1998).

An assessment of the contents of six facilities in the Plutonium Finishing Plant complex was conducted during fiscal year 1998. These buildings/structures included the 234-5Z Plutonium Finishing Plant, 291-Z Exhaust Stack, 2704-Z Safeguards and Security Building, and the 2736-Z, ZA and ZB Plutonium Storage Facilities. Because of security/radiological exposure concerns and/or inaccessibility, a number of identified artifacts were not tagged. These included a classified documents vault, plutonium storage vaults, and a dry air glove box. In 234-5Z, the entire Remote Mechanical C line (gloveboxes) and control room, and the Remote Mechanical A line (gloveboxes) and control room, were identified and tagged. A walkthrough of the Analytical Laboratories in 234-5Z resulted in identification and tagging of ten additional Cold War era artifacts. An assessment was also conducted of the 2704-C Building in 200 East but no artifacts were identified for tagging.

4.5.6.3 300 Area

Much of the 300 Area has been highly disturbed by industrial activities. Five recorded archaeological sites, including campsites, housepits, and a historic trash scatter are located at least partially within the 300 Area; many more may be located in subsurface deposits. Twenty-seven archaeological sites and 13 isolated artifacts have been recorded within 2 km (1.2 mi) of the 300 Area fence. The historic archeological sites contain debris scatters and roadbeds associated with farmsteads. One archaeological site has been tested and is recognized as eligible for listing in the National Register. Several archaeological sites in this area are in the Hanford South Archaeological District, which is listed in the Washington Heritage Register. Disturbance maps and reports have been prepared for the 300 Area. Contact the DOE, Richland Operations Office Cultural Resource Program manager for further information.

One documented locality with great importance to the historic Wanapum is located near the 300 Area. Certain areas near the 300 Area have been found to be of great importance to the Native Americans and are fenced.

The 300 Area, the location of the uranium fuel fabrication plants that manufactured fuel rods to be irradiated in the Site reactors, provided the first essential step in the plutonium production process. The 300 Area was also the location of most of the Site's research and development laboratories. One hundred fifty-eight buildings/structures in the 300 Area have been inventoried on historic property inventory forms. Of that number, 47 buildings/structures have been determined eligible for the National Register as contributing properties within the Historic District recommended for mitigation. This total includes the 305 Test Pile, 313 Fuels Fabrication Facility, 314 Metal Press/Extrusion Building, 318 High Temperature Lattice Test

Reactor, 321 Separation Building, 325 Radiochemistry Laboratory, 333 Fuel Cladding Facility, 3706 Radiochemistry Laboratory, and the 3760 (former) Hanford Technical Library (Marceau 1998).

Assessments of the contents of former fuel manufacturing facilities in the 300 Area were conducted, including the 303-A Magazine Product Storage Building, 306-W Materials Development Laboratory, 313 Fuels Fabrication Facility/Metal Fabrication Building, 314 Press Building, and the 333 Fuel Cladding Facility. The 11 Manhattan Project/Cold War era artifacts that were identified and tagged are mainly industrial in nature associated with the fuel manufacturing process. A second walkthrough of Building 333 resulted in an additional 12 artifacts being identified that included a selection of safety signs/posters, a control panel, a safety shower, protective worker clothes, and a sample uranium fuel element.

Other 300 Area buildings assessed included the 304 Uranium Scrap Concentration Storage Facility, 334 Chemical Handling Facility, 334-A Acid Pump House, 3701-D (former) Hanford Patrol Building, 3716 Fuels Manufacturing Storage/Automotive Repair Shop, 3727 Classified Storage Facility, 3746 Radiological Physics Building, and the 3762 Technical Safety Building. The only artifacts identified and tagged in these facilities were Hanford Site Emergency Response Signs located in 3701-D.

4.5.6.4 400 Area

Most of the 400 Area has been so disrupted by construction activities that archaeologists surveying the site in 1978 were able to find only 30 acres that were undisturbed (Rice et al. 1978). They found no cultural resources in those 30 acres. No archaeological sites are known to be located within 2 km (1.2 mi) of the 400 Area.

The 400 Area consists of the Fast Flux Test Facility (FFTF) complex. The 405 Reactor Containment Building includes a 400 megawatt, sodium-cooled test reactor designed primarily to test fuels and materials for advanced nuclear power plants. All the buildings and structures in the 400 Area were constructed during the Cold War era. Twenty-one building/structures have been recorded on historic property inventory forms. Of that number, six have been determined eligible for the National Register as contributing properties within the Historic District recommended for mitigation. These include the 405 Reactor Containment Building, 436 Training Facility, 4621-W Auxiliary Equipment Facility, 4703 FFTF Control Building, 4710 Operation Support Building, and the 4790 Patrol Headquarters (Marceau 1998).

4.5.6.5 600 Area

The 600 Area contains a diverse wealth of cultural resources and traditional cultural properties representing a full range of human activity across the Hanford Site. Project-driven surveys have been conducted throughout the area, but much of the 600 Area remains unsurveyed. Several National Register Districts are located within the 600 Area, including the Hanford Archaeological Site, the Hanford North Archaeological District, the Paris Archaeological Site, Rattlesnake Springs Sites, Savage Island Archaeological District, Snively Basin Archaeological District, and the Wooded Island Archaeological District. The McGee Ranch/Cold Creek Valley District has been determined to be eligible for listing on the National Register, and the Gable Mountain Cultural District is pending nomination to the National Register. Areas of traditional cultural importance include Rattlesnake Mountain and foothills, the Columbia River, and Gable Mountain and Butte.

The 600 Area contains facilities that served more than one specific Site area such as roads and railroads (and support structures). Former townsites, farmsteads, roads, and rail lines are widely scattered throughout the 600 Area. Pre-Hanford Site properties in the 600 Area include the former Hanford townsite, high school, and electric substation; the former White Bluffs townsite, bank, ferry landing, and East White Bluffs cabin; the Chicago, Milwaukee and St. Paul rail line and associated whistle stops; and the Hanford Irrigation Ditch.

Fifteen Cold War era buildings/structures, including the underground missile storage facility, have been inventoried at the former Nike launch and control center (6652) in the Fitzner/Eberhardt ALE Reserve. The 622 Meteorological Complex, located near 200 West, includes seven inventoried properties. Both complexes have been determined eligible for the National Register as contributing properties within the Historic District recommended for mitigation. An assessment of the contents of 622-F and the 6652 Nike site were conducted. No artifacts of interpretive or educational value were identified. Five other 600 Area properties, 604 Yakima Patrol Checking Station, 604-A Sentry House, 607 Batch Plant, 618-10 Solid Waste Burial Trench, and the Hanford Site Railroad, have been determined eligible for the National Register as contributing properties within the Historic District recommended for mitigation.

Five anti-aircraft artillery sites located in the 600 Area and associated with Camp Hanford's defense of the Hanford Site during the 1950s have been determined eligible for the National Register. The former Central Shops complex located in the 600 Area north of the 200 Areas was determined to be ineligible for the National Register (DOE 1998a).

4.5.6.6 700 Area

The 700 Area was the location of the administrative functions of the early Hanford Site period. Most of the 700 Area has been highly disturbed by industrial activities. Of the seven Manhattan Project and Cold War era buildings/structures identified in this area, the 703 Administrative Building, 712 Records/Printing/Mail Office Facility, and the 748 Radiosurgery/Emergency Decontamination Facility have been determined eligible for listing in the National Register as contributing properties within the Historic District recommended for mitigation (Marceau 1998).

4.5.6.7 1100 Area

Land ownership of the former 1100 Area was transferred from DOE to the Port of Benton on October 1, 1998. As a result of this land transfer, archaeologists and historians investigated lands and buildings/structures within the former 1100 Area to ensure that all historic cultural resources were identified and are evaluated for listing in the National Register (Hale 1998)[f]. Archival research and field surveys revealed the presence of eighteen historic archaeological sites and one isolated find. The archaeological sites fall into two categories: concentrations of historic debris and farmstead complexes. Most of these historic archaeological sites pre-date federal acquisition of the Hanford Site in 1943 and represent an important era in Euro-American settlement with regard to early irrigation and agricultural techniques. All the historic archaeological sites were evaluated in 1998. Sites found to be eligible for listing in the

---

[f] Unpublished survey report: Hale, L. 1998. *Cultural Resources Report Narrative #97-1100-003, Transfer of 1100 Area and Hanford Southern Rail Connection.* Cultural Resources Report Narrative, Hanford Cultural Resources Laboratory. Pacific Northwest National Laboratory, Richland, Washington.

National Register will be managed by the Port of Benton according to National Historic Preservation Act requirements.

In addition to historic archaeological sites, the former 1100 Area contains transportation maintenance buildings/structures from the Cold War period. Of the 19 Cold War era buildings/structures identified in this area, the 1170 Bus Terminal/Dispatcher Facility, 1171 Transportation Maintenance Shops, 1167 Warehouse, 1167-A Excess Salvage Office, X-1 Railroad Scale House, and the X-4 Railroad Maintenance Shed have been determined eligible for listing in the National Register as contributing properties within the Historic District recommended for mitigation (Marceau 1998).

Assessments of the 1170 Dispatcher Office, the 1171 Transportation Maintenance Shop, the X-1 Railroad Scale house, the X-4 Railroad Maintenance Shed, the 1167 Warehouse, and the 1167-A Excess Salvage Office were conducted for the purpose of identifying important Cold War artifacts. The assessment team identified and tagged 32 artifacts in 1171, four in 1170, and one in X-1. Subsequent changes in collection guidelines have resulted in more selective identification procedures, thus, reducing the number of 1100 Area Cold War era artifacts to 16 to be preserved.

4.5.6.8 North Richland Area

Archaeological surveys conducted adjacent to the North Richland Area have been confined to a narrow strip along the Columbia River (Cleveland et al. 1976; Drucker 1948; Rice 1968a; Thoms 1983). Twelve sites are within 2 km (1.2 mi) of the area. Many of these sites are included in the Hanford South Archaeological District, which was nominated for listing in the National Register in 1983.

During World War II, the North Richland Area was the locale for a camp that housed Hanford Site construction personnel. No historic archaeological sites have been recorded for this area, but homesteads and remnants of the former North Richland townsite, Manhattan Project/Cold War construction camp, and industrial facilities associated with the 1950s Camp Hanford are found there. Seventeen former Camp Hanford industrial buildings/structures located in the former 3000 Area adjacent to the North Richland Area have been inventoried and determined not eligible for the National Register.

4.6 Socioeconomics

R. A. Fowler

Activity on the Hanford Site plays a dominant role in the socioeconomics of the Tri-Cities and other parts of Benton and Franklin counties. The agricultural community also has a significant effect on the local economy. Any major changes in Hanford activity would potentially affect the Tri-Cities and other areas of Benton and Franklin counties.

4.6.1 Local Economy

Three major sectors have been the principal driving forces of the economy in the Tri-Cities since the early 1970s: 1) DOE and its contractors operating the Hanford Site; 2) Energy Northwest (formerly the Washington Public Power Supply System) in its construction and operation of nuclear power plants; and 3) the agricultural community, including a substantial food-processing component. With the exception of a minor amount of agricultural commodities sold to local-area consumers, the goods and services produced by these sectors are exported outside the Tri-Cities. In addition to the direct employment and payrolls, these major sectors also support a sizable number of jobs in the local economy through their procurement of equipment, supplies, and business services.

In addition to these three major employment sectors, three other components can be readily identified as contributors to the economic base of the Tri-Cities. The first of these, loosely termed "other major employers," includes the five major non-Hanford employers in the region. The second component is tourism. The Tri-Cities area has increased its convention business substantially in recent years, in addition to recreational travel. The final component in the economic base relates to the local purchasing power generated not from current employees but from retired former employees. Government transfer payments in the form of pension benefits constitute a significant proportion of total spendable income in the local economy.

4.6.1.1 DOE Contractors (Hanford)

The Hanford Site is the largest single source of employment in the Tri-Cities. DOE and its contractors, including Fluor Daniel Hanford, Inc. (and its six major subcontractors), Pacific Northwest National Laboratory (PNNL), Bechtel Hanford, Inc., and the Hanford Environmental Health Foundation, employed an average of 10,420 employees during FY 1998. Year-end contractor employment was 10,155. In FY 1997, average employment was 11,120, and in 1996, average employment was 11,940. The drop between FY 1996 and FY 1998 reflects both employment declines and reorganization of the DOE contractors under the Project Hanford Management Contract (PHMC) which was created in 1996. Under the PHMC, almost 2200 employees of the former management and operations contractor were moved into six "enterprise companies" (ENCOs) and ceased to be counted as official Hanford employees.

The number of employees at Hanford is down considerably from a peak of 19,200 in FY 1994, and is the smallest since 1975, but still represents nearly 12% of the total jobs in the economy (86,600). The total wage payroll for the Hanford Site was estimated at $519 million in FY 1998, which accounted for nearly 22% of the total wage income in the area. Direct procurements plus subcontracts by the DOE contractors represented 11-12% of the total sales in the Tri-Cities economy during FY 1998.

The impact of Hanford payrolls and other spending on the Tri-Cities economy is significant. A model created by PNNL indicates that about 20,550 total Tri-Cities jobs were supported directly or indirectly by the Hanford payroll and about 10,650 by procurements and the ENCO contracts, for a total of 31,200. This represents 36% of the jobs in the economy. Fully 64% of the wage income in the economy may depend directly or indirectly on Hanford Site payrolls and procurements (DOE-RL 1999).

The bulk of Hanford Site employees live in Benton and Franklin counties. Based on employee residence records as of December 1998, 93% of the direct employment of Hanford live in Benton and Franklin counties. Approximately 75% of Hanford employees reside in Richland, Pasco, or Kennewick. More than 37% are Richland residents, 9% are Pasco residents, and 29% live in Kennewick. Residents of other areas of Benton and Franklin counties, including West Richland, Benton City, and Prosser, account for about 18% of total Hanford Site employment.

4.6.1.2 Energy Northwest

Although activity related to nuclear power construction ceased with the completion of the WNP-2 reactor in 1983, Energy Northwest continues to be a major employer in the Tri-Cities area. Headquarters personnel based in Richland oversee the operation of WNP-2 and perform a variety of functions related to Hanford Generating Project. Decommissioning of two mothballed nuclear power plants (WNP-1 and WNP-4), which were never completed or refueled, began in 1995. In 1998, Energy Northwest employed around 46 people at the two plants, one-half the 90 people that were employed in 1994, as a result of decommissioning activities. As part of an effort to reduce electricity production costs, Energy Northwest headquarters decreased the size of its workforce from over 1900 in 1994 to 1069 at the end of 1998. Energy Northwest activities generated a payroll of approximately $67 million during FY 1998. Employment is expected to remain steady for the next few years, as most of the reductions have been achieved.

4.6.1.3 Agriculture

In 1997, agricultural production in the bi-county area generated about 10,392 wage and salary jobs, or about 13% of the area's total employment, as represented by the employees covered by unemployment insurance. Seasonal farm workers are not included in that total but are estimated by the U.S. Department of Labor for the agricultural areas in the state of Washington. In 1998, seasonal farm workers in Benton, Franklin, and Walla Walla counties averaged 7028 per month, ranging from 1373 workers during the winter pruning season to 15,711 workers at the peak of harvest. An estimated average of 6014 seasonal workers were classified as local (ranging from 1254 to 12,999); an average of 47 were classified as intrastate (ranging from 0 to 172), and an average of 967 were classified as interstate (ranging from 119 to 2540). The weighted seasonal wage for 1998 ranged from $5.40/hr to $7.20/hr, with an average wage of $6.07/hr (U.S. Department of Labor 1998).

According to the U.S. Department of Commerce's Regional Economic Information System, about 2,280 people were classified as farm proprietors in 1996. Farm proprietors' income, according to this same source, was estimated to be $70 million.

The area's farms and ranches generate a sizable number of jobs in supporting activities, such as agricultural services (e.g., application of pesticides and fertilizers and irrigation system development) and farm supply and equipment sales. Although formally classified as a manufacturing activity, food processing is a natural extension of the farm sector. More than 20 food processors in Benton and Franklin counties produce such items as potato products, canned fruits and vegetables, wine, and animal feed.

4.6.1.4 Other Major Employers

In 1998, the five largest non-Hanford Site employers employed approximately 4950 people in Benton and Franklin counties. These companies include: 1) Lamb Weston, which employed 1700; 2) Iowa Beef Processing Inc., which employed 1500; 3) Siemens Power Corporation, which employed 730; 4) Boise Cascade/Paper Group, which employed 520; and 5) Burlington Northern Santa Fe (BNSF) Railroad, which employed 500. Both Boise Cascade and Iowa Beef lie outside of Benton and Franklin counties, but most of their workforce resides in the area.

4.6.1.5 Tourism

An increase in the number of visitors to the Tri-Cites over the last several years has resulted in tourism playing an increasing role in helping to diversify and stabilize the area economy. Overall tourism expenditures in the Tri-Cities were roughly $182.2 million in 1997, down slightly from $183.4 million in 1996. Travel-generated employment in Benton and Franklin counties was about 3014 with an estimated $33.1 million in payroll, down slightly from the estimated 3212 employed and a $33.7 million payroll in 1996. In addition, tourism generated $2.7 million in local taxes and $11.4 million in state taxes in 1997 (Washington State Community, Trade and Economic Development 1998).

The Tri-Cities Visitors and Convention Bureau reported 192 meetings and events were held in the Tri-Cities in 1998, which drew 83,410 people and generated an estimated $27.5 million in local revenue. The number of convention delegates has increased 90% from 1995 and nearly 180% from the number of delegates that visited in 1991.

4.6.1.6 Retirees

Although Benton and Franklin counties have a relatively young population (approximately 53% under the age of 35) 18,261 people over the age of 65 resided in Benton and Franklin counties in 1998. The portion of the total population 65 years and older in Benton and Franklin counties accounts for 10% of the total population, which is below the 11.4% for of the state of Washington. This segment of the population supports the local economy on the basis of income received from government transfer payments and pensions, private pension benefits, and prior individual savings.

Although information on private pensions and savings is not available, data are available regarding the magnitude of government transfer payments. The U.S. Department of Commerce's Regional Economic Information System has estimated transfer payments by various programs at the county level. A summary of estimated major government pension benefits received by the residents of Benton and Franklin counties in 1996 is shown in Table 4.6-1. About two-thirds of Social Security payments go to retired workers; the remainder are for disability and other payments. The historical importance of government activity in the Tri-Cities area is reflected in the relative magnitude of the government employee pension benefits as compared to total payments.

Table 4.6-1. Government Retirement Payments in Benton and Franklin Counties, 1996 (millions of dollars)[a]

Government Retirement Payments	Benton County	Franklin County	Total
Social Security (including survivors and disability)	148.2	43.3	191.5
Railroad retirement	4.3	4.4	8.7
Federal civilian retirement	14.0	2.9	16.9
Veterans pension and military retirement	21.5	4.3	25.7
State and local employee retirement	33.7	6.9	40.7
Total	221.7	61.8	283.5

[a] U.S. Department of Commerce, REIS (1998).

4.6.2 Employment and Income

Nonagricultural employment in the Tri-Cities grew steadily from 1988 to 1994. However, the total annual average employment fell in 1995, 1996, and 1997. In 1998, nonagricultural employment rose 1%. Table 4.6-2 provides a breakdown of nonagricultural wage and salary workers employed in Benton and Franklin Counties in 1997 and 1998 (Washington State Employment Security 1998). There was an average of 71,100 jobs in the Tri-Cities in 1998, up approximately 800 from 1997. The services sector experienced the largest increase as 700 jobs were added during the year. Employment in wholesale and retail trade gained 400 jobs, and manufacturing, government, and the finance, insurance, and real estate sectors each grew by 100 jobs. The contract construction sector dropped 200; and transportation and public utilities dropped 400 jobs (Washington State Employment Security 1998).

Three measures of area income are presented in this section: total personal income, per capita income, and median household income. Total personal income comprises all forms of income received by the populace, including wages, dividends, and other revenues. Per capita income is roughly equivalent to total personal income divided by the number of people residing in the area. Median household income is the point at which half of the households have an income greater than the median and half have less. The source for total personal income and per capita income was the U.S. Department of Commerce's Regional Economic Information System, while median income figures for Washington State were provided by the U. S. Office of Financial Management (OFM) (OFM 1998a).

In 1996, the total personal income for Benton County was $3007 million, Franklin County was $800 million, and Washington State was $139.5 billion. Per capita income in 1996 for Benton County was $22,354, Franklin County was $17,493, and Washington State was $25,277. Median household income in 1996 for Benton County was estimated to be $42,833, Franklin County was estimated at $30,903, and Washington State was estimated at $39,899.

Table 4.6-2. Nonagricultural Wage and Salary Workers in Benton and Franklin Counties, 1997 and 1998[a]

Industry	1997 Annual Average	1998 Annual Average	Change 1997-1998 (%)
Nonagricultural wage and salary workers	70,400	71,100	1.0
Manufacturing	5,900	6,000	1.7
Contract construction	4,100	3,900	-4.9
Transportation and public utilities	8,900	8,400	-5.6
Wholesale and retail trade	15,900	16,300	2.5
Finance, insurance, and real estate	2,200	2,300	4.5
Services	19,800	20,500	3.5
Government	13,500	13,600	0.7

[a] Source: Washington State Employment Security Department.

4.6.3 Demography

Estimates for 1998 placed population totals for Benton and Franklin counties at 137,500 and 44,400, respectively (OFM 1998a). When compared to the 1990 census data in which Benton County had 112,560 residents and Franklin County's population totaled 37,473, the current population totals reflect the continued growth occurring in these two counties. The population in Benton County grew by 3,400 in 1998 while Franklin County added 500 people.

Within each county, the 1998 estimates distributed the Tri-Cities population as follows: Richland 36,860; Pasco 26,090; and Kennewick 50,390. The combined populations of Benton City, Prosser, and West Richland totaled 14,335 in 1998. The unincorporated population of Benton County was 35,915. In Franklin County, incorporated areas other than Pasco had a total population of 3467. The unincorporated population of Franklin County was 14,843 (OFM 1998a).

