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Columbia River Impact Evaluation Plan

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1.0 INTRODUCTION

As a result of past-practices, four areas of the Hanford Site (the 100, 200, 300, and 1100 Areas) have been included on the U.S. Environmental Protection Agency's (EPA's) National Priorities List (NPL) under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA, 42 USC 9601 et seq.). In addition to the four NPL sites, there are over 60 Resource Conservation and Recovery Act (RCRA, 42 USC 6901 et seq.) treatment, storage, or disposal facilities that will be closed or permitted to operate in accordance with RCRA regulations. To accomplish the timely cleanup of the past-practice units, the Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement or TPA, Ecology et al. 1989) was signed by the Washington State Department of Ecology (Ecology), EPA, and the U.S. Department of Energy (DOE).

To support the Tri-Party Agreement, milestones were adopted. These milestones represent the actions needed to ensure acceptable progress toward Hanford Site compliance with CERCLA, RCRA, and the Washington State Hazardous Waste Management Act. This report was prepared to fulfill the requirement of TPA Milestone M-30-02 which requires a plan to determine cumulative health and environmental impacts to the Columbia River. This plan supplements the CERCLA remedial investigations/ feasibility studies (RI/FSs) and RCRA facility investigations/corrective measures studies (RFI/CMSs) that will be undertaken in the 100 Area.

To support the plan development process, existing information was reviewed and a preliminary impact evaluation based on this information was performed. The purpose of the preliminary impact evaluation was to assess the adequacy of existing data and proposed data collection activities. Based on the results of the evaluation, a plan is proposed to collect additional data or make changes to existing or proposed data collection activities.

The purpose, objectives, and scope of this document are presented in Section 1.1. The approach used to evaluate existing environmental data is described in Section 1.2. Relevant environmental statutes, regulations, and guidelines are discussed in Section 1.3. The report organization is detailed in Section 1.4.

1.1 PURPOSE AND OBJECTIVES OF THE REPORT

In May 1991, the TPA was amended by the Hanford Federal Facility Agreement and Consent Order Change Package (DOE-RL 1991a) and Milestones M-30-01 through M-30-05 were proposed to guide data collection activities in the 100 Aggregate Area. These Milestones were added to implement the Hanford Site Past-Practice Strategy and complement the rescoping of 100 Area operable unit work plans. The goal of these 100 Aggregate Area milestones is to develop a focused and comprehensive review of available data on current river impacts and coordinate remedial investigation activities in the operable units that are related to the Columbia River.

The purpose of this report is to satisfy Milestone M-30-02 which is, "Submit a plan (primary document) to EPA and Ecology to determine cumulative health and environmental impacts to the Columbia River, incorporating results obtained under

M-30-01." Milestone M-30-01 is, "Submit a report (secondary document) to EPA and Ecology evaluating the impact to the Columbia River from contaminated springs and seeps as described in the operable unit work plans listed in M-30-03."

To satisfy Milestone M-30-02, a preliminary impact evaluation was conducted to assess the adequacy of existing data and proposed data collection programs for evaluating cumulative health and environmental impacts to the Columbia River due to past practices at the Hanford Site. The results of this evaluation were used to develop a plan that would ensure collection of sufficient data to ensure adequate characterization of the Columbia River along the 100 Area for CERCLA purposes. By using such an approach, both key exposure pathways and potential risk-driving contaminants are identified. In addition, the potential risks to human health and the environment are preliminarily quantified.

The use of a preliminary impact evaluation of contaminant releases attributable to Site operations is a practical way to evaluate and prioritize the necessity and effectiveness of existing monitoring programs and proposed characterization and restoration activities. Thus, the objective of the plan included in this document is to evaluate impacts to the Columbia River in the vicinity of 100 Area and its environs and assess the need for specific characterization efforts that will provide information for the 100 Area risk assessment.

Based on the guidance in Milestone M-30-00, this document focuses on the Hanford Reach of the Columbia River (see subsection 2.1.1) along the 100 Area, including: river sediments, islands, both river banks, and associated biota. In addition, the study extends upstream a sufficient distance to provide appropriate control information for evaluating impacts. The use of sample locations at Priest Rapids Dam or Vernita Bridge as controls assumes that these areas have not been significantly impacted by Hanford Site air emissions. In general, the downstream impact evaluation boundary was the Hanford Townsite, except the City of Richland was used to evaluate residential drinking water exposure, and the entire 94 km (58 mi) section of the Hanford Reach for human ingestion of fish. The evaluation was conducted for existing land and water use conditions.

Although this plan is limited in scope to the 100 Area and contaminants that are found there, the DOE, EPA & Ecology agree that an entire Hanford Reach approach to future river assessments is desirable. A quantitative baseline Hanford Reach risk assessment should be conducted to support final records of decision at Hanford. The method for achieving this is under discussion.

1.2 IMPACT EVALUATION APPROACH

For this report, impacts are defined as identifiable and measurable contamination that results from past and present 100 Area operations. Significant adverse impacts are defined, to be consistent with the National Oil and Hazardous Substance Pollution Contingency Plan (NCP; 40 CFR §300.430(d)2), as contaminant concentrations that pose a potential threat to human health or the environment in the absence of remedial action. The main parameters for detection and quantification of impacts are elevated concentrations of contaminants relative to control (i.e. reference or area-specific background) conditions.

The scope of this document includes the review of relevant existing data and Hanford Site data collection programs. There has been an extensive effort expended since the beginning of reactor operations at the Hanford Site to monitor impacts to human health and the environment that are caused by Site activities. The program responsible for this, the Hanford Site Surface Environmental Surveillance Project, is conducted by the Pacific Northwest Laboratory (PNL) pursuant to DOE Order 5400.1, "General Environmental Protection Program." This monitoring effort is ongoing. As a consequence of the extensive environmental monitoring, there is a considerable amount of available data. To complete this plan, only existing, readily-available information was used (see Chapter 6). Other readily available information that was not referenced, but provided background information, is included in Appendix A (Bibliography). For most of the data evaluated in this evaluation, 1989 was the most complete data set. Data from previous or more recent data collection activities is included for completeness. However, 1989 data services as the baseline for evaluating impacts in this document.

The following approach was used to develop the preliminary impact evaluation:

1. <u>Identify contaminants of potential concern in the Hanford Reach and groundwater.</u> Contaminants of potential concern due to Hanford Site operations in the 100 Area that might impact the Hanford Reach ecosystem were identified based on groundwater concentrations that exceeded ambient water quality or drinking water standards. This approach is consistent with the designation of the Hanford Reach of the Columbia River by the State of Washington as a Class A (Excellent) surface water body.

2. <u>Develop a conceptual model.</u> Conceptual model development required identification of the major components of the Hanford Reach ecosystem together with the likely pathways along which contaminants of potential concern might move. Hanford Reach ecosystem components are included in the conceptual model if river water was identified as the primary transport medium of the contaminant to the component.

3. <u>Identify fate, transport, and migration of contaminants of potential concern.</u> The potential exposure pathways to ecosystem components were identified for those contaminants found to pose a potential significant adverse impact to the environment or human health. This pathways assessment included identification of hazardous substance release and transport mechanisms, exposure media and routes, and receptors.

4. <u>Evaluate potential environmental and human health impacts.</u> The threats to human health and the environment by contaminants of potential concern attributable to releases from 100 Area operations were evaluated for selected exposure pathways judged most likely to result in significant adverse health or environmental impacts. Threats were evaluated preliminarily in a manner consistent with NCP risk assessment requirements.

5. <u>Identify data gaps.</u> If, during the course of the impact evaluation, there were insufficient data to accurately predict impacts for a particular medium or pathway, a data gap was identified. These data gaps were summarized to

provide guidance of future data gathering activities proposed in 100 Area operational areas that might potentially impact the Hanford Reach.

6. Develop plan for Columbia River Impact Assessment. Based on identified data gaps, a plan is developed to ensure adequate data collection that will support subsequent 100 Area risk assessments.

1.3 RELEVANT ENVIRONMENTAL STATUTES, REGULATIONS, AND GUIDANCE

The Hanford Site environmental restoration activities are being conducted pursuant to multiple federal and state statutes, regulation, and guidelines. The primary federal statutes relevant to the impact assessment process are CERCLA and RCRA. The primary Washington State statutes that are potential applicable or relevant and appropriate requirements (ARARs) for this activity include the Model Toxics Control Act (MTCA, Ch. 70.105D RCW) and the Hazardous Waste Management Act (HWMA, Ch. 70.105 RCW).

Additional guidance documents or potential ARARs specific to the impact evaluation have also been used and are cited throughout the document, as appropriate.

1.4 DOCUMENT ORGANIZATION

Six chapters, including this introduction, are included in this document, which has been structured to provide the necessary framework to modify or initiate data collection activities to support subsequent risk assessments of the Hanford Reach that are related to the 100 Area. Chapter 2 presents the physical and environmental setting of the Hanford Reach, including the nature and extent of contamination that can be attributed to the 100 Area.

Available data on potential contaminant exposure pathways are reviewed in Chapter 3. Based on the current understanding of contamination in the various environmental media, conceptual exposure pathways are developed.

The preliminary evaluation of potential impacts to human health or the environment is presented in Chapter 4. This evaluation is used to identify the completeness of collected data and identify areas where additional data should be collected.

Chapter 5 includes a summary of the preliminary impact evaluation results (Section 5.1), and a plan and schedule of tasks and activities needed to acquire additional information to be used to assess cumulative impacts to the Hanford Reach due to 100 Area operational activities (Section 5.2). The latter section also discusses the data quality objectives for the proposed data collection activities. References used to develop this document are provided in Chapter 6.

Appendices to this plan include supporting information that were used to develop the document. These appendices are:

- Appendix A: Bibliography
- Appendix B: Description of Hydrogeology and Groundwater Contamination at the 100 Area of the Hanford Site.

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2.0 CHARACTERISTICS AND NATURE OF CONTAMINATION IN THE HANFORD REACH VICINITY

This chapter summarizes the relevant physical, biological, and sociological setting for the Hanford Reach of the Columbia River. The Hanford Reach encompasses the portion of the Columbia River that lies adjacent to the 100 Area. Much of the environmental monitoring and research of the Columbia River conducted by Hanford Site programs has concentrated on the Hanford Reach. It is expected that any significant adverse impacts associated with activities in the 100 Area would be observed in the Columbia River at the point of impact or immediately downstream of the 100 Area. Published data about the Hanford Reach environment, organisms that inhabit or use the area, and the known or suspected levels of contamination were used to prepare this chapter.

2.1 PHYSICAL SETTING OF THE HANFORD REACH

Given the important ecological functions of the Hanford Reach of the Columbia River, the purpose of this section is to describe the location of the Hanford Reach, the history of Hanford Site operations along the Hanford Reach, and the physical and biological characteristics of the Hanford Reach.

2.1.1 Environmental Characteristics of the Hanford Reach

The Hanford Reach of the Columbia River is located in southeastern Washington and extends 94 km (58 mi) from Priest Rapids Dam (approximately 8.5 km [5.3 mi] above the Hanford Site boundary) to the head of Lake Wallula (near Richland; see Figure 2-1). It is the last free-flowing, non-tidal stretch of the Columbia River in the United States. The remainder of the Columbia River below the United States/Canada border has been impounded. Because it is the last free-flowing stretch in the United States, the Hanford Reach retains many important ecological functions. Namely, it is one of the last mainstream spawning grounds for fall chinook salmon (*Oncorhyncus tshawytsha*) (Dauble and Watson 1990). In addition, it is becoming an essential spawning ground for other anadromous salmon (*O.* spp.) and steelhead trout (*O. mykiss*) (Fickeisen et al. 1980). In 1988, a study of the Hanford Reach was authorized to determine its eligibility for designation as a Wild and Scenic River (Public Law 100-605). The environmental impact statement for this study was published in June, 1992 (National Park Service 1992).

The area around the Hanford Reach is a semiarid desert dominated by a shrub-steppe grassland community. The shrub-steppe habitat of the Hanford Reach is characterized by low precipitation and seasonal temperature extremes. Climatological summaries from the Hanford Meteorological Station (HMS; Stone et al. 1983) show the average annual precipitation is 16 cm (6.3 in), falling predominantly during the winter. Snowfall accounts for approximately 40% of the precipitation falling during December through February. Average monthly temperatures range from a low of -2°C (29°F) in January to a high of 24°C (76°F) in July. The annual average temperature is 12°C (53°F). Prevailing winds are from the northwest with a secondary maximum for southwesterly winds.

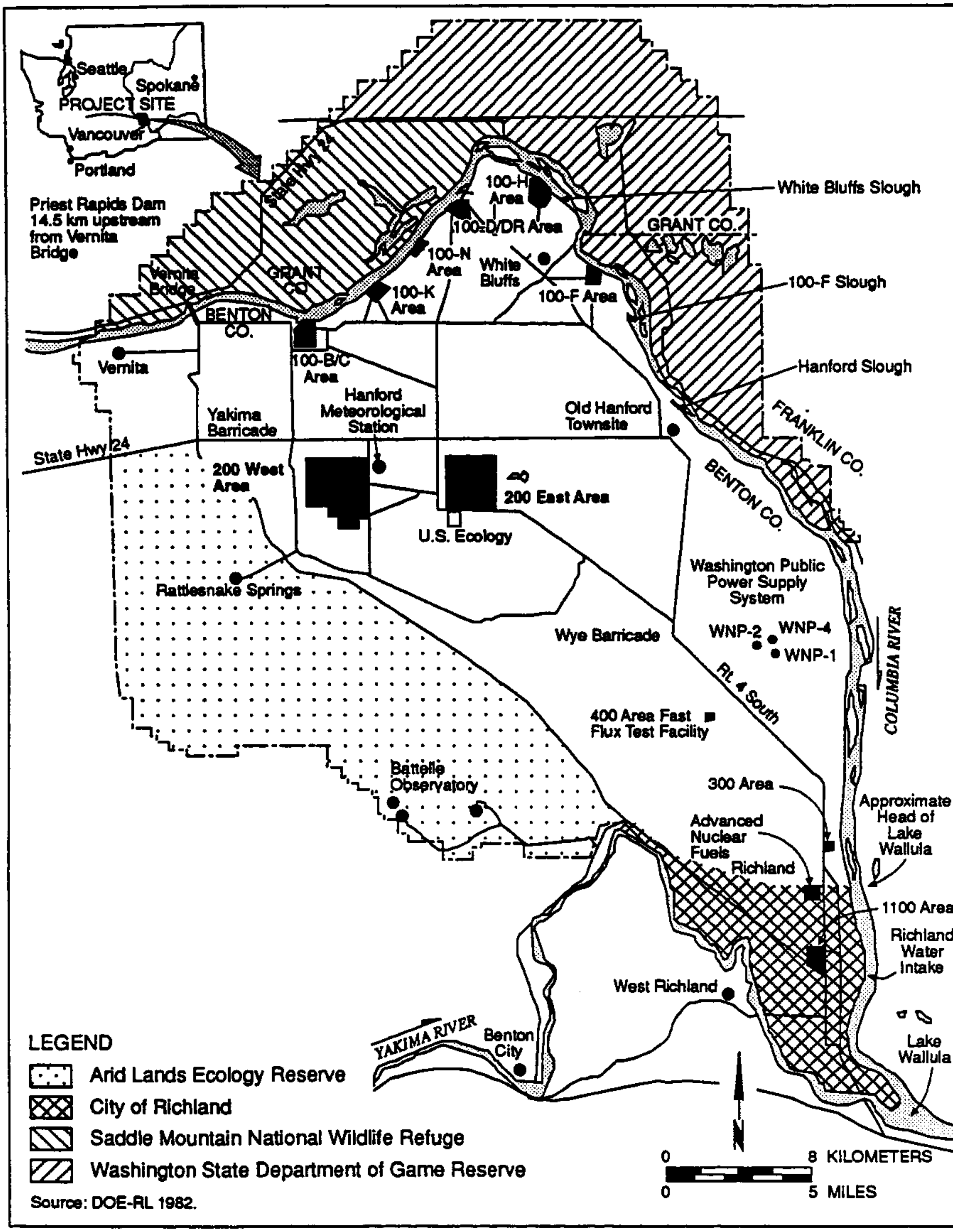

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Figure 2-1. Hanford Site

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Since 1943, the U.S. Government has maintained a facility (the Hanford Site) along the Hanford Reach for energy research and production of nuclear materials that are used in nuclear weapons. The Hanford Reach has played an important role in Hanford Site operations, especially in the 100 Area. The 100 Area is located in the north-central portion of the Site along the Hanford Reach (Figure 2-1). This area contains the nine plutonium-producing reactors that used the river as a source of cooling water from 1944 to 1986. Eight of these reactors were constructed so as to allow direct contact between the reactor core and the cooling water. As a consequence, significant amounts of radioactivity, chemicals, and heat were released to the river environment during the operational period of these eight reactors. The last of the direct-contact, single-pass reactors ceased operations in 1971. Further details on reactor operations can be found in operable unit work plans.

2.1.2 Sociological Characteristics

The population in the area surrounding the Hanford Site is predominantly rural, with the exception of the cities of Kennewick, Pasco, and Richland. Using the HMS tower as a reference point that is approximately in the center of the Site and 1980 census data, the total population within 80 km (50 mi) from the tower is 340,943. The number residing in incorporated cities is 210,999 (Jaquish and Bryce 1990).

Recreational activities associated with the Columbia River include hunting, fishing, boating, water skiing, and swimming. Agricultural activities near the Hanford Site include irrigated and dryland farming, and livestock grazing. During the growing season, about one-third of the crop acreage is irrigated, one-third in dryland production, and the remaining one-third is idle or in summer fallow (Watson et al. 1991).

2.1.3 Hydrological Characteristics

The dominant hydrologic feature of the Hanford Site is the Columbia River, which flows through the northern portion of the Site and forms part of the eastern Site boundary. The Columbia River is the fifth largest river by volume in North America (Stenner et al. 1988). The river originates in the Canadian Rockies of eastern British Columbia and drains approximately 250,000 km^2 (97,000 mi^2) before reaching the Hanford Site. Flow of the river is regulated by ten major dams, within both the United States and Canada, that are upstream of the Hanford Site. These dams provide a storage capacity of greater than 46 km^3 (11 mi^3) of water (Stenner et al. 1988). Average annual flow of the Columbia River is approximately 3,400 m^3/s (120,000 ft^3/s), but daily averages can vary from 1,000 to 7,000 m^3/s (35,000 to 250,000 ft^3/s).

Although the Columbia River is free-flowing through the Hanford Reach, the flow rate is regulated. A minimum flow rate of 1,020 m^3/s (36,000 ft^3/s) has been established at Priest Rapids Dam, but flows may vary significantly because of the relatively small storage capacities and operational practices of upstream dams. Flows up to 12,700 m^3/s (448,000 ft^3/s) are frequently recorded during periods of peak spring runoff (Energy Research and Development Administration, ERDA 1975). Average monthly flow rates generally peak from April through June, and the lowest monthly mean flows are observed during September and October. Recent annual average flows at Priest Rapids Dam range from 2,830 to 3,400 m^3/s (99,900 to 120,000 ft^3/s). The long-term average annual flow at

Priest Rapids Dam, based on 68 years of record, is approximately 3,400 m^3/s (120,000 ft^3/s) (McGavock et al. 1987).

Along the Hanford Reach, the river channel is generally 370-to-550-m (1,200-to-1,800-ft) wide and 3-to-12-m (10-to-39-ft) deep (ERDA 1975). The channel does not meander strongly, but contains large longitudinal bars, of which a few may support tree growth. The river channel remains relatively stable because the river flow rate is regulated by upstream dams. Channel sediments consist primarily of sands and gravels with cobbles that range up to 20 cm (8 in) in diameter. Silt- and clay-sized material accumulates in areas of low-energy flow, such as pools and channel margins.

2.1.4 Ecological Characteristics of the Hanford Reach

For this report, the Hanford Reach is comprised of two general habitat types: riverine (river channel to the high-water mark) and riparian (dependent solely on water provided by the river and may be subjected to periodic inundation). The diversity and largely unaltered character of these habitats makes the Hanford Reach ecosystem unique. Many of the wetlands along the Hanford Reach were classified as lacustrine, limnetic, and open water wetland by the U.S. Fish and Wildlife Service (USFWS 1976 a,b,c,d,e,f,g). Other wetland types identified along the Reach included lacustrine, littoral, unconsolidated shore, seasonal, and impounded; and palustrine, emergent, persistent, seasonal, and impounded.

Because these habitats have been impacted and disturbed throughout much of eastern Washington, the Hanford Reach may be particularly important to certain endangered, threatened, and sensitive species. Based on an ecological approach, the Hanford Reach received the second highest rating from the USFWS (1978) in the State of Washington as an important fish and wildlife habitat. More details of the ecological resources of the Hanford Reach can be found in Fickeisen et al. (1980), Cushing (1988), Sackschewsky and Landeen (1992), and Weiss and Mitchell (1992).

2.1.4.1 Riverine Zone. The riverine zone is comprised of those aquatic habitats that are submerged for much of the year. The river supports a large and diverse assemblage of plankton, periphyton, macrophytes, benthic invertebrates, and fish. Phytoplankton include diatoms (90% of the community), blue-green algae, red algae, green algae, and yellow-brown algae (Neitzel et al. 1982). These forms are typical of those found in lakes and ponds, and likely originate in upstream reservoirs. These communities are largely transient, flowing from one reservoir to another, as river flows are too high in the Hanford Reach for endemic populations to develop.

A number of free-floating algae originate as benthic periphyton that become detached and suspended by currents and frequent water-level fluctuations. These organisms develop on suitable solid substrates wherever there is sufficient light for photosynthesis (Neitzel et al. 1982). Both the phytoplankton and periphyton serve as important food sources for herbivores, such as immature aquatic insects and certain fishes.

Macrophytes are sparse in the riverine zone of the Hanford Reach because of the strong currents, rocky substrate, and fluctuating water levels. Rushes and sedges may occur in the riverine zone along sloughs and slack-water areas. Macrophytes are also present along gently sloping shorelines. Commonly found plants include duckweed

(*Lemna* spp.), pondweed (*Potamogeton* spp.), waterweed (*Elodea canadensis*), and watermilfoil (*Myriophyllum* spp.). Where present, the macrophytes can provide food and shelter for juvenile fish, waterfowl, and aquatic insects and spawning areas for some warm-water fish species.

All major freshwater benthic macroinvertebrate taxa are represented in the Hanford Reach (Fickeisen et al. 1980). Insect larvae (e.g., caddisflies, *Trichoptera;* midge flies, *Chironomidae;* and black flies, *Simuliidae*) are dominant. Other benthic organisms include snails *(Physa* spp and *Lyminaea* spp.), sponge *(Spongella lucustrus)*, and crayfish *(Pacifasticus leniusculus)*. Benthic organisms are found either attached to or closely associated with the substrate. Two species of invertebrates are candidates for federal listing as endangered species: the shortface lanx (*Fisherola nuttalli*) and the Columbia pebblesnail (*Fluminicola columbiana*).

Gray and Dauble (1977) list 43 species of fish found in the Hanford Reach. Of these 43 species, chinook salmon (*Oncorhynchus tshawytscha*), sockeye salmon (*O. nerka*), coho salmon (*O. kisutch*), and steelhead trout (*O. mykiss*) are of the greatest economic and recreational importance. These four species use the river as a migration route to and from upstream spawning grounds. The Hanford Reach, especially the 100 Area segment, is an important spawning area for fall chinook salmon (upriver brights). During the ten-year period of 1980 to 1989, numbers of spawning fall chinook salmon in the Hanford Reach range from a low of 15,069 in 1981 to a high of 90,553 in 1987 (Carlson and Dell 1990). The ten-year average was 50,712. The destruction of other mainstream Columbia River spawning grounds by dams has increased the relative importance of the Hanford Reach.

Although other resident species of the Hanford Reach have not received as much attention as the anadramous species, they are no less important from an ecological perspective. Many resident species are important forage species for avian and mammalian predators. Among the other fish identified in the Hanford Reach are the white sturgeon (*Acipenser transmontanus*), bass (*Micropterus* spp.), panfish (*Lepomis* spp.), lake whitefish (*Coregonus clupeaformis*), channel catfish (*Ictalurus punctatus*), carp (*Cyprinus carpio*), and the northern squawfish (*Ptychocheilus oregonensis*).

The river also serves as an important source of water for the human populations that reside along the Hanford Reach. Water from the Hanford Reach is used for drinking by the Hanford Site and the community of Richland, as well as for a variety of industrial uses. Extensive tracts of farmland east of the Hanford Reach (in the vicinity of Ringold) are irrigated using river water. In addition, water from the river is used for recreational activities such as fishing, hunting, boating, and swimming.

The Hanford Reach has been designated by the State of Washington as a Class A (Excellent) water body (Ch. 173-201 WAC). Such waters are suitable (and must be maintained suitable) for essentially all uses, including raw drinking water, recreation, and wildlife habitat. Thus, the Hanford Reach represents a significant resource to Washington.

2.1.4.2 Riparian Zone. The Hanford Reach is a mosaic of sloughs, slack-water areas, and shores with fast moving water. The riparian zone is an econtone between the largely undeveloped upland shrub-steppe community of the Hanford Site and the aquatic habitat of the river. The riparian zone provides food and cover for many species, including several that are endangered or threatened.

In general, the riparian plant communities developed in response to the shore substrate and the degree of water level fluctuation (Fickeisen et al. 1980). Typically, the riparian vegetation consists of a narrow zone of grasses and forbs, interspersed with a few scattered deciduous shrubs and trees that are able to establish and grow in a cobble and gravel substrate. Predominant plant species include various grasses, sedges, rushes, and forbs (e.g., reed canarygrass, *Phalaris arundinacea*; sedges, *Carex* spp.; rushes, *Juncus* spp.; wiregrass, *Eleocharis* spp.; lupine, *Lupinus* spp.). A detailed listing of flora known to occur along the Columbia River within the 100 Area of the Hanford Site can be found in Sackschewsky and Landeen (1992).

Typical riparian tree species that characteristically border most streams and rivers are scarce along the Hanford Reach. Many of the groves of trees conspicuous along the Hanford Reach were planted by ranchers and farmers prior to 1943. These trees include exotics such as black locust (*Robinia pseudacacia*), Siberian elm (*Elmus pumila*), Russian olive (*Elaeagnus angustifolia*), and white mulberry (*Morus alba*). Native species such as willows (*Salix* spp.) and cottonwood (*Populus trichocarpa*) also occur occasionally. Mulberry, Russian olive, and cottonwoods serve as invading species at favorable microsites in the riparian zone. Although many are not native, the trees add to the habitat diversity of this semiarid region and are important to many wildlife species.

A number of plant species are found in the riparian zone of the Hanford Reach that are considered endangered, threatened, or sensitive. Persistentsepal yellowcress (*Rorippa columbiae*) is found in Washington along the Hanford Reach on gently sloping gravel banks. It is considered endangered by the Washington Department of Natural Resources (DNR 1990) and is a candidate for listing under the federal Endangered Species Act. Four additional plant species that are also found along the Hanford Reach are considered sensitive in Washington (DNR 1990): southern mudwort (*Limosella acaulis*), shining flatsedge (*Cyperus rivularus*), dense sedge (*Carex densa*), and false-pimpernel (*Lindernia anagallidea*). These plants are typically found on periodically inundated mud flats, except dense sedge which is found above the average high-water mark.

The riparian zone provides valuable habitat for many wildlife species along the Hanford Reach. Many invertebrates, birds, reptiles, amphibians, and mammals (e.g., mallard, *Anas platyrhynchos*; Canada goose, *Branta canadensis moffitti*; great blue heron, *Ardea herodias*; bald eagle, *Haliaeetus leucocephalus*; hawks, *Buteo* spp.; mule deer, *Odocoileus hemionus*; badger, *Taxidea taxus*; bobcat, *Lynx rufus*) use the riparian zone for food and cover.

The riparian zone serves as sensitive habitat for several species that are listed as endangered or threatened. The bald eagle, a common winter resident along the Hanford Reach, is a state and federal threatened species. The white pelican (*Pelecanus erythrorhynchos*) is a state-endangered species that occasionally uses the Hanford Reach as a wintering ground. Other riparian species that are candidates for listing include the great blue heron and the common loon (*Gavia immer*).