The 1998 estimates of racial categories by the OFM (OFM 1998a) indicate that in Benton and Franklin counties, Asians represent a lower proportion and individuals of Hispanic origin represent a higher proportion of the racial distribution than those in the state of Washington. Countywide, Benton and Franklin counties exhibit varying racial distributions, as indicated by the data in Table 4.6-3.

Benton and Franklin counties accounted for 3.2% of Washington State's population (OFM 1998b). In 1998, the population demographics of Benton and Franklin counties are quite similar to those found within Washington State. The population in Benton and Franklin counties under the age of 35 is 52.8%, compared to 49.8% for Washington State. In general, the population of Benton and Franklin counties is somewhat younger than that of Washington State. The 0- to 14-year old age group accounts for 26.4% of the total bi-county population as compared to 22.6% for Washington State. In 1997, the 65-year old and older age group constituted 10% of the population of Benton and Franklin Counties compared to 11.4% for Washington State.

Table 4.6-3. Population Estimates and Percentages by Race and Hispanic Origin, 1998.[a]

Area	Total	White/ Caucasian	Black/ African American	Indian, Eskimo, and Aleut	Asian and Pacific Islander	Hispanic Origin[b]
Washington State	5,685,300	5,047345 (88.8%)	192,546 (3.4%)	109,803 (1.9%)	335,606 (5.9%)	343,225 (6.0%)
Benton and Franklin Counties[c]	181,900	171,565 (94.3%)	3,085 (1.7%)	1,670 (0.9%)	5,580 (3.1%)	35,717 (19.6%)
Benton County[c]	137,500	130,788 (95.1%)	1,647 (1.2%)	1,241 (0.9%)	3,825 (2.8%)	15,374 (11.2%)
Franklin County[c]	44,400	40,777 (91.8%)	1,439 (3.2%)	429 (1.0%)	1,755 (4.0%)	20,343 (45.8%)

(a) From OFM 1998a - Population Estimates by Race and Hispanic Origin by County, October 1998; Racial Classifications Based on OMB Directive 15.

(b) Hispanic Origin is not a racial category: it may be viewed as the ancestry, nationality group, lineage, or country of birth of the person or person's parents or ancestors before arrival in the United States. Persons of Hispanic origin may be of any race and are counted in the racial categories shown.

(c) Percentage figures refer to county, not state, populations.

4.6.4 Environmental Justice

Environmental justice refers to fair treatment of all races, cultures, and income levels with respect to laws, policies, and government actions. Executive Order (E.O.) 12898, *Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations* (CEQ 1995), directs federal agencies to identify and address, as appropriate, disproportionately high and adverse human health or environmental effects of their programs, policies, and activities on minority and low-income populations.

Minority populations are defined as all nonwhite individuals, plus all individuals of Hispanic origin, as reported in the 1990 census. Low-income persons are defined as living in households in the 1990 census that reported an annual income less than the United States official poverty level. The poverty level varies by size and relationship of the members of the household. The 1990 census states poverty level was $12,674 for a family of 4. Nationally, in 1990, 24.2% of all persons were minorities, and 13.1% of all households had incomes less than the poverty level.

The distribution of minority populations residing in various areas surrounding the Hanford Site in 1990 is shown in Table 4.6-4. The table shows minority populations within an 80 km (50 mi) radius. For comparison, minority populations are also shown for those counties with boundaries at least partially within the circle. Counties included in the circle are Benton, Franklin, Walla Walla, Adams, Grant, Kittitas, Yakima, and Klickitat in Washington State; and Umatilla in Oregon.

The racial and ethnic composition of minorities surrounding the Hanford Site is also illustrated in Table 4.6-4. At the time of the 1990 census, Hispanics comprised nearly 81% of the minority population surrounding the Hanford Site. The Site is also surrounded by a relatively large percentage (about 8%) of Native Americans because of the presence of the Yakama Reservation and tribal headquarters in Toppenish, Washington.

Table 4.6-4. Distribution of Minority Populations in Counties Surrounding the Hanford Site, 1990.

Minority Population Distribution	Number
Population within 80 km (50 mi) of center of Site	383,934
Minority population within 80 km (50 mi) of center of Site	95,041
American Indian, Eskimo, or Aleut population	7,913
Asian or Pacific Islander population	5,296
African American population	4,331
Other race	568
Hispanic origin population[a]	76,933
Percentage of minority population within 80 km (50 mi) of center of Site	25
Population in counties surrounding the Site	565,871
Minority population in counties surrounding the Site	116,610
Percentage of minority population in counties surrounding the Site	21

[a] Hispanic origin is not a racial category. It may be viewed as the ancestry, nationality group, lineage, or country of birth of the person or person's parents or ancestors before arrival in the United States. Persons of Hispanic origin may be of any race and are counted in the racial categories shown.

Table 4.6-5 demonstrates the number of low-income households in the area surrounding the Hanford Site. Block groups containing 50% or more low-income households lie largely south of the Site.

Figures 4.6-1 and 4.6-2 show the geographic distribution of minority and low-income population within census block groups (areas defined for monitoring census data of approximately 250 to 550 housing units) that are within 80 km (50 mi) of the 200 East Area (approximately the center of the Hanford Site).

Table 4.6-5. Distribution of Low-Income Households in Counties Surrounding the Hanford Site, 1990.

Distribution of Low-Income Households	Number of Households
Households within 80 km (50 mi) of the Site	136,496
Low-income households within 80 km (50 mi) of the Site	57,667
Percentage of low-income households within 80 km (50 mi) of the Site	42
Households in counties surrounding the Site	204,501
Low-income households in counties surrounding the Site	86,693
Percentage of low-income households in counties surrounding the Site	42

There is not yet an agreed-upon standard within the emerging federal guidance on environmental justice for what constitutes an area that has a minority or low-income population large enough to act as a test for disproportionate impact (CEQ 1995). For example, it has not been decided in the case of minority residents whether the standard ought to be 50% minority residents, more than the national average of minority residents (24.2%), more than the state average, or some other number that takes into account other regional population characteristics. It is even more problematic to define low-income residents, since less income is needed to maintain a given living standard in areas with a relatively low cost of living. Several different definitions have been proposed, but each potential definition has strengths and weaknesses.

Therefore, Figures 4.6-1 and 4.6-2 each employs a graduated shading scheme that indicates those areas of small and roughly equal numbers of housing units that have heavy concentrations of minority and low-income residents as well as those areas that have lighter concentrations of such residents. Shaded areas generally indicate those census block groups that have more than the national average percentages of minority and low-income populations, with heavier shading showing heavier concentrations. There are no residents within the irregularly shaped census block shown in the center of Figures 4.6-1 and 4.6-2 that contains the 200 East location. This block is the Hanford Site.

4.6.5 Housing

In FY1998, 2057 houses were sold in the Tri-Cities at an average price of $115,700, compared to 1815 houses sold at an average price of $115,300 in 1997. In FY1998, 639 single-family houses were built, up almost 15% from the 557 that were built in 1997, but down sharply from a peak of 1117 in 1994.

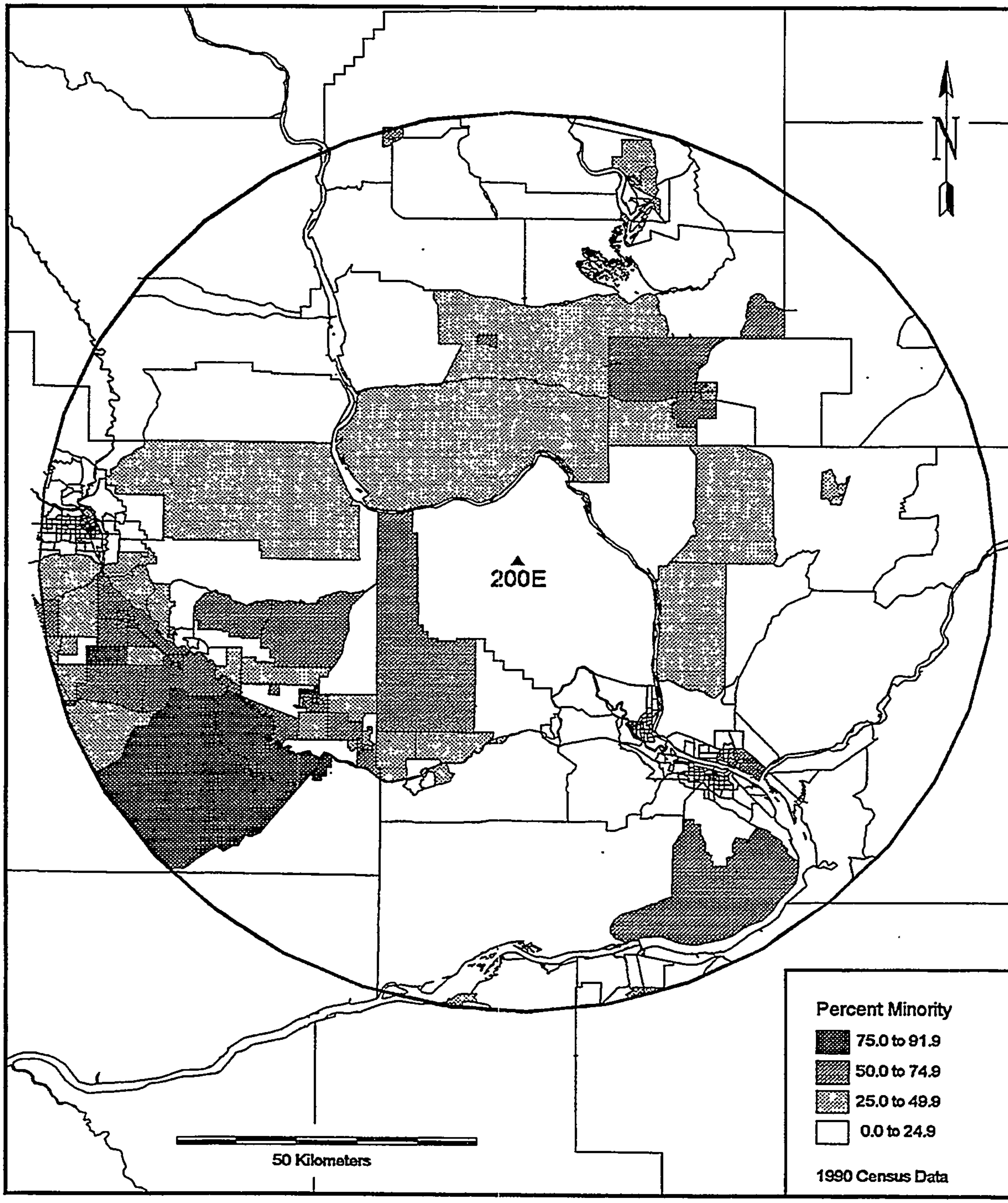


Figure 4.6-1. Distribution of Minority Populations Within 80 km (50 mi) of the 200 East Area of the Hanford Site.

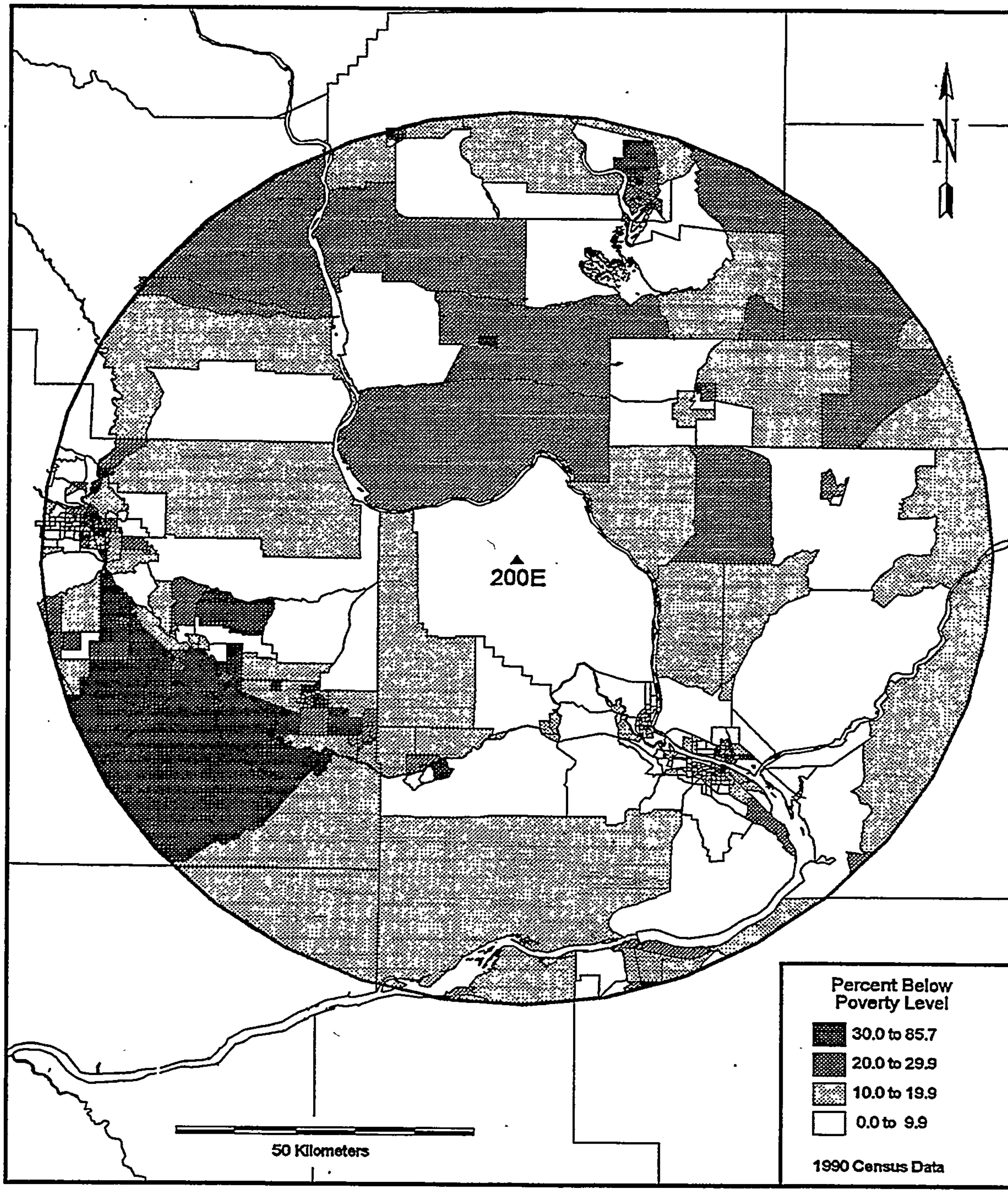


Figure 4.6-2. Distribution of Low-Income Populations Within 80 km (50 mi) of the 200 East Area of the Hanford Site.

In 1998, 91% of all housing (47,111 total units) in the Tri-Cities were occupied. Single-unit housing, which represents nearly 59% of the total units, had a 95% occupancy rate throughout the Tri-Cities. Multiple-unit housing, defined as housing with two or more units, had an occupancy rate of 87%. Representing 11% of the housing unit types, mobile homes had the lowest occupancy rate at 84%. Pasco had the lowest occupancy rate in all categories of housing with 90%, followed by Kennewick with 91%, and Richland with 92%. In 1995, 95% of all housing units in the Tri-Cities were occupied, but the combination of staff reductions by Hanford employers and a surge in single-family housing and apartment construction toward the end of 1995 and early 1996 has had an impact on occupancy rates in the late 1990s. The most significant drop was in multiple-unit housing, which had a 94% occupancy rate in 1995. Table 4.6-6 shows a detailed listing of total units and occupancy rate by type in the Tri-Cities.

Table 4.6-6. Total Units and Occupancy Rates, 1998 Estimates (OFM 1998a).

City	All Units	Rate %	Single Units	Rate %	Multiple Units	Rate %	Manufactured Homes	Rate %
Richland	16,318	92	10,921	95	4,410	88	987	89
Pasco	9,849	90	5,414	95	3,033	85	1,402	83
Kennewick	20,944	91	11,232	95	7,065	88	2,647	83
Tri-Cities Total	47,111	91	27,567	95	14,508	87	5,036	84

4.6.6 Transportation

The Tri-Cities serves as a regional transportation and distribution center with major air, land, and river connections. BNSF and Union Pacific provide direct rail service. Union Pacific operates the largest fleet of refrigerated rail cars in the United States and is essential to food processors, which ship frozen food from this area. Passenger rail service is provided by Amtrak, which has a station in Pasco.

Docking facilities at the Ports of Benton, Kennewick, and Pasco are important aspects of this region's infrastructure. These facilities are located on the 525-km-(325.5-mi)-long commercial waterway, which includes the Snake and Columbia rivers, that extends from the Ports of Lewiston-Clarkston in Idaho to the deep-water ports of Portland, Oregon, and Vancouver, Washington. The average shipping time from the Tri-Cities to these deep-water ports by barge is 36 hours (Evergreen Community Development Association 1986).

Daily air passenger and freight services connect the area with most major cities through the Tri-Cities Airport, located in Pasco. This modern commercial airport links the Tri-Cities to major hubs and access to destinations anywhere in the world. Delta Airlines, United Express, and Horizon Air offer 33 flights into and out of the Tri-Cities on a daily basis connecting to domestic and international flights through Salt Lake City, Seattle, and Portland. There are two runways, a main and minor crosswind. The main runway is equipped for precision instrumentation landings and takeoffs. Each runway is 2347 m (7700 ft) long and 46 m (150 ft) wide, and can accommodate landings and takeoffs by medium-range commercial aircraft, such as the Boeing 727-200 and Douglas DC-9. The Tri-Cities Airport handled 197,268 passengers (enplanements) in 1998, which is up 7.8% from 1997, and was the most recorded since 1986. Projections indicate that the terminal can serve almost 300,000 passengers annually.

The Tri-Cities region has three general aviation airports that serve private aircraft. Air freight shippers that service the region include Airborne from Richland, United Parcel Service from Kennewick, and Federal Express from the Tri-Cities Airport in Pasco.

The regional transportation network in the Hanford vicinity includes the areas in Benton and Franklin counties from which most of the commuter traffic associated with the Site originates. Interstate highways that serve the area are I-82, I-182, I-84, and I-90. Interstate-82 is 8 km (5 mi) south-southwest of the Site. Interstate-182, a 24-km (15-mi) long urban connector route, located 8 km (5 mi) south-southeast of the Site, provides an east-west corridor linking I-82 to the Tri-Cities area. I-90, located north of the Site, is the major link to Seattle and Spokane and extends to the East Coast; I-82 serves as a primary link between Hanford and I-90, as well as Interstate-84. I-84, located south of the Site in Oregon, is a major corridor leading to Portland. SR 224, south of the Site, serves as a 16-km (10-mi) link between I-82 and SR 240. SR 24 enters the Site from the west, continues eastward across the northernmost portion of the Site, and intersects SR 17 approximately 24 km (15 mi) east of the Site boundary. SR 17 is a north-south route that links I-90 to the Tri-Cities and joins U.S. Route 395, which continues south through the Tri-Cities. SR 14 connects with I-90 at Vantage, Washington, and provides ready access to I-84 at several locations along the Oregon and Washington border. SRs 240 and 24 traverse the Hanford Site and are maintained by Washington State. Other roads within the Hanford Site are maintained by DOE.

4.6.7 Educational Services

Primary and secondary education in the Tri-Cities area is served by the Richland, Pasco, Kennewick, Benton City, and Finley School Districts. The combined 1998 fall enrollment for all districts was approximately 33,900 students, an increase of 0.7% from the 1997 total of 33,670 students. The 1998 total includes 9111 from the Richland School District, 8392 students from the Pasco School District, 13,518 students from the Kennewick School District, 1688 from the Benton City School District, and 1197 students from Finley School District.

In addition, there are several private elementary and secondary schools in the area, including Bethlehem Lutheran (K-8), Christ the King (K-8), Faith Christian (1-12), Liberty Christian (K-12), Riverview Baptist (K-12), St. Patricks (K-8), St. Josephs (K-8), Tri-City Junior Academy (K-10), and Tri-Cities Prep Catholic High School. Fall 1998 enrollment at these schools totaled 2140 students.

Post-secondary education in the Tri-Cities area is provided by a junior college, Columbia Basin College (CBC), City University, and the Washington State University, Tri-Cities branch campus (WSU-TC). The 1998 fall/winter enrollment was approximately 7190 at CBC, 139 at City University, and 1171 at WSU-TC. Many of the programs offered by these three institutions are geared toward the vocational and technical needs of the area. Currently, 27 associate degree programs are available at CBC. City University offers 2 associate degree programs, 4 undergraduate, and 3 graduate programs plus access to several more programs through Distance Learning. WSU-TC offers 10 undergraduate and 16 graduate programs, as well as access to 8 more graduate programs via satellite.

4.6.8 Health Care and Human Services

The Tri-Cities has three major hospitals and five minor emergency centers. All three hospitals offer general medical services and include a 24-hour emergency room, basic surgical services, intensive care, and neonatal care.

Kadlec Medical Center, located in Richland, has 124 beds and functioned at 52% capacity with 5,869 total admissions in 1998. Non-Medicare/Medicaid patients accounted for 45% of Kadlec's annual admissions in 1998. An average stay of 3.8 days per admission was reported for 1998.

Kennewick General Hospital maintained a 53.5% occupancy rate of its 70 beds with 4549 annual admissions in 1998. Non-Medicare/Medicaid patients represented 47.3% of its total admissions. An average stay of 3 days per admission was reported in 1998.

Our Lady of Lourdes Hospital operates a 132-bed Health Center, located in Pasco, providing acute, sub-acute, skilled nursing and rehabilitation, and alcohol and chemical dependency services. Our Lady of Lourdes also operates the Carondolet Psychiatric Care Center, a 32-bed psychiatric hospital located in Richland. They also provide a significant amount of outpatient and home health services. For their calendar year 1998, Our Lady of Lourdes had a total of 4444 admissions, 27% of which were non-Medicare/Medicaid. Lourdes had an average acute care length of stay of 3.0 days, and the occupancy rate was 41.6% in 1998.