2.2 NATURE AND EXTENT OF CONTAMINATION

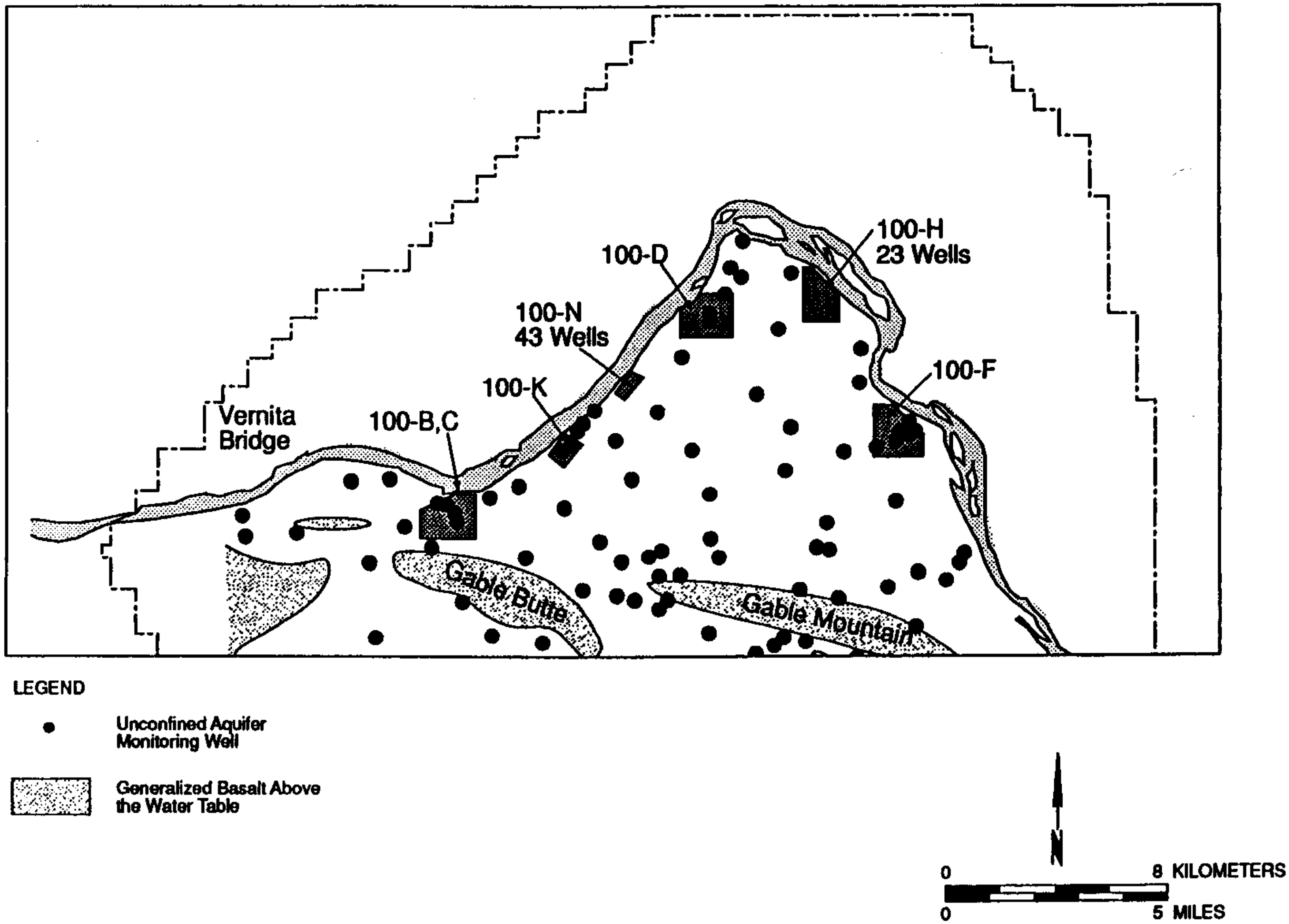
The known nature and extent of contamination of the Hanford Reach is summarized below by environmental medium. This summary provides the basis for the subsequent assessment of current impacts to the river provided in Chapter 4.

2.2.1 Subsurface and Groundwater Contamination

Groundwater at the Hanford Site is monitored by the PNL as part of the Site-Wide Groundwater Monitoring Project (Evans et al. 1990). Well networks used to collect groundwater samples have been designed for facility-specific, operational, and groundwater surveillance activities. Locations of the Hanford Site groundwater monitoring wells near the 100 Area associated with the Environmental Monitoring Program are shown in Figure 2-2. During 1989, 567 wells across the Hanford Site were sampled and analyzed for both radiological and chemical constituents.

For the purposes of this study, infiltration and migration of wastes through the soil to groundwater culminating in the discharge of contaminated groundwater to the Columbia River is considered the current primary pathway for environmental contamination and impact on the Columbia River. An additional exposure pathway consists of the phenomenon called "skyshine", which is due to reflection/refraction of radiation (originating from terrestrial sources) by clouds or dust back to the earth's surface (Brown and Perkins 1991). Although this phenomenon is known to exist in 100 Area operable units, for this report skyshine is not considered as an input of contaminants to the river ecosystem. Known subsurface soil contamination in the individual operation areas and operable units across the 100 Area has been discussed in draft environmental restoration investigation/study work plans, such as those for operable units 100-BC-1 (DOE-RL 1991b), 100-KR-1 (DOE-RL 1992a), 100-DR-1 (DOE-RL 1991c), 100-HR-1 (DOE-RL 1992b), 100-FR-1 (DOE-RL 1991d), and 100-NR-1 (DOE-RL 1991e).

The major chemical and radiological contaminants found in groundwater at the Hanford Site associated with 100 Area operations include: tritium (^{3}H), cobalt-60 (^{60}Co), strontium-90 (^{90}Sr), hexavalent chromium (Cr), and sulfate (SO_4) (Evans et.al. 1990). In general, groundwater contaminant plumes that are flowing toward the Columbia River have been identified using nitrate (NO_3) and ^{3}H as conservative indicators of contaminated groundwater movement (Figures 2-3 and 2-4). These plumes are associated with past liquid disposal practices using trenches, cribs, french drains, tile lines, etc. at the individual reactor operation areas in the 100 Area. These disposal facilities were designed to allow the percolation of contaminated effluents through the soil. Thus, large quantities of contaminants were discharged to the soil column with the potential to eventually reach groundwater in the unconfined aquifer. The NO_3 and ^{3}H plume maps show that contaminants associated with 100 Area operations have the potential to reach the Hanford Reach ecosystem.



Source: Woodruff and Hanf, 1991.

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Figure 2-2. 100 Area Unconfined Aquifer Monitoring Well Locations, 1990.

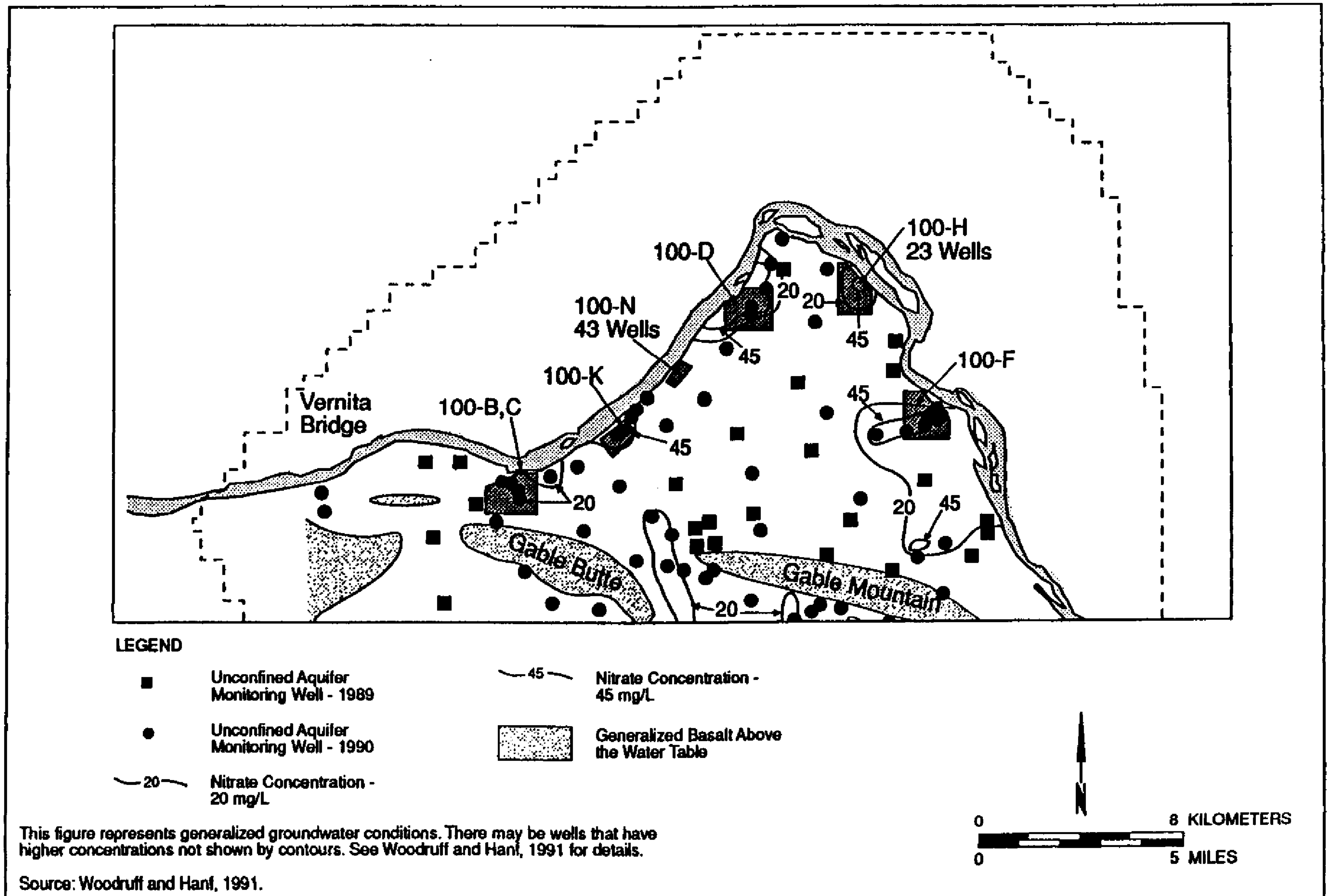

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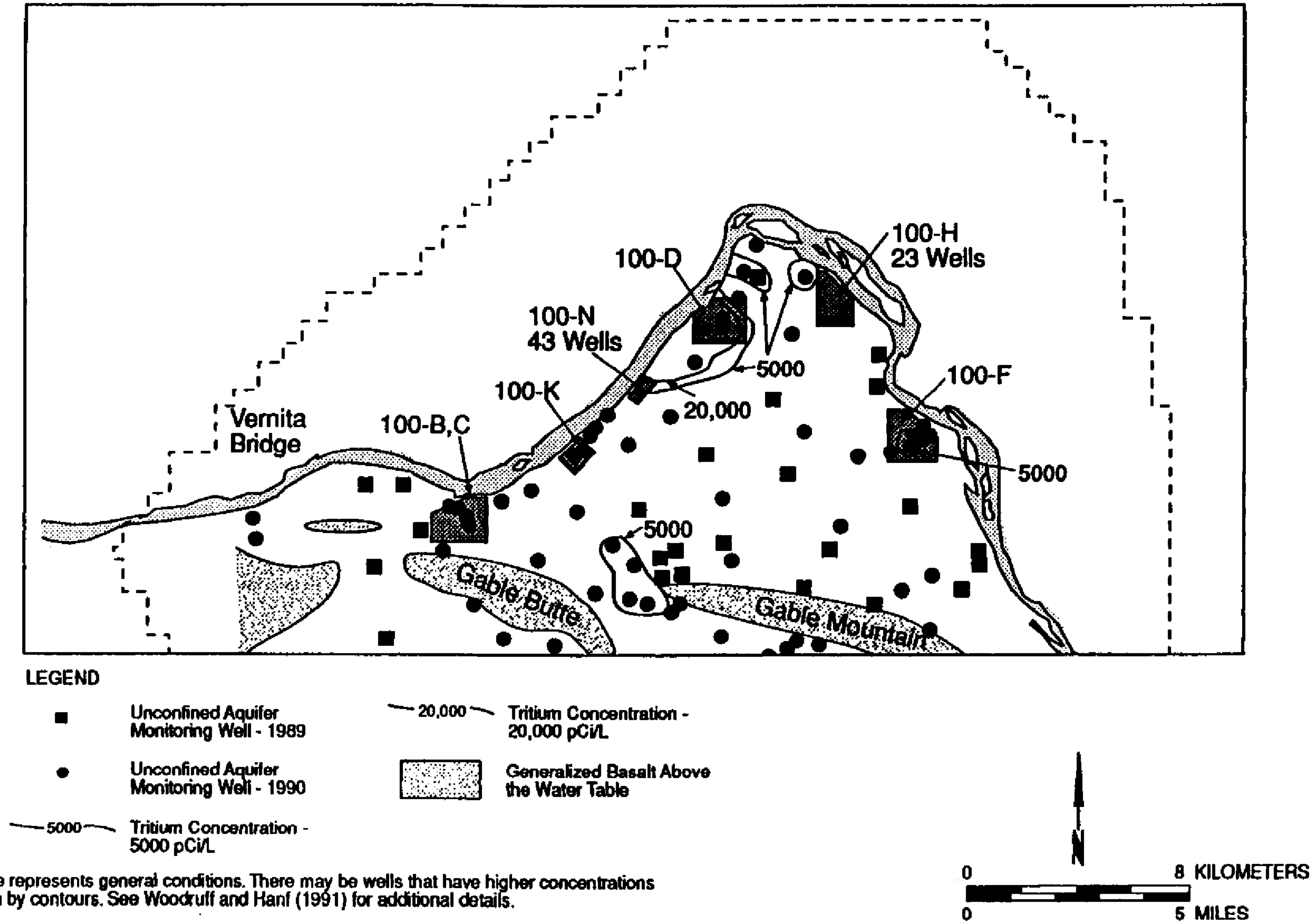
Figure 2-3. Nitrate (NO_3) Concentrations in the 100 Area Unconfined Aquifer, 1990.



This figure represents general conditions. There may be wells that have higher concentrations not shown by contours. See Woodruff and Hanf (1991) for additional details.

Source: Woodruff and Hanf, 1991.

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Figure 2-4. Tritium (^{3}H) Concentrations in the 100 Area Unconfined Aquifer, 1990.

On the basis of 1989 results from Evans et al. (1990), the groundwater contaminants were regarded as contaminants of potential concern in this evaluation if their concentrations exceeded the more stringent of standards promulgated in either the drinking-water standards (40 CFR 141 - 143, and Ch. 248-54 WAC) ambient water quality criteria (EPA 1986a) or the groundwater standards of the Model Toxics Control Act Cleanup Regulation (MTCACR; Ch. 173-340 WAC) (see Appendix B for further details). Based on these standards, the following constituents were identified as contaminants: Cr, $N0_3$, ^3H, ^{90}Sr, technetium-99 (^{99}Tc), and total uranium (U).

Contaminant groundwater plumes and their projected flow directions are discussed in more detail in Appendix B. The locations of these plumes are only approximate and are used only for this preliminary impact evaluation in the absence of more specific information. For illustrative purposes, the relative plume locations and flow directions are shown on Figure 2-5 (note that this figure is not to scale and is for conceptual purposes only). In addition, the groundwater discharge rate for each plume is estimated in Appendix B.

Table 2-1 shows the mean, standard deviation, and range for contaminants of potential concern in groundwater plumes identified in Appendix B. These statistics were computed using data from wells that were sampled and analyzed during the indicated period. Because some wells were not necessarily analyzed during each sampling period and the locations of wells within a given plume is not necessarily representative of the entire plume, the statistics are only general indicators of groundwater quality. Thus, this table is only meant to show relative trends in groundwater quality. Only 1989 data was used for this document. Table 2-2 identifies the contaminants, their 1989 maximum source concentration, and the estimated flow rate for each plume. On the basis of this information, it is evident that contaminants generated by past operations in the 100 Area affect the Hanford Reach.

In the following paragraphs, the various contaminant of potential concern will be discussed individually to provide more detail about the contaminant concentrations at the riverbank and the locations of the specific plumes which are identified in Appendix B. These plumes and the contaminant concentrations will serve as the basis for the impact evaluation in Chapter 4. Although it is possible that all contaminants are not identified, those that are identified are sufficient given the preliminary and qualitative nature of the impact evaluation in Chapter 4. Future risk assessments will identify contaminants of potential concern using a more thorough screening process set forth in the Hanford Site Baseline Risk Assessment Methodology (DOE-RL 1992c).

2.2.1.1 Chemical Contaminants.

Chromium. Hexavalent chromium has been detected in groundwater monitoring wells in the 100-B (plume 100BC-1), 100-D (plume 100D-1), 100-H (plumes 100H-1 and 100H-2), and the 100-K operable units (plumes 100K-2 and 100K-3). Hexavalent Cr was commonly used for water treatment to inhibit corrosion of piping in the reactors. Thus, large quantities of Cr were disposed in and near the Hanford Reach in the liquid disposal, trenches, cribs, etc.

Chromium has been detected in groundwater monitoring wells located near the river (Evans et al. 1990). Chromium was not detected in any water samples collected by Dirkes (1990) from Hanford Reach springs; however, during 1991 spring sampling

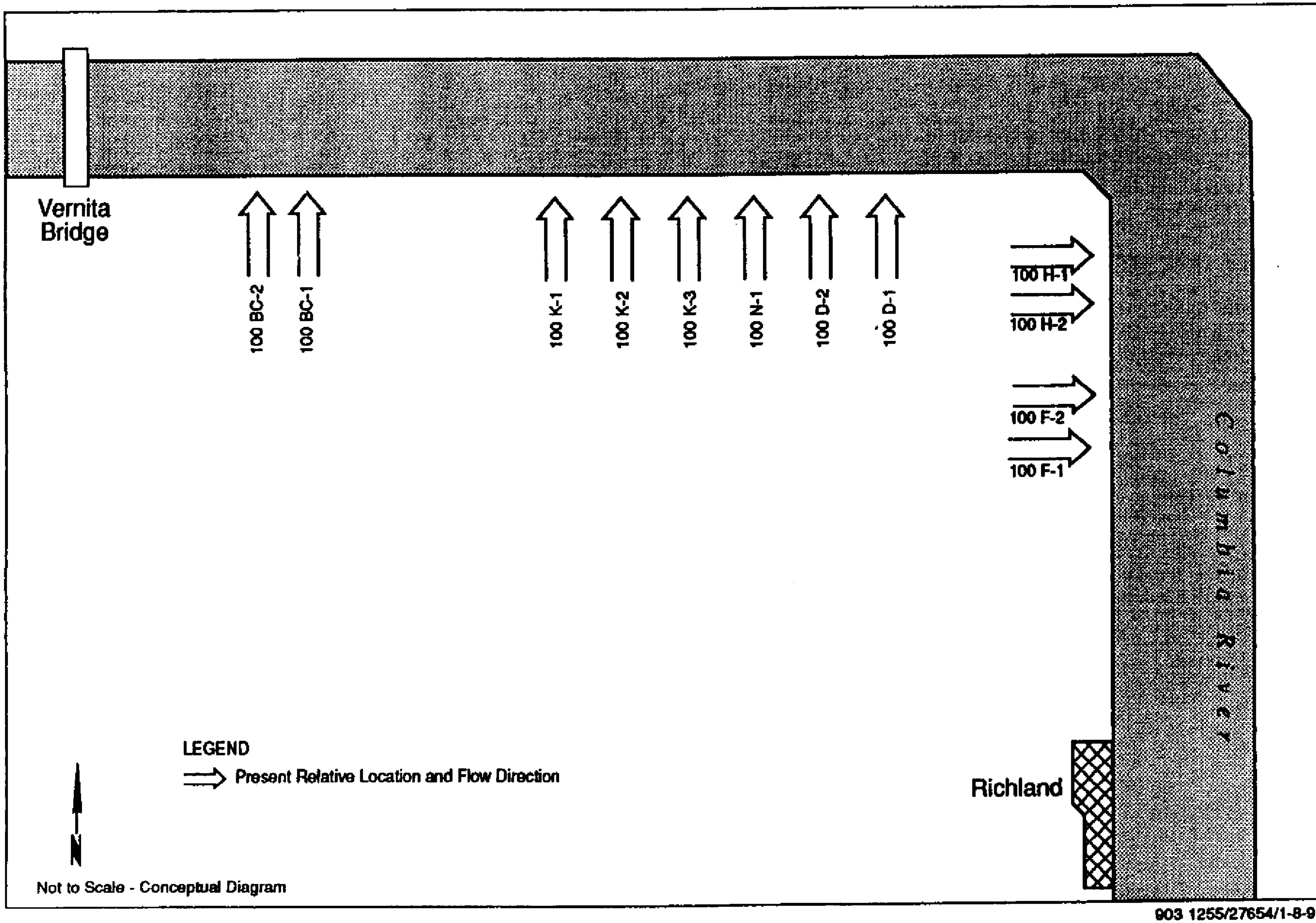

Figure 2-5. Relative Plume Locations and Projected Flow Directions Along the Hanford Reach.

9 3 1 2 7 5 3 1 6 2 9

Table 2-1. Summary of Groundwater Contaminants.

Plume[a]	Constituent[b]		1987	1988	1989	1990
	Strontium-90 (pCi/L)	mean ± std dev	31.2 ± 4.06	24.5 ± 4.98	26.3 ± 11.6	27.0 ± 0.990
		range	27.3 - 35.4	17.8 - 32.6	16.7 - 53.5	26.3 - 27.7
		n	3	8	8	2
100BC-1	Chromium (mg/L)	mean ± std dev	0.05 ± 0.011	0.033 ± 0.005	0.018	0.017
		range	0.047 - 0.062	0.029 - 0.036	0.018	0.017
		n	2	2	1	1
	Nitrate (mg/L)	mean ± std dev	37.4 ± 9.95	26.9 ± 1.44	40.4 ± 8.79	33.3
		range	29.8 - 55.6	25.0 - 28.5	31.0 - 55.6	33.3
		n	6	4	3	1
	Strontium-90 (pCi/L)	mean ± std dev	55.2	53.8 ± 5.30	50.4 ± 3.04	39.7
		range	55.2	50 - 57.5	48.3 - 52.6	39.7
		n	1	2	2	1
100K-1	Nitrate (mg/L)	mean ± std dev	23.8 ± 18.60	26.5 ± 26.10	22.4 ± 19.38	19.6 ± 16.64
		range	7.0 - 58.5	7.9 - 70.1	3.0 - 66.0	5.1 - 42.3
		n	19	8	12	4
	Tritium (pCi/L)	mean ± std dev	207,959 ± 390,618	304,841 ± 552,632	196,234 ± 304,641	242,148 ± 391,936
		range	1,350 - 1,300,000	1,850 - 1,220,000	2,200 - 882,000	1,860 - 823,000
		n	16	8	12	4
100K-2	Chromium (mg/L)	mean ± std dev	0.099 ± 0.002	NR	0.112	0.109
		range	0.097 ± 0.101	NR	0.112	0.109
		n	3		1	1
100K-2 cont.	Nitrate (mg/L)	mean ± std dev	58.6 ± 9.92	63.9 ± 15.86	51.3	35.5
		range	36.3 - 68.9	41.5 - 86.8	51.3	35.5
		n	9	6	1	1
100K-3	Chromium (mg/L)	mean ± std dev	0.172 ± 0.039	NR	0.129 ± 0.044	0.157 ± 0.001
		range	0.137 - 0.231	NR	0.098 - 0.160	0.156 - 0.157
		n	6	NR	2	2

Table 2-9. Summary of Groundwater Contaminants. (Cont.)

Plume[a]	Constituent[b]		1987	1988	1989	1990
100N-1	Strontium-90 (pCi/L)	mean ± std dev	450 ± 1,285	692 ± 1,525	1,064 ± 3,471	849 ± 2,048
		range	0.08 - 10,400	-0.50 - 13,800	-0.48 - 23,400	-0.30 - 8,980
		n	95	107	84	19
	Tritium (pCi/L)	mean ± std dev	77,318 ± 70,727	87,217 ± 82,896	47,177 ± 48,098	85,383 ± 76,161
		range	195 - 249,000	57 - 459,000	166 - 218,000	8,380 - 260,000
		n	106	107	84	19
100D-2	Tritium (pCi/L)	mean ± std dev	84,567 ± 21,447	111,625 ± 19,886	94,200 ± 2,263	NR
		range	59,400 - 121,000	92,900 - 133,000	92,600 - 95,800	NR
		n	6	4	2	NR
100D-1	Chromium (mg/L)	mean ± std dev	0.787 ± 0.775	NR	0.327 ± 0.317	0.243 ± 0.192
		range	0.094 - 1.69	NR	0.120 - 0.692	0.120 - 0.464
		n	7	NR	3	3
	Nitrate (mg/L)	mean ± std dev	59.4 ± 25.41	73.3 ± 21.32	85.0 ± 21.13	93.9 ± 34.19
		range	23.7 - 99.8	38.7 - 109.0	57.0 - 122.0	54.8 - 118.0
		n	13	10	9	3
	Strontium-90 (mg/L)	mean ± std dev	23 ± 32.6	12 ± 18.0	16 ± 22.4	18 ± 29.6
		range	-0.16 - 46	-0.07 - 40	-0.06 - 45	0.22 - 53
		n	2	7	6	3
	Tritium (pCi/L)	mean ± std dev	11,299 ± 10,328	20,416 ± 12,991	25,403 ± 19,013	21,593 ± 16,017
		range	4,130 - 32,400	3,990 - 33,500	3,690 - 53,300	3,180 - 32,300
		n	12	8	6	3

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Table 2-1. Summary of Groundwater Contaminants. (Cont.)

Plume[a]	Constituent[b]		1987	1988	1989	1990
100H-1	Chromium (mg/L)	mean ± std dev	0.116 ± 0.071	0.142 ± 0.107	0.119 ± 0.098	0.125 ± 0.087
		range	0.010 - 0.331	0.033 - 0.474	0.039 - 0.420	0.037 - 0.359
		n	157	72	36	20
	Nitrate (mg/L)	mean ± std dev	28.5 ± 8.044	31.4 ± 10.68	35.0 ± 9.994	35.1 ± 12.14
		range	15.6 - 48.5	17.0 - 52.4	18.1 - 56.00	15,700 - 58.8
		n	80	36	18	10
100H-2	Chromium (mg/L)	mean ± std dev	0.228 ± 0.091	0.180 ± 0.064	0.140 ± 0.106	0.106 ± 0.028
		range	0.024 - 0.437	0.054 - 0.364	0.018 - 0.789	0.068 - 0.160
		n	126	119	58	38
	Nitrate (mg/L)	mean ± std dev	232 ± 248.8	169 ± 138.3	133. ± 142.8	87.3 ± 71.56
		range	9.7 - 1,020	15.3 - 663	9.7 - 524	4.2 - 240
		n	67	67	30	22
	Technetium-99 (pCi/L)	mean ± std dev	2,613 ± 1,423	876 ± 1,012	691 ± 1,138	343 ± 429
		range	1,170 - 3,860	-1.85 - 4,430	-1.54 - 3,650	-0.414 - 1,060
		n	4	43	22	6
	Uranium (pCi/L)	mean ± std dev	19 ± 26	NR	27 ± 38	19 ± 25
		range	0.54 - 67	NR	1.6 - 145	0.031 - 93
		n	8	NR	22	32
100F-2	Nitrate (mg/L)	mean ± std dev	120 ± 48.31	150 ± 62.59	120 ± 41.58	111 ± 27.10
		range	52.5 - 218	65.8 - 244	64.3 - 167	74.1 - 134
		n	24	24	8	4
	Uranium pCi/L	mean ± std dev	158 ± 127	158 ± 117	57 ± 53	37 ± 33
		range	4 - 362	6.2 - 414	6.7 - 143	7.1 - 72
		n	24	20	6	3

Table 2-1. Summary of Groundwater Contaminants. (Cont.)

Plume[a]	Constituent[b]		1987	1988	1989	1990
100F-1	Strontium-90 (pCi/L)	mean ± std dev	19 ± 26	NR	27 ± 38	19 ± 25
		range	0.54 - 67	NR	1.6 - 145	0.031 - 93
		n	8	NR	22	32

Information complied using data complied from PNL Groundwater Database, accessed September, 1992.
1989 data is used for subsequent evaluations, remaining data is included for completeness
NR = not reported
[a]Plumes in order of occurrence proceeding downstream from Vernita Bridge, see Figure 2-5.
[b]Contaminants of potential concern for this report.

Table 2-2. Estimated Ground-Water Flow Rates and Contaminant Source Concentrations in Hanford 100 Area Ground-Water Plumes.

Groundwater Plume	Contaminant of Potential Concern	Maximum Source Concentration (1989 data)	Estimated Flow Rate
100BC-2	^{90}Sr	54 pCi/L	757 L/min
100BC-1	^{90}Sr	53 pCi/L	757 L/min
	Cr	0.02 mg/L	
	NO_3	56 mg/L	
100K-1	NO_3	66 mg/L	1,938 L/min
	^{3}H	880,000 pCi/L	
100K-2	NO_3	51 mg/L	1,938 L/min
	Cr	0.11 mg/L	
100K-3	Cr	0.16 mg/L	3,785 L/min
100N-1	^{90}Sr	23,000 pCi/L	2,650 L/min
	^{3}H	220,000 pCi/L	
100D-2	^{3}H	96,000 pCi/L	3,785 L/min
100D-1	^{90}Sr	45 pCi/L	3,028 L/min
	^{3}H	53,000 pCi/L	
	Cr	0.69 mg/L	
	NO_3	120 mg/L	
100H-1	NO_3	56 mg/L	757 L/min
	Cr	0.42 mg/L	
100H-2	^{99}Tc	3,700 pCi/L	233 L/min
	U	150 pCi/L	
	Cr	0.79 mg/L	
	NO_3	520 mg/L	
100F-2	U	143 pCi/L	1,163 L/min
	NO_3	170 mg/L	
100F-1	^{90}Sr	145 pCi/L	1,163 L/min

Reference: Evans et al. 1990, PNL Groundwater Database accessed September 1992.
*See Appendix B for details.

(DOE-RL 1992d), Cr was found to be entering the river from springs in the 100-B/C, 100-K, 100-D, 100-H, and 100-F Areas. Thus, Cr^{6+} due to 100 Area activities is impacting the Hanford Reach.

Nitrate. Nitrate was present in many waste streams. The source for contamination of groundwater in the 100 Area may reflect the extensive use of nitric acid in decontamination operations.

Figure 2-3 shows the distribution of NO_3 in groundwater beneath the 100 Area of the Hanford Site. It is evident that NO_3 contamination of groundwater is associated with reactor operation facilities in the 100 Area. The NO_3 plumes associated with these operations currently discharge to the river (Dirkes 1990 and DOE-RL 1992d); thus, there is an impact of the Hanford Reach by NO_3-contaminated groundwater.

2.2.1.2 Radiological Contaminants.

Tritium. Tritium was present in many waste streams that were discharged to the soil column at the 100 Area. It is the most mobile radiological contaminant present and provides an indication of the extent of groundwater contamination that can be attributed to Site operations. The distribution of ^3H in the groundwater during 1989 is shown in Figure 2-4. During the 1992 sampling of 100 Area springs (DOE-RL 1992d), detectable concentrations of ^3H were found in springs adjacent to the 100-B/C, 100-K, 100-N, 100-D, and 100-H Areas. As a result of Hanford Site operations, there are ^3H plumes extending from reactor operations areas to the Hanford Reach and there is an impact on this system.

Strontium-90. Strontium-90 has been detected in a number of plumes across the Hanford Site. The contamination is associated with past liquid disposal practices in the 100 Area (plumes 100BC-1, 100BC-2, 100N-1, 100D-1, and 100F-1). In the 100 Area, ^{90}Sr-contaminated groundwater is entering the river through spring discharge (Dirkes 1990 and DOE-RL 1992d), thus causing an impact.

Technetium-99. Technetium-99 is found in a groundwater plume in the 100-H Area (plume 100H-2). Technetium-99 was detected during the 1991 sampling of 100 Area springs (DOE-RL 1992d) in the vicinity of the 100-K, 100-N, 100-D, and 100-H Areas.

Uranium. Uranium-contaminated groundwater was found in monitoring wells associated with liquid-waste-disposal facilities at the 100-F (plume 100F-2) and 100-H Areas (plume 100H-2) (Evans et al. 1990). Detectable concentrations of uranium were found to be entering the river during the 1991 sampling of 100 Area springs (DOE-RL 1992d) in springs adjacent to the 100-B/C, 100-K, 100-N, 100-H, and 100-F Areas.

2.2.2 Surface-Water Contamination

A summary of past and existing levels of surface-water contamination is presented below in two parts: the first focusing on the Hanford Reach the second on riverbank springs.

2.2.2.1 **Hanford Reach.** The Hanford Reach has received radiological and chemical contaminants as a result of past operations at the Hanford Site. From 1944 until 1971, river water was used to cool, in a once-through-flow manner, as many as eight single-purpose nuclear reactors. During reactor operations the cooling water became contaminated with radionuclides, heat, and other chemicals used for water treatment. These contaminants entered the river as direct effluent discharges during reactor operations. As single-purpose reactor operations were terminated, the direct discharges to the river were reduced. In addition to direct discharges of contaminated cooling water, the Hanford Reach received and continues to receive contaminants indirectly through groundwater discharge. Groundwater was contaminated either through direct discharge of contaminated effluent to soil column waste disposal units or through leaks from pipelines and retention basins. Groundwater discharge to the river is currently a major source of contaminants in the Hanford Reach.

A summary of radioactive constituents discharged during 1990 to the Hanford Reach from the 100 Area is shown in Table 2-3. In addition, radioactive and non-radioactive constituents discharged during 1990 in liquids to ground-disposal facilities are shown in Table 2-4. These discharges are allowed under a National Pollutant Discharge Elimination System (NPDES) permit issued to the DOE Richland Field Office (DOE-RL). In addition to permitted discharges, quantities of contaminants (low-level mixed wastes) continue to enter the river through seepage of groundwater that was contaminated by past disposal practices. Although additional contaminants are disposed of in the river, the focus of this document remains on the contaminants of potential concern identified in subsection 2.2.1.

Table 2-3. Radionuclides in Liquid Effluents Discharged to the Hanford Reach from the 100 Area in 1990 (Woodruff and Hanf 1991).

Radionuclide	Release, Ci
tritium	38
strontium-90	1.9
cesium-137	0.11
ruthenium-106	0.07
cobalt-60	0.04
cesium-134	0.02
antimony-125	0.02
manganese-54	0.015
plutonium-239,240	0.0000021
plutonium-238	0.00000036

Water quality in the Hanford Reach has been routinely monitored and reported by Site contractors almost since the beginning of reactor operations. Initially, the results of these water-quality studies were published monthly in the H.I. Environs Reports by the General Electric Company. Since 1965, PNL has been responsible for environmental monitoring and reporting at the Hanford Site. In recent years, the summary results have been published in the annual Hanford Site Environmental Report.

Water-quality samples from the Columbia River have been collected upstream of the Hanford Site (at Vernita Bridge and at Priest Rapids Dam), and downstream of the Site (at the Richland Pumphouse [water intake]) to determine the effect of Hanford operations on river-water quality. Initially, water samples were only analyzed for radiological contaminants. These results were reported as gross-alpha or gross-beta activity. Analytical techniques were not initially available to identify specific radionuclides.

In a recent Hanford Site Environmental Report (Jaquish and Bryce 1990), PNL routinely measured river-water samples at upstream and downstream locations for gross alpha, gross beta, and gamma-emitting radionuclides. The report provides quantitative data for those specific radionuclides detected, such as ^{3}H, ^{60}Co, strontium-89 (^{89}Sr), ^{90}Sr, ^{99}Tc, iodine-129 (^{129}I), iodine-131 (^{131}I), cesium-137 (^{137}Cs), uranium-234 (^{234}U), uranium-235 (^{235}U), uranium-238 (^{238}U), and $^{239,240}Pu$. Chemical analyses of river water conducted by PNL include pH, NO_3, total and fecal coliform bacteria, and biological oxygen demand. Additional water-quality data collected by the U.S. Geological Survey (USGS) for temperature, dissolved oxygen, turbidity, pH, suspended solids, dissolved solids, specific conductance, hardness,

Table 2-4. Liquids Effluents Discharged to Ground Disposal Facilities in the 100 Area in 1990 (Woodruff and Hanf, 1991).

Nonradioactive constituents

Constituent	Release, kg
Aluminum Sulfate	69,300
Polyacrylamide	205
Sodium Sulfate	110,230

Radioactive constituents

Radionuclide	Release, Ci
tritium	38
manganese-54	0.26
cobalt-60	7.8
strontium-90	14
cesium-134	0.12
cesium-137	7.1
plutonium-238	0.0025
plutonium-241	0.047

total phosphorus (P), dissolved Cr, Kjeldahl nitrogen, total organic carbon, dissolved iron, and dissolved ammonia are also published annually (e.g. Miles et al. 1992). Selected available water quality data for the Hanford Reach are summarized in Table 2-5. The 1990 Hanford Site Environmental Report (Woodruff and Hanf 1991) did not contain complete results for upstream and downstream constituent concentrations. Therefore, the evaluation of impacts to the Hanford Reach due to Site activities.

Hanford Site Environmental Reports from 1970 to 1990 were used to construct Figures 2-6 through 2-8. Data used to develop these figures are annual averages for the various constituents. It was not possible to use the same reporting period for every

Table 2-5. Hanford Reach Water Quality. (Sheet 1 of 2)

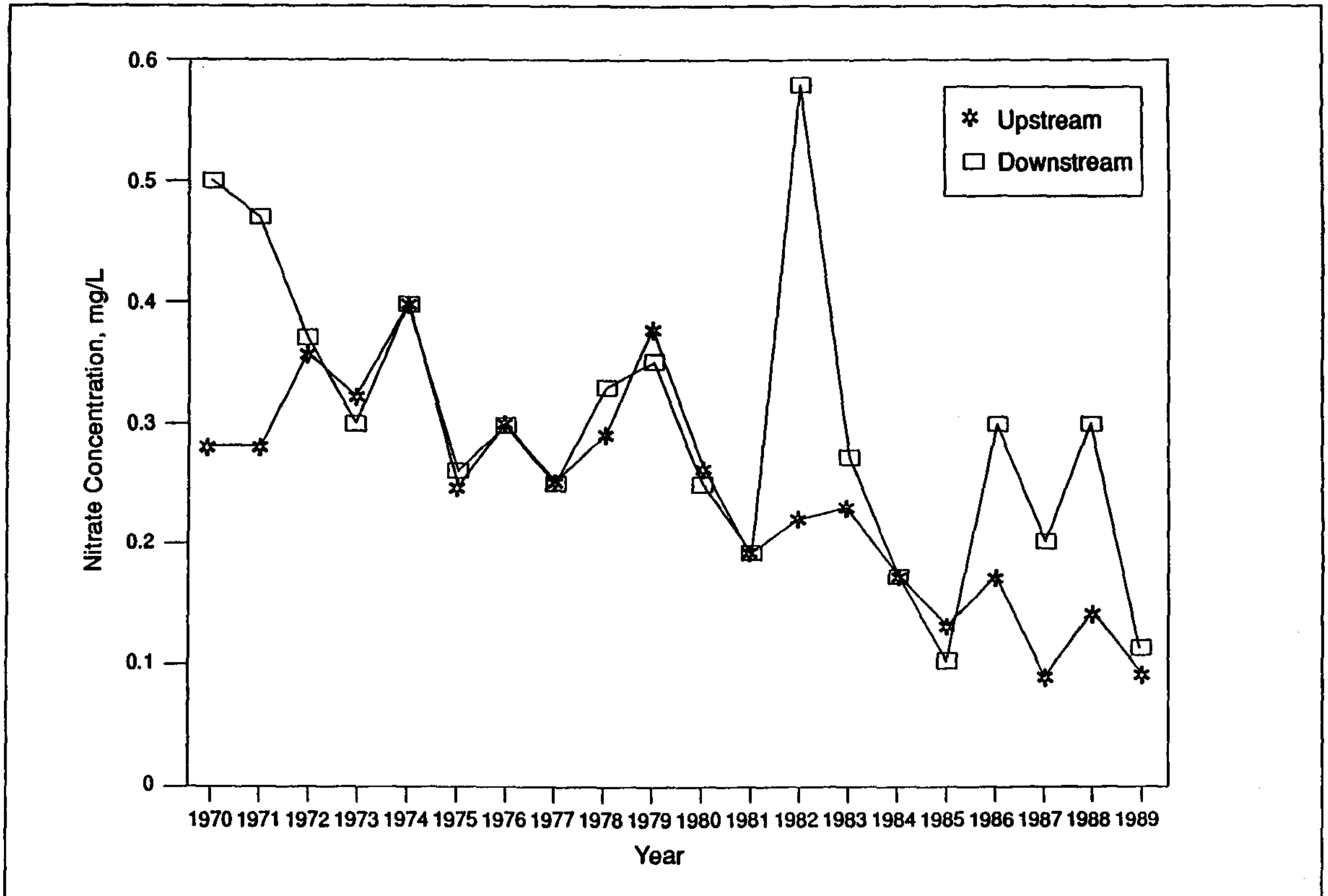
Constituent	1951[a]	1952[a]	1970[b]	1971[c]	1972[d]	1973[e]	1974[f]	1975[g]	1976[h]	1977[i]	1978[j]	1979[k]
Sample Location: Upstream (Priest Rapids or Vernita Bridge												
NO_3 (mg/L)	0.035	NR	0.28	0.28	0.36	0.32	0.4	<0.25	<0.3	<0.25	<0.29	0.38 ±1.2
Cr (mg/L)	NR	NR	ND	NR	NR	NR	NR	NR	NR	NR	NR	NR
Gross Alpha (pCi/L)	NR	NR	0.59	0.84	0.54	0.51	<0.4	<0.27	NR	NR	NR	NR
Gross Beta (pCi/L)	1.5	1.2	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
^{3}H (pCi/L)	NR	NR	840	1100	110	510	<330	370	<562	<420	<360	290 ±450
^{90}Sr (pCi/L)	NR	NR	0.44	0.36	0.5	0.66	0.5	0.35 ±0.40	0.27 ±0.14	0.3 ±0.3	0.33 ±0.10	0.72 ±1.4
^{137}Cs (pCi/L)	NR	NR	NR	0.41	NR	NR	<22	<26	<0.05	<0.02	NR	0.10 ±0.73
^{60}Co (pCi/L)	NR	NR	NR	NR	NR	NR	<20	<24	<0.001	<0.003	<0.034	0.79 ±3.0
^{99}Tc (pCi/L)	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
U (pCi/L)	NR	NR	NR	NR	NR	NR	NR	NR	0.4 ±0.3	0.6 ±1.3	0.39 ±0.28	0.45 ±0.31
$^{239,240}Pu$ (pCi/L)	NR	NR	NR	NR	NR	NR	<0.02	<0.03	3E-04 ±7E-04	<1.9E-04	<1.3E-04	2E-04 ±4E-04
Sample Location: Downstream (Richland Pumphouse)												
NO_3 (mg/L)	0.07	NR	0.5	0.47	0.37	0.30	<0.4	<0.26	<0.3	<0.25	<0.33	0.35 ±0.41
Cr (mg/L)	NR	NR	8E-04	NR	NR	NR	NR	NR	NR	NR	NR	NR
Gross Alpha (pCi/L)	NR	NR	0.6	1.01	0.67	0.49	<0.4	<0.34	NR	NR	NR	NR
Gross Beta (pCi/L)	285	223	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
^{3}H (pCi/L)	NR	NR	1100	780	110	610	<480	<454	<540	<670	<450	360 ±430
^{90}Sr (pCi/L)	NR	NR	0.14	0.85	0.35	0.33	0.3 ±0.1	0.46 ±0.59	0.24 ±0.08	0.3	0.46 ±0.43	0.34 ±0.27
^{137}Cs (pCi/L)	NR	NR	NR	5.9	NR	NR	<22	<26	<0.01	<0.02	NR	0.03 ±0.15
^{60}Co (pCi/L)	NR	NR	NR	NR	NR	NR	<20	<24	<0.02	0.01 ±0.005	<0.035	0.09 ±0.28
^{99}Tc (pCi/L)	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
U (pCi/L)	NR	NR	NR	3.4	NR	NR	NR	NR	0.5 ±0.4	0.7 ±0.6	0.54 ±0.27	0.50 ±0.44
$^{239,240}Pu$ (pCi/L)	NR	NR	NR	NR	NR	NR	<0.002	<0.002	4E-04 ±7E-04	<2.E-04	<1.1E-04	3.1E-04 ±5.7E-04

Table 2-5. Hanford Reach Water Quality. (Sheet 2 of 2)

Constituent	1980[l]	1981[m]	1982[n]	1983[o]	1984[p]	1985[q]	1986[r]	1987[s]	1988[t]	1989[u]	1990[v]
Sample Location: Upstream (Priest Rapids or Vernita Bridge											
NO_3 (mg/L)	0.26 ±0.15	0.19 ±0.03	0.22 ±0.08	0.23 ±0.042	0.17 ±0.11	0.13 ±0.08	0.17 ±0.08	0.09 ±0.03	0.14 ±0.03	0.09 ±0.02	0.18 ±0.14
Cr (mg/L)	NR	NR	<20	<10	<1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Gross Alpha (pCi/L)	NR	NR	NR	NR	NR	NR	0.51 ±0.16	0.44 ±0.16	0.31 ±0.17	0.83 ±0.33	0.85 ±0.25
Gross Beta (pCi/L)	NR	NR	NR	NR	NR	NR	1.9 ±0.6	0.92 ±0.52	0.96 ±0.40	1.5 ±0.68	2.42 ±0.92
^{3}H (pCi/L)	230 ±310	170 ±30	160 ±40	100 ±26	130 ±15	110 ±18	100 ±10	70 ±10	70 ±6	63 ±5	52 ±2.5
^{90}Sr (pCi/L)	0.24 ±0.23	0.14 ±0.04	0.18 ±0.05	0.18 ±0.061	0.14 ±0.02	0.15 ±0.025	0.15 ±0.02	0.14 ±0.02	0.10 ±0.02	0.08 ±0.01	0.072 ± 0.015
^{137}Cs (pCi/L)	0.01 ±0.05	0.024 ±0.011	0.069 ±0.017	0.039 ±0.0058	0.029 ±0.0044	0.018 ±0.0058	0.0003 ±0.0031	-0.0014 ±0.0026	2.8E-03 ±0.0011	0.002 ±0.001	NR
^{60}Co (pCi/L)	0.01 ±0.05	NR	<0.01	0.0042 ±0.0025	0.0033 ±0.0030	2.6E-05 ±0.0033	-8E-05 ±0.0030	-4E-04 ±0.0026	9.0E-04 ±0.0011	0.0012 ±0.0005	NR
^{99}Tc (pCi/L)	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.07 ±0.95	NR
U (pCi/L)	0.40 ±0.25	0.41 ±0.08	0.36 ±0.08	0.27 ±0.080	0.33 ±0.047	0.38 ±0.10	0.46	0.46 ±0.04	0.37 ±0.04	0.46 ±0.03	0.418 ±0.042
$^{239,240}Pu$ (pCi/L)	3.3E-04 ±3.7E-04	1.8E-04 ±1.1E-04	9E-06 ±7E-06	-6E-06 ±2E-05	3E-04 ±1.9E-04	3.5E-04 ±4.4E-04	4.8E-05 ±7.5E-05	1.1E-04 ±4E-05	6.0E-05 ±4E-05	4E-06 ±1.8E-05	NR
Sample Location: Downstream (Richland Pumphouse)											
NO_3 (mg/L)	0.25 ±0.14	0.19 ±0.04	0.58 ±0.68	0.27 ±0.077	0.17 ±0.064	0.10 ±0.05	0.3 ±0.2	0.2 ±0.1	0.3 ±0.2	0.11 ±0.3	[illegible] ±[illegible]
Cr (mg/L)	NR	NR	<10	<10	NR	<0.010	<0.015	<0.007	<0.001	<0.001	<0.001
Gross Alpha (pCi/L)	NR	NR	NR	NR	NR	NR	0.6 ±0.6	0.53 ±0.21	0.29 ±0.13	0.60 ±0.19	0.79 ±0.42
Gross Beta (pCi/L)	NR	NR	NR	NR	NR	NR	1.6 ±0.6	1.1 ±0.5	0.87 ±0.29	1.3 ±0.4	2.54 ±0.77
^{3}H (pCi/L)	265 ±274	200 ±30	220 ±60	130 ±28	170 ±23	150 ±21	150 ±20	130 ±10	132 ±0.02	129 ±18	105 ±17.6
^{90}Sr (pCi/L)	0.20 ±0.16	0.23 ±0.05	0.17 ±0.07	0.22 ±0.048	0.17 ±0.041	0.16 ±0.029	0.16 ±0.03	0.13 ±0.02	0.12 ±0.02	0.07 ±0.02	0.75 ±0.01
^{137}Cs (pCi/L)	0.02 ±0.10	<0.027 ±0.014	0.055 ±0.006	0.036 ±0.0038	0.023 ±0.0023	0.016 ±0.0049	0.0014 ±0.0029	-4.4E-03 ±0.0032	3.1E-03 ±0.0014	1.8E-03 ±0.0007	NR
^{60}Co (pCi/L)	0.03 ±0.06	<0.018	0.015 ±0.009	8.5E-03 ±0.0030	0.012 ±0.0077	7.6E-03 ±0.0036	0.002 ±0.003	1.8E-03 ±0.0029	2.9E-03 ±0.0011	1.7E-03 ±0.0007	NR
^{99}Tc (pCi/L)	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.5 ±0.0007	NR
U (pCi/L)	0.54 ±0.34	0.42 ±0.07	0.38 ±0.07	0.50 ±0.15	0.45 ±0.85	0.48 ±0.19	0.50	0.51 ±0.08	0.41 ±0.07	0.44 ±0.07	0.45 ±0.038
$^{239,240}Pu$ (pCi/L)	3.2E-04 ±3.2E-04	1.1E-04 ±4.7E-05	1E-05 ±6.9E-06	6.7E-05 ±7.3E-05	<1.5E-04 ±1.8E-04	2.8E-04 ±1.9E-04	1.2E-04 ±2.7E-04	8E-05 ±3E-05	3.0E-05 ±3E-05	2.2E-05 ±2.5E-05	NR

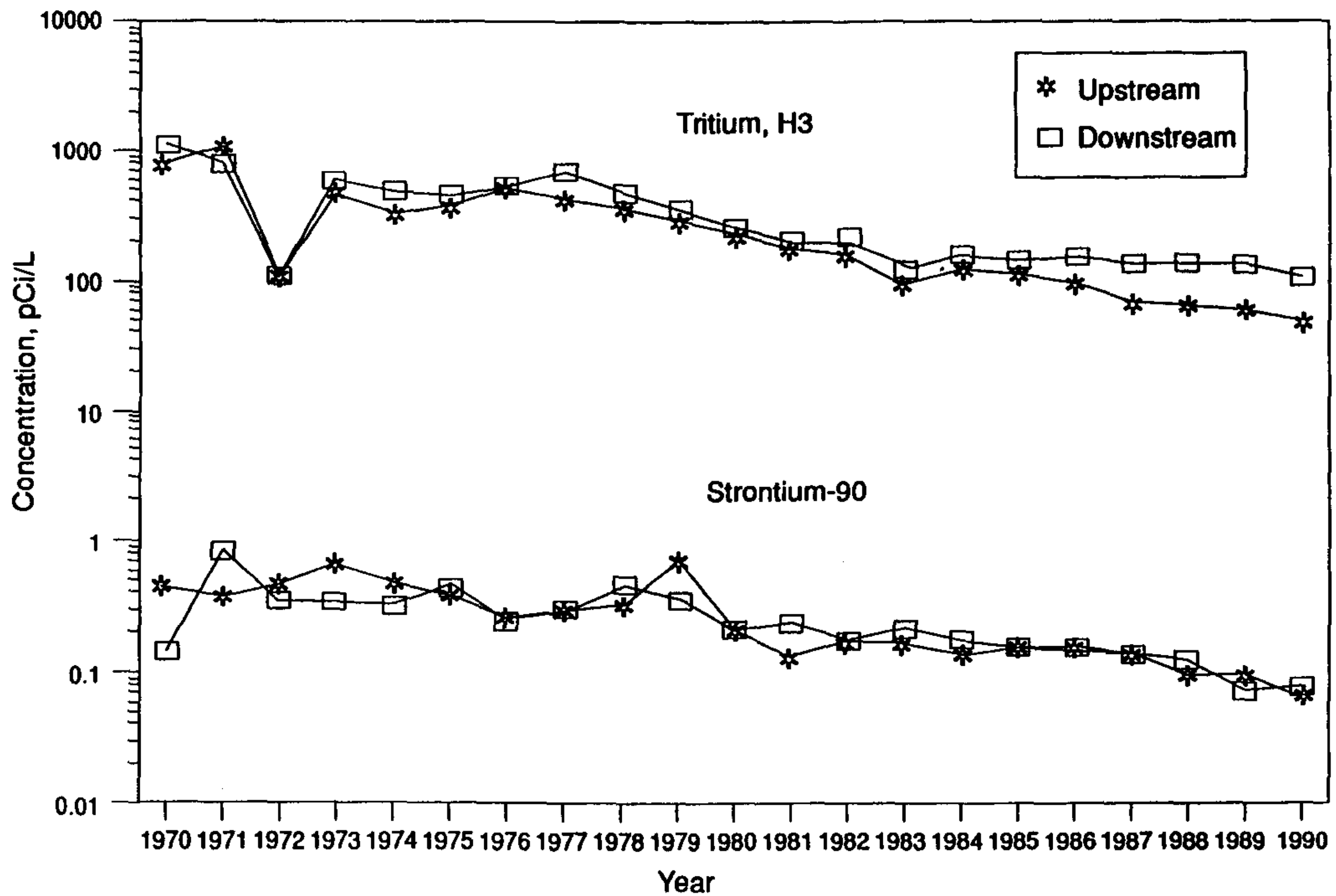
[a]Robeck et al. 1954
[b]Corley 1973
[c]Bramson and Corley 1972
[d]Bramson and Corley 1973
[e]Nees and Corley 1974
[f]Fix 1975
[g]Spear et al. 1976
[h]Fix et al. 1977
[i]Houston and Blumer 1978
[j]Houston and Blumer 1979
[k]Houston and Blumer 1980
[l]Sula and Blumer 1981
[m]Sula et al. 1982
[n]Sula et al. 1983
[o]Price et al. 1984
[p]Price et al. 1985
[q]Price 1986
[r]PNL 1987
[s]Jaquish and Mitchell 1988
[t]Jaquish and Bryce 1989
[u]Jaquish and Bryce 1990
[v]Bisping and Woodruff 1992

Notes:
NR = not reported
Values are averages ± times standard error where available.



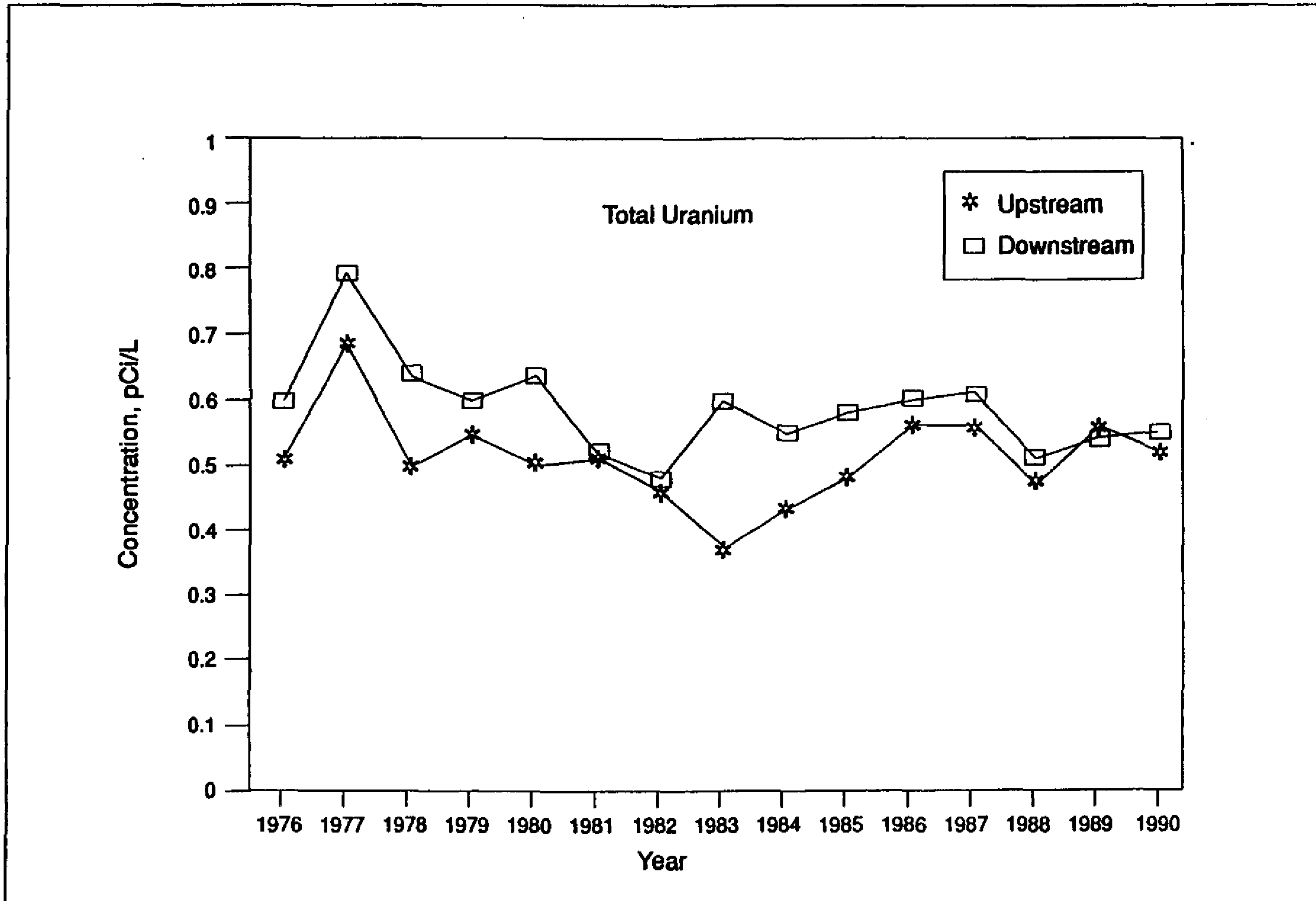
903 1255/27586/01-15-93

Figure 2-6. Nitrate Concentrations in the Columbia River Since Reactor Shutdown.



903 1255/27588/1-18-93

Figure 2-7. ^{3}H and ^{90}Sr Concentrations in the Columbia River Since Reactor Shutdown.



903 1255/28523/01-15-93

Figure 2-8. Total Uranium in the Columbia River Since Reactor Shutdown.

Table 2-6. Differences in Contaminant Concentrations in the Columbia River at Sample Locations Upstream and Downstream of the Hanford Site.