The Tri-Cities offers a broad range of social services. State human service offices in the Tri-Cities include the Job Service Center within the Employment Security Department; food stamp offices; the Developmental Disabilities Division; financial and medical assistance; the Child Protective Service; emergency medical service; a senior companion program; and vocational rehabilitation.

The Tri-Cities is also served by a large number of private agencies and voluntary human service organizations. The United Way, an umbrella fund-raising organization, incorporates 21 participating agencies offering 40 programs. These member agencies had a cumulative budget total of $21.4 million in 1998. In addition, there were 496 organizations that received funds as part of the United Way-Franklin County donor designation program.

4.6.9 Police and Fire Protection

Police protection in Benton and Franklin counties is provided by Benton and Franklin counties' sheriff departments, local municipal police departments, and the Washington State Patrol Division with headquarters in Kennewick. Table 4.6-7 shows the number of commissioned officers and patrol cars in each department in April 1999. The Kennewick Municipal Police Department maintains the largest staff of commissioned officers with 78.

Fire protection is provided by the fire departments of the cities of Kennewick, Pasco, and Richland, and by Benton County Rural Fire Departments #1, #2, and #4. Table 4.6-8 indicates the number of fire fighting personnel, both paid and unpaid, on the staffs of fire districts in the area.

The Hanford Fire Department currently has four fire stations strategically located on the Hanford Site. From these stations four pumper crews, staffed with at least three firefighters each, provide suppression response. Four ambulance crews (one in each fire station), staffed with two firefighters (EMT- or paramedic-trained), provide emergency medical services 24 hours a day, 7 days a week. A total of 40 emergency response vehicles, representing diverse capabilities, are maintained at the four fire stations. Some emergency equipment was specifically to control situations unique to the Hanford Site.

The Hanford Fire Department provides coverage to the entire Hanford Site (560 square miles) and to SR 240 and SR 24. Coverage on the highways extends from the Vernita Bridge to the Silver Dollar Cafe on SR 24 and along SR 240 from the Yakima Barricade to the intersection with SR 225. Additionally, the Hanford Fire Department responds to mutual aid requests from 10 surrounding fire districts.

Table 4.6-7. Police Personnel in the Tri-Cities, 1999.[a]

Area	Commissioned Officers	Reserve Officers	Patrol Cars
Kennewick Municipal	78	10	53
Pasco Municipal	44	20	15
Richland Municipal	50	13	13
West Richland Municipal	13	8	14
Benton County Sheriff	48	10	59
Franklin County Sheriff	19	19	22

[a] Source: Personal communication with each department office, April 1999.

Table 4.6-8. Fire Protection Personnel in the Tri-Cities, 1999.[a]

Fire Station[b]	Fire Fighting Personnel	Volunteers	Total	Service Area
Kennewick	67	0	67	City of Kennewick
Pasco	39	0	39	City of Pasco
Richland	52	0	52	City of Richland
BCRFD 1	5	85	90	Kennewick Area
BCRFD 2	4	35	39	Benton City
BCRFD 4	5	35	40	West Richland

[a] Source: Personal communication with each department office, April 1999.
[b] BCRFD = Benton County Rural Fire Department.

4.6.10 Parks and Recreation

The convergence of the Columbia, Snake, and Yakima rivers offers the residents of the Tri-Cities a variety of recreational opportunities.

The Lower Snake River Project includes Ice Harbor, Lower Monumental, Little Goose, and Lower Granite locks and dams, and a levee system and parkway at Clarkston and Lewiston. While navigation capabilities and the electrical output are the major benefits of this project, recreational benefits have also resulted. The Lower Snake River Project provides boating, camping, and picnicking facilities in nearly a dozen areas along the Snake River. In 1996, nearly 2 million people visited the area and participated in activities along the river.

Similarly, the Columbia River provides ample water recreational opportunities on the lakes formed by the dams. Lake Wallula, formed by McNary Dam, offers a large variety of parks and activities, which attracted more than 4.3 million visitors in 1996. The Columbia River Basin is also a popular area for migratory waterfowl and upland game bird hunting.

Other opportunities for recreational activities in the Tri-Cities are accommodated by the indoor and outdoor facilities available, some of which are listed in Table 4.6-9. Numerous tennis courts, ball fields, and golf courses offer outdoor recreation to residents and tourists. Several privately owned health clubs in the area offer indoor tennis and racquetball courts, pools, and exercise programs. Bowling lanes and skating rinks also serve the Tri-Cities.

Table 4.6-9. Examples of Physical Recreational Facilities Available in the Tri-Cities.

Activity	Facilities
Team Sports	Baseball fields and basketball courts are located throughout the Tri-Cities. Soccer and football fields are also located in various areas.
Bowling	Lanes in each city including Fiesta Bowling Center, Celebrity Bowl, Columbia Lanes, and Go-Bowl.
Camping	Several hundred campsites within driving distance from the Tri-Cities area, including Fishhook Park and Sun Lakes.
Fishing	Steelhead, sturgeon, trout, walleye, bass, and crappie fishing in the lakes and rivers near the Tri-Cities.
Golf	6 public courses including Canyon Lakes, Horn Rapids, and West Richland Municipal, two private courses, and a number of driving ranges and pro shops are available.
Hunting	Duck, geese, pheasant, and quail hunting. Deer and elk hunting in the Blue Mountains and the Cascade Range.
Roller skating	Roller skating in Richland, Kennewick, and Prosser.
Swimming	Private and public swimming pools in the area. Boating, water-skiing, and swimming on the Columbia River.
Tennis	20 outdoor city courts, with additional outdoor courts located at area schools.
Walking/Bicycling	The region has over 32 miles of paved bike/hike paths.

4.6.11 Utilities

The principal source of water in the Tri-Cities and the Hanford Site is the Columbia River. The water systems of Richland, Pasco, and Kennewick draw a large portion of the 49.2-billion L (13-billion gal) used in 1998 from the Columbia River. Each city operates its own supply and treatment system. The Richland water supply system derives about two-thirds of its water directly from the Columbia River, while the remainder is split between a well field in North Richland (which is recharged from the river) and groundwater wells. The City of Richland's total usage in 1998 was 27.2 billion L (7.2 billion gal). The City of Pasco system also draws from the Columbia River for its water needs. In 1998, Pasco consumed 9.8 billion L (2.6 billion gal). The Kennewick system uses two wells and the Columbia River for its supply. These wells serve as the sole source of water between November and March and can provide approximately 43% of the total maximum supply of 30 billion L (8 billion gal). Total 1998 usage in Kennewick was 12.7 billion L (3.2 billion gal).

The major incorporated areas of Benton and Franklin counties are served by municipal wastewater treatment systems, whereas the unincorporated areas are served by onsite septic systems. Richland's wastewater treatment system is designed to treat a total capacity of 45.4 million L/d (12 million gal/d) and processed an average flow of 24.2 million L/d (6.4 million gal/d) in 1998. Kennewick's waste treatment system processed an average 18.6 million L/d (4.9 million gal/d) in 1998, while the system is capable of treating about 41.6 million L/d (11 million gal/d). Pasco's waste treatment system processed an average 9.8 million L/d (2.6 million gal/d) while the system is capable of treating 16.3 million L/d (4.3 million gal/d).

In the Tri-Cities, the Benton County Public Utility District, Benton Rural Electrical Association, Franklin County Public Utility District, and City of Richland Energy Services Department provide electricity. All the power that these utilities provide in the local area is purchased from the Bonneville Power Administration (BPA), a federal power marketing agency. The average rate for residential customers served by the four local utilities was approximately $0.059/kWh in 1998. Total electrical consumption in 1998 was 3.45 billion kWh. Electrical power for the Hanford Site is purchased wholesale from BPA. Energy requirements for the Site during FY 1998 were nearly 306 million kWh for a total cost of $7.4 million. Additionally, the Site spends about $0.03/kWh for electrical transportation and distribution within the Hanford Site.

Natural gas, provided by the Cascade Natural Gas Corporation, serves a small portion of residents, with 8,685 residential customers as of April 1999. The average annual gas bill for residential customers is $314. The Cascade Natural Gas Corporation also serves the 300 Area of the Hanford Site.

In the Pacific Northwest, hydropower, and to a lesser extent, coal and nuclear power, constitute the region's electrical generation system. The system is capable of delivering approximately 20,300 average megawatts of guaranteed energy. Of that, approximately 62% are derived from hydropower, 16% from coal, and less than 7% from nuclear plants. One commercial nuclear power plant, WNP-2, remains in service in the Pacific Northwest, with an average generating capability of 833 megawatts. The Trojan nuclear power plant, in Oregon, was permanently shut down on January 4, 1993.

The region's electrical power system, more than any other system in the nation, is dominated by hydropower. In a given peak demand hour, the hydropower system is capable of providing nearly 30,000 megawatts of capacity. Variable precipitation and limited storage capabilities alter the system's output from 12,300 average megawatt under critical water conditions to 20,000 average megawatt in record high-water years. The Pacific Northwest system's reliance on hydroelectric power means that it is more constrained by the seasonal variations in peak demand than in meeting momentary peak demand.

Additional constraints on hydroelectric production are measures designed to protect and enhance the production of salmon, as many salmon runs have dwindled to the point of being threatened or endangered. These measures, outlined by the Northwest Power Planning Council's (NPPC) Columbia River Basin Fish and Wildlife Program, include minimum flow levels and a "water budget," which refers to water in the Columbia and Snake rivers that is released to speed the migration of young fish to the sea. Generation capacity of the hydroelectric system is decreased with these measures, as less water is available to pass through the turbines.

Throughout the 1980s, the Pacific Northwest had more electric power than it required and was operating with a surplus. This surplus has been exhausted, however, and there is only enough power supplied by the system to meet regional electricity needs. In the 1991 Northwest Power Plan, the NPPC set a goal of purchasing more than 1500 megawatts of energy savings by the year 2000 to help the existing system meet with rising electricity demand. NPPC estimates that the Pacific Northwest will need an additional 2000 megawatts over 1991 consumption by the turn of the century.

4.6.12 Land Use

The 1,450 km^2 (560 mi^2) Hanford Site includes several DOE operational areas. The entire Hanford Site has been designated a National Environmental Research Park. The major areas on the Site are as follows:

- The 100 Areas, bordering on the right bank (south shore) of the Columbia River, are the sites of eight retired plutonium production reactors and the N Reactor. The facilities in the 100 Areas are being placed in a stabilized state for ultimate decommissioning. The N Reactor Deactivation Program covers the period from FY 1992 through FY 1997. The 100 Areas occupy about 11 km^2 (4 mi^2).

- The 200 West and 200 East Areas are located on a plateau about 8 and 11 km (5 and 7 mi), respectively, from the Columbia River. These areas have been committed for some time to fuel reprocessing and waste management and disposal activities. The 200 Areas cover about 16 km^2 (6 mi^2).

- The 300 Area, located just north of the city of Richland, is the site of nuclear and non-nuclear research and development. This area covers 1.5 km^2 (0.6 mi^2).

- The 400 Area is about 8 km (5 mi) north of the 300 Area and is the site of the FFTF used in the testing of breeder reactor systems. In December 1993, the Secretary of Energy ordered the FFTF to be shut down, with a goal to reach a radiologically and industrially safe shutdown in approximately 5 years. The Secretary also indicated that tritium was not to be produced at FFTF. Defueling of FFTF, which was the first major phase of deactivation, was completed in April 1995, four and a half months ahead of schedule. The next several phases are currently under way; however, DOE is also studying whether the shutdown reactor should be revived for the purposes of producing tritium for defense purposes, the production of medical isotopes, and burning weapons-grade plutonium. Also included in this area is the Fuels and Materials Examination Facility.

- The 600 Area includes all of the Hanford Site not occupied by the 100, 200, 300, or 400 Areas. Land uses within the 600 Area include the following:

  — 310 km^2 (120 mi^2), known as the Fitzner/Eberhardt ALE Reserve, is managed by the U.S. Fish and Wildlife Service for the U.S. Department of Energy. It serves as a research natural area and is used by a consortium of educational and scientific groups for public education programs.

  — 0.4 km^2 (0.2 mi^2) is leased by Washington State, a part of which is used for commercial low-level radioactive waste disposal.

  — 4.4 km^2 (1.6 mi^2) is used by Energy Northwest for nuclear power plants.

  — 2.6 km^2 (1 mi^2) is owned by Washington State and is being held as a potential site for the disposal of nonradioactive hazardous wastes.

  — approximately 130 km^2 (50 mi^2) is under revocable use permit to the U.S. Fish and Wildlife Service for Saddle Mountain Wildlife Refuge.

  — 225 km^2 (87 mi^2) on the Wahluke Slope is under revocable use permit to the Washington State Department of Fish and Wildlife for recreational game management (the Wahluke Wildlife Area).

  — support facilities.

An area of approximately 668 km^2 (258 mi^2) has been designated for research or as wildlife refuges. This includes ALE, lands managed by the U.S. Fish and Wildlife Service, and Washington State Department of Fish and Wildlife management areas.

The area known as the Hanford Reach, the area from Priest Rapids Dam (river mile 396) to McNary Pool (river mile 345), includes a quarter-mile strip of public land on either side of the Columbia River as well as the Saddle Mountain National Wildlife Refuge and the Wahluke Wildlife Area. The Hanford Reach is the last free-flowing, nontidal segment of the Columbia River in the United States. In 1988, Congress passed Public Law 100-605 which required the Secretary of the Interior to prepare a study in consultation with the Secretary of Energy to evaluate the outstanding feature of the Reach and its immediate environment and instituted interim protection measures (see Section 6.2.6). Also, alternatives for preserving those features were examined, including the designation of the Reach as part of the National Wild and Scenic Rivers System. The results of the study can be found in the *Hanford Reach of the Columbia River - Comprehensive River Conservation Study and Environmental Impact Statement* (DOI 1994). The Record of Decision for this EIS recommended designation of lands in the Hanford Reach as a wildlife refuge with a recreational river designation for the river (DOI 1996). (Public Law 100-605 expired was amended as Public Law 104-333 in 1996 to extend the protection measures indefinitely).

The Hanford Remedial Action Environmental Impact Statement (HRA-EIS) is being used by DOE and its nine cooperating and consulting agencies to develop a comprehensive land-use plan (CLUP) for the Hanford Site. DOE/EIS-0222 was prepared in August 1996, and a second draft was completed in April 1999. A final EIS and a Record of Decision is expected in fall 1999.

The Columbia River, which is adjacent to and runs through the Hanford Site, provides access to the public for boating, water skiing, fishing, and hunting of upland game birds and migratory waterfowl. Some land access along the shore and on certain islands is available for public use.

Land use in other areas includes urban and industrial development, irrigated and dry-land farming, and grazing. In 1997, over one-half million acres of crop land were planted in Benton and Franklin counties, including 262,000 acres of wheat, 42,700 acres of sweet corn, 63,000 acres of potatoes, and 64,200 acres of alfalfa. Other major crops include apples, cherries, dry beans, asparagus, and grapes.

4.6.13 Visual Resources

With the exception of Rattlesnake Mountain, the land near the Hanford Site is generally flat with little relief. Rattlesnake Mountain, rising to 1,060 m (3,477 ft) above mean sea level, forms the western boundary of the Site, and Gable Mountain and Gable Butte are the highest land forms within the Site. The view towards Rattlesnake Mountain is visually pleasing, especially in the springtime when wildflowers are in bloom. Large rolling hills are located to the west and far north. The Columbia River, flowing across the northern part of the Site and forming the eastern boundary, is generally considered scenic, with its contrasting blue against a background of brown basaltic rocks and sagebrush. The White Bluffs, steep whitish-brown bluffs adjacent to the Columbia River and above the northern boundary of the river in this region, are a strong feature of the landscape.

Traditional Native American religion is manifest in the earth, water, sky, and all animate or inanimate beings that inhabit a given location. The National Historic Preservation Act, the Native American Graves Protection and Repatriation Act, the Archaeological Resources Protection Act, and DOE's American Indian Policy, among other legislation and guidelines, all require the identification and protection of areas and resources of concern to Native Americans.

The acquisition of spiritual guidance and assistance through personal vision quests is deeply rooted in the religious practices of the indigenous people of the Columbia Basin. High spots were selected because they afforded extensive views of the natural landscape and seclusion for quiet meditation.

4.7 Noise

T. M. Poston

Noise is technically defined as sound waves that are unwanted and perceived as a nuisance by humans. Sound waves are characterized by frequency, measured in Hertz (Hz), and sound pressure expressed as decibels (dB). Humans have a perceptible hearing range of 31 to 20,000 Hz. The decibel is a value equal to 10 times the logarithm of the ratio of a sound pressure squared to a standard reference sound-pressure level (20 micropascals) squared. The threshold of audibility ranges from about 60 dB at a frequency of 31 Hz to less than about 1 dB between

900 and 8000 Hz. (For regulatory purposes, noise levels for perceptible frequencies are weighted to provide an A-weighted sound level [dBA] that correlates highly with individual community response to noise.) Sound pressure levels outside the range of human hearing are not considered noise in a regulatory sense, even though wildlife may be able to hear at these frequencies.

Noise levels are often reported as the equivalent sound level (L_{eq}). The L_{eq} is expressed in dBA over a specified period of time, usually 1 or 24 hours. The L_{eq} is the equivalent steady sound level that, if continuous during a specified time period, would contain the same total energy as the actual time-varying sound over the monitored or modeled time period.

4.7.1 Background Information

Studies of the propagation of noise at Hanford have been concerned primarily with occupational noise at work sites. Environmental noise levels have not been extensively evaluated because of the remoteness of most Hanford activities and isolation from receptors that are covered by federal or state statutes. This discussion focuses on what few environmental noise data are available. The majority of available information consists of model predictions, which in many cases have not been verified because the predictions indicated that the potential to violate federal or state standards is remote or unrealistic.

4.7.2 Environmental Noise Regulations

The Noise Control Act of 1972 and its subsequent amendments (Quiet Communities Act of 1978 and 40 CFR 201-211) direct the regulation of environmental noise to the state. The state of Washington has adopted Revised Code of Washington (RCW) 70.107, which authorizes Ecology to implement rules consistent with federal noise control legislation. RCW 70.107 and the implementing regulations embodied in WAC 173-60 through 173-70 defined the regulation of environmental noise levels. Maximum noise levels are defined for the zoning of the area in accord with environmental designation for noise abatement (EDNA). The Hanford Site is classified as a Class C EDNA on the basis of industrial activities. Unoccupied areas are also classified as Class C areas by default because they are neither Class A (residential) nor Class B (commercial). Maximum noise levels are established based on the EDNA classification of the receiving area and the source area (Table 4.7-1).

4.7.3 Hanford Site Sound Levels

Most industrial facilities on the Hanford Site are located far enough away from the Site boundary that noise levels at the boundary are not measurable or are barely distinguishable from background noise levels. Modeling of environmental noises has been performed for commercial reactors and SR 240 through the Hanford Site. These data are not concerned with background levels of noise and are not reviewed here. There are two sources of measured environmental noise at Hanford. Environmental noise measurements were made in 1981 during site characterization for the Skagit/Hanford Nuclear Power Plant Site (NRC 1982). Measurements were also made when the Hanford Site was considered for a geologic waste repository (Basalt Waste Isolation Project) for spent commercial nuclear fuel and other high-level nuclear waste. Site characterization studies performed in 1987 included measurement of background environmental noise levels at five locations on the Hanford Site. Additionally, certain activities such as well drilling and sampling have the potential for producing noise in the field apart from major permanent facilities.

Recently, the potential impact of traffic noise resulting from Hanford Site activities has been evaluated for a draft EIS addressing the siting of the proposed New Production Reactor (NPR) (DOE 1991). While this EIS does not include any new baseline measurements, it does address the traffic component of noise and provides modeled "baseline" measurements of traffic noise for the Hanford Site and adjacent communities.

Table 4.7-1. Applicable State Noise Limitations for the Hanford Site Based on Source and Receptor EDNA Designation.

Source Hanford Site	Receptor: Class A Residential (dBA)	Receptor: Class B Commercial (dBA)	Receptor: Class C Industrial (dBA)
Class C - Day	60	65	70
Night	50	--	--

4.7.3.1 Skagit/Hanford Data

Pre-construction measurements of environmental noise were taken in June 1981 on the Hanford Site during site characterization for the Skagit/Hanford Nuclear Power Plant (NRC 1982). Fifteen sites were monitored, and noise levels ranged from 30 to 60.5 dBA (L_{eq}). The values for isolated areas ranged from 30 to 38.8 dBA. Measurements taken around the sites where Energy Northwest was constructing nuclear power plants (WNP-1, WNP-2, and WNP-4) ranged from 50.6 to 64 dBA. Measurements taken along the Columbia River near the intake structures for WNP-2 were 47.7 and 52.1 dBA compared with more remote river noise levels of 45.9 dBA (measured about 4.8 km [3 mi] upstream of the intake structures). Community noise levels in North Richland (Horn Rapids Road and SR 240) were 60.5 dBA.

4.7.3.2 BWIP Data

Background noise levels were determined at five locations within the Hanford Site (Figure 4.7-1). Noise levels are expressed as L_{eqs} for 24 hours (L_{eq-24}). Sample location, date, and L_{eq}-24 are listed in Table 4.7-2. Wind was identified as the primary contributor to background noise levels, with winds exceeding 19 km/h (12 mi/h) significantly affecting noise levels. Background noise levels in undeveloped areas at Hanford can best be described as a mean L_{eq}-24 of 24 to 36 dBA. Periods of high wind, which normally occur in the spring, would elevate background noise levels.

4.7.3.3 New Production Reactor EIS

Baseline noise estimates were determined for two locations: SR 24, leading from the Hanford Site west to Yakima, and SR 240, south of the Site and west of Richland where it handles maximum traffic volume (DOE 1991). Traffic volumes were predicted based on an operational work force and a construction work force. Both peak (rush hour) and off-peak hours were modeled. Noise levels were expressed in L_{eq} for 1-hr periods in dBA at a receptor located 15 m (49 ft) from the road edge (Table 4.7-3). Adverse community responses would not be expected at increases of 5 dBA over background noise levels.