	1989		1988		1987		1986		1985	
	upstream	downstream	upstream	downstream	upstream	downstream	upstream	downstream	upstream	downstream
Tritium										
mean (pCi/L)	63	129	70	132	70	130	100	150	110	150
sd	8.66	31.18	10.39	17.32	17.32	17.32	17.32	34.64	31.18	36.37
n	12	12	12	12	12	12	12	12	12	12
t_c	-7.065*		-10.633*		-8.485*		-4.472*		-2.892*	
Strontium-90										
mean (pCi/L)	0.08	0.07	0.1	0.12	0.14	0.13	0.15	0.16	0.15	0.16
sd	0.017	0.035	0.035	0.035	0.035	0.035	0.035	0.052	0.043	0.05
n	12	12	12	12	12	12	12	12	12	12
t_c	0.890		-1.399		0.699		-0.552		-0.525	
Technetium-99										
mean (pCi/L)	0.07	0.5	nm	nm	nm	nm	nm	nm	nm	nm
sd	1.645	1.559	nm	nm	nm	nm	nm	nm	nm	nm
n	12	12	nm	nm	nm	nm	nm	nm	nm	nm
t_c	-0.657		-	-	-	-	-	-	-	-
Uranium-total										
mean (pCi/L)	0.46	0.44	0.37	0.41	0.46	0.51	nr	nr	0.38	0.48
sd	0.052	0.121	0.069	0.121	0.069	0.139	nr	nr	0.173	0.329
n	12	12	12	12	12	12	nr	nr	12	12
t_c	0.526		-0.994		-1.116		-	-	-0.931	
Nitrate										
mean (mg/L)	0.09	0.11	0.14	0.3	0.09	0.2	0.17	0.3	0.13	0.1
sd	0.036	0.541	0.052	0.346	0.052	0.173	0.139	0.52	0.139	0.087
n	13	13	12	12	12	12	12	12	13	13
t_c	-0.132		-1.584		-2.109*		-0.836		0.659	

Notes:

1. Upstream sample location Priest Rapids Dam for ^{3}H, ^{90}Sr, ^{99}Tc and Vernita Bridge for nitrate. Downstream sample location is Richland Pumphouse for all constituents.
2. nm = not measured; nr = not reported
3. sd = standard deviation, n = number of samples, t_c computed t value between upstream and downstream means for each year
4. $H_0 \mu_{up} = \mu_{down}$; $H_1 : \mu_{up} = \mu_{down}$; criteria for rejecting H_0: $t_c < - t_{(\alpha, n(up)+n(down)-2)}$ $t_{0.05,22} = 1.717$, $t_{0.05,24} = 1.711$; * Upstream concentration significantly less than downstream concentration, $p<0.05$

potential contaminant because the data were not measured every year, were not detected, or were simply not reported in each annual environmental report. In addition, some data were reported as negative numbers (due to correction for laboratory background radiation levels) and could not be used for logarithmic plots.

These figures illustrate recent trends in river-water quality for important contaminants that have been identified in groundwater at the Hanford Site. Overall, these figures show:

- the levels of contaminants in river water have been decreasing; and

- except for ^{3}H and nitrate in 1987 , levels of contaminants of potential concern measured downstream of the Hanford Site (Richland Pumphouse) are not significantly different (Table 2-6; one-sided t-test of 1985 to 1989 means with $\alpha=0.05$) from levels measured upstream of the Hanford Site (Priest Rapids Dam or Vernita Bridge).

Thus, except for ^{3}H, these data do not show any significant adverse impact on overall river-water quality that can be attributed to Hanford Site operations at this time. Because there is the possibility that sources at the Hanford Site in addition to the 100 Area have contributed ^{3}H, impacts to the Hanford Reach water quality can not be attributed solely to 100 Area operations, at this time.

In addition to routine river-water monitoring conducted by Hanford Site contractors, there have been a number of special studies conducted that included measurements of river-water quality, including Robeck et al. (1954), Dirkes (1990) and DOE-RL (1992d).

Robeck et al. reports the findings of a comprehensive study of the Columbia River to:

- provide baseline data on physical, chemical, and biological characteristics before construction of proposed impoundments; and

- determine the effects of radioactive wastes on stream purification factors.

This study (Robeck et al. 1954) entailed sampling both water and aquatic organisms at numerous points along the Columbia River, including the then-proposed site of Priest Rapids Dam, Vernita Bridge, along the Hanford Reach, and the Richland Pumphouse. Therefore, this study provides insight into the degree of river contamination that existed during reactor operations. The study found that reactor operations:

- released significant quantities of radioisotopes;

- these isotopes accumulated in aquatic organisms; and

- measurable quantities of radioisotopes were entering the public drinking-water supply for Richland.

The study concluded, however, that the levels of radioactivity found in the river during the study "had no apparent immediate effect on aquatic populations" and were well below the maximum permissible concentrations of the time.

Other studies of Hanford Reach water quality include the 1988 and 1991 special studies of riverbank springs entering the Hanford Reach adjacent to the Hanford Site (Dirkes 1990) and DOE-RL (1992d). The Dirkes included analyses of radiological and chemical components sampled from above the Hanford Site (Priest Rapids Dam) and below the Hanford Site (Richland Pumphouse) together with spring sampling. The purpose of river sampling was to provide information about the impact of groundwater discharge on river-water quality. River-water sampling was conducted once during this study, and samples were analyzed for a comprehensive list of potential contaminants that include the dangerous waste constituents as identified by the State of Washington in WAC 173-303-9905. The DOE-RL (1992d) study concentrated on springs entering the river along the 100 Area and only analyzed the samples for radionuclides and inorganic constituents.

Groundwater monitoring shows the groundwater beneath Hanford has been contaminated by past practices (Evans et al. 1990). Both spring studies found the discharges from springs were small relative to the flow of the Columbia River, and downstream river sampling demonstrated that the impacts to river-water quality of groundwater discharges were minimal, and, in most cases, negligible. According to the Dirkes study, localized areas of impact were observed within the river near the spring discharge zone, with radionuclide concentrations above drinking water standards. For example, a spring samples near the 100-N Area (Hanford river mile 8.9) showed near-shore ^{3}H and ^{90}Sr concentrations of 75,800 and 7,279 pCi/L, respectively. The samples of nearshore river water at that location had ^{3}H and ^{90}Sr concentrations of 76,400 and 6,740 pCi/L, respectively. In 1991, DOE-RL (1992d) samples a spring and the river at Hanford river mile 9.0. The ^{3}H and ^{90}Sr concentration in the spring were 15,900 and 3,210 pCi/L, respectively. In the river, ^{3}H and ^{90}Sr concentrations were 300 and 8.1 pCi/L, respectively. Although the river provides considerable dilution capacity, it is evident that groundwater discharges to the river cause localized impacts on a small scale. Outside of the areas near the spring discharge zones, however, average river-water contaminant concentrations were below drinking-water standards (chemical contaminants were generally undetectable) (Dirkes 1990).

2.2.2.2 Riverbank Springs. Spring discharges into the Hanford Reach existed prior to the startup of Hanford operations. These relatively small springs flow intermittently and appear to be influenced by the river stage (Dirkes 1990; DOE-RL 1992d). Seepage to the river through surface springs is thought to contribute a small fraction of the total amount of groundwater entering the river, but provides an opportunity to estimate the types of contaminants entering the river.

Groundwater discharge in the vicinity of the 100-N Area liquid waste disposal trenches have been periodically monitored (Perkins 1988, Perkins 1989). In addition, special studies have been conducted to characterize the groundwater that enters the Hanford Reach through adjacent springs and seeps. These include McCormack and Carlile (1984), Buske and Josephson (1989), Dirkes (1990), and DOE-RL (1992d). These studies located springs and seeps along the Hanford Site shoreline, generally beginning upstream of the 100 Area reactors and continued downstream below the 300 Area, although DOE-RL (1992d) focused solely on springs in the 100 Area. Samples from identified springs were collected to screen groundwater plumes for radiological (McCormack and Carlile 1984; Buske and Josephson 1989; Dirkes 1990; DOE-RL 1992d) and chemical parameters (McCormack and Carlile 1984; Dirkes 1990; DOE/RL 1992d).

All four of the above studies noted the presence of radiological and chemical constituents found in the groundwater were also present in the riverbank springs seepage along the 100 Area. These studies have found that spring discharges to the Hanford Reach Area occur primarily in the 100-N area although spring discharges also occur in the 100-B, 100-D 100-H,.and 100-F areas. In the most recent study of 100 area springs, the tritium was the most widespread contaminant present, ranging from less than 200 pCi/L to a maximum of 24,3000 pCi/L in the 100-N area. Measured ^{3}H concentrations above 20,000 pCi/L were located at the 100-B/C and 100-N areas. Strontium-90 concentrations ranged from <0.2 to 3,200 pCi/L. The maximum ^{90}Sr concentration was found in the 100-N area. Concentrations of 100-N, 100-H, 100-K, and 100-F areas. Chromium concentrations ranged from <0.002 mg/L to a maximum of 0.124 mg/L found in the 100-D area. Springs with concentrations exceeding 0.05 mg/L were found in the 100B/C, 100-K, 100-D, and 100-H areas. Nitrate concentrations ranged 1.6 to 5.5 mg/L and was detected in all springs sampled.

Thus, the springs represent a potential zone of impact and are a point of exposure for the river ecosystem. The reports further noted that localized zones of contaminated river-water quality were observed; however, the zones of impact rapidly dissipated downstream. Downstream river sampling demonstrated that the effects of groundwater discharges on river-water quality were very small due to the high dilution factor.

2.2.3 River-Sediment Contamination

Sediments of the Hanford Reach are known to contain low levels of radionuclides of Hanford origin. The sampling of sediment on the shoreline and river bottom along the Hanford Reach has been performed intermittently between 1957 and 1989. In 1989, radionuclide levels in sediments were measured at locations upstream of Hanford operations (behind Priest Rapids Dam), along the Hanford Reach (White Bluffs Slough, 100-F Slough, and the Hanford Slough), and downstream of Hanford operations (McNary Dam) (Jaquish and Bryce 1990). The results of these analyses are shown in Table 2-7. Using the data from Jaquish and Bryce (1990), concentrations of ^{60}Co, ^{90}Sr, ^{137}Cs, europium-154 (^{154}Eu), europium-155 (^{155}Eu), and ^{239,240}Pu are significantly higher in sediments collected at McNary Dam compared to sediments collected upstream of the Priest Rapids Dam (using a one-sided t-test of the sample means, α=0.05). Sediment samples from White Bluff Slough, 100-F Slough, and Hanford Slough were compared to sediment samples from Priest Rapids Dam using an upper tolerance limit (UTL). The UTL (Hines and Montgomery 1980) is calculated as $\bar{X} + KS$, where $\bar{X}$ is the sample mean, K is constant, and S is the sample standard deviation, for a give confidence level (α) and proportion of the population (P). The UTL for Priest Rapid Dam sediments (Table 2-6) was calculated from $\alpha = 0.05$, $P = 0.95$, and a sample size of four, resulting in a K value of 5.145. Based on the UTL, sediments from White Bluff Slough probably have higher concentrations of ^{60}Co, ^{90}Sr,, and ruthenium-106 (^{106}Ru) Sediments from 100-F Slough probably have higher concentrations of ^{60}Co and ^{90}Sr; and sediments from Hanford Slough probably have higher concentrations of 60, ^{90}Sr, ^{106}Ru, and ^{238}Pu. Woodruff and Hanf (1991) did not provide sediment sampling results for 1990.

The 1991 sampling of the 100 Area springs (DOE-RL 1992d) also sampled sediments from springs along the 100 Area of the Columbia River. The collected samples were analyzed for a variety of chemical and radionuclide constituents. Sediments showed

Table 2-7. Radionuclide Concentrations in Sediments Along the Hanford Reach (Jaquish and Bryce 1990).

Radionuclide	Priest Rapids Dam[1]	White Bluffs Slough[2]	100-F Slough[2]	Hanford Slough[2]	McNary Dam[3]
	pCi/g (dry weight)				
cobalt-60	-0.002$\pm$0.009 (0.003)	0.035	0.055	0.036	0.278$\pm$0.145
strontium-90	0.014$\pm$0.002 (0.024)	0.006	0.005	0.021	0.037$\pm$0.018
ruthenium-106	0.014$\pm$0.021 (0.122)	0.210	-0.083	0.176	-0.076$\pm$0.068
cesium-134	-0.079$\pm$0.061 (0.235)	-0.032	-0.042	-0.042	-0.028$\pm$0.006
cesium-137	0.265$\pm$0.051 (0.527)	0.284	0.231	0.210	0.708$\pm$0.144
europium-152	nm*	nm	nm	nm	0.774$\pm$412
europium-154	0.019$\pm$0.028 (0.163)	0.071	0.021	-0.016	0.125$\pm$0.019
europium-155	0.049$\pm$0.025 (0.178)	0.091	0.055	0.077	0.093$\pm$0.007
uranium-235	nm	0.090	0.086	0.063	0.065$\pm$0.104
uranium-238	0.761$\pm$0.132 (1.44)	0.639	0.583	0.696	0.624$\pm$197
plutonium-238	0.0002$\pm$0.0001 (0.001)	0.00005	0.0003	0.004	0.0009$\pm$0.0009
plutonium-239,240	0.0022$\pm$0.0006 (0.005)	0.0008	0.0013	0.0035	0.014$\pm$0.006

[1]Average $\pm$ standard deviation, upper tolerance limit in parentheses.
[2]Concentration from single sample.
[3]Average $\pm$ standard deviation.
*not measured.

detectable concentrations of ^{90}Sr, ^{137}Cs, radium-226 (^{226}Ra), thorium-228 (^{228}Th), thorium-232 (^{232}Th), aluminum, antimony, barium, cadmium, calcium, chromium, cobalt, copper, iron, magnesium, manganese, nickel, potassium, sodium, vanadium, and zinc. There were no reference samples collected, however, so it is unknown if the detected levels represent elevated concentrations.

Radionuclides attributed to Hanford operations have been detected downstream to the Columbia River estuary (Renfro 1971; Hubbel and Glenn 1977). In a 1965 survey of sediments in the Columbia River estuary, Hubbel and Glenn (1977) found the stratigraphic distribution of radionuclides varied considerably due to cyclic erosion and deposition. On average, however, 66% of the total measured radionuclides (excluding naturally occurring potassium-40 [^{40}K]) occurred within 20 cm (8 in) of the bed surface, and averaged 39 μCi/m^2 (3.6 μCi/ft^2). Chromium-51 (^{51}Cr) and zinc-65 (^{65}Zn) were the most abundant radionuclides found during the survey. Renfro (1971) routinely measured radionuclide concentrations in the Columbia River estuary during 1968 to 1970, and estimated that greater than 95% of the radionuclides in the study site were associated with the inorganic fraction of the bottom sediments. Zinc-65 and ^{51}Cr were the two most abundant radionuclides and were found predominantly within 3 cm (1 in) of the bed surface.

Since the shutdown of the once-through reactors, short- and intermediate-lived radionuclides have decayed to very low levels (Robertson and Fix 1977). Chromium-51 and ^{65}Zn were the principal radionuclides found in sediments during the peak years of Pu production at Hanford. Following shutdown of the last once-through reactor in 1971, the radionuclide spectrum shifted (due to decay of short-lived radionuclides) to iron-55 (^{55}Fe), ^{60}Co, ^{137}Cs, europium-152 (^{152}Eu), ^{154}Eu, ^{238}Pu, ^{239,240}Pu, and americium-241 (^{241}Am). The surface sediments behind McNary Dam now contain low concentrations of radionuclides due to fresh deposits of relatively uncontaminated sediments (Robertson and Fix 1977). Because of the continued influx of uncontaminated sediments from upstream and export of contaminated sediments downstream, it is anticipated that there will be further dilution of radioactivity in sediments along the Hanford Reach.

The present Environmental Monitoring Program includes radiation surveillance at selected locations along the Hanford Reach (Woodruff and Hanf 1991). This program only provides an estimate of exposure and does not identify levels of contamination. There have been several radiological surveys of the exposed shorelines along the Hanford Reach since the shutdown of the Pu-production reactors (Sula 1980; Reiman and Dahlstrom 1988). These surveys were performed to evaluate the magnitude and distribution of radioactive contamination. Sula (1980) found that contamination on exposed island and shoreline areas was present in three different distributions:

- a fairly constant, uniformly distributed layer of contamination was observed over the entire study area with exposure rates along the Hanford Reach approximately 50% higher than along upstream shorelines;

- areas of increased contamination due to sediment concentration as a result of hydraulic actions; and

- discrete particles of contamination, containing ^{60}Co, believed to be metallic flakes, possibly pump or valve components used in the production reactors.

The aerial survey of the Hanford Site performed in 1988 (Reiman and Dahlstrom 1990) collected information of gamma-ray emitting radioisotopes. This survey noted the presence of a number of areas along the Hanford Reach outside of constructed facilities that have elevated radioisotope concentrations. The most common radionuclides identified by the survey were ${}^{60}Co$ and ${}^{137}Cs$.

2.2.4 Ecological Contamination

Environmental monitoring and scientific studies at the Hanford Site have been conducted for more than 45 years. Such monitoring and studies have allowed Site managers to assess effects that Site activities have on vegetation, wildlife, and humans within and around the Site boundaries.

Becker (1990) reviewed and summarized the findings of bioenvironmental studies related to the Hanford Reach conducted from 1944 to 1984. These studies involved field and laboratory studies that evaluated the potential effects of specific Site operations on the aquatic biota and the physicochemical properties of the river ecosystem. These studies were undertaken because early Site managers recognized that the use of water from the Hanford Reach for Site operations might affect its quality and create environmental problems. Concerns associated with potential adverse environmental effects from discharging radioactive materials prompted initiation of many radioecological studies at the Site (Becker 1990).

Initial studies of radioactivity in Hanford Reach biota emphasized the effects of exposure to radiation and reactor effluent, especially the short-lived radionuclides (e.g., ${}^{32}P$ [half-life of 14.3 days] and ${}^{65}Zn$ [half-life of 245 days]) that were released in large quantities. These studies were conducted to determine if actual dose rates were apt to result in adverse effects. Chemical effects studies were also performed. For example, long-term chronic bioassays were conducted with hexavalent Cr to determine effects on trout and salmon mortality and growth. These studies led to a recommended ambient hexavalent Cr limit of 0.02 mg/L in the Columbia River (Becker 1990).

Initial surveys of the uptake and accumulation of radionuclides by river organisms led to increased knowledge about radionuclide transport and dispersion of radioactivity in the Columbia River ecosystem. These studies determined that radionuclides accumulated in aquatic organisms and that highest radioactivity levels were found in the free-floating plankton. Although the food web accounted for transfer of radionuclides through the river ecosystem, the concentration factors for most radionuclides were lowest at the higher trophic levels (Becker 1990). Thus, food chains appear to result in a biodilution of radionuclide concentrations in larger animals.

Following the shutdown of once-through reactors at the Site, the levels of selected radionuclides in plankton, periphyton, invertebrates, and fish were studied (Cushing et al. 1981). Results showed that the measurable body burden of fission-produced radionuclides decreased to essentially unmeasurable levels within 18 to 24 months of reactor shutdown. Eberhardt et al. (1989) provided additional details about long-term trends of radionuclide concentrations in aquatic biota collected along the Hanford Reach. In general, most radionuclides exhibited a downward trend, especially ${}^{137}Cs$ and ${}^{65}Zn$. For ${}^{90}Sr$, however, the trend was less evident and tended to fluctuate randomly. These fluctuations may be attributable to truly random events, as well as changes in Site activities, worldwide fallout, monitoring strategies, and analytical methods. Eberhardt et al. could not identify actual sources of variability.

The Hanford Environmental Monitoring Program entails opportunistic sampling of biota at the Site, including aquatic biota from the Hanford Reach. During 1990, radionuclides (^{60}Co,^{90}Sr, and ^{137}Cs) were measured in fish (whitefish, bass, and carp) collected upstream and downstream of the Site in the Hanford Reach. The 1990 results (Woodruff and Hanf 1991) showed that ^{60}Co and ^{137}Cs were typically below detection limits with no differences between species or sample location. Strontium-90 was more variable; however, mean concentrations were low (less than 0.04 pCi/g wet weight) in all samples. Jaquish and Bryce (1989) could find no meaningful differences between fish samples collected upstream and downstream of the Site, and therefore could not find any measurable influence on fish from radionuclides released to the Hanford Reach due to current or past Site operations. However, it should be noted that fish are mobile within the Hanford Reach and the opportunistic sampling methods used by the Environmental Monitoring Program may be insufficient to detect impacts.

Radionuclide concentrations found in Canada goose muscle tissue are similar to those expected from worldwide fallout (Jaquish and Bryce 1990). Canada goose eggshells collected from island along Hanford Reach have detectable levels of ^{90}Sr with the highest average concentration, from 1986 to 1987, measuring 1.6 pCi/g (Rickard and Price 1990). These levels were attributed to a source of Sr^{90} in addition to worldwide fallout such as shoreline plants that were downstream of the 100-N Area (Rickard and Price 1990). Woodruff and Hanf (1991) also included data on radionuclide concentrations in waterfowl tissue collected along the Hanford Reach near the 100-N Area. Radionuclides (^{60}Co,^{90}Sr, and ^{137}Cs) were not detected in tissue samples of mallard ducks collected along the Hanford Reach.

Numerous studies have reported on radioactive contaminants in wildlife that could be attributed to Site operations; however, chemical contaminants in the Hanford Reach are not as widely studied. Metals (lead, cadmium, and mercury) were measured in nest debris (feces and food scraps) at a great blue heron rookery at the Site. The levels of these metals in the heron rookery were less than levels reported at other Pacific Northwest locations (Fitzner et al. 1982). Organochlorine residues were found in low, measurable concentrations in great blue herons collected along the Hanford Reach (Fitzner et al. 1988). According to the authors, these residues seemed to exert little influence on reproductive success, and were believed to originate on heron wintering grounds located off the Hanford Site.

Cushing (1979) examined trace element concentrations in aquatic biota along the Hanford Reach to establish trophic-level relationships among the biotic components. He found that only K increased in concentration through the food web, and most elements (including Cr, Cs, scandium, and Zn) decreased in concentration in higher trophic levels. As an example, Cr concentrations were 22.8 mg/kg in phytoplankton, 1.8 mg/kg in caddisfly larvae, and 0.11 mg/kg in whitefish. Four elements (bromine, mercury, rubinium, and selenium) remained relatively constant.

Contaminants attributable to Hanford Site operations are found throughout the Hanford Reach ecosystem. Contaminants attributable to operations in the 100 Area were discharged to the river in the past and currently continue to enter the river. Environmental studies and monitoring to date has not shown, however, that the observed contaminant concentrations have resulted in any significant adverse impact to the Hanford Reach ecosystem.

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3.0 CONTAMINANT FATE AND TRANSPORT

To evaluate the threats posed to human health and environment by contaminants of potential concern released from past operations at Hanford to the Hanford Reach the pathways and mechanisms by which contaminants of potential concern are distributed among the various environmental media must be identified. This chapter provides an analysis of the environmental fate and transport of those contaminants of potential concern identified in Chapter 2. Thus, the nature and extent of contaminants of potential concern can be extrapolated to provide a conceptual model of the types and distributions of contaminants of potential concern within the Hanford Reach environment.

Section 3.1 discusses potential contaminant migration pathways that are significant to the Hanford Reach ecosystem. Contaminant-fate (i.e., physical, chemical, or biochemical transformations experienced by particular contaminants under environmental conditions) assumptions are discussed in Section 3.2. This chapter concludes with an analysis of contaminant transport through each significant migration pathway in Section 3.3.

3.1 POTENTIAL PATHWAYS OF CONTAMINANT MIGRATION

A contaminant migration pathway is the route, often involving multiple environmental media, by which contaminants are transported, and that results in exposure to humans or other organisms. Each exposure pathway consists of the following five elements (EPA 1986b):

- a contaminant source;
- a contaminant release mechanism;
- an environmental transport medium;
- an exposure route; and
- a receptor.

Contaminant sources that might impact the Hanford Reach have been identified in Section 2.2. Therefore this section will focus on release mechanisms, transport media, exposure routes, and potential receptors. Figure 3-1 illustrates the potential contaminant migration pathways and the relationships among the Hanford Reach ecosystem components. Those pathways that could possibly result in a significant impact to an ecosystem component are emphasized on Figure 3-1. These selected pathways were judged most significant because they represent the most direct exposure pathway from the contaminant source to the receptor. In the following sections, emphasized pathways are discussed qualitatively by the predominant environmental medium involved.

3.1.1 Groundwater Pathways

Past liquid- and solid-waste-disposal practices resulted in direct discharges of mixed, low-level radioactive and hazardous wastes to soil and groundwater in areas near the reactors. As such disposal practices are no longer common, the contaminated soil and groundwater are now secondary sources of contamination.

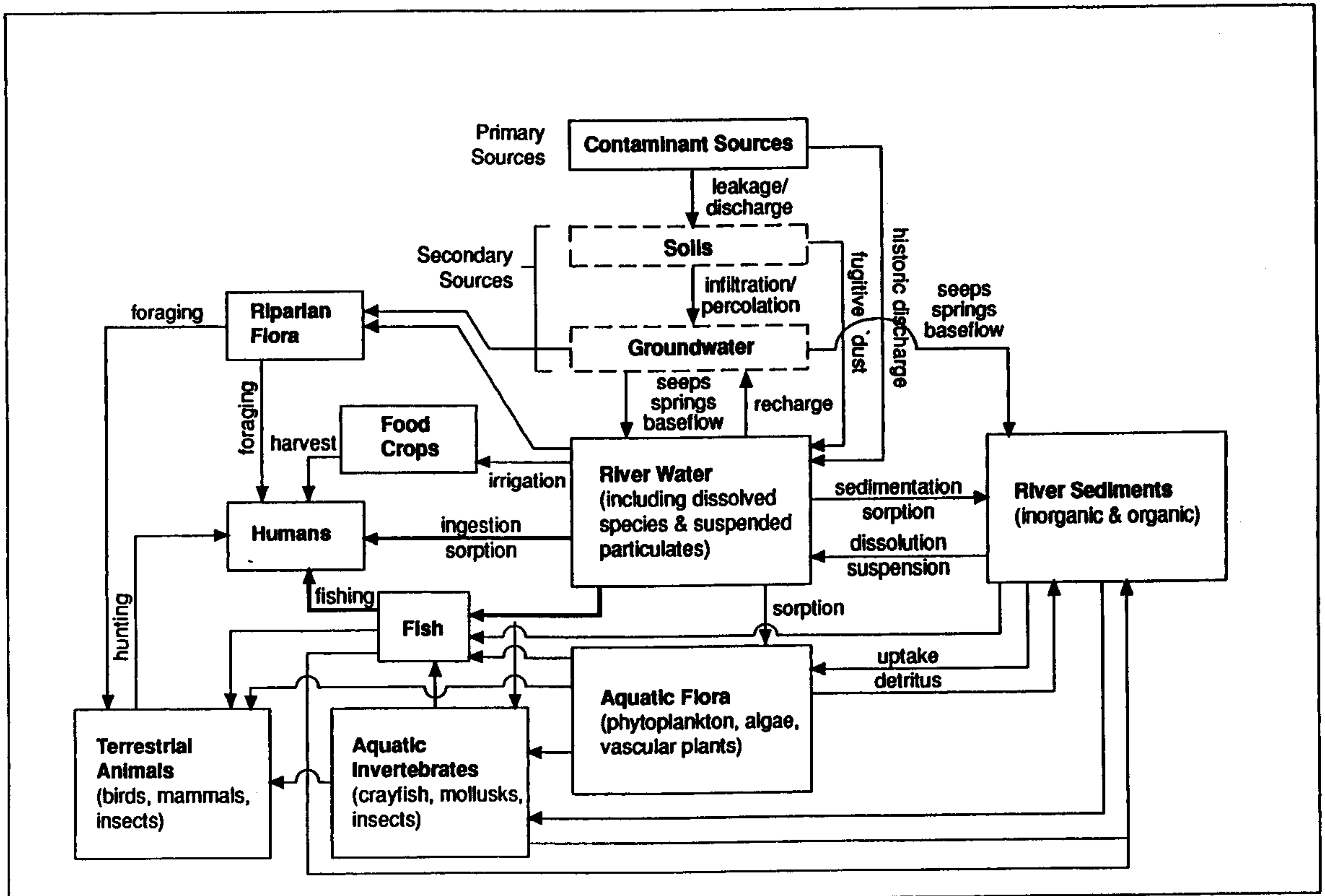

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Figure 3-1. Potential Pathways for Contaminant Movement Among Hanford Reach Ecosystem Components.

Monitoring at the Hanford Site shows that subsurface migration of contaminants toward the river is occurring through groundwater flow. Groundwater plumes for radionuclides, as well as chemical contaminants, have been identified in the 100 Area that are presently entering the river.

Groundwater enters the river along the Hanford Reach either as surface or subsurface seeps and springs. There is no quantitative information to partition groundwater flow between the surface or subsurface seeps; however, the consensus is that subsurface flow predominates (Dirkes 1990; DOE-RL 1992d). Subsurface seeps and springs would represent a potential exposure point to 100 Area contaminants for aquatic organisms, especially those that might burrow or dig into the sediments.