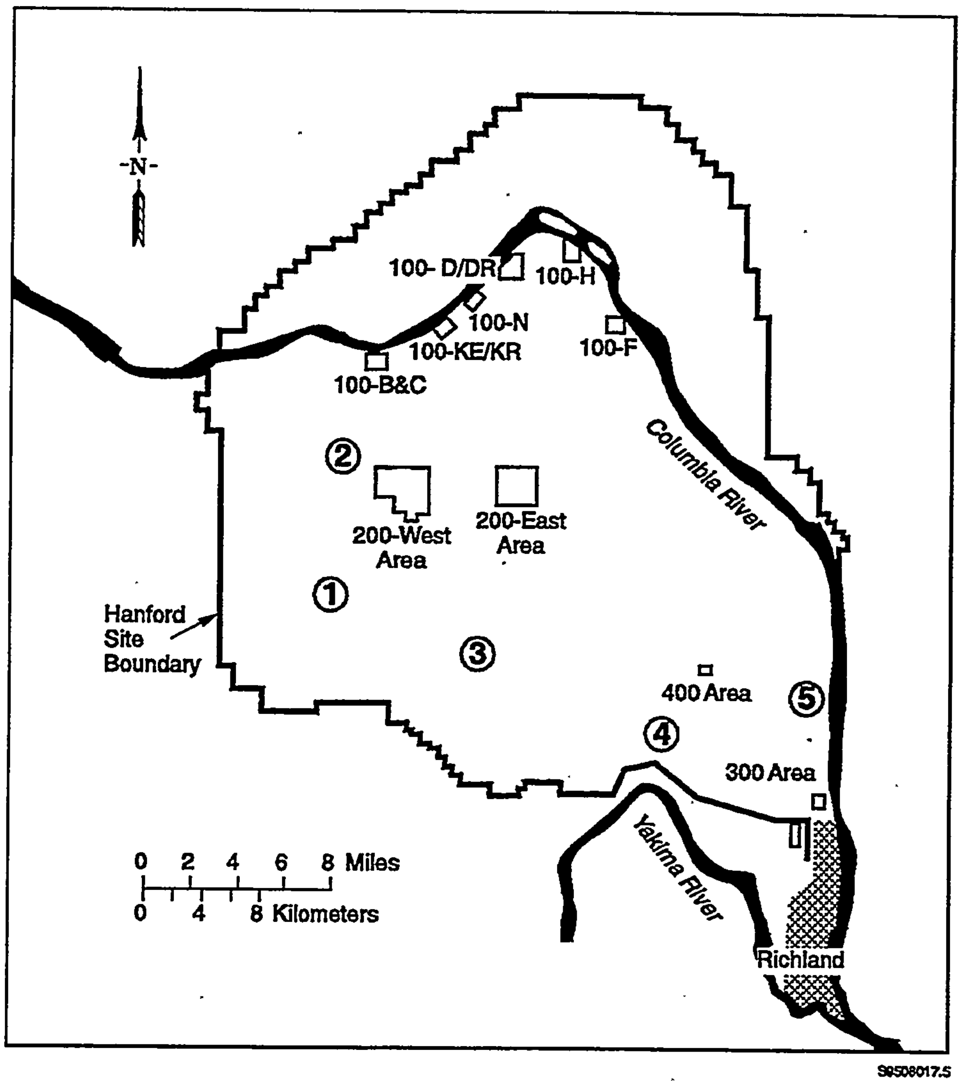


Figure 4.7-1. Location of Background Noise Measurements (see Table 4.7-2).

Table 4.7-2. Background Noise Levels Measured at Isolated Areas.

Site	Location: Section	Range	Township	Date	L_{eq}-24 (dBA)
1	9	R25E	T12N	07-10-87	41.7
				07-11-87	40.7
				07-12-87	36.0
				07-13-87	37.2
				07-14-87	35.6
2	26	R25E	T13N	07-25-87	43.9
				07-26-87	38.8
				07-27-87	43.8
				07-28-87	37.7
				07-29-87	43.2
3	18	R26E	T12N	08-08-87	39.0
				08-09-87	35.4
				08-10-87	51.4[a]
				08-11-87	56.7[a]
				08-12-87	36.0
4	34	R27E	T11N	09-09-87	35.2
				09-10-87	34.8
				09-11-87	36.0
				09-12-87	33.2
				09-13-87	37.3
5	14	R28E	T11N	10-15-87	40.8
				10-16-87	36.8
				10-17-87	33.7
				10-18-87	31.3
				10-19-87	35.9

(a) L_{eq} includes grader noise.

Table 4.7-3. Modeled Noise Resulting from Automobile Traffic at Hanford in Association with the New Production Reactor Environmental Impact Statement (DOE 1991).[a]

		Traffic flow (Vehicles/h)		Noise levels (L_{eq}-1 h in dBA)		
Location[b]	Scenario	Baseline	Maximum[c]	Baseline noise levels	Modeled noise levels[c]	Maximum increase (dBA)
Construction Phase						
SR 24	Off-Peak	91	91	62.0	62.0	0.0
	Peak	91	343	62.0		
SR 240	Off-Peak	571	579	70.2	70.6	0.4
	Peak	571	2839	70.2	73.5	3.3
Operation Phase						
SR 24	Off-Peak	91	91	62.0	62.0	0.0
	Peak	300	386	65.7	66.2	1.5
SR 240	Off-Peak	571	582	70.2	70.5	0.3
	Peak	2239	3009	74.1	74.7	0.6

(a) Measured 15 m (49 ft) from the road edge.
(b) SR 24 leads to Yakima; SR 240 leads to the Tri-Cities area.
(c) Traffic flow and noise estimates varied with NPR technology; the maximum impacts from three NPR techniques are shown here.

4.7.3.4 Noise Levels of Hanford Field Activities

In the interest of protecting Hanford workers and complying with Occupational Safety and Health Administration (OSHA) standards for noise in the workplace, the HEHF has monitored noise levels resulting from several routine operations performed at Hanford. Occupational sources of noise propagated in the field have been summarized in Table 4.7-4. These levels are reported here because operations such as well sampling are conducted in the field away from established industrial areas and have the potential for disturbing sensitive wildlife.

Table 4.7-4. Monitored Levels of Noise Propagated from Outdoor Activities at the Hanford Site.[a]

Activity	Average Noise Level	Maximum Noise Level	Year Measured	Distance
Water wagon operation[a]	104.5	111.9	1984	On staff member
Well sampling[a]	74.8 - 78.2	.	1987	On staff member
Truck[a]	78 - 83		1989	On staff member
Compressor[b]	88 - 90			0.3 m (1 ft) from truck
Generator[b]	93 - 95			0.3 m (1 ft) from truck
Well drilling, Well 32-2[a]	98 - 102	102	1987	23 m (75 ft)
Well drilling, Well 32-3[a]	105 - 11	120 - 125	1987	15 m (49 ft)
Well drilling, Well 33-29[a]	89 - 91		1987	15 m (49 ft)
Pile driver[a]	118 - 119		1981	1.5 m (5 ft)
Tank farm filter building[a]	86		1976	9.0 m (30 ft)

[a] Noise levels measured in A weighted dB (dBA).
[b] Noise levels measured in decibels (dB).

4.8 Occupational Safety

E. J. Antonio

Total occupational work hours at the Hanford Site from 1993 through 1997, were 157,322,471 hours, or about 78,760 worker-years (DOE 1998b). Approximately 7.6 % of these (11,973,212) hours were tallied in construction categories. The remaining 92.4 % (145,280,962 hours) were tallied in non-construction categories and are assumed related to Hanford Site operations, services, and support. The DOE records measurement of occupational injury and illnesses in four categories pertinent to NEPA analysis. Total Recordable Cases (TRC) are work-related deaths, illnesses, or injuries that resulted in loss of consciousness, restriction of work or motion, transfer to another job, or required medical treatment for first aid. Lost Workday Cases (LWC) involve days away from work or days of restricted work activity, or both. Lost Workdays (LWD) are the number of workdays (consecutive or not), beyond the day of injury or onset of illness, an employee was away from work or limited to restricted work activity because of an occupational injury or illness. Fatalities are the number of occupation-related deaths.

Occupational injury and illness incidence rates at the Hanford Site have been decreasing since 1994. Figure 4.8-1 shows 4.9 TRC per 200,000 worker hours (100 worker years) in 1994. By 1997 the rate had decreased to 3.0 cases per 200,000 worker hours and during the first 6 months of 1998 the rate further decreased to 2.3 cases per 200,000 worker hours. Over the 5-year period from 1993 through 1997, the average Hanford Site incidence rate was higher than the average incidence rate for the entire DOE complex, 4.4 to 3.6 cases per 200,000 worker hours. Incidence rates at Hanford for 1997 and the first 6 months of 1998 were below the DOE-wide incidence rates in all categories.

Table 4.8-1 shows 5-year occupational injury, illness, and fatality rates reported for the private sector by the Bureau of Labor Statistics (U.S. Department of Labor) for the entire U.S. DOE complex and for the DOE-Richland Operations Office Hanford Site. Occupational injury and incidence rates at DOE-RL/Hanford and the DOE complex are significantly lower than in the private sector. Since 1993, Hanford has had one occupational fatality that occurred during the second quarter of 1993. The incidence rate for fatalities at Hanford is lower than the rates for the private sector and the DOE complex. Incidence rates are also presented separately for construction and non-construction labor categories at the Hanford Site.

Figure 4.8-1. Occupational Injury and Illness Incidence Rates at the Hanford Site (DOE 1998b).

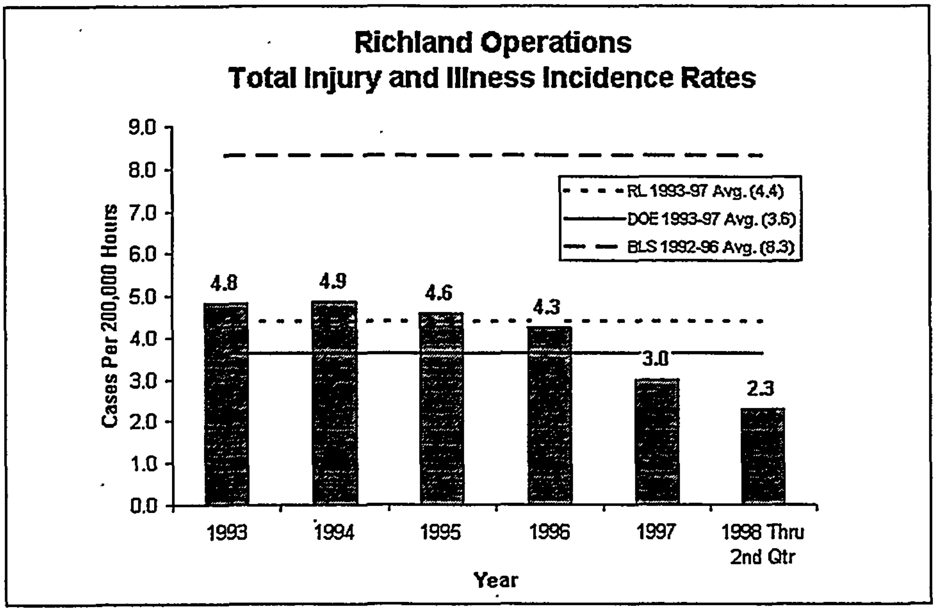


Table 4.8-1. Occupational Injury, Illness and Fatality Incidence Rate Statistics (DOE 1998b).[a]

	Total Recordable Cases	Lost Work Cases	Lost Work Days	Fatality
Bureau of Labor Statistics[b]	8.3	3.7	n/a[c]	0.0051
U.S. Department of Energy[d]	3.6	1.7	48.9	0.0027
DOE-Richland Operations Office (DOE-RL), Hanford Site[d]	4.4	1.8	61.9	0.0008[e]
DOE-RL construction	11.9	4.9	96.0	0
DOE-RL non-construction	3.8	1.5	57.4	0.0014

[a] Per 200,000 worker hours (100 worker-years).
[b] BLS values are average rates for the private sector from 1992 through 1996.
[c] n/a = data not available.
[d] DOE values are average rates from 1993 through 1997.
[e] One occupational fatality occurred in 1993, during this period.

[This Page Intentionally Left Blank]

References

Andrefsky, Jr., W., L. L. Hale, and D. A. Harder. 1996. *1995 WSU Archaeological Block Survey of the Hanford 600 Area*. Project Report No. 29. Center for Northwest Anthropology, Department of Anthropology, Washington State University, Pullman, Washington.

Backman, G. E. 1962. *Dispersion of 300 Area Liquid Effluent in the Columbia River*. HW-73672, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Baker, V. R. 1978. "Large-Scale Erosional and Depositional Features of the Channeled Scabland." In *The Channeled Scabland*, eds. V. R. Baker and D. Nummedal. National Aeronautics and Space Administration, Washington, DC.

Baker, V. R., B. N. Bjornstad, A. J. Busacca, K. R. Fecht, U. L. Moody, J. G. Rigby, D. F. Stradling, and A. M. Tallman. 1991. "Quaternary Geology of the Columbia Plateau." In *Quaternary Nonglacial Geology; Conterminous U.S.*, ed., R. B. Morrison, The Geology of North America, Geological Society of America, Vol. K-2, Boulder, Colorado.

Bard, J. C. 1997. "Ethnographic /Contact Period (Lewis and Clark 1805 – Hanford Engineer Works 1943) of the Hanford Site, Washington." In *National Register of Historic Places Multiple Property Documentation Form – Historic, Archaeological and Traditional Cultural Properties of the Hanford Site, Washington.* DOE/RL-97-02. Richland, Washington.

Bauer, H. H., and J. J. Vaccaro. 1990. *Estimates of Ground-Water Recharge to the Columbia Plateau Regional Aquifer System, Washington, Oregon, and Idaho for Predevelopment and Current Land-Use Conditions*. Water Resources Investigation Report 88-4108, U.S. Geological Survey, Tacoma, Washington.

Bauer, H. H., J. J. Vaccaro, and R. C. Lane. 1985. *Maps Showing Ground-Water Levels in the Columbia River Basalt and Overlying Materials, Spring 1983, Southeastern Washington*. Water Resources Investigation Report 84-4360, U.S. Geological Survey, Tacoma, Washington.

Beak Consultants Inc. 1980. *Aquatic Ecological Studies Near WNP-1, 2 and 4*. August 1978-March 1980. WPPSS Columbia River Ecology Studies, Vol. 7, prepared for Washington Public Power Supply System by Beak Consultants Inc., Portland, Oregon.

Becker, J. M. 1993. *A Preliminary Survey of Selected Structures on the Hanford Site for Townsend's Big-Eared Bat (Plecotus townsendii)*. PNL-8916, Pacific Northwest Laboratory, Richland, Washington.

Bentley, R. D., J. L. Anderson, N. P. Campbell, and D. A. Swanson. 1980. *Stratigraphy and Structure of the Yakima Reservation, with Emphasis on the Columbia River Basalt Group*. Open-File Report 80-200, U.S. Geological Survey, Washington, DC.

Birnbaum, C.A. 1999. *Preserving Cultural Landscapes: Planning, Treatment, and Management of Historic Landscapes*. Historic Preservation Service Bulletin #36. (Web Site: http://www2.cr.nps.gov/tps/briefs/brief36.htm).

Bjornstad, B. N. 1984. *Suprabasalt Stratigraphy Within and Adjacent to the Reference Repository Location.* SD-BWI-DP-039, Rockwell Hanford Operations, Richland, Washington.

Bjornstad, B. N. 1985. "Late-Cenozoic Stratigraphy and Tectonic Evolution Within a Subsiding Basin, South-Central Washington." *Geological Society of America Abstracts with Programs* 17(7):524.

Bjornstad, B. N., and K. R. Fecht. 1989. "Pre-Wisconsin Glacial Outburst Floods: Pedogenic and Paleomagnetic Evidence from the Pasco Basin and Adjacent Channeled Scabland." *Geological Society of America Abstracts with Programs* 21(5):58.

Bjornstad, B. N., K. R. Fecht, and A. M. Tallman. 1987. *Quarternary Stratigraphy of the Pasco Basin Area, South-central Washington.* RHO-BW-SA-563A, Rockwell Hanford Operations, Richland, Washington.

Brandt, C. A., C. E. Cushing, W. H. Rickard, N. A. Cadoret, and R. Mazaika. 1993. *Biological Resources of the 300-FF-5 Operable Unit.* WHC-SD-EN-TI-121, Westinghouse Hanford Company, Richland, Washington.

Brown, D. J. 1960. *An Eolian Deposit Beneath 200-West Area.* HW- 67549, General Electric Company, Richland, Washington.

Brown, R. E. 1970. *Interrelationships of Geologic Formations and Processes Affecting Ecology as Exposed at Rattlesnake Springs, Hanford Project.* BNWL-B-29, Pacific Northwest Laboratories, Richland, Washington.

Brown, R. E. 1979. *A Review of Water Well Data from the Unconfined Aquifer in the Eastern and Southern Parts of the Pasco Basin.* RHO-BWI-C-56, Rockwell Hanford Operations, Richland, Washington.

Cadwell, L. L. 1994. *Wildlife Studies on the Hanford Site: 1993 Highlights Report.* PNL-9380, Pacific Northwest Laboratory, Richland, Washington.

Cardenas, A., J. Lewinsohn, C. Auger, J. L. Downs, L. L. Cadwell, and R. Burrows. 1997. *Characterization of a Sagebrush (Artemisia tridentata spp. wyomingensis) Die-Off on the Hanford Site.* PNNL-11673, Pacific Northwest National Laboratory, Richland, Washington.

CEQ (see Council on Environmental Quality).

Chatters, J. C. 1982. "Prehistoric Settlement and Land Use in the Dry Columbia Basin." *Northwest Anthropol. Res. Notes* 16:125-147.

Chatters, J. C., ed. 1989. *Hanford Cultural Resources Management Plan.* PNL-6942, Pacific Northwest Laboratory, Richland, Washington.

Chatters, J. C., and N. A. Cadoret. 1990. *Archeological Survey of the 200-East and 200-West Areas, Hanford Site, Washington.* PNL-7264, Pacific Northwest Laboratory, Richland, Washington.

Chatters, J. C., and H. A. Gard. 1992. *Hanford Cultural Resources Laboratory Annual Report for Fiscal Year 1991.* PNL-8101, Pacific Northwest Laboratory, Richland, Washington.

Chatters, J. C., N. A. Cadoret, and P. E. Minthorn. 1990. *Hanford Cultural Resources Laboratory Annual Report for Fiscal Year 1989*. PNL-7362, Pacific Northwest Laboratory, Richland, Washington.

Chatters J. C., H. A. Gard, and P. E. Minthorn. 1991. *Hanford Cultural Resources Laboratory Annual Report for Fiscal Year 1990*. PNL-7853, Pacific Northwest Laboratory, Richland, Washington.

Chatters, J. C., H. A. Gard, and P. E. Minthorn. 1992. *Fiscal Year 1991 Report on Archaeological Surveys of the 100 Areas, Hanford Site, Washington*. PNL-8143, Pacific Northwest Laboratory, Richland, Washington.

Cleveland, G. C., B. Cochran, J. Giniger, and H. H. Hammatt. 1976. *Archaeological Reconnaissance on the Mid-Columbia and Lower Snake River Reservoirs for the Walla Walla District Corps of Engineers*. Washington Archaeological Research Center Project Report 27, Washington State University, Pullman, Washington.

CNSS (see Council of the National Seismic System).

Connelly, M. P., B. H. Ford, and J. V. Borghese. 1992a. *Hydrogeologic Model for the 200 West Groundwater Aggregate Area*. WHC-SD-EN-TI-014, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Connelly, M. P., B. H. Ford, J. W. Lindberg, S. J. Trent, C. D. Delaney, and J. V. Borghese. 1992b. *Hydrogeologic Model for the 200 East Groundwater Aggregate Area*. WHC-SD-EN-TI-019, Westinghouse Hanford Company, Richland, Washington.

Council on Environmental Quality (CEQ). 1995. *Environmental Justice. Guidance Under the National Environmental Policy Act.* Executive Office of the President, Washington, DC.

Council of the National Seismic System (CNSS). 1999. On-line Earthquake Catalog. Council of the National Seismic System. (Web Site: http://www.quake.geo.berkley.edu/cnss).

Critchfield, H. J. 1974. *General Climatology*. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Cushing, C. E., Jr. 1967a. "Concentration and Transport of ^{32}P and ^{65}Z by Columbia River Plankton." *Limnol. Oceanogr*. 12:330-332.

Cushing, C. E., Jr. 1967b. "Periphyton Productivity and Radionuclide Accumulation in the Columbia River, Washington, USA" *Hydrobiologia* 29:125-139.

Cushing, C. E., and E. G. Wolf. 1982. "Organic Energy Budget of Rattlesnake Springs, Washington." *Am. Midl. Nat.* 107(2):404-407.

Cushing, C. E., and E. G. Wolf. 1984. "Primary Production in Rattlesnake Springs, a Cold Desert Spring-Stream." *Hydrobiologia* 114:229-236.

Cushing, C. E., C. D. McIntire, J. R. Sedell, K. W. Cummins, G. W. Minshall, R. C. Petersen, and R. L. Vannote. 1980. "Comparative Study of Physical-Chemical Variables of Streams Using Multivariate Analyses." *Arch. Hydrobiologia* 89(3):343-352.

DART (See Data Aquisition in Real Time).

Data Aquisition in Real Time (DART). 1999. Columbia Basin Research Project, Department of Fisheries, University of Washington, Seattle, Washington. (Web Site: http://www.cqs.washington.edu/index.html)

Daubenmire, R. 1970. *Steppe Vegetation of Washington.* Technical Bulletin 62, Experimental Station, Washington State University, Pullman, Washington.

Dauble, D. D., and D. G. Watson. 1990. *Spawning and Abundance of Fall Chinook Salmon (Oncorhynchus tshawytscha) in the Hanford Reach of the Columbia River, 1948-1988.* PNL-7289, Pacific Northwest Laboratory, Richland, Washington.

Dauble, D. D., R. M. Ecker, L. W. Vail, and D. A. Neitzel. 1987. *Downstream Extent of the N Reactor Plume.* PNL-6310, Pacific Northwest Laboratory, Richland, Washington.

Daugherty, R. D. 1952. "Archaeological Investigations of O'Sullivan Reservoir, Grant County, Washington." *American Antiquity* 17:274-278.

Delaney, C. D., K. A. Lindsey, and S. P. Reidel. 1991. *Geology and Hydrology of the Hanford Site: A Standardized Text for Use in Westinghouse Hanford Company Documents and Reports.* WHC-SD-ER-TI-0003, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Dirkes, R. L. 1990. *1988 Hanford Riverbank Springs Characterization Report..* PNL-7500, Pacific Northwest Laboratory, Richland, Washington.

Dirkes, R. L. 1993. *Columbia River Monitoring: Distribution of Tritium in Columbia River Water at the Richland Pumphouse.* PNL-8531, Pacific Northwest Laboratory, Richland, Washington.

Dirkes, R. L., and R. W. Hanf. 1995. *Hanford Site Environmental Report for Calendar Year 1994.* PNL-10574, Pacific Northwest Laboratory, Richland, Washington.

Dirkes, R. L. and R. W. Hanf. 1997. *Hanford Site Environmental Report for Calendar Year 1996.* PNNL – 11472, Pacific Northwest National Laboratory, Richland, Washington.

Dirkes, R. L., and R. W. Hanf. 1998. *Hanford Site Environmental Report for Calendar Year 1997.* PNNL-11795, Pacific Northwest National Laboratory, Richland, Washington.

Dirkes, R. L., R. W. Hanf, R. K. Woodruff, and R. E. Lundgren. 1994. *Hanford Site Environmental Report for Calendar Year 1993.* PNL-9823, Pacific Northwest Laboratory, Richland, Washington.

DOE (see U.S. Department of Energy).

DOI (see U.S. Department of the Interior).

Downs, J. L., W. H. Rickard, C. A. Brandt, L. L. Cadwell, C. E. Cushing, D. R. Geist, R. M. Mazaika, D. A. Neitzel, L. E. Rogers, M. R. Sackschewsky, and J. J. Nugent. 1993. *Habitat Types on the Hanford Site: Wildlife and Plant Species of Concern.* PNL-8942, Pacific Northwest Laboratory, Richland, Washington.

Drost, B. W., K. M. Schurr, and W. E. Lum II. 1989. *Selected Ground-Water Information for the Pasco Basin and Adjacent Areas, Washington, 1986-1989*. Open-File Report 89-228, U.S. Geological Survey, Tacoma, Washington.

Drucker, P. 1948. *Appraisal of the Archaeological Resources of the McNary Reservoir, Oregon-Washington*. Report on file, Columbia Basin Project, River Basin Survey, Smithsonian Institution, Washington, DC.

Eberhardt, L. E., R. E. Anthony, and W. H. Rickard. 1989. "Survival of Juvenile Canada Geese during the Rearing Period." *J. Wildlife Management* 53:372-377.

Ecology (see Washington State Department of Ecology).

Emery, R. M., and M. C. McShane. 1980. "Nuclear Waste Ponds and Streams on the Hanford Site: An Ecological Search for Radiation Effects." *Health Phys*ics 38:787-809.

ERDA (see U.S. Energy Research and Development Administration).

ERTEC. 1981. *Cultural Resources Survey and Exploratory Excavations for the Skagit-Hanford Nuclear Power Project*. ERTEC Northwest, Seattle, Washington.

ERTEC. 1982. *A Cultural Resources Overview and Scenic and Natural Resources Assessment for the Skagit-Hanford Nuclear Power Project*. ERTEC Northwest, Seattle, Washington.

Evergreen Community Development Association. 1986. *Tri-Cities Enterprise Center Business Development Plan*. Evergreen Community Development Association, Richland, Washington.

Fayer, M. J., and T. B. Walters. 1995. *Estimated Recharge Rates at the Hanford Site*. PNL-10285, Pacific Northwest Laboratory, Richland, Washington.

Fecht, K. R., R. E. Gephart, D. L. Graham, S. P. Reidel, and A. C. Rohay. 1984. *Summary of Geotechnical Information in the Rattlesnake Mountain Area*. SD-BWI-TI-247, Rockwell Hanford Operations, Richland, Washington.

Fitzner, R. E., and R. H. Gray. 1991. "The Status, Distribution, and Ecology of Wildlife on the U.S. DOE Hanford Site: A Historical Overview of Research Activities." *Environ. Monit. Assess.* 18:173-202.

Fitzner, R. E., and S. G. Weiss. 1994. *Bald Eagle Site Management Plan for the Hanford Site, South Central Washington*. DOE/RL-94-150, U.S. Department of Energy, Richland, Washington.

Fitzner, R. E., S. G. Weiss, and J. A. Stegen. 1994. *Threatened and Endangered Wildlife Species of the Hanford Site Related to CERCLA Characterization Activities*. WHC-EP-0513, Westinghouse Hanford Company, Richland, Washington.

Frest, T. J., and E. J. Johannes. 1993. *Mollusc Survey of the Hanford Site, Benton and Franklin Counties, Washington*. PNL-8653, Pacific Northwest Laboratory, Richland, Washington.

Gaines, W. E. 1987. *Secondary Production of Benthic Insects in Three Cold Desert Streams.* PNL-6286, Pacific Northwest Laboratory, Richland, Washington.

Gaines, W. L., C. E. Cushing, and S. D. Smith. 1992. "Secondary Production Estimates of Benthic Insects in Three Cold Desert Streams." *Great Basin Naturalist* 52(1):11-24.

Gard, H. A., and R. M. Poet. 1992. *Archaeological Survey of the McGee Ranch Vicinity, Hanford Site, Washington.* PNL-8186, Pacific Northwest Laboratory, Richland, Washington.

Gee, G. W., and P. R. Heller. 1985. *Unsaturated Water Flow at the Hanford Site: A Review of Literature and Annotated Bibliography.* PNL-5428, Pacific Northwest Laboratory, Richland, Washington.

Gee, G. W., and R. R. Kirkham. 1984. *Arid Site Water Balance: Evaporation Modeling and Measurement.* PNL-5177, Pacific Northwest Laboratory, Richland, Washington.

Gee, G. W., M. J. Fayer, M. L. Rockhold, and M. D. Campbell. 1992. "Variations in Recharge at the Hanford Site." *Northwest Science* 66(4):237.

Geomatrix. 1994. Probabilistic Seismic Hazard Assessment DOE Hanford Site, Washington. Prepared for Westinghouse Hanford Company. WHC-SD-W236A-TI-002, Westinghouse Hanford Company, Richland, Washington.

Geomatrix. 1996. Probabilistic Seismic Hazard Analysis DOE Hanford Site, Washington. Prepared for Westinghouse Hanford Company. WHC-SD-W236A-TI-002, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

Gephardt, R. E., P. A. Eddy, R. C. Arnett, and G. A. Robinson. 1976. *Geohydrologic Study of the West Lake Basin.* ARH-CD-775, Atlantic Richfield Hanford Company, Richland, Washington.

Gilmore, T. J., D. R. Newcomer, S. K. Wurstner, and F. A. Spane Jr. 1992. *Calculation of Groundwater Discharge to the Columbia River in the 100-N Area.* PNL-8057, Pacific Northwest Laboratory, Richland, Washington.

Graham, M. J., M. D. Hall, S. R. Straight, and W. R. Brown. 1981. *Hydrology of the Separations Area.* RHO-ST-42, Rockwell Hanford Operations, Richland, Washington.

Graham, M. J., G. V. Last, and K. R. Fecht. 1984. *An Assessment of Aquifer Intercommunication with B Pond-Gable Mountain Pond Area of the Hanford Site.* RHO-RE-ST-12P, Rockwell Hanford Operations, Richland, Washington.

Gray, R. H., and D. D. Dauble. 1977. "Checklist and Relative Abundance of Fish Species from the Hanford Reach of the Columbia River." *Northwest Science* 51:208-215.

Grazulis, T. P. 1984. *Violent Tornado Climatology, 1880-1982.* NUREG/CR-3670, U.S. Nuclear Regulatory Commission, Washington, DC.

Greene, G. S. 1975. *Prehistoric Utilization of the Channeled Scablands of Eastern Washington.* Ph.D. Dissertation, Department of Anthropology, Washington State University, Pullman, Washington.

Greengo, R. E. 1982. *Studies in Prehistory: Priest Rapids and Wanapum Reservoir Areas, Columbia River, Washington.* Department of Anthropology, University of Washington, Seattle, Washington.

Grolier, M. J. 1978. *Geology of Parts of Grant, Adams, and Franklin Counties, East-Central Washington.* Bulletin 71, Washington State Department of Natural Resources, Olympia, Washington.

Grolier, M. J., and J. W. Bingham. 1978. *Geology of Parts of Grant, Adams, and Franklin Counties, East-Central Washington.* Bulletin 71, Washington State Department of Natural Resources, Olympia, Washington.

Gustafson, E. P. 1973. *The Vertebrate Fauna of the Late Pliocene Ringold Formation, South-Central Washington.* Washington State University, Pullman, Washington.

Hagood, M. C. 1985. *Structure and Evolution of the Horse Heaven Hills in South-Central Washington.* RHO-BWI-SA-344 P, Rockwell Hanford Operations, Richland, Washington.

Hajek, B. F. 1966. *Soil Survey: Hanford Project in Benton County, Washington.* BNWL-243, Pacific Northwest Laboratories, Richland, Washington.

Hall, John A. (ed.). 1998. *Biodiversity Inventory and Analysis of the Hanford Site, 1997 Annual Report.* The Nature Conservancy of Washington, Seattle, Washington.

Hanson, W. C., and R. L. Browning. 1959. "Nesting Studies of Canada Geese on the Hanford Reservation, 1953-1956." *J. Wildlife Manage.* 23:129-137.

Hartman, M. J., and P. E. Dresel (eds). 1998. *Hanford Site Groundwater Monitoring for Fiscal Year 1997*, PNNL-11793, Pacific Northwest National Laboratory, Richland Washington.

Hartman, M. J., and K. A. Lindsey. 1993. *Hydrogeology of the 100-N Area, Hanford Site, Washington.* WHC-SD-EN-EV-027, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Hartman, M. J., and R. E. Peterson. 1992. *Hydrologic Information Summary for the Northern Hanford Site.* WHC-SD-EN-TI-023, Westinghouse Hanford Company, Richland, Washington.

Hitchcock, C.L., and A. Cronquist. 1973. *Flora of the Pacific Northwest.* University of Washington Press, Seattle, Washington.

Hoitink, D. J., and K. W. Burk. 1997. *Climatological Data Summary 1996 with Historical Data.* PNL-11471, Pacific Northwest Laboratory, Richland, Washington.

Hoitink, D.J., K.W. Burk and J.V. Ramsdell. 1999. *Hanford Site Climatological Data Summary 1998 With Historical Data.* PNNL-12087, Pacific Northwest National Laboratory, Richland, Washington.

Jamison, J. D. 1982. *Standardized Input for Hanford Environmental Impact Statements Part II: Site Descriptions.* PNL-3509, Pt. 2, Pacific Northwest Laboratory, Richland, Washington.

Jenkins, O. P. 1922. *Underground Water Supply of the Region About White Bluffs and Hanford.* Bulletin No. 26, Division of Geology, State of Washington Department of Conservation and Development, Olympia, Washington.

Jensen, E. J. 1987. *An Evaluation of Aquifer Intercommunication Between the Unconfined and Rattlesnake Ridge Aquifers on the Hanford Site.* PNL-6313, Pacific Northwest Laboratory, Richland, Washington.

Johnson, V. G., F. N. Hodges, and S. P. Reidel. 1992. "Arid Environment Aquifers: An Example from South Central Washington." *Geological Society of America* (ABS) 24(5):36.

Johnson, V. G., D. L. Graham, and S. P. Reidel. 1993. "Methane in Columbia River Basalt Aquifers: Isotopic and Geohydrologic Evidence for a Deep Coal-Bed Gas Source in the Columbia Basin, Washington." *American Association of Petroleum Geologists Bulletin* 77(7):1192-1207.

Kincaid, C.T., M.P. Bergeron, C.R. Cole, M.D. Freshley, N.L. Hassig, V.G. Johnson, D.I. Kaplan, R.J. Serne, G.P. Streile, D.L. Strenge, P.D. Thorne, L.W. Vail, G.A. Whyatt, and S.K. Wurstner. 1998. *Composite Analysis for Low-Level Waste Disposal in the 200 Areas Plateau of the Hanford Site.* PNNL-11800, Pacific Northwest National Laboratory, Richland, Washington.

Kipp, K. L., and R. D. Mudd. 1973. *Collection and Analysis of Pump Test Data for Transmissivity Values.* BNWL-1709, Pacific Northwest Laboratories, Richland, Washington.

Krieger, H. W. 1928. "A Prehistoric Pithouse Village Site at Wahluke, Grant County, Washington." *Proc. U.S. Natl. Mus.* 73:1-29.

Landeen, D. (ed.). 1996. Wetes pe m'e wes - I am of this land. [Wildlife of the Hanford Site]. Confluence Press, Lewiston, Idaho.

Landeen, D. S., M. R. Sackschewsky, and S. Weiss. 1993. *100 Areas CERCLA Ecological Investigations.* WHC-EP-0620, Westinghouse Hanford Company, Richland, Washington.

Last, G. V., B. N. Bjornstad, M. P. Bergeron, D. W. Wallace, D. R. Newcomer, J. A. Schremke, M. A. Chamness, C. S. Cline, S. P. Airhart, and J. S. Wilbur. 1989. *Hydrogeology of the 200 Areas Low Level Burial Grounds - An Interim Report.* PNL-6820, Pacific Northwest Laboratory, Richland, Washington.

Last, G. V., M. K. Wright, M. E. Crist, N. A. Cadoret, M. V. Dawson, K. A. Simmons, D. W. Harvey, and J. G. Longenecker. 1993. *Hanford Cultural Resources Laboratory Annual Report for Fiscal Year 1993.* PNL-10077, Pacific Northwest Laboratory, Richland, Washington.

Leonhardy, F. C., and D. G. Rice. 1970. "A Proposed Culture Typology for the Lower Snake River Region, Southeastern Washington." *Northwest Anthropol. Res. Notes* 4:1-29.

Liikala, T. L., R. L. Aaberg, N. J. Aimo, D. J. Bates, T. J. Gilmore, E. J. Jensen, G. V. Last, P.L. Oberlander, K. B. Olsen, K. R. Oster, L. R. Roome, J. C. Simpson, S. S. Teel, and . J. Westergard. 1988. *Geohydrologic Characterization of the Area Surrounding the 183-H Solar Evaporation Basins.* PNL-6728, Pacific Northwest Laboratory, Richland, Washington.

Lindberg, J. W. 1993a. *Geology of the 100-B/C Area, Hanford Site, South-Central Washington*. WHC-SD-EN-TI-133, Westinghouse Hanford Company, Richland, Washington.

Lindberg, J. W. 1993b. *Geology of the 100-K Area, Hanford Site, South-Central Washington*. WHC-SD-EN-TI-155, Westinghouse Hanford Company, Richland, Washington.

Lindsey, K. A. 1991a. *Revised Stratigraphy for the Ringold Formation, Hanford Site, South-Central Washington*. WHC-SD-EN-EE-004, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Lindsey, K. A. 1991b. *Revised Stratigraphy for the Ringold Formation, Hanford Site, South-Central Washington*. WHC-SD-EN-EE-004, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Lindsey, K. A. 1992. *Geology of the Northern Part of the Hanford Site: An Outline of Data Sources and the Geologic Setting of the 100 Areas*. WHC-SD-EN-TI-011, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Lindsey, K. A. 1996. *The Miocene to Pliocene Ringold Formation and Associated Deposits of the Ancestral Columbia River System, South-central Washington and North-central Oregon*. Washington Division of Geology and Earth Resources Open File Report 96-8, Washington State Department of Natural Resources, Olympia, Washington.

Lindsey, K. A. and D. R. Gaylord. 1990. *Sedimentology and Stratigraphy of the Miocene-Pliocene Ringold Formation, Hanford Site, South-central Washington*. Northwest Science 64:165-180.

Lindsey, K. A., and G. K. Jaeger. 1993. *Geologic Setting of the 100-HR-3 Operable Unit, Hanford Site, South-Central Washington*. WHC-SD-EN-TI-132, Westinghouse Hanford Company, Richland, Washington.

Lindsey, K. A., B. N. Bjornstad, J. W. Lindberg, and K. M. Hoffman. 1992. *Geologic Setting of the 200 East Area: An Update*. WHC-SD-EN-TI-012, Westinghouse Hanford Company, Richland, Washington.

Lindsey, K. A., J. L. Slate, G. K. Jaeger, K. J. Swett, and R. B. Mercer. 1994. *Geologic Setting of the Low-Level Burial Grounds*. WHC-SD-EN-TI-290, Rev. 0., Westinghouse Hanford Company, Richland, Washington.

Malde, H. E. 1968. *The Catastrophic Late Pleistocene Bonneville Flood in the Snake River Plain, Idaho*. Professional Paper 596, U.S. Geological Survey, Washington, DC.

Marceau, T. E. 1998. *Hanford Site Manhattan Project and Cold War Era Historic Treatment Plan*. DOE/RL-97-56 Rev. 1, U.S. Department of Energy, Richland, Washington.

McCormack, W. D., and J.M.V. Carlile. 1984. *Investigation of Ground-Water Seepage from the Hanford Shoreline of the Columbia River*. PNL-5289, Pacific Northwest Laboratory, Richland, Washington.

McGavock, E. H., W. D. Wiggens, R. L. Blazs, P. R. Boucher, L. L. Reed, and M. C. Smith. 1987. *Water Resources Data Washington Water Year 1985*. U.S. Geological Survey, Tacoma, Washington.

McMahon, W. J., and R. E. Peterson. 1992. *Estimating Aquifer Hydraulic Properties Using the Ferris Method, Hanford Site, Washington*. DOE/RL-92-64, U.S. Department of Energy, Richland, Washington.

Mize, A. L. 1993. *Differential Utilization of Allochthonous and Autochthonous Carbon By Aquatic Insects of Two Shrub-Steppe Desert Spring-Streams: A Stable Carbon Isotope Analysis and Critique of the Method*. PNL-8684, Pacific Northwest Laboratory, Richland, Washington.

Morgan, V. 1981. *Archaeological Reconnaissance of the North Richland Toll Bridge and Associated Access Roads (L6909)*. Archaeological and Historical Services, Eastern Washington University, Cheney, Washington.

Mullineaux, D. R., R. E. Wilcox, W. F. Ebaugh, R. Fryxell, and M. Rubin. 1978. "Age of the Last Major Scabland Flood of the Columbia Plateau in Eastern Washington." *Quaternary Research* 10:171-180.

Myers, C. W., S. M. Price, J. A. Caggiano, M. P. Cochran, W. J. Czimer, N. J. Davidson, R. C. Edwards, K. R. Fecht, G. E. Holmes, M. G. Jones, J. R. Kunk, R. D. Landon, K. Ledgerwood, J. T. Lillie, P. E. Long, T. H. Mitchell, E. H. Price, S. P. Reidel, and A. M. Tallman. 1979. *Geologic Studies of the Columbia Plateau Status Report*. RHO-BWI-ST-4, Rockwell Hanford Operations, Richland, Washington.

Napier, B. A., R. A. Peloquin, D. L. Strenge, and J. V. Ramsdell. 1988. *GENII - The Hanford Environmental Dosimetry Software System. Volume I - Conceptual Representation*. PNL-6584, Pacific Northwest Laboratory, Richland, Washington.

Neitzel, D. A., T. L. Page, and R. W. Hanf, Jr. 1982a. "Mid-Columbia River Microflora." *J. Freshwater Ecology* 1(5):495-505.

Neitzel, D. A., T. L. Page, and R. W. Hanf, Jr. 1982b. "Mid-Columbia River Zooplankton." *Northwest Science* 57:112-118.

Newcomb, R. C. 1958. *Ringold Formation of Pleistocene age in type locality, the White Bluffs, Washington*. American Journal of Science 256: 328-340.

Newcomb, R. C., J. R. Strand, and F. J. Frank. 1972. *Geology and Ground-Water Characteristics of the Hanford Reservation of the U.S. Atomic Energy Commission, Washington*. Professional Paper 717, U.S. Geological Survey, Washington, DC.

Newcomer, D. R., K. D. Pohlod, and J. P. McDonald. 1991. *Water-Table Elevations on the Hanford Site, 1990*. PNL-7693, Pacific Northwest Laboratory, Richland, Washington.

NRC (see U.S. Nuclear Regulatory Commission).

Office of Financial Management (OFM). 1998a. *1998 Data Book, State of Washington*. Office of Financial Management, Forecasting Division, Olympia, Washington.

Office of Financial Management (OFM). 1998b. *1998 Population Trends for Washington State*. Office of Financial Management, Forecasting Division, Olympia, Washington.

Pabst, R. J. (Ed). 1995. *Biodiversity Inventory and Analysis of the Hanford Site, 1994 Annual Report*. Nature Conservancy of Washington, Seattle, Washington.

Page, T. L., and D. A. Neitzel. 1978. "Columbia River Benthic Macrofauna and Microfauna Near WNP 1, 2, and 4: January through December 1977." In *Aquatic Ecological Studies Near WNP 1, 2, and 4, January through December 1977, WPPSS Columbia River Ecology Studies*, Vol. 5, Section 4. Battelle, Pacific Northwest Laboratories, Richland, Washington.

Page, T. L., D. A. Neitzel, and R. W. Hanf. 1979. "Columbia River Benthic Macrofauna and Microflora Near WNP 1, 2, and 4: January through August 1978." In *Aquatic Ecological Studies Near WNP 1, 2, and 4, January through August 1978, WPPSS Columbia River Ecology Studies*, Vol. 6, Section 4. Battelle, Pacific Northwest Laboratories, Richland, Washington.

Parker, P. L. and T. F. King. 1990. *Guidelines for Evaluating and Documenting Traditional Cultural Properties*. National Register Bulletin 38, National Park Service, Washington, DC.