The other possible exposure point to the 100 Area groundwater contaminants is the surface seeps and springs. Locations and contaminant concentrations have been documented for many surface seeps and springs along the Hanford Reach. Thus, it is known that the surface seeps and springs represent a potential source of contaminant migration from the groundwater to ecosystem receptors. Potential impacts, however, would be limited to environmental receptors since human access to the 100 Area is limited by institutional controls. In addition, the seeps and springs are not always accessible, evident, or conducive to water collection.

3.1.2 Surface-Water Pathways

The surface-water pathway is one of two primary pathways (in addition to the river sediment pathway) for exposure of Hanford Reach ecosystem components to contaminants attributable to past and present Hanford Site operations. Along the Hanford Reach, contaminant inputs to the river occur as indirect discharges from groundwater and as direct discharges from facilities in the 100 Area (Woodruff and Hanf 1991). As Figure 3-1 shows, every other component of the Hanford Reach ecosystem could be directly exposed to contaminants in the river-water column.

Contaminants, especially radionuclides, have been detected in abiotic and biotic components of the Hanford Reach ecosystem. Recent analyses of river-water quality do not show appreciable differences between sampling points that are upstream and downstream of the Hanford Site. In addition, river-water sampling conducted in conjunction with spring sampling shows that impacts to river-water quality dissipate rapidly downstream due to high dilution factors (subsection 2.2.2.2). Consequently, it is not likely that any significant adverse downstream environmental or health impact associated with the river-water column would be extensive. The most significant contaminant exposure pathways are judged to be human ingestion of water and fish and aquatic organism immersion within the water column.

3.1.3 River Sediment Pathways

River sediments represent the other primary pathway for contaminant migration from river water to certain biotic components. Although river sediments are known to be contaminated, a consensus impact assessment methodology does not exist at this time (Adams et al. 1992). In addition, there is no evidence of past or present significant ecological impacts associated with contaminated sediments. This does not necessarily mean that significant impacts have not occurred, only that the tools to evaluate impacts are lacking. Consequently, impacts due to river sediments will not be evaluated further in this report. However, data collection activities needed to fill this data gap are discussed in Section 5.2.

3.1.4 Biotic Pathways

It is known that contaminants associated with past 100 Area operations are migrating from soil/groundwater sources through the surface water to aquatic biota. Biotic pathways of contaminant transport in the Hanford Reach are difficult to evaluate due to ecosystem complexity, but are based to a large degree on the food chain.

The Hanford Reach provides habitat for a number of plants and animals that are used by humans as food, and provides a source of water for crop irrigation. However, human ingestion of fish is judged to be the most significant biotic pathways for evaluating human exposure to contaminants in the river (Woodruff and Hanf 1991). Therefore, for the purposes of this report the fish ingestion pathway is evaluated to investigate the potential for any impacts to human health. Potential environmental impacts were evaluated by considering contaminant uptake by fish and by comparing derived contaminant concentrations in the river to ambient water quality criteria.

Other pathways not evaluated in the qualitative evaluation that should be kept in mind for future quantitative assessments include human ingestion of waterfowl, venison, irrigated crops, riparian vegetation, and beef and milk obtained from cattle fed irrigated forage. These pathways are evaluated in the Site Environmental Surveillance Program as part of the annual public dose assessment (Woodruff and Hanf 1991). Although this program considers a number of potential exposure pathways, in 1990 the primary pathway of population exposure related to the Hanford Reach was consumption of drinking water contaminated by Hanford Site radionuclides (Woodruff and Hanf 1991).

Exposures in non-aquatic sensitive habitats (as derived from 40 CFR Part 300, Appendix A) or in non-aquatic critical habitats (as defined in 50 CFR § 424.02(d)) of endangered or threatened species to contaminants in the Hanford Reach does not, at this time, appear to be significant concerns from the perspective of the environmental evaluation. The 100 Area portion of the Hanford Reach, for example, could be considered a critical habitat due to seasonal use by threatened bald eagles and the endangered white pelican. The eagles, however, primarily consume spawned-out chinook salmon which, during their life cycle, spend little time within the Hanford Reach, and, while within the Reach, do not feed during spawning. Thus, the potential exposure to the eagles by contaminants in the Hanford Reach is judged to be negligible (Weiss and Mitchell 1992). Although the white pelican consumes live fish during its period of residence, recent environmental surveillance reports show no measurable influence on fish from radionuclides released to the Hanford Reach during current or past Site operations (Jaquish and Bryce 1990, Woodruff and Hanf 1991). Thus, it is unlikely that white pelicans are adversely impacted at the present time by exposure to contaminants in the river.

3.2 CONTAMINANT FATE

In keeping with the qualitative and conservative nature of the model used for this impact evaluation and the absence of Site-specific data, biological (except bioaccumulation), chemical, and physical processes that would affect contaminant fate were generally disregarded. There is assumed to be no decay of radionuclides, no retardation of contaminants within aquifer or river sediments, and no transformation of any contaminant that would reduce its concentration or toxicity during transport from source to receptor.

Such assumptions are justified in the absence of Site-specific data. Because of these assumptions, however, the impact evaluation in Chapter 4 should be considered preliminary and the results represent a conservative estimate of the potential exposure to the evaluated contaminants of potential concern.

3.3 CONTAMINANT TRANSPORT

In Section 2.2, empirical data from surface springs and seeps, groundwater monitoring wells located near the river's edge, and surface-water monitoring of the Hanford Reach were used to assess the current status of contaminants in the groundwater (at the river's edge) and in the ambient river-water column.

This section provides details and assumptions necessary to estimate groundwater movement and expected contaminant concentrations in the groundwater (at the riverbank) and in the river-water. These data are the basis for estimating potential impacts by past 100 Area operations to potential human and environmental receptors that use the Hanford Reach. Contaminant transport is addressed below by subsurface, surface-water, and biological considerations.

3.3.1 Subsurface Transport

Subsurface transport was estimated based on information presented in Appendix B. This appendix identifies groundwater plumes, groundwater flow direction, and estimated groundwater flow rates. The contaminant concentrations together with the estimated flow rates were used to derive a contaminant flux for each groundwater plume. Principal assumptions that were used to project the groundwater plume from the source to the riverbank were:

- infinite source mass;
- infinite time; and
- no transformations during transport (see Section 3.2).

Table 2-3 shows the estimated groundwater flow rates and source concentrations derived from information in Appendix B. The groundwater source concentrations under the above assumptions become the current plume-specific riverbank concentrations for each identified contaminant of potential concern.

3.3.2 Hanford Reach Contaminant Transport Modelling

This subsection describes the computational model used to estimate contaminant concentrations in the Hanford Reach that result from groundwater discharge the 100 Area. The model presented is standard to surface-water mixing calculations and is explained in detail in Fischer et al. (1979).

For this application, contaminants enter the Hanford Reach through the groundwater. In the river, the contaminants undergo mixing and are subsequently transported downstream. The concentrations downstream from the source inputs are estimated using the computational model. The concentration information provides input for the preliminary impact evaluation of the Hanford Reach.

3.3.2.1 Computational Model Assumptions and Development. The computational model makes several assumptions concerning the natural system:

- the river channel is rectangular in cross-section and straight along its length;
- river flow velocity is constant, uniform, and one-dimensional in the downstream direction;
- the contaminant source for the river is a vertical line source with an infinitesimal width and constant contaminant mass discharge rate that is distributed uniformly over the depth of the river at the river bank; and
- the mixing processes in the river include transverse dispersion across the river and advection in the downstream direction.

The first three assumptions are illustrated in Figure 3-2. The river channel is rectangular in cross-section and straight along its length. The flow velocity in the river does not change with time or space. Contaminant mass discharge to the river is represented by a vertical line source. The mass discharge rate from the line source is uniform over the depth of the river.

The fourth assumption, which concerns mixing processes, is illustrated in Figure 3-3. The water flow in the river moves the contaminants downstream and turbulent mixing distributes the contaminants across the river away from the river bank where discharge occurs. Contaminant discharge is uniform over the depth of the river, therefore contaminant concentration is invariant with respect to the depth. Downstream turbulent mixing is neglected because the downstream flow rate is assumed to be far greater than the rate of downstream turbulent mixing (Fischer et al. 1979).

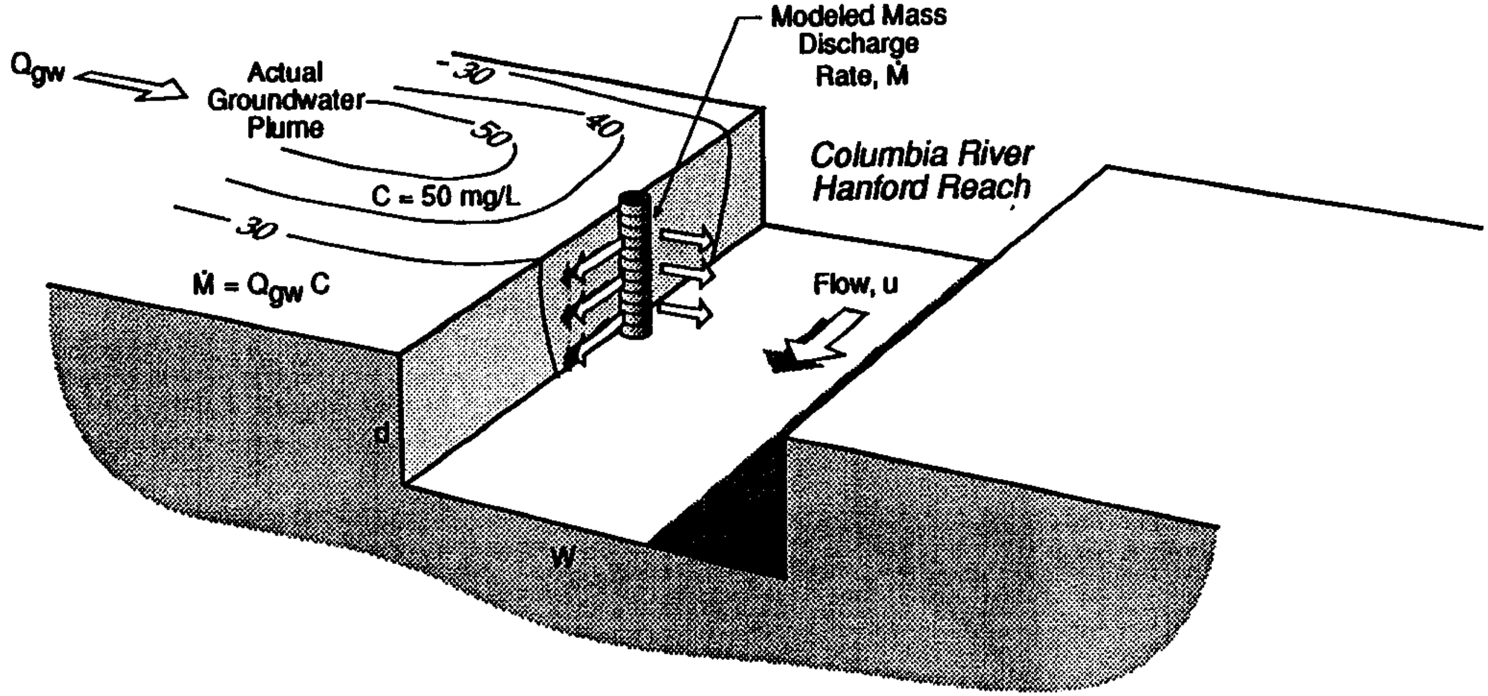

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Figure 3-2. Mass Discharge Source Term for Hanford Reach Mixing Model

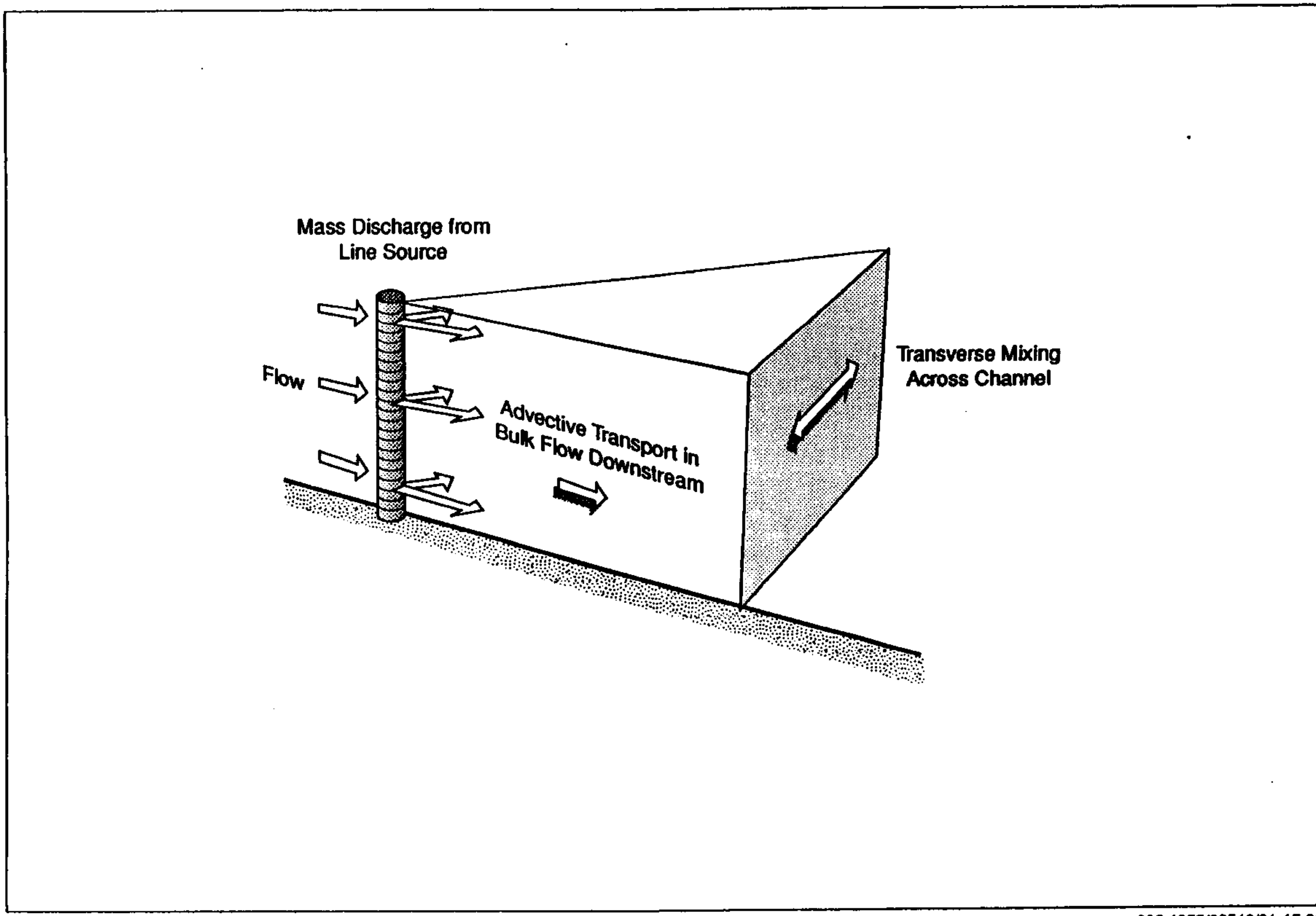

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Figure 3-3. Transport Processes of Hanford Reach Mixing Model

The computational model is developed from a solution for a point source. This point source solution is modified in two steps to obtain the desired model. These two steps enable the computational model to account for the river bank boundary conditions and the occurrence of multiple source inputs to the river. The final form of the model is:

$$C(x,y) = \int_0^x [\frac{2\dot{M}(\tau)}{du\sqrt{4\pi\epsilon_t(x-\tau)/u}} \sum_{n=-2}^{2} \exp(-\frac{(y-nW)^2 u}{4\epsilon_t(x-\tau)})] d\tau \qquad (1)$$

where

C(x,y)	concentration at location x,y (M/L^3),
M(τ)	total contaminant discharge rate at location τ (M/Lt),
d	depth of river (L),
u	average river flow velocity (L/t),
ϵ_t	transverse dispersion coefficient (L^2/t),
W	river width (L),
x	downstream coordinate (L),
y	across stream coordinate (L),
n	summation variable,
τ	integration variable (L), and
dτ	integration differential (L).

This equation accounts for multiple sources where the sources are expressed by the function M(τ). For this application, the source term is discrete and has the value of 0 at locations other than the source location (see Figure 3-4). Boundary conditions are set so that $\partial C/\partial y = 0$ at y = 0 and y = W, where W is the channel width.

The output of the model consists of estimated concentrations C(x,y), where x is the downstream coordinate and y is the across stream coordinate. The concentration is invariant with respect to depth, thus C(x,y,z) = C(x,y). The coordinate x is defined on the interval (0,+∞); the coordinate y is defined on the interval (0,W). Note that the concentration C(x,y) goes to +∞ as the point of evaluation approaches the point of contaminant input (x) because the term (x-τ) would be 0 in the denominator. In addition, because the equation uses the groundwater contaminant mass discharge rate and not the groundwater concentration, the river water concentration C(x,y) will not equal the groundwater concentration at the point of discharge. Thus, for this evaluation the river water concentration is evaluated at a point 1 meter (3.28 feet) downstream of the assumed point of contaminant input. This level of resolution is judged to be adequate for a 94 km (58 miles) length of river.

The parameters in the Equation 1 are obtained in a straight forward manner. The depth and width of the channel are estimated, and a conservative low flow velocity for the river is obtained from the volumetric flow rate and the cross-section area of the channel (velocity = flow rate / cross-section area). Based on a review of ERDA (1975) and USGS topographic maps, the following assumptions appear appropriate for use in the model:

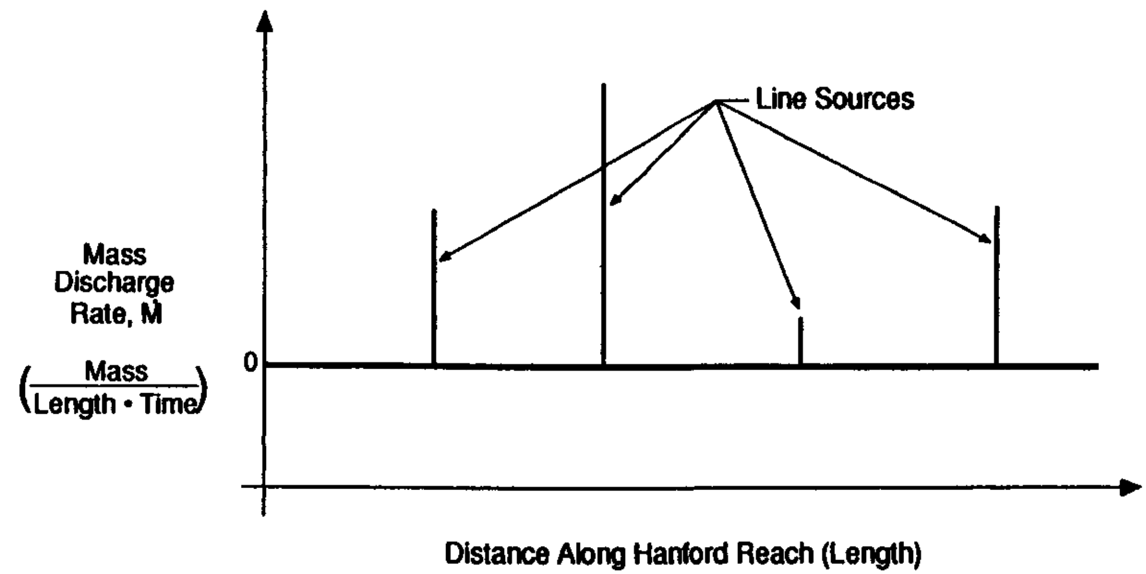

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Figure 3-4. Example Mass Discharge Function for the Hanford Reach Mixing Model

- low-stage river discharge = 1,000 m^3/s (35,000 ft^3/s)
- river depth = 6 m (20 ft)
- river width = 500 m (1,600 ft)
- average velocity = 0.3 m/s (1 ft/s)

The contaminant discharge rate is based on groundwater data collected in the groundwater plume areas. For this analysis, the groundwater concentration and the groundwater discharge rate for each plume (Table 2-3) were used to calculate the groundwater contaminant flux into the river (Table 3-1).

The transverse dispersion coefficient is a calculated parameter based on a correlation for natural streams (Fischer et al. 1979). This coefficient accounts for turbulent mixing processes resulting from variation in the flow velocity across the channel. Variations in the channel flow velocity may result from frictional drag along the channel bottom, irregularities in the channel shape (depth and width), and variability in bottom roughness. The transverse dispersion coefficient is computed from:

$$\frac{\epsilon_t}{\sqrt{g d^3 S}} = 0.6 \qquad (2)$$

where

- ϵ_t transverse dispersion coefficient (0.4) (L^2/t),
- d channel depth (L),
- S channel slope, ($2x10^{-4}$)
- g gravitational constant (L^2/t).

Equation 2 is likely to be correct within an error bound of approximately 50% for straight, rectangular channel. The coefficient value of 0.6 is based on experimental observations from a variety of rivers in North America (Fischer et al. 1979).

3.3.2.2 Quality of Model Results. If the data available for the model parameters are reasonably well known and the model is appropriately applied, (i.e., conditions in the river are not widely different from the assumed conditions), the concentration estimates provided by the computational model are order of magnitude results. This level of accuracy is adequate for the preliminary and qualitative nature of this impact evaluation. If the concentration estimate is an order-of-magnitude or more above or below a benchmark concentration, we may conclude that a problem does or does not exist. Likewise, the contaminant discharges may be ranked as long as the ranking is in terms of the order of magnitude of the result. Results of the same order of magnitude are indistinguishable from one another and require further analysis if they are to be separated.

The use of a line source to represent contaminant release resulting from groundwater discharge is likely the largest departure from the natural system incorporated into the model. The line source approximation to groundwater discharge of contaminants is a conservative assumption because it overestimates the contaminant concentrations at the

Table 3-1. Estimated Groundwater Contaminant Fluxes and Source Concentrations in and along the 100 Area Segment of Hanford Reach.

Groundwater Plume	Contaminant of Potential Concern	Estimated Contaminant Flux	Source Concentration
100BC-2	^{90}Sr	680 pCi/s	54 pCi/L
100BC-1	^{90}Sr	670 pCi/s	53 pCi/L
	Cr	0.25 mg/s	0.02 mg/L
	NO_3	710 mg/s	56 mg/L
100K-1	NO_3	2,100 mg/s	66 mg/L
	^{3}H	28,000,000 pCi/s	880,000 pCi/L
100K-2	NO_3	1,600 mg/s	51 mg/L
	Cr	3.6 mg/s	0.11 mg/L
100K-3	Cr	10 mg/s	0.16 mg/L
100N-1	^{90}Sr	1,000,000 pCi/s	23,000 pCi/L
	^{3}H	9,700,000 pCi/s	220,000 pCi/L
100D-2	^{3}H	6,100,000 pCi/s	96,000 pCi/L
100D-1	^{90}Sr	2,300 pCi/s	45 pCi/L
	^{3}H	2,700,000 pCi/s	53,000 pCi/L
	Cr	35 mg/s	0.69 mg/L
	NO_3	6,100 mg/s	120 mg/L
100H-1	NO_3	710 mg/s	56 mg/L
	Cr	5.3 mg/s	0.42 mg/L
100H-2	^{99}Tc	14,000 pCi/s	3,700 pCi/L
	U	580 pCi/s	150 pCi/L
	Cr	3.1 mg/s	0.79 mg/L
	NO_3	2,000 mg/s	520 mg/L
100F-2	U	2,800 pCi/s	143 pCi/L
	NO_3	3,300 mg/s	170 mg/L
100F-1	^{90}Sr	2,800 pCi/s	145 pCi/L

point of discharge. In the natural system, we anticipate the groundwater discharge to occur throughout the surface area of the river bottom, resulting in a distributed contaminant source. In the computational model this source is represented by a vertical line of infinitesimal width along the river bank. Consequently, the model has a tendency to overestimate the contaminant concentrations in the source areas due to the highly concentrated source term or underestimate the concentration at the discharge point due to the assumption of instantaneous vertical mixing. Away from the source areas, the estimated concentrations become representative of the release from the distributed source. A more accurate representation of contaminant discharge in the 100 Area will require further characterization to determine the interaction between groundwater and the Columbia River.

3.3.2.3 Model Results. Using the model discussed above, predicted contaminant concentrations in the Hanford Reach, due to 100 Area activities, were calculated and are illustrated in Figures 3-5 to 3-10. These figures show the predicted cumulative concentration effect of successive plumes within the Hanford Reach. These plots also show the predicted average concentration along the right bank of the Hanford Reach downstream of the contaminant discharge ($\bar{C}$), the predicted contaminant concentration at the Richland water intake (C_R), reference (upstream) concentration (C_O), and the ambient water quality criterion. The predicted average concentration for each contaminant ($\bar{C}$) is calculated over the distance of the Hanford Reach (94 km).

The cumulative effect of successive contaminant plumes on the contaminant concentration is well exemplified in Figure 3-5. The measured background concentration of ^{90}Sr, at the Priest Rapid Dam in 1989, was .07 pCi/L. Each successive contaminant plume can be seen to shift the concentration curve upward from the trend of the previous curve (particularly the 100N-1 plume). In this case, the model predicts that the concentration of ^{90}Sr will be 0.6 pCi/L at the Richland Water Intake. The measured value (1989) of ^{90}Sr was 0.08 pCi/L. The order-of-magnitude difference in these values can be explained by the conservative assumptions used by this model, especially the use of maximum groundwater concentrations together with low river flow conditions to try and predict a yearly average. For all other contaminants, the predicted concentrations at the Richland water intake were less than 1989 measured values (cf. Table 2-5). It should be noted that the empirical values include any contributions from non-100 Area sources.

3.3.3 Biological Transport

The biological transport of the contaminants of potential concern is focused on the transport of groundwater inputs to the river-water column where fish can ingest the contaminants. The concentration in the fish tissue is assumed to be directly proportional, in relation to a contaminant-specific bioconcentration factor (BCF), to the concentration of the contaminant in the water column. The estimated concentration of each contaminant of potential concern in fish under future conditions is calculated using the conservatively predicted average contaminant concentration along the right bank of the Hanford Reach ($\bar{C}$) (see Figures 3-5 to 3-10):

$$C_f = (\bar{C})(BCF)$$

where C_f is the contaminant concentration in fish tissue.

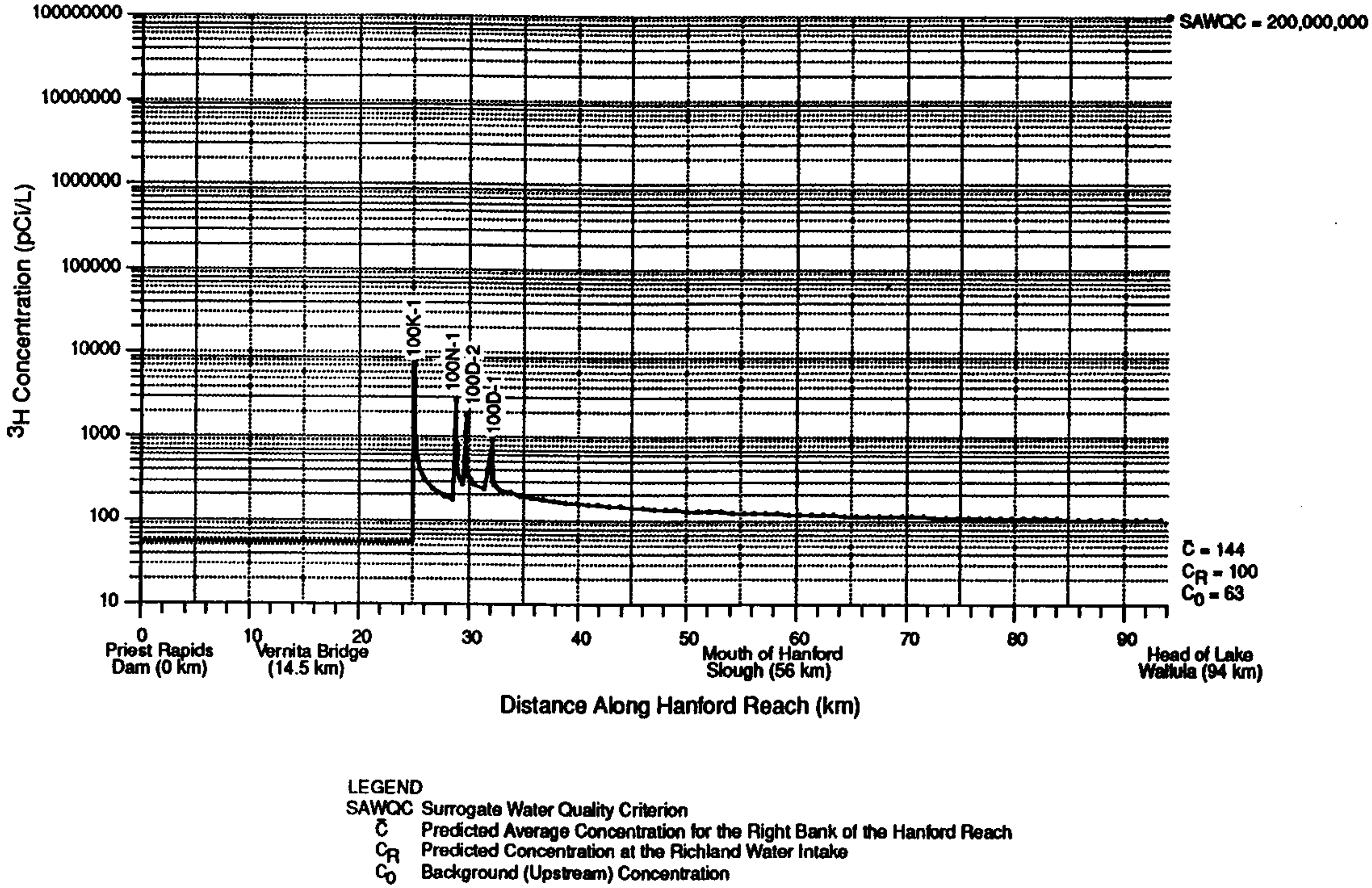

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Figure 3-5. Predicted Tritium River Water Concentration Along the Right Bank of the Hanford Reach.

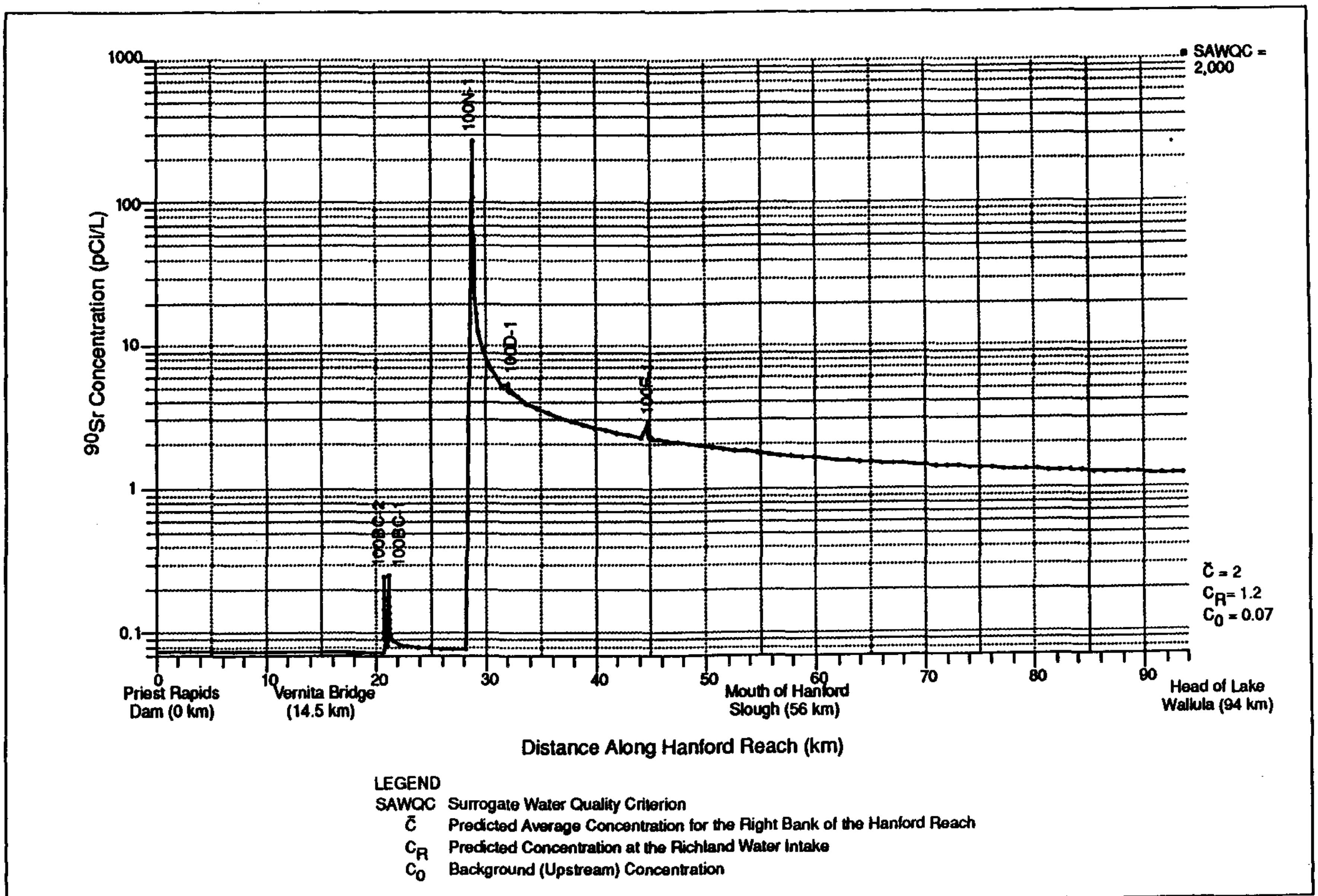

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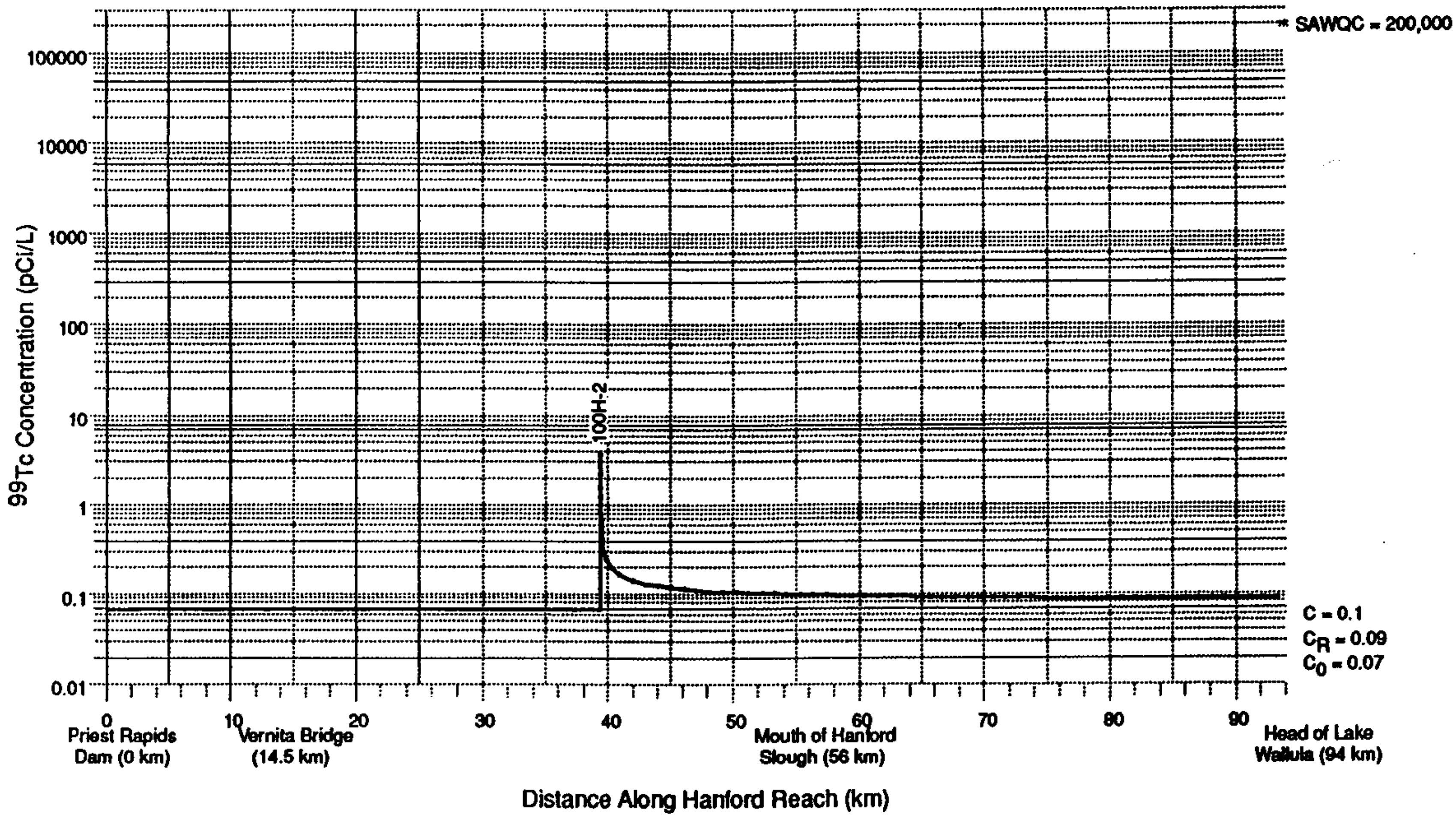
Figure 3-6. Predicted Strontium-90 River Water Concentration Along the Right Bank of the Hanford Reach.



LEGEND

SAWQC Surrogate Water Quality Criterion
C Predicted Average Concentration for the Right Bank of the Hanford Reach
C_R Predicted Concentration at the Richland Water Intake
C_0 Background (Upstream) Concentration

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Figure 3-7. Predicted Technetium-99 River Water Concentration Along the Right Bank of the Hanford Reach.

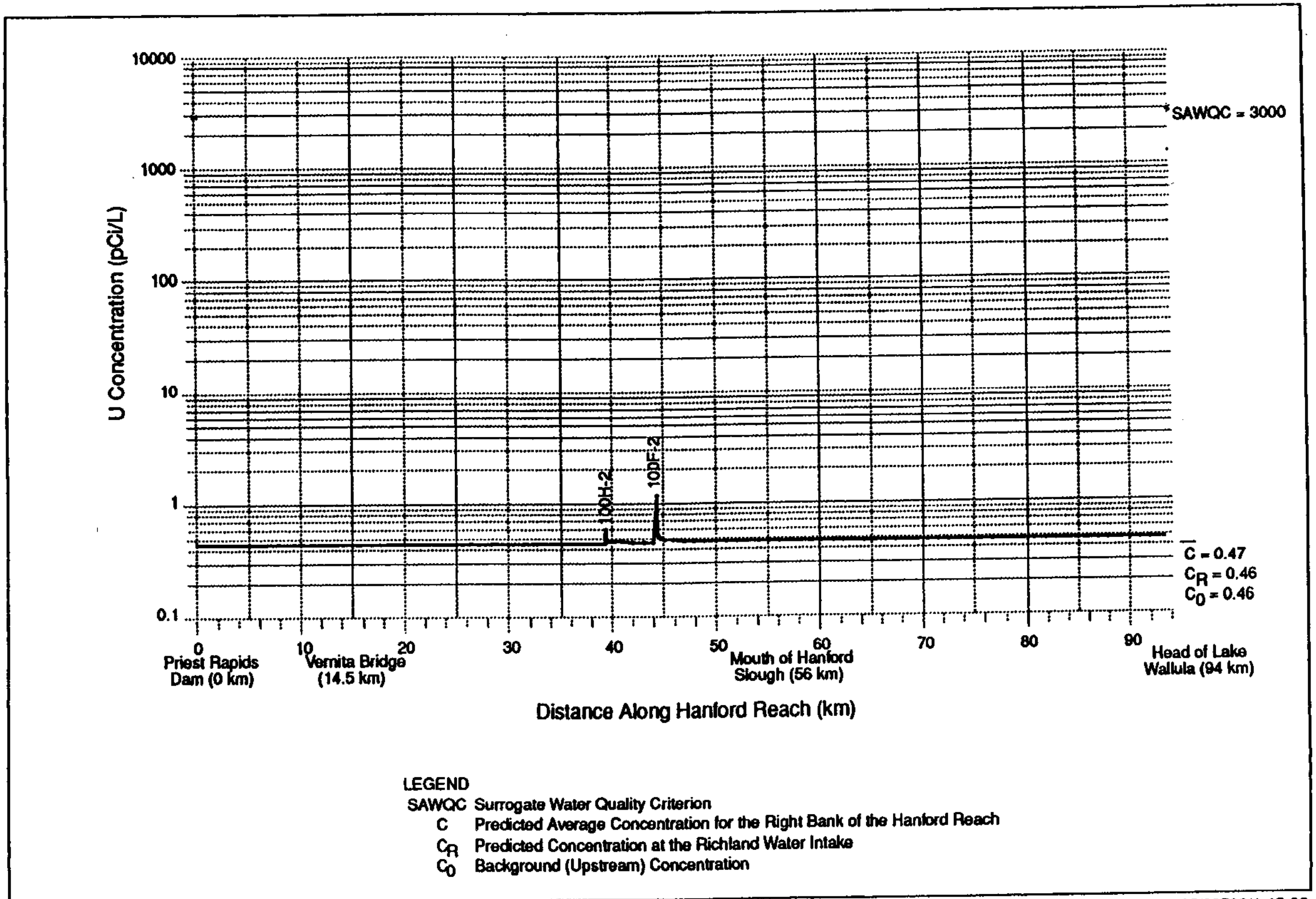

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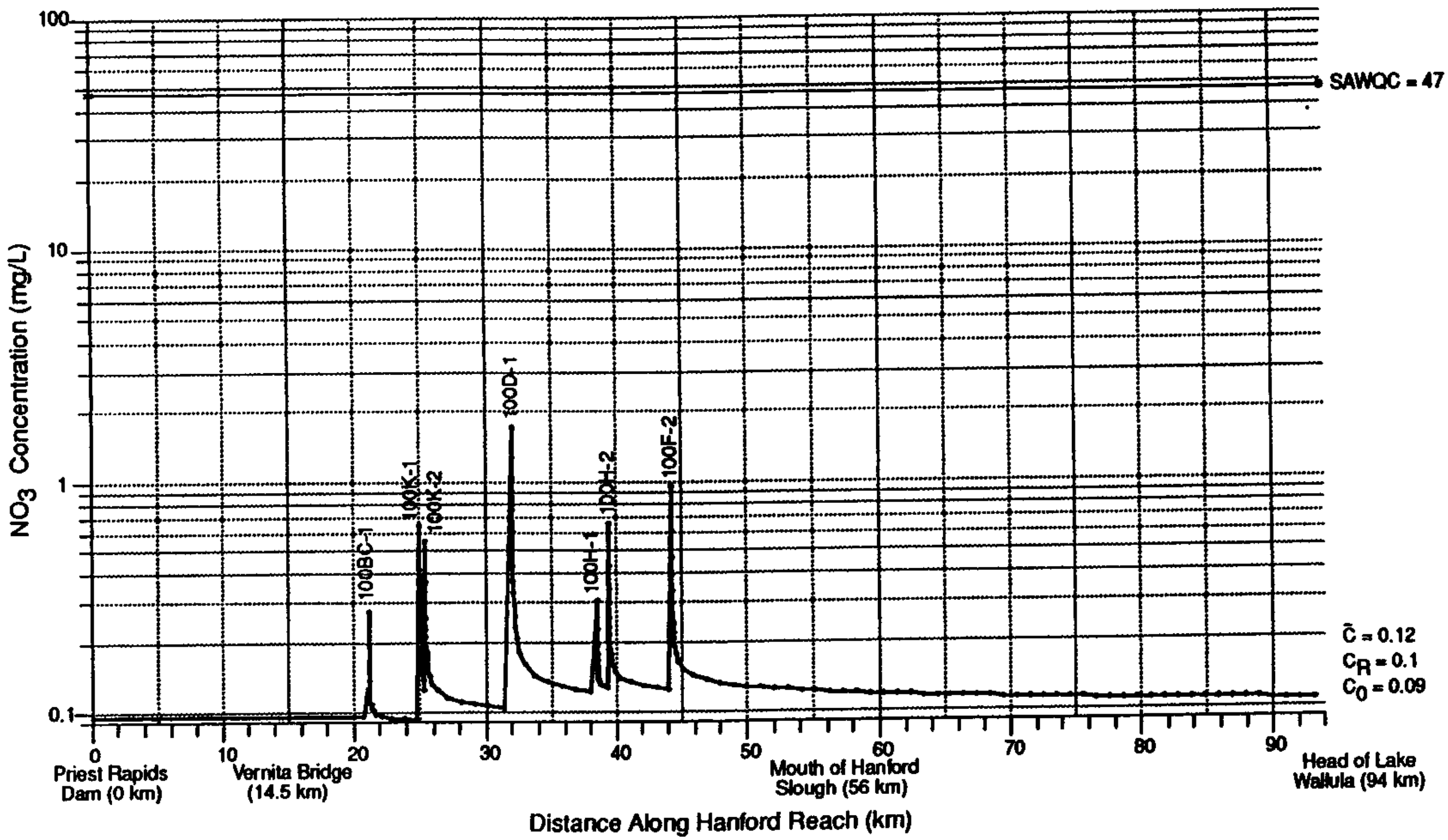
Figure 3-8. Predicted Uranium River Water Concentration Along the Right Bank of the Hanford Reach.



LEGEND

SAWQC	Surrogate Water Quality Criterion
$\bar{C}$	Predicted Average Concentration for the Right Bank of the Hanford Reach
C_R	Predicted Concentration at the Richland Water Intake
C_0	Background (Upstream) Concentration

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Figure 3-9. Predicted Nitrate River Water Concentration Along the Right Bank of the Hanford Reach.

9 3 1 2 7 5 3 1 6 5 9

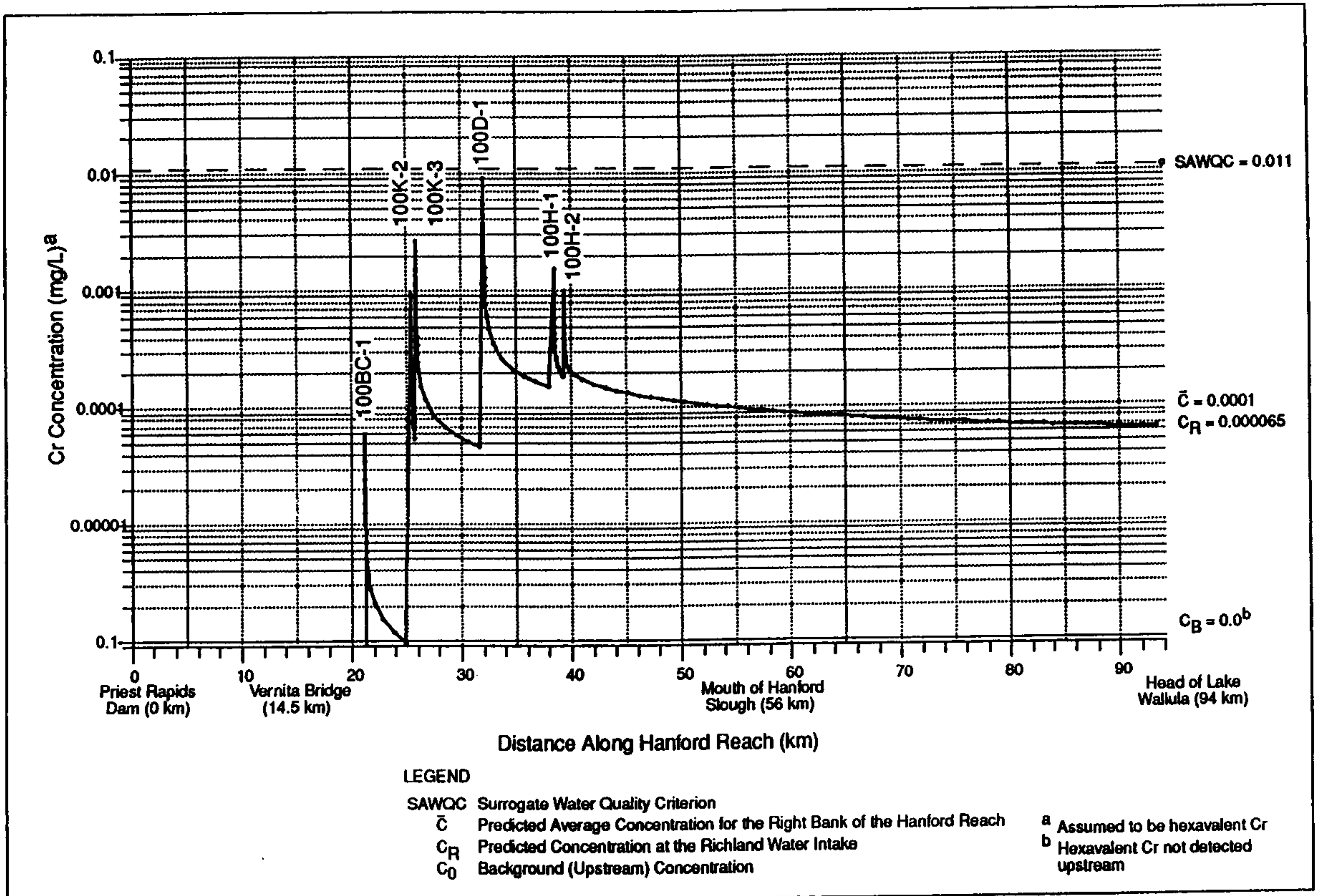

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Figure 3-10. Predicted Chromium River Water Concentration Along the Right Bank of the Hanford Reach.

A summary of the BCFs used and the resulting fish contaminant concentrations is provided in Table 3-2. A BCF is not available for NO_3 (EPA 1986a) because there is no evidence that this substance bioaccumulates.

Table 3-2. Summary of Estimated Contaminant Concentrations in Fish.

Contaminants of Potential Concern	Estimated Water Concentration[a]	BCF[b] (L/kg)	Estimated Concentration in Fish[c]
Chemical Contaminants			
Cr	0.0001	16	0.002
NO_3	0.12	--	--
Radioactive Contaminants			
^{3}H	140	1	0.14
^{90}Sr	2	30	0.06
^{99}Tc	0.1	15	0.002
U	0.43	8	0.003

[a] Estimated average water concentrations along the right bank of the Hanford Reach.
Chemical units are mg/L
Radioactive units are pCi/L
[b]Chemical BCFs from EPA 1986b
Radioactive BCFs from NRC 1977; Till and Meyer 1983
BCFs listed are appropriate for fish flesh.
[c]Chemical units are mg/kg
Radioactive units are pCi/g

4.0 IMPACT EVALUATION

This chapter provides a preliminary and qualitative evaluation of the human health and environmental impacts to the Hanford Reach of the Columbia River associated with past and current practices at the 100 Area. The human health impacts are assessed in Section 4.1, and the environmental impacts are preliminarily assessed in Section 4.2.

4.1 HUMAN HEALTH EVALUATION

The human health evaluation utilizes four elements of impact assessment — contaminant identification, exposure assessment, toxicity assessment, and impact characterization — to assess the potential impacts to human receptors.

4.1.1 Contaminant Identification

As discussed in Section 2.2, several contaminants related to Hanford Site past and ongoing practices in the 100 Area have been identified in groundwater that currently impact the Hanford Reach. The contaminants of potential concern include five radioactive and two non-radioactive contaminants.

4.1.1.1 Radioactive Contaminants. The radioactive contaminants of potential concern are ^{3}H, ^{90}Sr, ^{99}Tc, and U. All of these have been detected in groundwater seeps and springs along the river.

Background levels of radionuclides are an important consideration when determining what constitutes a contaminant. In addition to its use at Hanford, U is a naturally occurring radionuclide (>9wt% ^{238}U) with a Columbia River reference concentration of approximately 0.3 pCi/L. Natural groundwater concentrations of U range from 0.7 to 10 pCi/L (Becker 1990). Tritium is a natural as well as man-made radionuclide. The ^{3}H concentration at Priest Rapids Dam was 52 pCi/L in 1990 (Woodruff and Hanf 1991).

For comparison purposes, primary maximum contaminant levels (MCLs) and estimated concentrations at the Richland water intake are provided in Table 4-1. The listed radionuclide MCLs are proposed values, and are the concentrations estimated to result in an effective dose equivalent of 4 mrem/yr as the result of an annual intake of 730 L of drinking water. Estimated contaminant water concentrations are at least two orders of magnitude smaller than their respective MCLs. Although this comparison indicates that the contaminant concentrations pose no significant adverse impacts on human health, all radionuclides are retained for further analysis because acceptable exposure levels as defined in the NCP [i.e., a cancer risk below 10^{-4}; 40 CFR 300.430(e)(2)(i)(A)(2)] are more stringent than the cancer risk level upon which the proposed MCLs for radionuclides are based.

Table 4-1. National Primary Drinking Water Standards for Hanford Reach Contaminants

Contaminants of Potential Concern	Estimated Water Concentrations[a,b]	Measured Water Concentrations[a,d]	Primary Maximum Contaminant Level[b]
Non-radioactive			
Cr	6.5E-05	<0.001	0.1
NO_3	0.1	0.11	44
Radioactive			
^{3}H	120	129	60,900[c]
^{90}Sr	1.2	0.07	42[c]
^{99}Tc	0.09	0.5	3,790[c]
U	0.46	0.44	30[c]

[a]Concentration at the Richland water intake.
[b]Chemical units are mg/L
Radioactive units are pCi/L
[c]Proposed MCL (56 FR 33050)
[d]Jaquish and Bryce 1990

4.1.1.2 Chemical Contaminants. The chemical contaminants of potential concern (Cr and NO_3) are both inorganic substances. Both have been detected in groundwater seeps and springs at the river's edge.

Primary MCLs and estimated concentrations at the Richland water intake are provided in Table 4-1. Estimated contaminant water concentrations are at least two orders of magnitude smaller than their respective MCLs. However, both Cr and NO_3 are retained for further analysis.

4.1.2 Human Health Exposure Assessment

The purpose of an exposure assessment is to estimate the magnitude, frequency, duration, and route of exposure to potential chemical and radioactive contaminants that human receptors may experience. This exposure estimation can then be integrated with appropriate toxicity information to assess the nature and extent of any health threats.

The exposure assessment presented in the following paragraphs focuses on exposure pathways associated with Hanford Reach and humans that have contact with river water or biota associated with the river environment. As discussed in Sections 2.2 and 3.3, the contaminants evaluated in this assessment are both radioactive and chemical contaminants related to Hanford Site past practices in the 100 Area that are currently entering the Hanford Reach via the groundwater.

This exposure assessment is qualitative, but the qualitative discussion is supplemented by quantitative calculations of intake and risk for several potential exposure pathways identified in Section 3.1 and discussed in subsection 4.1.2.2.

4.1.2.1 Characterization of Potentially Exposed Populations. The potential human receptor populations have been identified based on current and probable near future use of the Columbia River along that portion of the Hanford Reach directly adjacent to or immediately downriver from the Hanford Site. Currently, the Columbia River is used as a source of drinking water, industrial process water, crop irrigation, and a variety of recreational activities including hunting, fishing, boating, water skiing, and swimming (Jaquish and Bryce 1990). Thus, toxic contaminants from Hanford Site operations that enter the river could result in exposures to residential, industrial, agricultural, or recreational receptor populations.

For the purposes of this report, two human receptor populations have been selected to assess the potential human health impacts. The first are residents, both children and adults, of the City of Richland. The City of Richland has a water intake located immediately downriver from the Hanford Site. The second receptor population is the adult recreational users of the Hanford Reach. As noted above, the river is used for a variety of recreational purposes. In addition, river users have limited access to the river bank along the Hanford Site up to the high water mark for such recreational activities as waterfowl hunting and fishing. Given that any access to the springs and seeps along the Hanford Site would require hiking up the riverbank or traveling by boat for miles, it is assumed that infants and young children would have no, or very limited access, to these locations on any ongoing basis. Therefore, the recreational scenario is evaluated only for an adult receptor over a lifetime.

These receptor populations have been selected because of the direct exposure pathways between the contaminants and the receptors. There is also a potential for the selected receptors to have long-term or chronic exposures, and the potential for the exposures to result in significant adverse impacts (e.g., direct ingestion of water contaminated with carcinogenic contaminants, sensitive subpopulations such as children ingesting NO_3 contaminated water, etc.). Impacts to other potential receptors who may be exposed through agricultural or industrial use of Hanford Reach water are qualitatively discussed in section 4.1.5 as part of the risk characterization.

4.1.2.2 Identification of Exposure Pathways. The potential exposure pathways for residential receptors are those pathways related to exposure to river water or to biota impacted by contaminated river water as discussed in Section 3.3. These pathways include:

- ingestion of water;
- dermal exposure to the water during bathing and showering;
- ingestion of fish from the Hanford Reach; and
- ingestion of plants or crops irrigated with Hanford Reach water.

A quantitative evaluation is presented for the ingestion of water and the ingestion of fish with a qualitative discussion of the potential impacts from exposures through the remaining pathways provided in subsection 4.1.5.

Exposure pathways for recreational users of the Hanford Reach include:

- ingestion of river water;
- dermal exposure to contaminants in the water;
- ingestion of fish from the Hanford Reach;
- ingestion of waterfowl or game using the river; and
- ingestion of plants growing in the riparian zone.

A quantitative evaluation is provided for the ingestion of river water and for the ingestion of fish from the Hanford Reach. Dermal exposures, and ingestion of waterfowl and game are discussed qualitatively in subsection 4.1.5.

As indicated in section 3.1.3, exposure to river sediments is not evaluated. When compared to the ingestion of water or fish, the potential for significant exposures to sediments is much lower because such exposures are usually of short duration. In addition, the likelihood of significant dermal absorption from sediments or ingestion of sediments is reduced because sediments tend to wash off during water activities.