Petersen, R. E. 1992. *Hydrologic and Geologic Data Available for the Region North of Gable Mountain, Hanford Site, Washington*. WHC-SD-EN-TI-006, Westinghouse Hanford Company, Richland, Washington.

Peterson, R. E., and V. G. Johnson. 1992. *Riverbank Seepage of Groundwater Along the 100 Areas Shoreline, Hanford Site*. WHC-EP-0609, Westinghouse Hanford Company, Richland, Washington.

Peterson, R. E., R. F. Raidl, and C. W. Denslow. 1996. *Conceptual Site Models for Groundwater Contamination at 100-BC-5, 100-KR-4, 100-HR-3, and 100-FR-3 Operable Units*. BHI-00917, Bechtel Hanford Incorporated, Richland, Washington.

Poston, T. M., K. R. Price, and D. R. Newcomer. 1991. *An Evaluation of the Chemical, Radiological, and Ecological Conditions of West Lake on the Hanford Site*. PNL-7662, Pacific Northwest Laboratory, Richland, Washington.

Puget Sound Power and Light Company (PSPL). 1982. *Preliminary Safety Analysis for Skagit/Hanford Nuclear Project*. Amendment 29, Puget Sound Power and Light Company, Bellevue, Washington.

Ramsdell, J. V., and G. L. Andrews. 1986. *Tornado Climatology of the Contiguous United States*. NUREG/CR-4461, U.S. Nuclear Regulatory Commission, Washington, DC.

Reidel, S. P. 1984. "The Saddle Mountains: The Evolution of an Anticline in the Yakima Fold Belt." *American Journal of Science* 284:942-978.

Reidel, S. P. and K. R. Fecht. 1981. "Wanapum and Saddle Mountains Basalts of the Cold Creek Syncline Area." In *Subsurface Geology of the Cold Creek Syncline*, eds. C. W. Myers and S. M. Price. RHO-BWI-ST-14, Rockwell Hanford Operations, Richland, Washington.

Reidel, S. P., and K. R. Fecht. 1994a. *Geologic map of the Richland 1:100,000 quadrangle, Washington.* Open File Report 94-8, 21 pp., 1 plate, Washington Division of Geology and Earth Resources, Olympia, Washington.

Reidel, S.P. and K.R. Fecht, K.R. 1994b. *Geologic map of the Priest Rapids 1:100,000 quadrangle, Washington.* Open File Rep. 94-13, 22 pp. 1 plate, Washington Division of Geology and Earth Resources, Olympia, Washington.

Reidel, S. P., K. R. Fecht, M. C. Hagood, and T. L. Tolan. 1989. "The Geologic Evolution of the Central Columbia Plateau." In *Volcanism and Tectonism in the Columbia River Flood-Basalt Province*, Special Paper 239, pp. 247-264, eds. S. P. Reidel and P. R. Hooper, Geological Society of America, Boulder, Colorado.

Reidel, S. P., K. A. Lindsey, and K. R. Fecht. 1992. *Field Trip Guide to the Hanford Site.* WHC-MR-0391. Westinghouse Hanford Company, Richland, Washington.

Reidel, S. P., N. P. Campbell, K. R. Fecht, and K. A. Lindsey. 1994. *Late Cenozoic Structure and Stratigraphy of South-central Washington. In:* Lasmanis, R. and E. S. Cheney, convenors, Regional Geology of Washington State. Washington Division of Geology and Earth Resources Bulletin 80: 159-180.

Relander, C. 1956. *Drummers and Dreamers*. Caxton Printers, Caldwell, Idaho.

Rice, D. G. 1968a. *Archaeological Reconnaissance: Ben Franklin Reservoir Area, 1968*. Washington State University, Laboratory of Anthropology, Pullman, Washington.

Rice, D. G. 1968b. *Archaeological Reconnaissance: Hanford Atomic Works*. U.S. Atomic Energy Commission, National Park Service and Washington State University, Pullman, Washington.

Rice, D. G. 1976. *The Log Structure at White Bluffs Landing, Franklin County, Washington.* Anthropological Research Manuscript Series No. 25, University of Idaho, Moscow, Idaho.

Rice, D. G. 1980a. *Overview of Cultural Resources on the Hanford Reservation in South Central Washington State*. Report submitted to U.S. Department of Energy, Richland Operations, Richland, Washington.

Rice, D. G. 1980b. *Cultural Resources Assessment of the Hanford Reach of the Columbia River, State of Washington*. U.S. Army Corps of Engineers, Seattle District, Seattle, Washington.

Rice, D. G. 1981. *Archaeological Transects Through Interior Dunes on the Hanford Reservation, Washington*. U.S. Department of Energy, Richland, Washington.

Rice, D. G. 1984. *Archaeological Inventory of the Basalt Waste Isolation Project, Hanford Reservation, Washington*. SD-BWI-TA-007, Rockwell Hanford Operations, Richland, Washington.

Rice, D. G. 1987. *Archaeological Reconnaissance of Gable Butte and Gable Mountain on the Hanford Site, Washington*. Westinghouse Hanford Company, Richland, Washington.

Rice, H. S., D. H. Stratton, and G. W. Lundeman. 1978. *An Archaeological and Historic Survey of the 400 Area, Hanford Reservation.* National Heritage, Inc., Pullman, Washington.

Rickard, W. H., and L. E. Rogers. 1983. "Industrial Land Use and the Conservation of Native Biota in the Shrub-Steppe Region of Western North America." *Environ. Conserv.* 10:205-211.

Rickard, W. H., R. E. Fitzner, and C. E. Cushing. 1981. "Biological Colonization of an Industrial Pond." *Environ. Conserv.* 8:241-247.

Rigby, J. G., and K. Othberg. 1979. *Reconnaissance Surficial Geologic Mapping of the Late Cenozoic Sediments of the Columbia Basin, Washington.* Open-File Report 79-3, Washington State Department of Natural Resources, Division of Geology and Earth Resources, Olympia, Washington.

Rogers, L. E., and W. H. Rickard. 1977. *Ecology of the 200 Area Plateau Waste Management Environs: A Status Report.* PNL-2253, Pacific Northwest Laboratory, Richland, Washington.

Rohay, A. C. 1987. *Earthquake Focal Mechanisms, Recurrence Rates and Deformation in the Columbia River Basalts.* RHO-BW-SA-666 P, Rockwell Hanford Operations, Richland, Washington.

Rohay, A. C. 1989. "Earthquake Recurrence Rate Estimates for Eastern Washington and the Hanford Site." In *Proceedings, Second DOE Natural Phenomena Hazards Mitigation Conference,* CONF-8910192, October 3-5, 1989, Knoxville, Tennessee, sponsored by U.S. Department of Energy Headquarters, Office of Nuclear Safety, NTIS, Springfield, Virginia.

Sackschewsky, M. R., D. S. Landeen, G. I. Baird, W. H. Rickard, and J. L. Downs. 1992. *Vascular Plants of the Hanford Site.* WHC-EP-0554, Westinghouse Hanford Company, Richland, Washington.

Schalla, R., R. W. Wallace, A. L. Aaberg, S. P. Arihart, D. J. Bates, J.V.M. Carlile, C. S. Cline, I. Dennison, M. D. Freshley, P. R. Heller, E. J. Jensen, K. B. Olsen, R. G. Parkhurst, J. T. Rieger, and E. J. Westergard. 1988. *Interim, Characterization Report for the 300 Area Process Trenches.* PNL-6716, Pacific Northwest Laboratory, Richland, Washington.

Schmincke, H. 1964. *Petrology, Paleocurrents, and Stratigraphy of the Ellensburg Formation.* Johns Hopkins University, Baltimore, Maryland.

Schreckhise, R. G., K. Rhoads, J. S. Davis, B. A. Napier, and J. V. Ramsdell. 1993. *Recommended Environmental Dose Calculation Methods and Hanford-Specific Parameters.* PNL-3777, Rev. 2, Pacific Northwest Laboratory, Richland, Washington.

Schwab, G. E., R. M. Colpitts Jr., and D. A. Schwab. 1979. *Spring Inventory of the Rattlesnake Hills.* W.K. Summers and Associates, Inc., Socorro, New Mexico.

Skaggs, R. L., and W. H. Walters. 1981. *Flood Risk Analysis of Cold Creek Near the Hanford Site.* RHO-BWI-C-120/PNL-4219, Rockwell Hanford Operations, Richland, Washington.

Slate, J. 1996. *Buried Carbonate Paleosols Developed in Pliocene-Pleistocene Deposits of the Pasco Basin, South-central Washington, U.S.A.* Quarternary International 34-36: 191-196. Published by Elsevier Science Ltd., Great Britain.

Smith, G. A. 1988. "Neogene Synvolcanic and Syntectonic Sedimentation in Central Washington." *Geologic Society of America Bulletin* 100:1479-1492.

Smith, W. C., M. L. Uebelacker, T. E. Eckert, and L. J. Nickel. 1977. *An Archaeological Historical Survey of the Proposed Transmission Power Line Corridor from Ashe Substation, Washington to Pebble Springs Substation, Oregon*. Washington Archaeological Research Center Project Report 42, Washington State University, Pullman, Washington.

Soll, J. A., and C. Soper (eds). 1996. *Biodiversity Inventory and Analysis of the Hanford Site, 1995 Annual Report*. The Nature Conservancy of Washington, Seattle, Washington.

Spane, F. A., Jr. 1987. *Fresh-Water Potentiometric Map and Inferred Flow Direction of Ground Water Within the Mabton Interbed, Hanford Site, Washington State - January 1987*. SD-BWI-TI-335, Rockwell Hanford Operations, Richland, Washington.

Spier, L. 1936. *Tribal Distribution in Washington*. General Services in Anthropology No. 3, George Banta Publishing Co., Menasha, Wisconsin.

Stone, W. A., D. E. Jenne, and J. M. Thorp. 1972. *Climatography of the Hanford Area*. BNWL-1605, Pacific Northwest Laboratories, Richland, Washington.

Stone, W. A., J. M. Thorp, O. P. Gifford, and D. J. Hoitink. 1983. *Climatological Summary for the Hanford Area*. PNL-4622, Pacific Northwest Laboratory, Richland, Washington.

Supply System (see Washington Public Power Supply System).

Swanson, D. A., J. L. Anderson, R. D. Bentley, V. E. Camp, J. N. Gardner, and T. L. Wright. 1979a. *Reconnaissance Geologic Map of the Columbia River Basalt Group in Eastern Washington and Northern Idaho*. Open-File Report 79-1363, U.S. Geological Survey, Washington, DC.

Swanson, D. A., T. L. Wright, P. R. Hooper, and R. D. Bentley. 1979b. *Revisions in Stratigraphic Nomenclature of the Columbia River Basalt Group*. USGS Bulletin 1457, U.S. Geological Survey, Boulder, Colorado.

Swanson, D. A., J. L. Anderson, V. E. Camp, P. R. Hooper, W. H. Taubeneck, and T. L. Wright. 1981. *Reconnaissance Geologic Map of the Columbia River Basalt Group, Northern Oregon and Western Idaho*. Open-File Report 81-0797, U.S. Geological Survey, Washington, DC.

Swanson, L. C. 1992. *Phase 1 Hydrogeologic Summary of the 300-FF-5 Operable Unit, 300 Area*. WHC-SD-EN-TI-052, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Tallman, A. M., K. R. Fecht, M. C. Marratt, and G. V. Last. 1979. *Geology of the Separation Areas Hanford Site, South-Central Washington*. RHO-ST-23, Rockwell Hanford Operations, Richland, Washington.

Tallman, A. M., J. T. Lillie, and K. R. Fecht. 1981. "Suprabasalt Sediments of the Cold Creek Syncline Area." In *Subsurface Geology of the Cold Creek Syncline*, eds. C. W. Myers and S. M. Price. RHO-BW1-ST-14, Rockwell Hanford Operations, Richland, Washington.

Thoms, A. V. 1983. *Archaeological Investigations in Upper McNary Reservoir: 1981-1982.* Laboratory of Archaeology and History Project Report No. 15, Washington State University, Pullman, Washington.

Thornbury, W. D. 1965. *Regional Geomorphology of the United States.* John Wiley and Sons, Inc., New York.

Thorne, P. D., M. A. Chamness, V. R. Vermeul, Q. C. MacDonald, and S. E. Schubert. 1994. *Three-Dimensional Conceptual Model for the Hanford Site Unconfined Aquifer System, FY 1994 Status Report.* PNL-10195, Pacific Northwest Laboratory, Richland, Washington.

Thorne, P. D., and D. R. Newcomer. 1992. *Summary and Evaluation of Available Hydraulic Property Data for the Hanford Site Unconfined Aquifer System.* PNL-8337, Pacific Northwest Laboratory, Richland, Washington.

Thorne, P. D., M. A. Chamness, F. A. Spane Jr., V. R. Vermeul, and W. D. Webber. 1993. *Three-Dimensional Conceptual Model for the Hanford Site Unconfined Aquifer System, FY 1993 Status Report.* PNL-8971, Pacific Northwest Laboratory, Richland, Washington.

Tiller, B. L., G. E. Dagle, L. L. Cadwell, T. M. Poston, and A. Oganesian. 1997. *Investigation of Anatomical Anomalies in Hanford Site Mule Deer.* PNL-11518, Pacific Northwest National Laboratory, Richland, Washington.

Tolan, T. L., S. P. Reidel, M. H. Beeson, J. L. Anderson, K. R. Fecht, and D. A. Swanson. 1987. "Revisions to the Areal Extent and Volume of the Columbia River Basalt Group." In *Abstracts with Programs* 19(6):458, 83rd Annual Meeting of the Cordilleran Section. Hilo, Hawaii, May 20-22, 1987, Geological Society of America.

Trafzer, C. E., and R. D. Scheuerman. 1986. *Renegade Tribe: The Palouse Indians and the Invasion of the Inland Pacific Northwest.* Washington State University Press, Pullman, Washington.

U.S. Army Corps of Engineers (Corps). 1989. *Water Control Manual for McNary Lock and Dam, Columbia River, Oregon and Washington.* U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

U.S. Department of the Army. 1990. *Final Environmental Impact Statement Yakima Firing Center Proposed Land Acquisition, Yakima Firing Center, Washington.* Department of Army, I Corps, Fort Lewis, Washington.

U.S. Department of Commerce. 1998. *Regional Economic Information System.* Bureau of Economic Analysis, U.S. Department of Commerce, Washington, DC.

U.S. Department of Energy (DOE). 1986. *Environmental Assessment, Reference Repository Location, Hanford Site, Washington.* DOE/RW-0070, U.S. Department of Energy, Washington, DC.

U.S. Department of Energy (DOE). 1987. *Final Environmental Impact Statement, Disposal of Hanford Defense High-Level, Transuranic and Tank Wastes, Hanford Site, Richland, Washington.* DOE/EIS-0113, Vol. I-III, U.S. Department of Energy, Washington, DC.

U.S. Department of Energy (DOE). 1988. *Consultation Draft: Site Characterization Plan, Reference Repository Location, Hanford Site, Washington.* DOE/RW-0164, U.S. Department of Energy, Washington, DC.

U.S. Department of Energy (DOE). 1991. *Draft Environmental Impact Statement for the Siting, Construction, and Operation of New Production Reactor Capacity.* DOE/EIS-0144D, Vol. 4, Appendix E, U.S. Department of Energy, Washington, DC.

U.S. Department of Energy (DOE). 1992a. *Annual Report of RCRA Groundwater Monitoring Projects at Hanford Site Facilities for 1991.* DOE/RL-92-03, U.S. Department of Energy, Richland Field Office, Richland, Washington.

U.S. Department of Energy (DOE). 1992b. *Hanford Site Groundwater Background.* DOE/RL-92-23, U.S. Department of Energy, Richland Field Office, Richland, Washington.

U.S. Department of Energy (DOE). 1996a. *Hanford Site Biological Resources Management Plan. Draft.* DOE/RL-96-32, Rev. 0. U.S. Department of Energy, Richland, Washington.

U.S. Department of Energy (DOE). 1996b. *Programmatic Agreement Among the U.S. Department of Energy Richland Operations Office, the Advisory Council on Historic Preservation, and the Washington State Historic Preservation Office for the Maintenance, Deactivation, Alteration, and Demolition of the Built Environment on the Hanford Site, Washington.* DOE/RL-96-77. U.S. Department of Energy, Richland, Washington.

U.S. Department of Energy (DOE). 1997a. *National Register of Historic Places Multiple Property Documentation Form - Historic, Archaeological and Traditional Cultural Properties of the Hanford Site, Washington.* DOE/RL-97-02. U.S. Department of Energy, Richland, Washington.

U.S. Department of Energy (DOE). 1997b. *Hanford Site Background: Part 3, Groundwater Background.* DOE/RL-96-61. U.S. Department of Energy, Richland, Washington.

U.S. Department of Energy (DOE). 1997c. *N Reactor Comprehensive Treatment Report, Hanford Site, Washington.* DOE/RL-96-91, Draft A, Volumes I, II, III. U.S. Department of Energy, Richland, Washington.

U.S. Department of Energy (DOE). 1998a. *Hanford Site Manhattan Project and Cold War Era Historic District Treatment Plan.* DOE/RL-97-56, Rev. 1. U.S. Department of Energy, Richland, Washington.

U.S. Department of Energy (DOE). 1998b. DOE Computerized Accident/Incident Reporting System (CAIRS), including "Occupational Injury and Property Damage Summary, January-June 1998." (Web Site: http://tis.eh.doe.gov/cairs). Data downloaded November 11-13, 1998.

U.S. Department of Energy, Richland Operations Office (DOE-RL). 1999. *Hanford, Diversification, and the Tri-Cities Economy, FY 1998.* DOE/RL-99-29, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

U.S. Department of the Interior (DOI). 1994. *Hanford Reach of the Columbia River: Comprehensive River Conservation Study and Environmental Impact Statement - Final.* Volumes I and II. U.S. Department of Interior, Washington, DC.

U.S. Department of the Interior (DOI). 1996. *Record of Decision Hanford Reach of the Columbia River. July 16, 1996.* U.S. Department of the Interior, Washington , DC.

U.S. Department of Labor, Employment and Training Administration. 1998. *Domestic Agricultural In-Season Farm Labor Report.* Monthly Farm Labor Abstracts, January-December 1998. Washington State Employment Security Department for the U.S. Department of Labor, Olympia, Washington.

U.S. Energy Research and Development Administration (ERDA). 1975. *Final Environmental Impact Statement of Waste Management Operations, Hanford Reservation, Richland, Washington, 2 vol.* ERDA-1538, U.S. Energy Research and Development Administration, Washington, DC.

U.S. Energy Research and Development Administration (ERDA). 1976. *Evaluation of Impact of Potential Flooding Criteria on the Hanford Project.* RLO-76-4, U.S. Energy Research and Development Administration, Richland, Washington.

U.S. Geological Survey (USGS). 1996. *National Seismic-Hazard Maps: Documentation June 1996.* U.S. Geological Survey Open-File Report 96-532, Denver, Colorado.

U.S. Geological Survey (USGS). 1999a. *Washington NWIS-W Data Retrieval.* April 1998. U.S. Geological Survey, Tacoma, Washington. (Web Site: http://h2o-nwisw.er.usgs.gov/nwis-w/WA/).

U.S. Geological Survey (USGS). 1999b. *Provisional Discharge Data (*provided by Dewey Copeland), U.S. Geological Survey, Pasco, Washington.

U.S. Nuclear Regulatory Commission (NRC). 1982. *Draft Environmental Statement Related to the Construction of Skagit/Hanford Nuclear Project, Units 1 and 2.* Prepared by Puget Sound Power & Light Company, Pacific Power and Light Company, the Washington Water Power Company, and Portland General Electric Company. NUREG-0894, U.S. Nuclear Regulatory Commission, Washington, DC.

University of Washington Geophysics Program (UWGP). 1999. On-line Earthquake Catalog. University of Washington Geophysics Program, Seattle, Washington. (Web Site: http://www.geophys.washington.edu/SEIS).

UWGP (see University of Washington Geophysics Program).

Waitt, R. B. 1980. "About Forty Last-Glacial Lake Missoula Jokulhlaups Through Southern Washington." *Journal of Geology* 88:653-679.

Warren, J. L. 1980. *Vegetation Maps of the Hanford Reach, Columbia River.* Prepared for the U.S. Army Corps of Engineers, Seattle District, Seattle, Washington, by Pacific Northwest Laboratory, Richland, Washington.

Washington Natural Heritage Program. 1997. *Rare Plant Species County List*. Washington Natural Heritage Program, Washington Department of Natural Resources, Olympia, Washington. (Web Site: http://www.wa.gov/dnr/htdocs/fr/nhp/inforeq.html).

Washington Public Power Supply System (Supply System). 1981. *Final Safety Analysis Report, Washington Nuclear Power Plant No. 2*. Amendment 18, Richland, Washington.

Washington State Community, Trade and Economic Development. 1998. *Washington State Travel Impacts, 1998p*. Washington State Tourism Division, Olympia, Washington.

Washington State Department of Ecology (Ecology). 1992. *Water Quality Standards for Waters of the State of Washington*. Washington Administrative Code, Chapter 173-201, Olympia, Washington.

Washington State Department of Ecology (Ecology). 1997. *1997 Air Quality Annual Report for Washington State*. #97-208. Washington State Department of Ecology, Olympia , Washington.

Washington State Department of Ecology (Ecology), 1998. *1996 Air Quality Data Summary*. #98-200. Washington State Department of Ecology, Olympia, Washington.

Washington State Department of Fish and Wildlife. 1999. *Priority Habitats and Species*. Washington State Department of Fish and Wildlife, Olympia, Washington. (Web Site: http://www.wa.gov/wdfw/hab/phslist.htm).

Washington State Employment Security. 1998. *Washington State Labor Summaries, February 1998*. Olympia, Washington.

Waters, A. C. 1961. "Stratigraphic and Lithologic Variations in the Columbia River Basalt." *American Journal of Science* 259:583-611.

Watson, D. G. 1970. *Fall Chinook Salmon Spawning in the Columbia River Near Hanford 1947-1969*. BNWL-1515, Pacific Northwest Laboratories, Richland, Washington.