4.1.2.3 Quantification of Exposures. The quantification of exposures requires the determination of exposure point concentrations (i.e., the concentration in the medium) and the calculation of daily intakes for the contaminants of potential concern. In order to evaluate the residential and recreational scenarios indicated above, exposure point concentrations for the contaminants of potential concern must be estimated for the Hanford Reach at the City of Richland water intake, fish in the Hanford Reach, and river water adjacent to the Hanford Site. The methods used to calculate contaminant water concentrations is described in Section 3.3. Contaminant concentrations in fish are provided in Table 3-2. The quantification of exposures is discussed below for radioactive and non-radioactive contaminants.

Exposure parameters used to calculate daily intakes are presented in Table 4-2. Standard EPA equations for exposure and impact assessment, as provided in EPA (1989a) and WAC 173-340, are used (with appropriate conversion factors, as necessary) as a basis for all calculations.

Table 4-2. Exposure Parameters.

Exposure Factor	Value		
	Residential Water Ingestion	Fish Ingestion	Recreational Water Ingestion
Ingestion rate	2 L/d (c) 1 L/d (n)	27 g/d[a]	1 L/d[b]
Exposure frequency	365 d/yr	365 d/yr	1 d/yr[b]
Exposure duration	30 yr (c) 6 yr (n)	30 yr	30 yr
Body weight	70 kg (c) 16 kg (n)	70 kg	70 kg
Averaging time (x 365 d/yr)	70 yr[c] (c) 6 yr (n)	70 yr[c] (c) 30 yr (n)	70 yr[c] (c) 30 yr (n)

Source is WAC 173-340-720, Method B, unless otherwise noted.

[a]54 g/d x 0.5 (diet fraction), WAC 173-340-730.
[b]Site-specific assumption.
[c]Standard Default Exposure Factors, OSWER Directive 9285.6-03, March 1991
(c) = value for carcinogens
(n) = value for noncarcinogens

Radioactive Contaminants

The equation for determining radionuclide intakes via the ingestion (water or biota) pathway is:

$$Intake = C \times IR \times EF \times ED \times CF$$

where:

Intake	=	radionuclide-specific intake via ingestion (pCi)
C	=	radionuclide concentration in medium of interest
IR	=	contact rate (medium-specific)
EF	=	exposure frequency (d/yr)
ED	=	exposure duration (yr)
CF	=	conversion factor (as appropriate)

This equation calculates the total intake of radioactivity for a given exposure duration (e.g., a lifetime). The exposure parameters and assumptions are provided in Table 4-2.

Non-Radioactive Contaminants

The basic equation for calculating intakes for non-radioactive contaminants via ingestion (water or biota) is:

$$Intake = \frac{C \times IR \times EF \times ED \times CF}{BW \times AT}$$

where :	Intake	=	contaminant-specific intake (mg/kg-d)
	C	=	concentration of contaminant in the medium
	IR	=	contact rate (medium-specific)
	EF	=	exposure frequency (d/yr)
	ED	=	exposure duration (yr)
	CF	=	conversion factor (as appropriate)
	BW	=	body weight (kg)
	AT	=	averaging time (yr x 365 d/yr)

This equation calculates a chronic daily contaminant intake. The exposure parameters, assumptions, and references are provided in Table 4-2.

Summary of Intakes for the Residential Scenario

Estimates of Hanford Reach contaminant concentrations at the City of Richland intake are used to calculate contaminant intakes via water ingestion for the residential scenario. For reasons described in subsection 4.1.3, background concentrations are subtracted from these estimated concentrations for carcinogenic contaminants (i.e., the radionuclides), while unadjusted water concentrations were used to calculate intakes of noncarcinogenic contaminants (i.e., Cr and NO_3). Since upstream and downstream concentrations of U are identical, the intake value for this radionuclide is zero; by accounting for background, the ^{3}H concentration is reduced by roughly half, and ^{99}Tc is reduced by a factor of four. Strontium-90 concentrations are only slightly reduced by accounting for background. A summary of contaminant intake values via water ingestion for the residential scenario are presented in Table 4-3.

Estimates of average Hanford Reach contaminant concentrations are used to calculate contaminant concentrations in fish. Upstream concentrations of carcinogenic contaminants are subtracted from average river concentrations prior to calculating fish concentrations. This is why fish concentrations presented in Table 4-3 do not necessarily agree with those presented in Table 4-2. This adjustment was not made for noncarcinogenic contaminants. A summary of contaminant intake values via fish ingestion for the residential scenario are presented in Table 4-3.

Summary of Intakes for the Recreational Scenario

Estimates of average Hanford Reach contaminant concentrations are used to calculate contaminant intakes via water ingestion for the recreational scenario. Upstream concentrations of carcinogenic contaminants are subtracted from average river concentrations prior to calculating contaminant intakes. This adjustment was not made for noncarcinogenic contaminants. A summary of the radioactive and non-radioactive intakes resulting from ingestion of water from the Hanford Reach are provided in Table 4-4.

Table 4-3. Summary of Human Health Assessment: Residential Scenario.

Exposure Route	Contaminant of Potential Concern	Estimated Concentration in Medium[a]	Noncarcinogens			Carcinogens		
			Intake (mg/kg-d)	Hazard Quotient	Hazard Index	Intake (pCi)	ICP[b]	Total ICP[b]
Water Ingestion	^{3}H	5.7E+01	NA	-		1.2E+06	6E-08	
	^{90}Sr	1E+00	NA	-		2E+04	7E-07	
	^{99}Tc	2E-02	NA	-		4E+02	5E-10	
	U	0.0	NA	-		0.0	-	
	Cr	6.5E-05	4.1E-06	0.0008[c]		NA	-	
	NO_3	1E-01	6E-03	0.00009	0.002	NA	-	8E-07
Fish Ingestion	^{3}H	9.7E-02	ND	-		2.9E+04	2E-09	
	^{90}Sr	6E-02	NA	-		2E+04	7E-07	
	^{99}Tc	4E-04	NA	-		1E+02	1E-10	
	U	8E-02	NA	-		2E+04	6E-07	
	Cr	2E-03	8E-07	0.0002		NA	-	
	NO_3	ND	-	-	0.0002	NA	-	1E-06

[a]Water concentrations expressed as mg/L (chemical) or pCi/L (radioactive); fish concentrations expressed as mg/kg (chemical) or pCi/g (radioactive).
[b]Incremental cancer probability.
[c]Assumes all chromium to be hexavalent.
NA = not applicable.

Table 4-4. Summary of Human Health Assessment: Recreational Scenario.

Exposure Route	Contaminant of Potential Concern	Estimated Concentration in Medium[a]	Noncarcinogens			Carcinogens		
			Intake (mg/kg-d)	Hazard Quotient	Hazard Index	Intake (pCi)	ICP[b]	Total ICP[b]
Water Ingestion	^{3}H	9.7E+01	NA	-		2.9E+03	2E-10	
	^{90}Sr	2E+00	NA	-		6E+01	2E-09	
	^{99}Tc	3E-02	NA	-		9E-01	1E-12	
	U	1E-02	NA	-		3E-01	8E-12	
	Cr	1E-04	4E-09	0.0000008[c]		NA	-	
	NO_3	1.2E-01	5E-06	0.0000007	0.000002	NA	-	2E-09

[a]Water concentrations expressed as mg/L (chemical) and pCi/L (radioactive).
[b]Incremental cancer probability.
[c]Assumes all as hexavalent chromium.
NA = not applicable.

4.1.3 Human Toxicity Assessment

The purpose of the toxicity assessment is to identify the potential adverse effects associated with exposure to the site-related contaminants of potential concern and to estimate, using numerical toxicity values, the likelihood that these adverse effects may occur based on the extent of the exposure.

4.1.3.1 Carcinogenic Effects. The toxicity values (i.e, slope factors) for carcinogens have been derived based on the conservative concept that for any exposure to a carcinogenic chemical there is always a carcinogenic response (i.e., there is no threshold). The slope factor (SF) is used in impact assessment to estimate an upper-bound lifetime probability of an individual developing cancer as a result of exposure to a particular level of a potential carcinogen.

The only carcinogenic contaminants being considered for this assessment are radionuclides (^{3}H, ^{90}Sr, ^{99}Tc, and U). All radionuclides are classified by EPA as Class A human carcinogens, and slope factors for these radionuclides are presented in Table 4-5. Cancer induction is the only human health effect of concern resulting from exposure to environmental radioactive contamination, such as ingestion of groundwater containing radionuclides. Systemic toxic effects occur only following relatively high doses of radiation that are not typical of exposures to environmental contamination.

Because the concern regarding cancer induction is one of an incremental increase above a background rate, only those carcinogens present in the Hanford Reach as a result of activities at the 100 Area are evaluated. Therefore, upstream concentrations of carcinogenic contaminants (i.e., radionuclides) are subtracted from the average river concentrations (used to derive contaminant concentrations in fish) or concentrations at the City of Richland water intake prior to calculating intake values.

4.1.3.2 Systemic Toxic Effects. The reference dose (RfD) is the toxicity value used to evaluate noncarcinogenic effects resulting from exposures to chemicals or radionuclides. The RfD has been developed based on the concept that protective mechanisms exist that must be overcome before an adverse effect is manifested (i.e., there is a threshold which must be reached before adverse effects occur). The chronic RfD is defined as an estimate of a daily exposure level for the human population, including sensitive subpopulations such as children or the elderly, that is likely to be without an appreciable risk of deleterious effects during a lifetime. In this assessment, all exposures are evaluated as chronic exposures. The RfDs for the contaminants of potential concern and supporting information are summarized in Table 4-5.

Because systemic toxins are assumed to have a threshold response, it is possible that the addition of such a contaminant to an already high natural background concentration in the Hanford Reach may be sufficient to cause an adverse health effect. For this reason, upstream concentrations of systemic toxins are not subtracted from the average river concentrations or concentrations at the City of Richland water intake prior to calculating intake values.

Table 4-5. Summary of Toxicity Information.

Contaminant	Systemic Toxicity						Carcinogenic Toxicity	
	Oral RfD (mg/kg-d)	Oral RfD Source[a]	Confidence Level[b]	Critical Effect	Uncertainty Factors[c]	Modifying Factors	Oral Slope Factor $(mg/kg\text{-}d)^{-1}$	Slope Factor Source[a,d]
Non-Radioactive								
Cr	5E-03[e]	IRIS[a]	L	None observed	500 (S,L)[f]	1	NA	IRIS
NO_3	7E+00[g]	IRIS	H	Methemoglobinemia	1	1	NA	--
Radioactive							$(pCi)^{-1}$	
^{3}H	NA	--	--	--	--	--	5.4E-14	HEAST
^{90}Sr	NA	--	--	--	--	--	3.6E-11	HEAST
^{99}Tc	NA	--	--	--	--	--	1.3E-12	HEAST
^{238}U	NA	--	--	--	--	--	2.8E-11	HEAST

[a]Integrated Risk Information System (EPA 1992a).
[b]L (Low), M (Medium), H (High) as designated in IRIS.
[c]Uncertainty adjustments (factor of 10 for each adjustment unless otherwise noted).
H = Variation in human sensitivity.
A = Animal to human extrapolation.
S = Extrapolation from subchronic to chronic no-observed-adverse-effect-level (NOAEL).
L = Extrapolation from lowest-observed-adverse-effect-level (LOAEL) to NOAEL.
[d]Health Effects Assessment Summary Tables (EPA 1992b).
[e]Assumes all as hexavalent chromium; RfD for chromium.
[f]Additional factor of 5 based on exposure duration of principal study.
[g]Expressed as Nitrate (1 mg nitrate-nitrogen=4.4 mg nitrate; RfD as nitrate-nitrogen=1.6 mg/kg-d).

In general, radionuclides are only evaluated with respect to the carcinogenic potential associated with ionizing radiation. Uranium, however, has demonstrated a toxic effect on the kidney that is unrelated to radioactive decay. No RfD has been established for U, and preliminary data suggests that the U drinking-water concentration associated with nephrotoxic effects is more than two orders of magnitude higher than that which may represent a health concern due to its radioactivity. Until an RfD is proposed, U will only be evaluated as a carcinogen.

4.1.3.3 Toxicity Profiles. A brief discussion of the toxicity associated with the contaminants of potential concern is provided below for the radioactive contaminants and the non-radioactive contaminants.

Radioactive Contaminants of Potential Concern

Tritium (Hydrogen-3) — The ingestion of tritiated water allows this radionuclide to distribute uniformly throughout body tissues, providing a whole body dose. Although it has a relatively long physical half-life (12.3 yr), the biological half-life for water is approximately 10 days, greatly limiting it presence in the body and thereby reducing its impact. Tritium is a pure, low-energy beta emitter, making this radionuclide a negligible external hazard.

Strontium-90 — Bone cancer is the primary health effect of concern from ingestion of radioactive isotopes of Sr. Being chemically similar to calcium, this element deposits in bone and is removed very slowly. In addition, this fission product has a long half-life (30 yr). Both ^{90}Sr and its daughter, yttrium-90 (^{90}Y), are high-energy beta emitters, making them important internal hazards.

Technetium-99 — This fission product is readily absorbed across the gut, from which it transfers to all tissues and organs to provide a whole body dose. In spite of its long physical half-life (2.1E+05 years), its biological half-life is only 2 days, greatly limiting its residence time in the body.

Uranium — Naturally occurring U is 99.28wt% ^{238}U. Solubility and uptake across the gut is highly dependent upon valence state. Some components are transferred to the bone and kidney. Because ^{238}U has an extremely long half-life (4.5E+09 yr), it emits radiation at a very slow rate. As a result, chemical damage to the kidney may be a relatively more important health concern that radiation-induced cancer. This isotope of U is a high-energy alpha emitter, making it an important internal hazard.

Non-radioactive Contaminants of Potential Concern

Chromium — Chromium is found in the environment in compounds as one of three valence states, +2, +3, and +6. The trivalent form is an essential human micronutrient that helps maintain normal metabolism of glucose, cholesterol, and fat. Adverse effects have not been associated with trivalent Cr except at very high doses. The hexavalent form is important industrially (typically in the form of chromates) and has been associated with serious toxicities. These effects occur at the point of exposure whether it is the skin, the respiratory tract, or the gastrointestinal tract. These effects include irritation, ulceration, and allergic reactions.

The EPA has determined the oral RfD for hexavalent Cr as 5E-03 mg/kg-d based on a drinking-water study in rats. The confidence in the study is low and no critical effects were observed because of a poor study design (EPA 1992a). Hexavalent Cr is classified by EPA as a known human carcinogen (weight-of-evidence classification A) by the inhalation exposure. No evidence exists to indicate that Cr is carcinogenic by the oral route. Therefore, there is not an oral SF for Cr (EPA 1992a).

Nitrate — Nitrate compounds have a variety of uses such as explosives, medications, fertilizers, and food preservatives. Nitrate occurs naturally, and the majority of dietary intake is from vegetables such as beets, celery, lettuce, and spinach. The dietary contribution from drinking water is usually quite small. Concern with NO_3 in the environment has arisen because NO_3 is highly soluble in water and very mobile in soil (Amdur et al. 1991).

Ingestion of NO_3 has been well studied in humans. As a class of compounds, NO_3 can produce headache, decreased blood pressure, blood vessel dilation, and methemoglobinemia, an impaired ability of the blood to transport oxygen. Methemoglobinemia is primarily caused by nitrite, which is produced in the body from NO_3. Infants are particularly susceptible to the methemoglobinemia, while adults are less sensitive to the effects.

Nitrate has an RfD of 1.6 mg/kg-d (EPA 1992a) expressed as NO_3-nitrogen (i.e., 7 mg/kg-d expressed as NO_3), based on human infant studies. The confidence level for the RfD is high. Nitrate is classified as a Group D carcinogen (not classifiable as to carcinogenicity) by EPA. Therefore, no SF is available for NO_3.

4.1.4 Human Health Impact Characterization

The information from the exposure assessment and the toxicity assessment are integrated to form the basis for the characterization of human health hazards. The impact characterization presents quantitative and qualitative descriptions of these hazards.

The following subsections describe the characterization of the human health impacts. Carcinogenic probability characterization is presented in subsection 4.1.4.1, noncarcinogenic hazard characterization is presented in 4.1.4.2, and assessment and presentation of uncertainty is discussed in subsection 4.1.4.3.

4.1.4.1 Quantification of Carcinogenic Probability. For carcinogens, impacts are estimated as the likelihood of an individual developing cancer over a lifetime as a result of exposure to a potential carcinogen (i.e., incremental or excess individual lifetime cancer probability). The slope factor converts contaminant intakes, as derived in the exposure assessment, directly to the estimated incremental probability of an individual developing cancer. The equation for probability estimation is:

Incremental Cancer Probability = (Contaminant Intake) x (Slope Factor).

This linear equation is only valid at low risk levels (i.e., below estimated probabilities of 1E-02), and, for chemical carcinogens, is an upperbound estimate based on the upper 95th percent confidence limit of the slope of the dose-response curve (i.e., the slope factor).

Thus, one can be reasonably confident that the actual probability is likely to be less than that predicted. Slope factors developed for radionuclides are best estimate values based on a 50th percent confidence limit. Cancer incidence estimates are expressed using one significant figure only. Slope factors for the carcinogenic contaminants of potential concern are listed in Table 4-5. The only carcinogens evaluated in this assessment are radioactive contaminants. The chemical contaminants of potential concern (i.e., Cr and NO_3) are not carcinogenic when ingested.

Residential Scenario

The residential water ingestion scenario is associated with a cancer probability of 8E-07 (Table 4-3), and is due almost entirely (≈90%) to ^{90}Sr. This is a negligible risk because it is less than the 1E-06 cancer probability considered insignificant for regulatory purposes (40 CFR 300.430). The probability of cancer incidence associated with the fish ingestion pathway is 1E-06 (Table 4-3), and is attributable to ^{90}Sr (54%) and uranium (46%). The incremental cancer probability associated with the recreational water ingestion scenario is negligible (2E-09; see Table 4-4). Therefore, the total cancer risk associated with the residential scenario that includes recreational use of the Hanford Reach.

Recreational Scenario

The incremental probability of cancer incidence associated with the recreational water ingestion scenario is negligible (2E-09; see Table 4-4). The estimated risk associated with fish ingestion (1E-06; see Table 4-3) can also be added to the recreational scenario to obtain an overall risk estimate for non-residents (of Richland) who recreate within the Hanford Reach. By considering both pathways, the total cancer risk associated with the recreational scenario is 1E-06.

4.1.4.2 Quantification of Systemic Toxicity. Potential human health hazards associated with exposure to noncarcinogenic substances, or carcinogenic substances with systemic toxicities other than cancer, are evaluated differently than cancer incidence. The daily intake over a specified time period (e.g., lifetime or some shorter time period) is compared to an RfD for a similar time period (e.g., chronic RfD or subchronic RfD) to determine a ratio called the hazard quotient. The formula for estimation of the hazard quotient is:

$$\text{Hazard Quotient} = \frac{\text{Daily Intake}}{\text{RfD}}$$

If the hazard quotient exceeds unity, the possibility exists for systemic toxic effects. The hazard quotient is not a mathematical prediction of the severity or incidence of the effects, but rather is an indication that effects may or may not occur, especially in sensitive subpopulations. The chemical-specific hazard quotients can be summed to determine a hazard index for a pathway or a site (based on the same scenario). If a hazard index exceeds unity, an evaluation of the specific substances is performed so that only substances with similar systemic toxic effects (i.e., similar effects in the same target organs via the same mechanism) are summed.

Residential Scenario

The hazard quotient index for water consumption under the assumptions of the residential scenario is 0.002, and is attributable to both chromium and NO_3 (Table 4-3). The hazard index for the fish ingestion pathway is 0.0002, due entirely to Cr and the hazard index for recreational water ingestion is 0.000002. Therefore, it is unlikely that adverse health effects would result from long-term consumption of water or fish containing the reported concentrations of NO_3 and Cr, even in sensitive subpopulations.

Recreational Scenario

The hazard index for recreational water ingestion is 0.000002. The estimated hazard index associated with fish ingestion (0.0002) can also be added to the recreational scenario. Therefore, the overall hazard index for this scenario is 0.0002.

4.1.5 Uncertainty Analysis

The impacts, both carcinogenic and noncarcinogenic, presented in this human health evaluation are not fully probabilistic estimates, but rather are deterministic estimates given multiple assumptions about exposures and toxicity. The exposure and toxicity assessments both contribute to uncertainty in the risk characterization. The uncertainties associated with the key assumptions in the evaluation are discussed below.

The extensive groundwater monitoring data from the 100 Area provide a good basis for the selection of mobile contaminants of potential concern that are being discharged to the Hanford Reach. While only six contaminants of potential concern were identified, the fact that ^{90}Sr and U account for 99% of the overall residential scenario risk estimate lends credence to the validity of the screening procedure used to select the contaminants included in the evaluation.

The use of maximum groundwater concentrations within each of the twelve plumes evaluated to develop contaminant loadings to the Reach contributes considerable conservatism to the evaluation, as does neglecting contaminant transformations such as radiological decay, Cr reduction, and NO_3 bioabsorption.

The river mixing model employed is also exceedingly conservative, and can be expected to yield gross overestimates of contaminant concentrations close to the groundwater discharge zones. The model deliberately examines only the right bank of the river, resulting in a further overestimate of contaminant concentrations throughout the Reach, but especially near the groundwater discharge zones.

The identification of the potential receptors, the exposure pathways to these receptors, and the exposure parameters are also sources of uncertainty in the impact assessment. Although general types of uses of the Hanford Reach are known, there is a limited amount of specific information on the frequencies of such activities. This assessment has used default exposure parameters and professional judgement. For example, the recreational scenario assumes that adults are the only receptor population, and that young children do not need to be evaluated for this scenario. This may represent actual conditions, or may underestimate potential exposures. On the other hand, assuming that anyone drinks a liter of river water (e.g., fills a canteen or drinks while recreating) may be overestimating the potential exposures. Most people bring soda and other beverages with them for consumption during recreational activities.

Another exposure parameter that may overestimate the exposures is the amount of contaminated fish consumed from the Hanford Reach. Default values are 54 g/d of fish intake with half of this derived from the contaminated source (about 2 oz/day; WAC 173-340-730). Salmon and steelhead are some of the fish more commonly caught from the river for consumption. These fish would be unlikely to have any significant amounts of contamination associated with the Hanford Reach because they primarily reside in the Pacific Ocean and only return to the Reach briefly only to spawn.

Estimates of contaminant intakes via fish ingestion require the use of bioconcentration factors when empirical data are not available. For the purpose of this study, contaminant intakes via the fish ingestion pathway are directly proportional to the assumed BCF. It is noted that BCFs for ^{90}Sr in freshwater fish range from 1 to 200 (NCRP 1985). Therefore, the intakes and risks associated with ^{90}Sr intake via fish ingestion can span two orders of magnitude.

A factor contributing to a potential underestimation of risk is the limitation of exposure pathway analysis to just water and fish ingestion. Other pathways, such as dermal and external radiation exposure and ingestion of agricultural products irrigated by Hanford Reach water. Ongoing annual dose assessments conducted by PNL, however, indicate that 75% of the 100 Area river-related contributions to incremental human radiation doses to individuals residing in Richland and recreating along the Reach are attributable to water and fish ingestion; the remaining 25% is attributable to exposure to agricultural products (Woodruff and Hanf 1992).

Given the above, the authors are highly confident that the overall exposure assessment is very conservative.

Uncertainty with respect to the toxicity assessment is related to uncertainty in the toxicity values used and uncertainty in the overall toxicity assessment. For the chemical contaminants, RfDs are available from IRIS for both contaminants. The RfDs have been peer reviewed. While confidence in the RfD for NO_3 is high, Cr has a low confidence level assigned to it because no critical adverse effects were observed in the supporting study. Therefore, the confidence is good that the systemic toxicities of the contaminants of potential concern have been identified and the RfDs are protective of human health.

Although all radionuclides are classified by EPA as Class A human carcinogens, there are many aspects of radiological impact assessment that contribute to uncertainty in radionuclide slope factors. The exposure condition upon which the assumption of carcinogenicity is based is one of high doses delivered at high dose rates (e.g., A-bomb detonations, therapeutic medical exposures). Predicting the consequences of radionuclide exposure to low-level environmental contamination requires very sophisticated modeling of physiological mechanisms and an accurate extrapolation to low dose and low dose rate exposures. The uncertainty inherent in either challenge is likely to bound the accuracy of slope factors to no less than an order of magnitude.

The EPA (1989b) estimate of average lifetime risk attributable to exposure to ionizing radiation incorporates the most conservative model assumptions utilized by the Biological Effects of Ionizing Radiations (BEIR) III Committee. However, this estimate was not derived using the most recent Japanese A-bomb survivor data; recent calculations based on similar assumptions but including revised data yield about three times higher risk. This revised data (provided in BEIR V, NRC 1990) is qualified with the statement the "the possibility that there may be no risks from exposures comparable to external natural background radiation cannot be ruled out. At such low doses and dose rates, it must be acknowledged that the lower limit of the range of uncertainty in the risk estimates extends to zero." Given such an extreme range, EPA radionuclide slope factors are likely to represent an upper bound estimate of the carcinogenic potential of radioactive contamination.

Given the conservative nature of the exposure and toxicity assessments, it is obvious that the resulting risk characterization is also conservative. The authors believe that relatively simple refinements in the river mixing model (e.g., evaluating predicted surface water contaminant concentrations in two-dimensions rather than in just one-dimension along the right bank of the river, and accounting for the actual location of the Richland water intake [15 m from the right bank rather than at the right bank]), would be more than adequate to demonstrate a bounding risk estimate for the residential scenario to be well below 1E-06.

It is of interest to note the relative significance of other radiation exposures along the Hanford Reach compared to cancer risk estimates resulting from ingestion of contaminated water. Skyshine resulting from ^{60}Co and ^{137}Cs gamma emissions from the 1301-N Liquid Waste Disposal Facility provide a maximum exposure rate of approximately 0.03 mrem/hr along the shoreline (Brown and Perkins 1991). Assuming a person recreates along the 100-N Area shoreline for 8 hr/d, 1 d/yr for 30 yr, the resulting lifetime dose would be less than 7 mrem, even if radioactive decay is ignored. This equates to an incremental cancer incidence risk of approximately 4E-06, which is larger than the risk estimation for residential water and fish ingestion pathways combined. While not directly related to river contamination, skyshine is a directly measurable source of exposure within the river environment resulting from past practices in the 100 Area which may be more significant than the other pathways presented in this evaluation.

4.1.6 Summary of Human Health Impacts

Four radionuclides (^{3}H, ^{90}Sr, ^{99}Tc, and U) and two chemical contaminants (Cr and NO_3) have been identified as contaminants of potential concern in the Hanford Reach resulting from activities at the 100 Area within the Hanford Site. Of these contaminants, only the radionuclides are considered carcinogenic via the ingestion route. Only the chemical contaminants are evaluated for systemic toxic effects.

The residential scenario is evaluated for water ingestion and fish ingestion pathways. The probabilities of cancer incidence associated with water ingestion (8E-07) and fish ingestion (1E-06) sum to a total of approximately 2E-06. This estimate is slightly above the level considered negligible for regulatory purposes, and is within the NCP range of acceptable exposure limits. The hazard indices for these two pathways (0.002 and 0.0002) are both sufficiently less than unity that it is extremely unlikely that adverse health effects would result from long-term consumption of water or fish containing the reported concentrations of NO_3 and Cr.

The recreational scenario is evaluated for a water ingestion pathway. The results of the fish ingestion pathway evaluated under the residential scenario may also be added to the recreational scenario. Both the cancer probability (2E-09) and the hazard index (0.000002) associated with recreational water ingestion are insignificant. If the cancer probability associated with the fish ingestion pathway (1E-06) is also considered, then the total cancer probability for the recreational scenario (1E-06) would equal the maximum level considered negligible for regulatory purposes. The hazard index associated with fish ingestion (0.0002) is sufficiently small that the total hazard index for the recreational scenario (0.002) is considered negligible.

4.2 ENVIRONMENTAL EVALUATION

As indicated in Section 3.1, the most significant pathway associated with potentially adverse, non-human environmental impacts to the Columbia River is the river water pathway in which organisms inhabiting this sensitive freshwater habitat are or could be exposed to a variety of contaminants discharged to the river from various groundwater plumes. Therefore, it is necessary to determine how the seep and spring data should be used to determine exposure concentrations of the environmental receptors. Although contaminant concentrations may be relatively high at input locations, mixing significantly reduces these concentrations downstream.

For the purpose of this assessment, exposure point concentrations are calculated by averaging the contaminant concentration over the length of the Hanford Reach (see Figure 2-1). This is reasonable because populations of environmental receptors are unlikely to remain in an area of peak contaminant concentration, and their mobility will, in effect, provide the receptors with a spatially-averaged exposure. Background (upstream) concentrations are not subtracted from average concentrations because the health effects of concern in an environmental evaluation are mostly systemic toxic effects assumed to have a threshold response.

The standard approach to evaluating aquatic environmental impacts is through the use of appropriate water-quality criteria developed by EPA, and adopted by the State of Washington, pursuant to the Clean Water Act. As such, the exposure assessment consists of compiling the measured and predicted local and ambient contaminant concentrations presented and developed within Sections 2.2 and 3.3, respectively.

The environmental toxicity assessment is presented within Subsection 4.2.1, below. This component of the assessment is followed by an environmental impact characterization (Subsection 4.2.2), an uncertainty analysis (Subsection 4.2.3), and an environmental impact characterization summary (Subsection 4.2.4).