Watson, D. G. 1973. *Fall Chinook Salmon Population Census*. BNWL-1750, Pacific Northwest Laboratories, Richland, Washington.

Watson, E. C., C. D. Becker, R. E. Fitzner, K. A. Gano, C. L. Imhoff, R. F. McCallum, A. Myers, T. L. Page, K. R. Price, J. V. Ramsdell, D. G. Rice, D. L. Schreiber, L. A. Skumatz, D. J. Sommer, J. J. Tawil, R. W. Wallace, and D. G. Watson. 1984. *Environmental Characterization of Two Potential Locations at Hanford for a New Production Reactor*. PNL-5275, Pacific Northwest Laboratory, Richland, Washington.

Weiss, S. G., and R. M. Mitchell. 1992. *A Synthesis of Ecological Data from the 100 Areas of the Hanford Site*. WHC-EP-0601, Westinghouse Hanford Company, Richland, Washington.

Westinghouse Hanford Company (WHC). 1989. *Primary Operable Units Designation Project*. WHC-EP-0216, Environmental Engineering Group, Westinghouse Hanford Company, Richland, Washington.

Wolf, E. G. 1976. "Characterization of the Benthos Community." In *Final Report on Aquatic Ecological Studies Conducted at the Hanford Generating Project*, prepared by Battelle, Pacific Northwest Laboratories for United Engineers and Constructors, Inc. for Washington Public Power Supply System under Contract No. 2311201335, Richland, Washington.

Wolf, E. G., T. L. Page, and D. A. Neitzel. 1976. "Phytoplankton Community: Primary Productivity, Pigment Concentration, Species Composition and Relative Abundance of Phytoplankton and Physicochemical Analysis," Section 2. In *Final Report on Aquatic Ecological Studies Conducted at the Hanford Generating Project, 1973-1974, WPPSS Columbia River Ecological Studies, Vol. 1.*, Prepared by Battelle, Pacific Northwest Laboratories for Washington Public Power Supply System, Richland, Washington.

Woodruff, R. K., R. W. Hanf, and R. E. Lundgren. 1993. *Hanford Site Environmental Report for Calendar Year 1992*. PNL-8682, Pacific Northwest Laboratory, Richland, Washington.

Wright, M. K. 1993. *Fiscal Year 1992 Report on Archaeological Surveys of the 100 Areas, Hanford Site, Washington*. PNL-8819, Pacific Northwest Laboratory, Richland, Washington.

Wurstner, S. K., and M. D. Freshley. 1994. *Predicted Impacts of Future Water Level Decline on Monitoring Wells Using a Ground-Water Model of the Hanford Site*. PNL-10196, Pacific Northwest Laboratory, Richland, Washington.

Zimmerman, D. A., A. E. Reisenauer, G. D. Black, and M. A. Young. 1986. *Hanford Site Water Table Changes, 1950 Through 1980 - Data Observations and Evaluation*. PNL-5506, Pacific Northwest Laboratory, Richland, Washington.

[This Page Intentionally Left Blank]

6.0 Statutory and Regulatory Requirements

P.L. Hendrickson

The Hanford Site is owned by the U.S. Government and is managed by the U.S. Department of Energy (DOE). It is the policy of the DOE to carry out its operations in compliance with all applicable federal, state, and local laws and regulations, presidential executive orders, DOE directives, and treaty rights. Environmental regulatory authority over the Hanford Site is vested both in federal agencies, primarily the U.S. Environmental Protection Agency (EPA), and in Washington State agencies, primarily the Washington State Department of Ecology (Ecology) and the Washington Department of Health (DOH). In addition, the Benton County Clean Air Authority (BCCAA) has certain regulatory authority over Hanford activities, including open burning, asbestos removal, and fugitive dust control. Significant environmental laws, regulations, and other requirements are discussed in this chapter in the following order:

- major federal environmental laws
- significant applicable federal and state regulations
- presidential executive orders
- DOE directives
- existing environmental permits covering activities at the Hanford Site
- environmental standards for protection of the public.

There are a number of sources of information available concerning statutory and regulatory requirements as they relate to the National Environmental Policy Act (NEPA) process. Sources available over the Internet include the following.

- DOE's NEPA web site at URL: http://www.eh.doe.gov/nepa/
- Council on Environmental Quality's (CEQ's) web site at URL: http://www.whitehouse.gov/CEQ/
- EPA's link to federal agencies' NEPA web sites at URL: http://es.epa.gov/oeca/ofa/nepaweb.html

The *National Environmental Policy Act Compliance Guide* (DOE 1998a) (see DOE's NEPA web site), issued by the DOE Office of Environment, Safety and Health, contains useful information including copies of relevant executive orders.

(The following introduction [boxed text] is intended to be explanatory for persons writing the chapter of a Hanford Site environmental impact statement [EIS] or environmental assessment [EA] covering regulatory requirements, but is not intended to be included in the EIS or EA.) The material following the boxed text can be used as is or modified at the discretion of EIS and EA authors.

Introduction

The CEQ regulations in the Code of Federal Regulations (CFR) at 40 CFR 1500-1508 implement NEPA and set forth requirements for the preparation of environmental documentation by federal agencies that satisfies NEPA. DOE has adopted the CEQ regulations as part of its NEPA implementing procedures (40 CFR 1021.103). The CEQ regulations identify the types of actions proposed by a federal agency that require preparation of an EIS, prescribe the content of an EIS, and identify actions and other environmental reviews that must or should be undertaken by the federal agency in preparing and circulating an EIS. In general, an EIS must be prepared by a federal agency for any major federal action significantly affecting the quality of the human environment (40 CFR 1502.3). The regulations also state reasons why an agency may want to prepare an EA instead of an EIS (40 CFR 1508.9).

A specific requirement in the CEQ regulations (40 CFR 1502.25) is that the draft EIS must list "all Federal permits, licenses, and other entitlements which must be obtained in implementing the proposal." If it is uncertain whether a federal permit or license is needed, the draft EIS is to so indicate. There is, however, no requirement in the CEQ regulations or in the DOE NEPA implementing procedures at 10 CFR Part 1021 that the EIS must list or discuss applicable environmental laws and regulations. Nevertheless, applicable environmental laws and regulations (federal, state, and local) have been discussed in recent Hanford Site EISs and EAs, and Chapter 6.0 of these EISs and EAs has evolved into a chapter on "Statutory and Regulatory Requirements." Given the large number of applicable environmental regulations, the rapidly changing character of environmental regulation, and the public's interest in environmental regulation, this practice is likely to continue.

Chapter 6 of Hanford Site EISs and EAs should include the list called for by 40 CFR 1502.25(b). The list should also include significant permits that will be needed from state and local government agencies. Chapter 6 should not normally include information on environmental impacts associated with any of the requirements. For example, Executive Order (E.O.) 12962 requires federal agencies to evaluate the effects of their actions on aquatic systems and recreational fisheries. Although E.O. 12962 should be mentioned in Chapter 6 in appropriate cases, the actual impacts of the alternatives on aquatic systems and recreational fisheries should be discussed in Chapter 5 of the EIS or EA and any recreational fisheries aspects of the affected environment should be discussed in Chapter 4 of the EIS or EA.

The purpose, then, of Chapter 6 in this document is to present a "reference" that can be used as the basis for the preparation of future Hanford Site EISs and EAs. The intent is to present a reasonably complete discussion of federal, state, and local environmental laws, regulations, and permit requirements that are applicable to activities at the Hanford Site. The information in this chapter can then be adapted to any future Hanford Site EIS/EA by deleting irrelevant parts and by adding some specificity with respect to the proposed action and the alternatives being considered.

It should be noted that environmental standards and permit requirements usually appear in regulations and not in the laws themselves. Thus, more emphasis is placed on regulations and less on laws in this chapter.

Federal and State Environmental Laws

Environmental regulation of federal facilities is governed by federal law. Most major federal environmental laws now include provisions for regulation of federal activities that impact the environment. The activity to be regulated is usually an activity being carried out by an agency of the executive branch. The federal environmental law will also typically designate a specific agency, such as the EPA or the U.S. Nuclear Regulatory Commission (NRC), as the regulator. In addition, federal laws may provide for the delegation of the environmental regulation of federal facilities to the states or may directly authorize the environmental regulation of federal facilities by the states through waivers of sovereign immunity. At Hanford, all these situations apply in varying degrees. The EPA has regulatory authority over Hanford facilities and has delegated regulatory authority to, shares regulatory authority with, or is in the process of delegating regulatory authority to the state of Washington. The state of Washington also asserts its own independent regulatory authority under federal waivers of sovereign immunity. Ecology has also delegated various air compliance responsibilities to the BCCAA.

As a legal matter at Hanford, applicable federal and state environmental standards must be met. As a practical matter, differences in language between federal and state laws and regulations may result in some differences in applicability and interpretation. Guidance on specific applicability should be obtained from the Office of Chief Counsel of the DOE Richland Operations Office (DOE-RL).

Citation of Laws and Regulations

Laws and regulations may be cited both by their common name and by their location in the appropriate document. Federal laws are most often cited by their common name (e.g., Clean Water Act [CWA]), by their public law (Pub. L. or PL) number, or by their location in the United States Code (USC). Section numbers differ between laws as enacted and as codified in the USC, so it must be understood which is being cited. Federal regulations appear in the CFR. Washington State laws are most often cited by their location in the Revised Code of Washington (RCW). Washington State regulations are cited by their location in the Washington Administrative Code (WAC). Announcements of proposed and final federal regulations appear in the Federal Register (FR). Announcements of proposed and final Washington State regulations appear in the Washington State Register (WSR).

Specific Federal Laws Cited in the CEQ Regulations

Four federal laws are specifically cited in the CEQ regulations [40 CFR 1502.25(a) and 1504.1(b)]:

- Section 309 of the Clean Air Act (CAA) (42 USC 7609)
- Fish and Wildlife Coordination Act (16 USC 661 et seq.)
- National Historic Preservation Act (NHPA) (16 USC 470 et seq.)
- Endangered Species Act (16 USC 1531 et seq.).

Section 309 of the CAA directs the EPA to review and comment in writing on the environmental impacts of any matter relating to EPA's authority contained in proposed legislation, federal construction projects, other federal actions requiring EISs, and new regulations. In addition to commenting on EISs, EPA rates every draft EIS prepared by a federal agency under its Section 309 authority. Ratings are made for the environmental impact of the proposed action and the adequacy of the impact statement. Rating categories for environmental impact are: LO - lack of objections, EC - environmental concern, EO - environmental objections, and EU - environmentally unsatisfactory. Rating categories for adequacy are: Category 1 - adequate, Category 2 - insufficient information, and Category 3 - inadequate. A summary of the EPA rating definitions can be found at URL: http://es.epa.gov/oeca/ofa/rating.html EPA's comments on the draft EIS are answered in the final EIS.

The CEQ regulations (40 CFR 1502.25[a]) direct federal agencies to prepare draft EISs concurrently with and integrated with environmental impact analyses and related surveys required by the Fish and Wildlife Coordination Act, the NHPA, the Endangered Species Act, and other environmental review laws and executive orders. The three preceding statutes should be cited in Chapter 6. Environmental impacts associated with the laws should be discussed in Chapter 5.

6.1 Federal Environmental Laws

Significant federal environmental laws applicable to the Hanford Site include the following:

- American Antiquities Act (16 USC 431 to 433)
- American Indian Religious Freedom Act (42 USC 1996)
- Archaeological and Historic Preservation Act (16 USC 469 to 469c)
- Archaeological Resources Protection Act (ARPA) (16 USC 470aa to 470mm)
- Bald and Golden Eagle Protection Act (16 USC 668 to 668c)
- Clean Air Act (CAA) (42 USC 7401 to 7642)
- Clean Water Act (CWA) (33 USC 1251 to 1387)
- Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) as amended by the Superfund Amendments and Reauthorization Act (SARA) (42 USC 9601 to 9675)
- Endangered Species Act (16 USC 1531 to 1544)
- Federal Facilities Compliance Act (FFCA) (42 USC 6901)
- Fish and Wildlife Coordination Act (16 USC 661 to 667c)

- Hanford Reach Act (PL 100-605), as amended by PL 104-333
- Migratory Bird Treaty Act (16 USC 703 to 712)
- National Historic Preservation Act (NHPA) (16 USC 470 to 470w-6)
- Native American Graves Protection and Repatriation Act (25 USC 3001 to 3013)
- National Environmental Policy Act (NEPA) (42 USC 4321 to 4347)
- Resource Conservation and Recovery Act (RCRA) of 1976 as amended by the Hazardous and Solid Waste Amendments (42 USC 6901 to 6991i) of 1984
- Safe Drinking Water Act (SDWA) (42 USC 300f to 300j-11)
- Toxic Substances Control Act (TSCA) (15 USC 2601 to 2692)

In addition, the Atomic Energy Act (AEA) (42 USC 2011 to 2286), the Low-Level Radioactive Waste Policy Act (LLWPA) (42 USC 2021b to 2021i), and the Nuclear Waste Policy Act (NWPA) (42 USC 10101 to 10270), while not environmental laws per se, contain provisions under which environmental regulations applicable to the Hanford Site may be or have been promulgated.

6.2 Federal and State Environmental Regulations

Under the Supremacy Clause of the U.S. Constitution (Article VI, Clause 2), activities of the federal government are ordinarily not subject to regulation by the states unless specific exceptions are created by Congress. Exceptions with respect to environmental regulation have been created by Congress and provisions in several federal laws give specific authority to the states to regulate federal activities affecting the environment. These waivers (or partial waivers) of sovereign immunity appear in Section 118 of the CAA, Section 313 of the CWA, Section 1447 of the SDWA, Section 6001 of RCRA, and Section 120 of CERCLA/SARA. The FFCA is an amendment to RCRA that makes the RCRA waiver of sovereign immunity more explicit. Many Washington State programs with respect to the environmental regulation of Hanford Site facilities under the preceding statutes are coordinated with the U.S. Environmental Protection Agency (EPA) Region 10 office.

Federal and state environmental regulations that may apply to operations at the Hanford Site have been promulgated under the CAA, CWA, SDWA, RCRA, CERCLA, SARA, AEA, LLWPA, NWPA, under other federal statutes, and under relevant state statutes. The CAA amendments of 1990 have resulted in extensive revisions of federal and state air quality regulations. Federal and state regulations relating to hazardous waste management continue to be promulgated under RCRA at a rapid rate.

Several of the more important existing federal and state environmental regulations are discussed briefly below. These regulations are grouped according to areas of environmental interest.

6.2.1 Air Quality

- 40 Code of Federal Regulations (CFR) 50, "National Primary and Secondary Ambient Air Quality

Standards." EPA regulations in 40 CFR 50 set national ambient air quality standards (NAAQSs) for air pollutants including sulfur oxides, particulate matter, carbon monoxide, ozone, nitrogen dioxide, and lead. These standards are not directly enforceable; but other, enforceable regulations are based on these standards. Washington's ambient air standards are at Washington Administrative Code (WAC) 173-470 through 173-481 and include standards for radionuclides and fluorides.

- 40 CFR 51-52, State Implementation Plans (SIPs). EPA regulations in 40 CFR 51-52 establish the requirements for SIPs and record the approved plans. The SIPs are directed at the control of emissions of chemicals for which ambient air standards exist.

- 40 CFR 60, "Standards of Performance for New Stationary Sources." EPA regulations in 40 CFR 60 provide standards for the control of the emission of pollutants to the atmosphere. Construction or modification of an emissions source in an attainment area such as Hanford can require a prevention of significant deterioration (PSD) of air quality permit under 40 CFR 52.21 and WAC 173-400-141.

- 40 CFR 61, "National Emission Standards for Hazardous Air Pollutants," (NESHAP); 40 CFR 63, National Emission Standards for Hazardous Air Pollutants for Source Categories." EPA hazardous emission standards in 40 CFR 61 provide for the control of the emission of hazardous pollutants to the atmosphere. Standards in 40 CFR 61 Subpart H apply specifically to the emission of radionuclides from DOE facilities. Approval to construct a new facility or to modify an existing one may be required (under 40 CFR 61.07) by these regulations. EPA has delegated interim authority to the State of Washington to implement and enforce 40 CFR 61 Subpart H, but has not yet delegated the construction approval authority (60 FR [Federal Register] 39263, August 2, 1995). Emission standards for sources of hazardous air pollutants designated in the 1990 CAA amendments appear at 40 CFR 63.

- 40 CFR 70, "State Operating Permit Programs." These regulations provide for the establishment of comprehensive state air quality permitting programs. All major sources of air pollutants including hazardous air pollutants are covered. EPA granted interim approval to Washington's operating permit program in November 1994 (59 FR 55813). Washington's operating permit regulations appear at WAC 173-401. The January 1999 proposed air operating permit for the Hanford Site can be accessed at URL: http://www.rl.gov:1050/wastemgt/aop/index.htm

- WAC 173-400 through 173-495, Washington State Air Pollution Control Regulations; General Regulation 1, BCCAA. Ecology air pollution control regulations, promulgated under the Washington CAA (Revised Code of Washington [RCW] 70.94), appear in WAC 173-400 through 173-495. These regulations include emission standards, ambient air quality standards, and the standards in WAC 173-460, "Controls for New Sources of Toxic Air Pollutants." The state of Washington has delegated much of its authority under the Washington CAA to the BCCAA. However, except for certain air pollution sources (e.g., asbestos removal, fugitive dust, and open burning) administered by the BCCAA, Ecology continues to administer air pollution control requirements for the Hanford Site.

- WAC 246-247, "Radiation Protection--Air Emissions." Washington DOH regulations in WAC 246-247 contain standards and permit requirements for the emission of radionuclides to the atmosphere.

- Regulation 1 of the Benton County Clean Air Authority can be accessed at URL:

http://www.cbvcp.com/bccaa/

6.2.2 Water Quality

- 40 CFR 121, "State Certification of Activities Requiring a Federal License or Permit." These regulations provide for state certification that any activity requiring a federal water permit, i.e., a National Pollutant Discharge Elimination System (NPDES) permit or a discharge of dredged or fill material permit, will not violate state water quality standards.

- 40 CFR 122, "EPA Administered Permit Programs: The National Pollutant Discharge Elimination System." EPA regulations in 40 CFR 122 (and also in 40 CFR 125 and 129) apply to the discharge of pollutants from any point source into waters of the United States. These regulations also now apply to the discharge of storm waters (40 CFR 122.26) and the discharge of runoff waters from construction areas over 2 ha (5 acres) in size into waters of the United States. NPDES permits may be required by 40 CFR 122. EPA has not delegated to the state of Washington the authority to issue NPDES permits at the Hanford Site.

- 40 CFR 141, "National Primary Drinking Water Regulations." EPA drinking water standards in 40 CFR 141 apply to Columbia River water at community water supply intakes downstream of the Hanford Site.

- 40 CFR 144-147, Underground Injection Control Program. EPA regulations in 40 CFR 144-147 apply to the underground injection of liquids and wastes and may require a permit for any underground injection. In Washington State, the EPA has approved Ecology regulations in WAC 173-218, "Underground Injection Control Program," to operate in lieu of the EPA program. The Ecology regulations provide standards and permit requirements for the disposal of fluids by well injection.

- 10 CFR 1022, "Compliance with Floodplain/Wetlands Environmental Review Requirements." DOE regulations in 10 CFR 1022 implement Executive Orders 11988 and 11990 and apply to DOE activities that are proposed to take place either in wetlands or in floodplains.

- 33 CFR 322-323, 40 CFR 230-233. Structures in the Columbia River and work in the Columbia River, as well as the discharge of dredged or fill material into the Columbia River, require permits under these U.S. Army Corps of Engineers and EPA regulations.

- WAC 173-160. Under WAC 173-160, DOE provides notification to Ecology for water-well drilling on the Hanford Site.

- WAC 173-216, "State Waste Discharge Permit Program." Ecology regulations in WAC 173-216 establish a state permit program for the discharge of waste materials from industrial, commercial, and municipal operations into ground and surface waters of the state. Discharges covered by NPDES or WAC 173-218 permits are excluded from the WAC 173-216 program. DOE has agreed to meet the requirements of this program at the Hanford Site for discharges of liquids to the ground.

- RCW 75.20.100, "Construction Projects in State Waters." WAC 220-110. As a matter of comity, DOE will obtain hydraulic project approval from the Washington State Department of Fish and Wildlife to construct any form of hydraulic project or perform work that will divert, obstruct, or change the natural flow of the Columbia River.

- WAC 332-30, "Aquatic Land Management." Where applicable, DOE will obtain an aquatic land use lease or permit from the Washington Department of Natural Resources for the placement of structures in the Columbia River on lands owned by the state of Washington. DOE owns most of the riverbed along the Hanford Site to the line of navigation.

- WAC 246-272-08001 and 246-272-09001. These regulations, administered by the Washington DOH, contain permit requirements for onsite sewage systems.

- WAC 246-290. These regulations, administered by the Washington DOH, contain requirements applicable to water systems providing piped water for human consumption.

6.2.3 Solids

- 40 CFR 260-268 and 270-272, Hazardous Waste Management. EPA RCRA regulations in 40 CFR 260-268 and 270-272 apply to the generation, transport, treatment, storage, and disposal of hazardous wastes (but not to source, by-product, or special nuclear material [i.e., not in general to radioactive wastes]), and apply to the hazardous component of hazardous radioactive mixed wastes (but not to the radioactive component) owned by DOE. RCRA regulations (40 CFR 268) require treatment of many hazardous wastes before they can be disposed of in landfills (land disposal restrictions). RCRA permits are required for the treatment, storage, or disposal of hazardous wastes. The regulations also require cleanup (corrective action) of any RCRA facility from which there is an unauthorized release before a RCRA permit may be granted. Ecology has been authorized by EPA to administer the RCRA program and all but the land disposal restriction and waste minimization provisions of the Hazardous and Solid Waste Amendments. Ecology has oversight authority for RCRA corrective actions at Hanford under the Tri-Party Agreement.

- 40 CFR 280-281, Underground Storage Tanks. EPA regulations in 40 CFR 280-281 apply to underground storage tanks and may require permits for new and existing tanks containing petroleum or substances regulated under CERCLA (except for hazardous wastes regulated under RCRA). EPA has authorized Washington State to administer this program. Washington's requirements are in RCW 90.76 and WAC 173-360.

- 40 CFR 300, "National Oil and Hazardous Substances Pollution Contingency Plan." EPA CERCLA regulations in 40 CFR 300 apply to the cleanup of inactive hazardous waste disposal sites, the cleanup of hazardous substances released into the environment, the reporting of hazardous substances released into the environment, and natural resource damage assessments. On November 3, 1989, (54 FR 41015) the Hanford Site was placed on the EPA's National Priorities List (NPL). Placement on the list requires DOE, in consultation with EPA and Washington State, to conduct remedial investigations and feasibility studies leading to a record of decision on the cleanup of inactive waste disposal sites at Hanford. Standards for cleanup under CERCLA are "applicable or relevant and appropriate requirements" (ARARs), which may include both federal and state laws and regulations. In anticipation of Hanford's being placed on the NPL, DOE, EPA, and Ecology signed the Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement) on May 15, 1989. This agreement describes the cleanup responsibilities and authorities of the three parties under CERCLA (and RCRA), and also provides for permitting of the treatment, storage, and disposal of hazardous wastes under RCRA. The Tri-Party Agreement has been amended a number of times. The agreement can be at URL: http://www.hanford.gov/tpa/tpahome.htm .

- WAC 173-303, "Dangerous Waste Regulations." The EPA has authorized the state of Washington through Ecology to conduct its own dangerous waste regulation program in lieu of major portions of the RCRA interim and final permit program for the treatment, storage, and disposal of hazardous wastes. Ecology is also authorized to conduct its own program for the hazardous portion of radioactive-mixed wastes. The state regulations include both standards and permit requirements, as well as a larger universe of covered materials than the federal hazardous waste program.

6.2.4 Species Protection

- 50 CFR 10-24, 222, 225-227, 402, and 450-453, Species Protection Regulations[g]. Regulations under the Endangered Species Act, the Bald and Golden Eagle Protection Act, and the Migratory Bird Treaty Act in 50 CFR 10-24 apply to the protection of these species on the Hanford Site. Regulations in 50 CFR 222, 225-227, 402, and 450-453 apply to endangered or threatened species. In addition, the Fish and Wildlife Coordination Act requires consultation with the U.S. Fish and Wildlife Service if any body of water over 4 ha (10 acres) in size is to be modified by a federal agency for any purpose. The purpose of this consultation is to prevent loss and damage to wildlife resources.

6.2.5 Historic and Cultural Resource Preservation

- 25 CFR 261; 36 CFR 60, 79, 800; 43 CFR 3, 7, 10; Historic Preservation Regulations. Regulations implementing the NHPA in 36 CFR 60 and 36 CFR 800; the American Antiquities Act in 25 CFR 261 and 43 CFR 3; the ARPA and the American Indian Religious Freedom Act in 43 CFR 7; and the Native American Graves Protection and Repatriation Act in 43 CFR 10 apply to the protection of historic and cultural properties, including both existing properties and those discovered during excavation and construction. Regulations in 36 CFR 79 establish procedures and guidelines to be followed by federal agencies to preserve collections of historical material, remains, ands records. Additional information on these statutes and regulations may be found by contacting the Department of Energy, Richland Operations Office Cultural Resources Program manager or by accessing the Hanford website at http://www.hanford.gov/doe/culres/index.htm

6.2.6 Land Use

The Hanford Reach Act (PL 100-605), as amended by section 404 of the Omnibus Parks and Public Lands Management Act of 1996 (PL 104-333), required the Secretary of the Interior, in consultation with the Secretary of Energy, to conduct a study of the Hanford Reach of the Columbia River that included identification and evaluation of geologic, scenic, historic, cultural, recreational, fish, wildlife, and natural features of the Hanford Reach. The Secretary of the Interior was also directed by Congress to examine alternatives for the preservation of these features. In addition, the amended Act establishes protections for the Reach by requiring parties planning new projects within one-quarter mile of the river to consult and coordinate with the Secretary of the Interior to minimize and provide mitigation for any direct and adverse effects on the values for which the river is under study. In addition, all existing projects that affect the study area are to be operated and maintained to minimize any direct and adverse effects on the values for which the river is under study, taking into account any existing and relevant license, permit, or agreement affecting the project.

A final study report was published in June 1994: *Hanford Reach of the Columbia River, Comprehensive River Conservation Study and Environmental Impact Statement* (59 FR 44430, August

[g] The applicability of the Migratory Bird Treaty Act is limited in the context of actions of the Federal Government as described in *Sierra Club v. Martin*, 110 F.3d 1551 (11th Cir. 1997).

29, 1994)(DOI 1994). The Record of Decision for this EIS, signed on July 16, 1996, by the Secretary of the Interior, recommended that Congress designate the Hanford Reach of the Columbia River and public land within one quarter mile of the river and all land in the Saddle Mountain National Wildlife Refuge and Wahluke State Wildlife Recreation Area as a new National Wildlife Refuge and National Wild and Scenic River.

In April 1999, DOE issed the Revised Draft Hanford Remedial Action Environmental Impact Statement and Comprehensive Land-Use Plan (DOE 1999). DOE held information meetings and public hearings on the Revised Draft EIS in 1999. A final EIS will be issued at a later date.

6.2.7 Other

- 40 CFR 191, "Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes." EPA regulations in 40 CFR 191 provide environmental standards for the management, storage, and disposal of spent nuclear fuel, high-level radioactive wastes, and transuranic radioactive wastes at high-level or transuranic waste disposal sites.

- 40 CFR 700-799, TSCA Regulations. EPA's regulations in 40 CFR 700-799 implement TSCA and, in particular, regulate polychlorinated biphenyls (PCBs) and dioxins and partially regulate asbestos.

- 40 CFR 1500-1508, "Council on Environmental Quality." The CEQ regulations in 40 CFR 1500-1508 provide for the preparation of environmental documentation on federal action impacting the environment, and require federal agencies to prepare an environmental impact statement (EIS) on any major federal action significantly affecting the quality of the human environment.

- 10 CFR 830, "Nuclear Safety Management." Part 830 contains nuclear safety management requirements applicable to DOE contractors.

- 10 CFR 835, "Occupational Radiation Protection." These DOE rules establish radiation protection standards, limits, and program requirements for protecting individuals from ionizing radiation resulting from DOE activities.

- 10 CFR 1021, "National Environmental Policy Act Implementing Procedures." DOE regulations in 10 CFR 1021 implement NEPA and the CEQ's NEPA regulations in 40 CFR 1500-1508.

- 49 CFR 171-179, Hazardous Materials Regulations. Department of Transportation regulations in 49 CFR 171-179 apply to the handling, packaging, labeling, and shipment of hazardous materials offsite, including radioactive materials and wastes.

6.3 Executive Orders

DOE is subject to a number of presidential executive orders (E.O.s) concerning environmental matters. Some of these orders may be appropriately considered in a Hanford EIS. Potentially relevant E.O.s include:

E.O. 11514 Protection and Enhancement of Environmental Quality

E.O. 11593	Protection and Enhancement of the Cultural Environment
E.O. 11987	Exotic Organisms
E.O. 11988	Floodplain Management
E.O. 11990	Protection of Wetlands
E.O. 12088	Federal Compliance with Pollution Control Standards
E.O. 12144	Environmental Effects Abroad of Major Federal Actions
E.O. 12580	Superfund Implementation (as amended by E.O. 13016)
E.O. 12843	Procurement Requirements and Policies for Federal Agencies for Ozone Depleting Substances
E.O. 12856	Federal Compliance with Right-to-Know Laws and Pollution Prevention Requirements
E.O. 12873	Federal Acquisition, Recycling, and Waste Prevention
E.O. 12898	Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations
E.O. 12902	Energy Efficiency and Water Conservation at Federal Facilities
E.O. 12962	Recreational Fisheries
E.O. 12969	Federal Acquisition and Community Right-to-Know
E.O. 13007	Indian Sacred Sites
E.O. 13045	Protection of Children from Environmental Health Risks and Safety Risks
E.O. 13101	Greening the Government through Waste Prevention, Recycling, and Federal Acquisition
E.O. 13112	Invasive Species

E.O.s can be accessed at the following URLs:

- http://es.epa.gov/program/exec/exec.html
- http://www.pub.whitehouse.gov/WH/Publications/html/Publications.html

6.4 DOE Directives

Categories of DOE directives include orders, policy statements, standards, notices, manuals, and contractor requirements documents.

DOE directives can be accessed at the following URL:

- http://www.explorer.doe.gov/

At the Hanford Site, active DOE-RL directives, implementing directives, procedures, policy directives, and manuals are available at URL: http://hanford.gov/doe/direct/index.htm

DOE directives have recently been extensively revised and consolidated. New directives are classified in the new series directives. Directives with particular application to DOE's environmental activities are found in the 400 series of the new series directives and the 5000 series (particularly the 5400 and 5800 series) under the old series directives.

DOE directives cover environmental protection, safety, and health protection standards; hazardous and radioactive-mixed waste management; cleanup of retired facilities; safety requirements for the packaging and transportation of hazardous materials; safety of nuclear facilities; radiation protection; and other standards for the safety and protection of workers and the public. Regulations and standards of other federal agencies and regulatory bodies, as well as other DOE directives, are incorporated by reference into DOE directives.

6.5 Treaties of the United States with American Indian Tribes of the Hanford Region

In June 1855 at Camp Stevens in the Walla Walla Valley, representatives of the United States negotiated treaties with leaders of various Columbia Plateau American Tribes and Bands. The negotiations resulted in three treaties, one with the 14 tribes and bands of what would become the Yakama Nation, one with the three tribes that would become the Confederated Tribes of the Umatilla Indian Reservation, and one with the Nez Perce Tribe. The treaties were ratified by the U.S. Senate in 1859. The negotiated treaties are as follows and can be viewed in Appendix A of the *Hanford Remedial Action Environmental Impact Statement and Comprehensive Land-Use Plan* (HRA-EIS) Revised Draft (DOE 1999):

1. Treaty with the Walla Walla, Cayuse, etc. (June 9, 1855; 12 Stats. 945)

2. Treaty with the Yakama (June 9, 1855; 12 Stats. 951)

3. Treaty with the Nez Perce (June 11, 1855; 12 Stats. 957).[h]

The Yakama Nation, the Confederated Tribes of the Umatilla Reservation, and the Nez Perce Tribe of Idaho are federally recognized tribes which have the immunities and rights available to other federally acknowledged Indian tribes by virtue of their government-to-government relationship with the United States as well as the responsibilities, powers, limitations and obligations of such tribes (63 FR 71941; December 30, 1998).

The terms of the three preceding treaties are similar. Each of the three Tribes agreed to cede large blocks of land to the United States. The Hanford Site is within the ceded lands. The Tribes retained certain lands for their exclusive use (the three reservations) and also retained certain rights and privileges

[h] The text of the three treaties can be accessed at the following URL: http://www.rootsweb.com/~usgenweb/wa/indians/treaties.htm.

to continue traditional activities outside the reservations. These included 1) the right to fish (and erect temporary fish-curing facilities) at usual and accustomed places in common with citizens of the United States, and 2) the privileges of hunting, gathering roots and berries, and pasturing horses and cattle on open and unclaimed lands.

DOE-RL interacts and consults on a direct basis with the three federally recognized tribes affected by Hanford operations, i.e., the Nez Perce, Umatilla, and Yakama tribes. In addition, the Wanapum people, who still live adjacent to the Hanford Site, are a non-federally recognized tribe who have strong cultural ties to the site. The Wanapum are also consulted on cultural resource issues in accordance with DOE-RL policy and relevant legislation.

6.6 Permits

Information on the status of environmental permits at Hanford is in DOE (1998b). Included are information on current and anticipated environmental permitting required by RCRA, the Hazardous and Solid Waste Amendments of 1984, and non-RCRA permitting (solid waste handling, Clean Air Act Amendments of 1990, Clean Water Act Amendments of 1987, Washington State waste discharge, and onsite sewage system).

The Hanford Facility is considered a single facility for RCRA and State of Washington Hazardous Waste Management Act of 1976 purposes. It has been issued the EPA/State identification number WA7890008967, which encompasses over 60 treatment, storage, and/or disposal (TSD) units (DOE 1998b).

The Washington State Department of Ecology and the EPA, pursuant to the Tri-Party Agreement issued a single RCRA permit to cover the Hanford facility. The initial permit was issued for less than the entire Hanford facility because all TSD units cannot be permitted at once. Through permit modification, all TSD units will be incorporated into the present permit (DOE 1998b).

Clean Air Act compliance requires both facility and sitewide compliance. DOE 1998b identifies existing facility-specific and sitewide compliance activities and requirements.

The Sitewide National Pollutant Discharge Elimination System Permit (NPDES) WA-000374-3 and the 300 Area Treated Effluent Disposal Facility NPDES Permit WA-002591-7 govern liquid process effluent discharges to the Columbia River (DOE 1998b).

DOE has asserted a federally reserved water withdrawal right with respect to its Hanford operations. Current Hanford activities use water withdrawn under the DOE's federally reserved water right.

6.7 Environmental Standards for Protection of the Public

Numerical standards for protection of the public from releases to the environment have been set by the EPA and appear in the CFR.

Standards in 40 CFR 61.92 apply to releases of radionuclides to the atmosphere from DOE facilities and state that:

> Emissions of radionuclides (other than radon-220 and radon-222) to the ambient air from Department of Energy facilities shall not exceed those amounts that

would cause any member of the public to receive in any year an effective dose equivalent of 10 mrem/yr.

Standards in 40 CFR 141.16 apply indirectly to releases of radionuclides from DOE facilities (and also non-DOE facilities) to the extent that the releases impact community water systems. The average annual concentration of beta particle and photon radioactivity from man-made radionuclides in drinking water are not to produce an annual dose equivalent to the body or any internal organ greater than 4 millirem/year. Maximum contaminant levels in community water systems of 5 pCi/L of combined radium-226 and radium-228, and maximum contaminant levels of 15 pCi/L of gross alpha particle activity, including radium-226 but excluding radon and uranium, are specified in 40 CFR 141.15.

EPA regulations in 40 CFR 264 contain numerical standards for protection of the public from releases of hazardous wastes from hazardous waste disposal sites.

References

U.S. Department of Energy (DOE). 1998a. *National Environmental Policy Act Compliance Guide Volume II (Reference Book)*. Washington, DC.

U.S. Department of Energy (DOE). 1998b. *Annual Hanford Site Environmental Permitting Status Report*. DOE/RL-96-63, Revision 2, U.S. Department of Energy, Richland, Washington.

U.S. Department of Energy (DOE). 1999. *Revised Draft Hanford Remedial Action Environmental Impact Statement and Comprehensive Land-Use Plan*. DOE/EIS-0222D. U.S. Department of Energy, Richland, Washington.

U.S. Department of the Interior (DOI). 1994. *Hanford Reach of the Columbia River: Comprehensive River Conservation Study and Environmental Impact Statement - Final*. Volumes I and II. U.S. Department of Interior, Washington, DC.

Distribution

No. of
Copies

OFFSITE

2 DOE Office of Scientific and
Technical Information

1 C. Borgstrom
U.S. Department of Energy (EH-42)
1000 Independence Avenue SW
Washington, DC 20585-0119

1 A. J. Dvorak
Environmental Assessment Division
Argonne National Laboratory
9700 S. Cass Avenue Bldg 900
Argonne, IL 60439-4832

2 B. Floyd
Benton County Planning Dept.
P.O. Box 910
Prosser, WA 99350

1 S. Frank
U.S. Department of Energy (EM-75)
1000 Independence Avenue SW
Washington, DC 20585

1 C. Hickey
NEPA Compliance Officer
U.S. Department of Energy
Office of Energy Research (ER-8)
19901 Germantown Road
Germantown, MD 20874-1290

1 T. Ikenberry
Dade Moeller & Associates
1845 Terminal Drive Suite 140
Richland, WA 99352

1 N. Lane
Lane Environmental, Inc.
P.O. Box 925
660 George Washington Way
Richland, WA 99352

No. of
Copies

1 T. McLoughlin
1201 Jadwin Avenue
Richland, WA 99352

1 D. Nichols
Jacobs Engineering
601 Williams Blvd
Richland, WA 99352

1 G. Palmer
U.S. Department of Energy (DP-45)
1000 Independence Avenue SW
Washington, DC 20585-0104

1 R. Sharma
NEPA Compliance Officer
U.S. Department of Energy (NE-47)
19901 Germantown Road
Germantown, MD 20874-1290

1 L. Williams
Jason Associates Corporation
3250 Port of Benton Blvd.
Richland, WA 99352

Native American Tribes

2 J. R. Wilkinson
Special Sciences & Resource Program
Confederated Tribes of the Umatilla
Indian Reservation
P.O. Box 638
Pendleton, OR 97801

4 R. Jim
Environmental Restoration/
Waste Management Program
Yakama Nation
2808 Main Street
Union Gap, WA 98903

No. of Copies		
3	Jason Lyon Environmental Restoration/Waste Management Program Nez Perce Tribe P.O. Box 365 Lapwai, ID 83540	
3	L. Seelatsee Wanapum Band Grant County P.U.D. 30 "C" Street, S.W. P.O. Box 878 Ephrata, WA 98823	

ONSITE

No. of Copies		
43	DOE Richland Operations Office	
	A V. Beard, WPD	S7-55
	M. E. Burandt, STO	K8-50
	B. F. Burton, SOD	T5-50
	R. M. Carosino, OCC	A4-52
	D. H. Chapin, SPO	R3-79
	C. E. Clark, EAP	A5-15
	K. V. Clarke, OEA	A7-75
	P. F. Dunigan, EAP (20)	A5-15
	W. F. Edwards, SID	A2-45
	T. W. Ferns, RPD	H0-12
	R. E. Gerton, RPS	H0-12
	L. A. Huffman, DPD	A0-21
	A. B. Joy, TPD	R3-79
	D. W. Lloyd, EAP	A5-15
	R. D. Hildebrand, RPD	H0-12
	E. V. Hiskes, OCC	A4-52
	R. A. Holten, RPD	H0-12
	R. R. McNulty, MSO	A2-22
	J. E. Rasmussen, EAP	A5-15
	W. D. Seaborg, TPD	R3-79
	C. V. Smith, OCC	A4-52
	D. C. Ward, EAP	A5-15
	B. D. Williamson, OCC	A4-52
	J. H. Zeisloft, EAP	H0-12
19	Bechtel Hanford, Inc.	
	J. W. Badden	H9-03
	R. A. Carlson	L6-06
	E. T. Coenenberg	H9-03
	K. R. Fecht	H0-02
	G. E. Fitzgibbon	H0-09
	K. A. Gano	H0-23
	G. C. Henckel	H0-09
	L. M. Johnson	H9-01
	R. J. Landon	H0-02
	T. E. Marceau	H0-23
	G. B. Mitchem	H0-17
	R. W. Ovink	H9-03
	J. E. Rugg	S3-21
	V. J. Rohay	H0-21
	D. D. Teel	H0-23
	B. L. Vedder	H0-02
	J. G. Woolard	H0-02
	S. G. Weiss	H9-01
	R. H. Wyer	H0-09
4	Fluor Daniel Hanford, Inc.	
	D. P. Demitruk	S3-96
	A. M. Hopkins	L5-65
	F. A. Ruck, III	H6-23
	D. J. Watson	X3-79
2	Fluor Daniel Northwest, Inc.	
	R. L. Newell	B4-68
	P. D. Rittmann	R3-26
3	DynCorp Tri-Cities Services, Inc.	
	R. L. Currier	G3-26
	B. J. Dixon	G3-26
	H. B. Hathaway	G3-07
1	Lockeed Martin Hanford Corporation.	
	B. G. Erlandson	R1-51

No. of Copies		
2	B&W Hanford Company	
	K. A. Hadley	R3-56
	B. B. Nelson-Maki	T5-54
1	Numatec Hanford Corporation	
	R. A. Kaldor	H5-25
1	Washington State University	
	R. G. Schreckhise	H2-52
5	Waste Management Federal Services of Hanford, Inc.	
	G. D. Cummins (5)	H6-20
2	Waste Management Federal Services, Northwest	
	J. J. Dorian	H1-11
	R. M. Mitchell	H1-11
72	Pacific Northwest National Laboratory	
	M. P. Bergeron	K9-36
	G. R. Bilyard	K8-03
	C. A. Brandt	K6-85
	R. W. Bryce (5)	K6-75
	A. L. Bunn	K6-85
	L. L. Cadwell	K6-85
	C. R. Cole	K9-36
	P. J. Cowley	K7-22
	P. M. Daling	K8-03
	D. D. Dauble	K6-85
	R. L. Dirkes	K6-75
	J. P. Duncan (15)	K6-85
	T. O. Eschbach	K6-75
	M. J. Fayer	K9-33
	R. A. Fowler	K8-17
	S. W. Gajewski	K8-03
	D. R. Geist	K6-85
	S. M. Goodwin	K6-81

No. of Copies		
	Pacific NW Natl. Laboratory (cont)	
	D. L. Hadley	K5-16
	J. C. Hail	P7-63
	D. W. Harvey	K6-75
	P. L. Hendrickson	K8-03
	D. J. Hoitink	K9-30
	D. J. Hostick	K8-17
	U. P. Jenquin	K8-34
	R. A. Kennedy	K7-63
	C. T. Kincaid	K9-33
	W. W. Laity	K9-85
	M. D. McKinney	K8-03
	B. A. Napier	K3-54
	D. A. Neitzel (5)	K6-85
	W. E. Nichols	K9-33
	G. P. O'Connor	K6-86
	T. L. Page	K9-18
	T. M. Poston	K6-75
	K. Rhoads	K3-54
	W. H. Rickard	K6-85
	M. R. Sackschewsky	K6-85
	M. J. Scott	K8-17
	D.C. Stapp	K6-75
	D. L. Strenge	K3-54
	K. M. Tominey	K7-97
	M. D. White	K9-36
	R. S. Weeks	P7-79
	M. K. Wright	K6-75
	Information Release Office (5)	K1-06
2	DOE Public Reading Room	H2-53