4.2.1 Ecotoxicity Assessment

Six contaminants of potential concern to the Hanford Reach were identified in Chapter 2. These contaminants are:

Radiological Contaminants of Potential Concern
- ^{3}H
- ^{90}Sr
- ^{99}Tc
- U

Chemical Contaminants of Potential Concern
- Cr
- NO_3

Of these six substances, EPA has promulgated chronic water-quality criteria for the protection of freshwater aquatic life EPA 1986a) for only one - Cr, (assumed here to be hexavalent C). However, surrogate criteria can be derived from chronic LC_{50}s· or risk-based calculations for ^{3}H, ^{90}Sr, ^{99}Tc, U, and NO_3.

4.2.1.1 Radioactive Contaminants of Potential Concern. Surrogate water quality criteria were developed after review of IAEA (1976), Kulikov and Molchanova (1982), Whicker and Schultz (1982), and NCRP (1991). These references summarize research on the nature and extent of observable adverse effects to environmental receptors. For the purposes of this evaluation, the environmental receptors of interest were limited to freshwater aquatic organisms.

The discharge of radioactive effluents into an aquatic environment, such as the Hanford Reach, has resulted in chronic exposure of aquatic organisms to radionuclides. The major concern for environmental risk assessment is the response and maintenance of endemic populations not the fate of individual organisms. Experimental studies to date have shown that fertility and fecundity of the organisms and embryonic development are probably the most sensitive components of the radiation response. It is these attributes which are important for determining the fate of a population.

Based on an evaluation of existing studies, the NCRP has established that a chronic dose rate of 0.4 mGy/hour (1 rad/day) to the maximally exposed individual in a population of aquatic organisms should ensure protection for the population. Based on this standard and dose conversion equations and factors in NCRP (1991), water concentrations for various radionuclides that would result in this dose were calculated. For all radionuclides these calculated concentrations (Table 4-6) were less than LOAELs or NOAELs found in the literature. Because these calculated concentrations were more conservative than the empirical evidence, they were used for this preliminary evaluation.

4.2.1.2 Chemical Constituents of Potential Concern.

EPA (1986) reports the chronic toxicity value for hexavalent Cr in rainbow trout is 265 µg/L. Growth of chinook salmon was found to be reduced at measured concentration of 16 µg/L (EPA 1986a). The chronic ambient water quality criterion for the protection of freshwater aquatic life for hexavalent Cr has been set at 11 µg/L by EPA.

In recognition of the fact that nitrate concentrations that would produce adverse effects in fish would rarely be encountered, the EPA (1986a) does not recommend a water quality criterion for the protection of freshwater aquatic life. However, EPA does note that largemouth bass (*Micropterus salmoides*) and channel catfish have been maintained indefinitely in water with nitrate concentrations as high as 400 mg/L. In addition, EPA reports seven-day freshwater LC_{50}s for rainbow trout fingerlings and chinook salmon as 4,690 and 4,780 mg/L, respectively.

Dividing the LC_{50}s by 100 yields surrogate chronic water quality criteria of 47 and 48 mg/L. As the coldwater salmonid species are more representative of typical Hanford Reach inhabitants, and as the data obtained from testing yields the more conservative criterion, 47 mg/L will be the surrogate criterion used in this evaluation.

Table 4-6. Water Quality Criteria and Surrogates for the Hanford Reach Contaminants of Potential Concern.

Contaminant	Criterion	Derivation and Source
^{3}H	200,000,000 pCi/L	calculated 0.4 mGy/yr dose to fish
^{90}Sr	2,000 pCi/L	calculated 0.4 mGy/yr dose to fish
^{99}Tc	200,000 pCi/L	calculated 0.4 mGy/yr dose to fish
U	3,000 pCi/L	calculated 0.4 mGy/yr dose to fish
Cr^{6+}	0.011 mg/L	chronic freshwater quality criterion (EPA 1986a)
NO_3	47 mg/L	chronic LD_{50} ÷ 100 (EPA 1986b)

[a]Not available or derivable

4.2.2 Environmental Impact Characterization

For environmental exposures, estimated contaminant concentrations are divided by the respective toxicity criterion to obtain a contaminant-specific environmental hazard quotient (EHQ). An EHQ in excess of unity (i.e., > 1) is interpreted to signify the potential for adverse toxicological impacts to the aquatic community of the Hanford Reach. The EHQs are, in turn, summed to obtain an overall environmental hazard index (EHI). The EHI assumes that the toxic effects of the various contaminants are additive, and an EHI in excess of unity is interpreted to signify the potential for adverse toxicological effects to the community.

The EHQs and EHIs for the ambient exposure scenario are presented in Table 4-7. In accordance with EPA risk assessment guidelines (EPA 1989b), EHQs and EHIs are presented only to one significant figure.

Table 4-7. Hanford Reach Environmental Impact Characterization-Ambient Exposure Scenario.

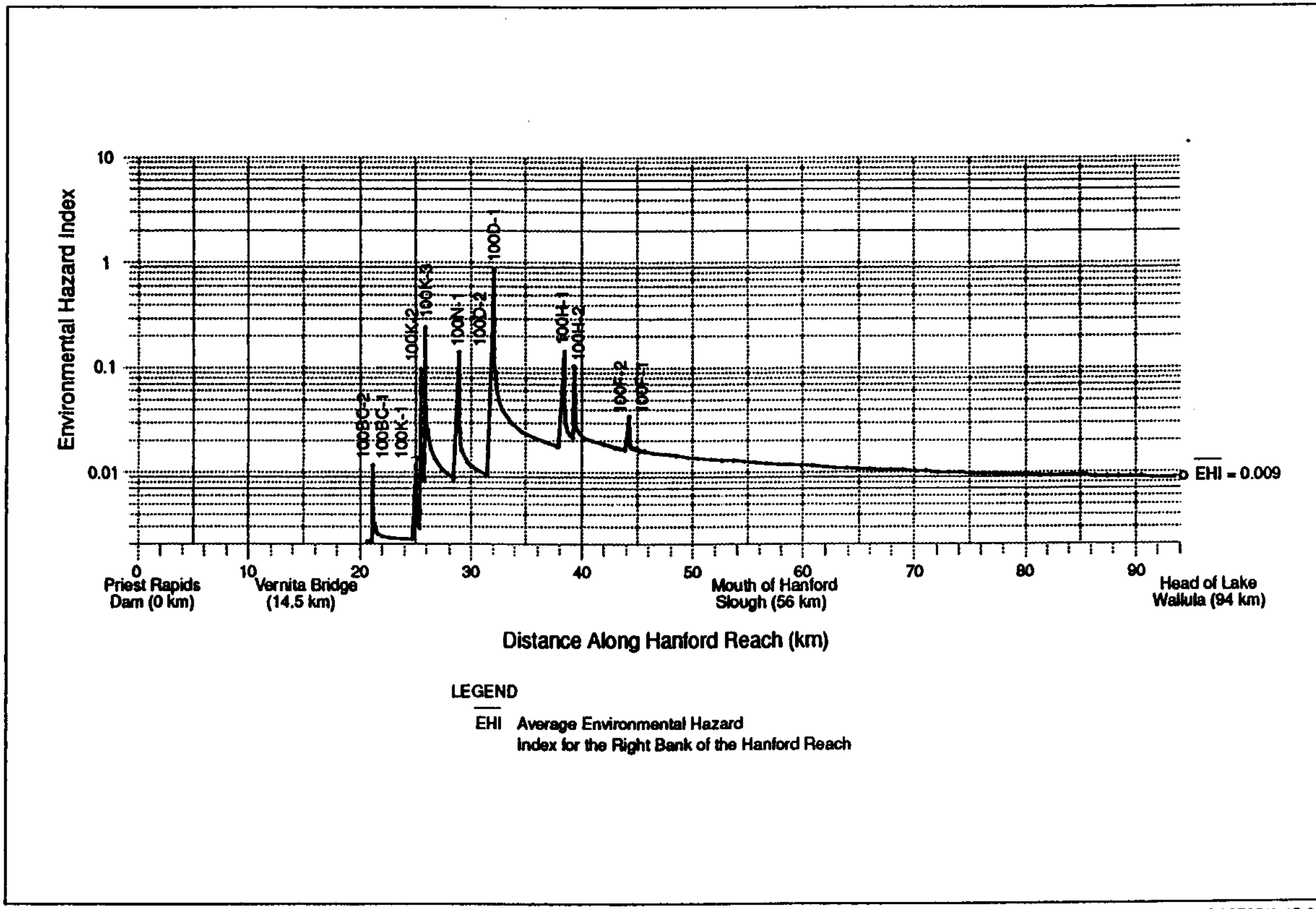
Contaminant of Potential Concern	Ambient Water Column Concentration[a]	EHQ
^{3}H	160 pCi/L	0.0000008
^{90}Sr	2 pCi/L	0.001
^{99}Tc	0.1 pCi/L	0.0000005
U	0.47 pCi/L	0.0002
Radionuclide EHI		0.001
Cr	1E-04	0.009
NO_3	0.12 mg/L	0.003
Chemical EHI		0.01
Total Current Ambient EHI		0.01

[a]Average Hanford Reach concentration (of the right bank) downstream of the 100 Area.

Table 4-7 indicates that the average contaminant concentrations in the Hanford Reach are at least two orders of magnitude less than their respective criteria. As a result, the EHI is 0.01, and is due almost entirely (98%) to Cr, $N0_3$, and ^{90}Sr. This suggests that the threat to environmental receptors posed by these contaminants does not exist.

The environmental evaluation is based on average water concentrations in the Hanford Reach due to 100 Area activities, it is interesting to note the EHI at each contaminant input location. This is accomplished by dividing the predicted water concentrations of each contaminant (Figures 3-5 through 3-11) by its respective criteria to yield a location-specific EHQ. The EHQs are then added together to yield a location-specific EHI, presented in Figure 4-1. The only contaminants which have a significant contribution to the EHI are ^{90}Sr and Cr. Figure 4-1 indicates that there are four EHI peaks with values greater than 0.1: an EHI of 0.26 attributable to Cr from 100K-3 (at 26 km); 0.15 due to ^{90}Sr from 100N-1 (at 32 km); 0.9 due to Cr from 100D-1 (at 32 km); and 0.16 due to Cr from 100H-1 (at 39 km).

There is one peak EHIs approximately equal to unity (Cr with 0.9), it is unlikely that such a condition represents an adverse impact to environmental receptors at the population level because it is improbable that entire populations of receptors would be confined to such a limited area. Therefore, the examination of localized EHIs can be considered a worst-case scenario. The fact that this scenario has a maximum EHI of 0.9 further indicates that the threat to environmental receptors is minimal.



903 1255/28725/1-15-93

Figure 4-1. Location-Specific Environmental Hazard Index Along the Right Bank of the Hanford Reach.

4.2.3 Uncertainty Analysis

The results of the above environmental impact assessment should be regarded as semiquantitative, at best. Obviously, much better data, in terms of both quantity and quality, will become available over the course of implementing the Hanford Site Environmental Restoration Program over the next several decades. Evaluation of environmental threats to the Hanford Reach and portions thereof will necessarily be an ongoing process during the program.

The purpose of this subsection is to briefly discuss major sources of uncertainty inherent in the preceding environmental evaluation in order to give the reader an appreciation as to how much confidence can be placed in the results. Each source of uncertainty can be placed within one of three categories with respect to how they bias the results of the evaluation:

- conservative (from an environmental regulatory perspective) assumptions;
- non-conservative assumptions; and
- assumptions with unknown effects.

Conservative assumptions are traditionally employed in baseline impact assessments to compensate for acknowledged uncertainty. Therefore, not surprisingly, many of the sources of uncertainty in the Hanford Reach environmental evaluation fall into this category. Examples include the conservative groundwater and surface-water mixing, and contaminant speciation assumptions employed in the evaluation.

The simple groundwater plume model that was used for the evaluation assumed infinite sources of contaminants, assumed maximum groundwater concentrations and provided infinite time to reach the river. These assumptions neglect contaminant partitioning on the solid matrix of the aquifer and the resulting retardation of transit time and the resulting decrease in contaminant concentrations.

Two assumptions incorporated into the evaluation can be regarded as non-conservative. The first assumes that groundwater investigations at Hanford are fairly complete. For the purposes of this environmental evaluation, it is likely that the most significant contaminants, in terms of concentration, toxicity, and persistence, have been included. However, ongoing and future groundwater investigations in support of the Environmental Restoration Program could conceivably result in the identification of additional contaminants of potential concern.

The second (and possibly the most non-conservative) assumption is associated with ignoring the river sediment medium. It is possible that some potentially significant contamination has accumulated within the depositional zones of the Hanford Reach and that this medium could be an important exposure pathway for the benthic community and the fish that feed upon this community. There are currently no accepted procedures for evaluating environmental exposures to contaminated sediments, (Adams et al. 1992, Burton and Scott 1992); however, EPA and Ecology are in the process of developing such procedures, and one may be available for use in the not-too-distant future.

It is difficult to assess the effect of several assumptions employed in the evaluation. The lack of ecotoxicological data imparts an unknown level of uncertainty. These data gaps could potentially be filled through further literature review. The factor-of-one-hundred adjustment made to LC_{50} data to derive surrogate toxicity criteria also have an uncertain effect. In employing an EHI, there is an implicit assumption of toxic effect additivity among all contaminants. This assumption ignores the potential for either synergistic, potentiation, or antagonistic effects.

The analysis of uncertainty in the human health evaluation (see subsection 4.1.5) contains discussions on the surface water mixing model and selection of contaminants of potential concern that are applicable to the environmental evaluation also.

4.2.4 Environmental Impact Characterization Summary

The preliminary environmental evaluation suggests that a significant adverse impact to the water column of the Hanford Reach due to past practices in the 100 Area does not exist. This conclusion is based on an examination of both the average EHI for the Hanford Reach and location-specific EHIs. The average EHI (0.01) was calculated by defining the area of interest to be the Hanford Reach. Chromium, $N0_3$ and ^{90}Sr are the only significant contributors to the average EHI (accounting for 98% of this value).

The location-specific EHI also indicates that ^{90}Sr and Cr are the only contaminants of potential significance. Strontium-90 from the 100N-1 plume provides a local EHI of 0.15, while Cr from the 100K-3, 100D-1, and 100H-1 plumes result in peak EHIs of 0.26, 0.9, and 0.16, respectively. However, due to the very short regions over which each contaminant input has a potential impact, it is unlikely that the estimated concentrations of these contaminants represent a significant adverse threat to environmental receptors. Based on the results of the river-mixing model used in this preliminary evaluation, the length of the Hanford Reach subject to significant adverse impacts is <12 m (< 1 m resolution x 12 plumes). This represents <0.01% of the length of the Hanford Reach.

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5.0 PROPOSED DATA COLLECTION PLAN

A summary of the impact assessment presented in this report is provided in Section 5.1. Based on the findings and data gaps identified, recommendations for further Hanford Reach characterization and monitoring activities were developed and are presented in Section 5.2. Specific plans (e.g., Descriptions of Work) will be developed for implementation of the necessary activities.

5.1 COLUMBIA RIVER IMPACT EVALUATION SUMMARY

The Hanford Reach is the last, free-flowing, non-tidal stretch of the Columbia River in the United States. As such, it has many important ecological functions, including providing important spawning grounds for salmon and steelhead trout and sensitive (or possibly critical) habitat for endangered and threatened species, including bald eagles, white pelicans, and persistentsepal yellowcress.

The shoreline along the Hanford Reach is largely undeveloped due to the presence of the Hanford Site. The Hanford Site is a DOE facility that was used from 1943 - 1981 for research and production of nuclear materials used in defense and energy. From 1943 - 1971, the Columbia River was used as a source of cooling water in as many as nine nuclear reactors that were used to produce Pu. As a result of Pu-production activities in the 100 Area, there have been significant quantities of contaminants (radionuclides and non-radionuclides) released to the Hanford Reach.

Radionuclides attributable to Hanford operations were detected in virtually all components of the ecosystem during reactor operations, but the Hanford Reach retains many of its functional qualities:

- salmon spawning has been increasing in the recent past;
- threatened and endangered species continue to use the Reach for habitat; and
- for most contaminants there is little significant difference in river-water quality between sampling points that are upstream and downstream of the Hanford Site.

Although there is evidence that shows contaminants may have localized impacts within the Hanford Reach, results of environmental monitoring conducted to date do not show any significant adverse impact to the Hanford Reach ecosystem.

The impact evaluation in Chapter 4 indicates there is little potential for adverse impacts to either human health or the environment under current contaminant exposure conditions due to 100 Area operations. Under existing conditions of contaminant loading to the river, the predicted adverse impacts to the Columbia River due to 100 Area activities are limited to very localized zones at the point of groundwater discharge and would not have an impact on populations of environmental receptors. These zones of impact dissipate quickly downstream due to contaminant dilution. Current contaminants of concern and associated groundwater plumes are:

- ^{90}Sr
  - 100N-1 — potential localized environmental impacts
- Cr
  - 100K-3, 100D-1, and 100H-1 — potential localized environmental impacts

5.2 PROPOSED DATA COLLECTION ACTIVITIES

During the preparation of this preliminary assessment, data gaps have been identified pertaining to the ability to properly evaluate, during the RI and RFI processes, impacts to the Hanford Reach attributable to past or present operations of the 100 Area. These data gaps and corresponding data needs can be classified by contaminant migration pathway:

- Contaminant input pathways (i.e., discharge of 100 Area affected groundwater, and other sources of contaminant input to the Reach);
- Surface water pathways;
- River sediment pathways; and
- Biological pathways.

Additional specific data are needed for each of these pathways to improve the conceptual understanding of contaminant movement and affects within the Columbia River habitat, and to conduct meaningful RI and RFI baseline risk assessments.

Much of the data needed to evaluate the migration and effects of contaminants released from 100 Area facilities is presently collected under ongoing, Site-wide environmental monitoring programs or will be generated by the operable-unit-specific facility and remedial investigations planned for the 100 Area. This section provides a plan to maximize the utilization of these ongoing and planned efforts to collect a sufficient amount of the data to allow for a conclusive assessment of baseline risks associated with contaminant releases from the 100 Area.

The scope of the preliminary impact evaluation presented in this report, along with the scope of the conceptual data collection program plan presented below in Subsection 5.2.2, is confined to 100 Area effects on the Columbia River. However, the consideration of spatial, ecological, temporal, and administrative factors for any investigation points to an eventual need for characterizing the river on a programmatic basis.

The most effective and efficient long-term investigation unit for the river appears to be the Hanford Reach, which can be defined as that segment of the river bounded by Priest Rapids Dam down to the head of Lake Wallula; however, the lower boundary should be extended to McNary Dam for the purpose of investigation of sediment and biotic media. The Hanford Reach forms an ideal unit for any subsequent study, remediation, and monitoring of the river, as well. Therefore, it is recommended that consideration be given to developing a Hanford Reach Aggregate Area for the purpose of consolidating resources and increasing efficiency of response actions required to comply with TPA requirements.

Subsection 5.2.1 discusses the data quality objectives for this river characterization program. A conceptual approach for generating the required data to allow for proper characterization of the river is presented in Subsection 5.2.2 in the form of an outline of recommended river investigation tasks.

5.2.1 Data Quality Objectives

The central rationale for undertaking a preliminary impact assessment of the Columbia River was to propose an efficient data collection program that will result in a characterization of the threats posed to the river and its associated receptors that are attributable to 100 Area operations. Prior to proposing such a data collection program, specific data quality objectives (DQOs) must be considered. The three stages of the DQO development process are (EPA 1987):

- Stage 1 — Identification of Decision Types;
- Stage 2 — Identification of Data Uses and Needs; and
- Stage 3 — Data Collection Program Design.

Each of these stages is discussed in Paragraphs 5.2.1.1, 5.2.1.2, and 5.2.1.3, respectively, to provide an understanding of the logic behind the development of the proposed river investigation plan for the 100 Area of the Hanford Site.

5.2.1.1 Stage 1 — Identification of Decision Types. This stage of the DQO development process entails the evaluation of available data, the development of a site-specific conceptual model, and the specification of objectives for the data collection program (EPA 1987).

Selected data most pertinent to Columbia River impacts associated with 100 Area operations are presented and evaluated in Chapters 2, 3, and 4 of this report, and a summary of this step of the process is presented in Section 5.1. The presentation and evaluation of available data includes a conceptual model that identifies major sources of 100 Area contaminant inputs to the river ecosystem, migration of these contaminants within the system, and system receptors and their potential routes of exposure to these contaminants. The conceptual model is discussed in Section 3.1 and graphically portrayed in Figure 3-1.

The results of the available data evaluation allow specific data collection program objectives to be developed. Before listing such objectives for each of the four contaminant migration pathway elements (contaminant inputs, surface water, river sediments, and biota), appropriate boundaries for the data collection program must be considered (Beanlands and Duinker 1983; National Research Council Commission on Life Sciences, Committee on the Applications of Ecological Theory to Environmental Problems 1986).

The following objectives for each of the four contaminant migration pathway elements are confined to the 100 Area.

Objectives specific to the contaminant input pathway element can be divided into two parts — inputs to the reach from the discharge of groundwater affected by 100 Area operations, and inputs to the reach from other sources of contamination. Objectives pertaining to the first are:

- Identification of contaminants of potential concern in the groundwaters affected by 100 Area operations;
- Definition of the magnitude and locations of contaminant fluxes to the Hanford Reach;
- Definition of the mechanisms and effects of contaminant transport specific to the process of groundwater discharging to the river water column through sediments and their associated interstitial waters; and,
- Determination of the speciation of Cr (which the preliminary impact assessment shows to be one of the most potentially significant river contaminants associated with the 100 Area) in the river sediments and water column.

Objectives specific to the characterization of contaminant inputs to the reach from sources other than the 100 Area are:

- Identification of other sources currently affecting the 100 Area of the Hanford Reach (e.g., groundwater and surface water discharges affected by regional agricultural operations); and
- Definition of the nature, magnitude, and locations of contaminant fluxes from these other sources.

Speciation of certain contaminants of potential concern attributable to non-100 Area sources may also be necessary to distinguish Hanford versus non-Hanford impacts.

Objectives specific to the surface water pathway element are:

- Definition of impacts to the water column for all contaminants of potential concern identified for the 100 Area; and
- Evaluation, selection, and implementation of an appropriate code(s) for characterizing dispersion of contaminants in the water column of the Hanford Reach.

The river sediment pathway objectives are:

- Definition of impacts to the sediments for all contaminants of potential concern identified for the 100 Area; and

- Evaluation, selection, and implementation of an appropriate code(s) for characterizing transport and deposition of contaminants in the sediments of the Hanford Reach.

Finally, the objectives specific to the biological pathway element are:

- Compilation of ecotoxicological data needed to assess risks associated with all contaminants of potential concern identified for the 100 Area;

- Evaluation of ongoing biocontaminant monitoring being conducted on the Hanford Reach; and

- Compilation of information on sensitive and critical habitats in and along the Hanford Reach.

5.2.1.2 Stage 2 — Identification of Data Uses and Needs. The second stage of the DQO development process consists of the identification of data quality needs, and the selection of a sampling approach to fulfill such needs. With regard to data quality, all samples obtained under the proposed data collection program should be subjected to analytical protocols set forth in published standard methods. This approach will ensure that all data generated will be of state-of-the-practice quality. With regard to recommended sampling approaches, a conceptual level of detail is provided within the recommended river investigation tasks presented in Subsection 5.2.2 below.

5.2.1.3 Stage 3 — Data Collection Program Design. The third and final stage of the DQO development process consists of the design of a data collection program to satisfy the established objectives. Subsection 5.2.2 describes the general approach to the data collection program and presents conceptual level detail for the various recommended tasks and associated activities.

The tasks and activities recommended will optimize the utilization of existing monitoring programs for the Hanford Reach and planned operable-unit-specific remedial and facility investigation program for the 100 Area. Specific details for this program are therefore deferred to any necessary additions to the existing environmental monitoring programs or to 100 Area operable unit work plans, as appropriate. If additional work not covered under one of these established or planned programs is required, descriptions of work (DOWs) will be developed to provide specific details for such components of the overall data collection program for the Hanford Reach.

5.2.2 Recommended Hanford Reach Investigation Tasks

As stated in Section 1.1, the impetus for this report is TPA Milestone M-30-02, which requires that a plan be developed to determine cumulative impacts to the Columbia River. The M-30 milestones were developed to provide guidance for integration of general investigations and studies for the 100 Area. Consequently, this report, including the recommended reach characterization plan below, focuses on the 100 Area segment of the Hanford Reach, which encompasses that portion of the reach extending from Vernita Bridge downstream to the Hanford Townsite.

The proposed reach investigation tasks are organized by the objectives, established in Paragraph 5.2.1.1, within each of the four contaminant migration pathway elements. Activities associated with characterization of contaminant inputs are outlined in Paragraph 5.2.2.1, those associated with surface water are outlined in Paragraph 5.2.2.2, those associated with river sediments are outlined in Paragraph 5.2.2.3, and those associated with biota are outlined in Paragraph 5.2.2.4.

5.2.2.1 Task 1 — Characterization of Contaminant Input Pathways. As indicated in Paragraph 5.2.1.1, contaminants are currently entering or have the potential to enter the Hanford Reach either by means of discharge of groundwaters affected by 100 Area operations, or by other pathways. Two subtasks are proposed, Subtask 1A to address the characterization of 100-Area-affected groundwater inputs to the reach, and Subtask 1B to address the characterization of the other input pathways; these subtasks are described below in Subparagraphs 5.2.2.1.1 and 5.2.2.1.2, respectively.

5.2.2.1.1 Subtask 1A — Characterization of 100 Area Contaminated Groundwater Inputs. Paragraph 5.2.1.1 establishes four objectives for this subtask: identification of contaminants of potential concern, definition of contaminant fluxes to the reach, definition of contaminant mixing in the groundwater discharge zones, speciation of Cr within the sediments and water column of the reach. Each of these objectives is addressed by a respective subtask activity and discussed below.

Activity 1A-1 — Identification of Contaminants of Potential Concern.

The significant source of 100-Area-related contaminant input to the Hanford Reach is groundwater discharge. Although there are other potential mechanisms of contaminant input to the Hanford Reach that are related to the 100 Area (e.g., operational outfalls, fugitive dust from contaminated soils), these inputs will be evaluated in Subtask 1B (subsection 5.2.2.1.2). To evaluate contaminated groundwater in the 100 Area, several groundwater operable units have been established within the 100 Area: 100-BC-5R, 100-KR-4, 100-NR-2, 100-HR-3, and 100-FR-3. Remedial investigation/feasibility study or RFI/CMS work plans are currently under development for all of these operable units. The groundwater investigation components of each should provide the information necessary to identify contaminants within the groundwater that may be of potential concern to the Hanford Reach. New information from the operable unit investigations will be used to update the impact assessment.

Contaminants of potential concern will be identified in accordance with the procedure established in the Hanford Site Baseline Risk Assessment Methodology (HSBRAM, DOE-RL 1992c) and the 100 Area operable unit work plans. As this action should take place on an operable-unit-by-operable-unit basis, Activity 1A-1 will consist of compilation and integration of the contaminant identification results for the 100 Area groundwater investigations.

Activity 1A-2 — Characterization of Contaminant Fluxes.

Groundwater discharges to the Hanford Reach through surficial springs adjacent to the river and through subsurficial seepage through the river sediments. Flow rates for springs are difficult if not impossible to obtain, therefore the only way to quantify the flux of a given contaminant along this pathway is through characterization of groundwater flow and contaminant transport. Knowledge of contaminant flux is essential to allow for prediction of potential reach-related impacts to human health and the environment.

The groundwater investigations planned for the operable units mentioned above under Activity 1A-1 should generate data necessary to determine the locations and magnitudes of the fluxes of the various contaminants of potential concern to the Hanford Reach. The preliminary contaminant transport evaluation presented in Section 3.3 of this report utilized very conservative fluxes and assumed that they entered the reach in a point-source manner. Groundwater operable unit investigations are expected to provide more realistic information concerning both flux magnitude and location (as opposed to a one-dimensional point source inputs, RI and FI information should allow for two-dimensional area source inputs).

As flux information should be developed on an operable-unit-by-operable-unit basis, Activity 1A-2 will consist of compilation and integration of the groundwater contaminant transport results obtained for the 100 Area groundwater operable units. This activity will also consist of the compilation of data generated from the spring monitoring program.

<u>Activity 1A-3 — Characterization of Contaminant Mixing in Discharge Zones.</u>

A potentially relevant and appropriate remediation standard for the 100 Area are the State of Washington's surface water cleanup standards promulgated in the Model Toxics Control Act Cleanup Regulation (MTCACR, WAC 173-340-730). Under WAC 173-340-730(6)(b), no dilution zone is allowed to demonstrate compliance with the calculated standard when a surface water body is impacted by contaminant discharges through groundwater.

The purpose of this activity is therefore to obtain empirical information to allow for a better understanding of contaminant mixing in the affected groundwater discharge zones in the 100 Area. Given the size of the Columbia River, the effects of mixing (as demonstrated by the results of the preliminary impact evaluation presented in this report) are expected to be substantial. This activity is thus needed to provide conclusive evidence that cleanup standards based on water quality standards will adequately protect both human health and the environment.

The 100 Area groundwater investigations mentioned above under Activities 1A-1 and 1A-2 will provide information on the magnitude of contamination in the groundwater medium. Recently conducted near-shore surface water characterization results show that the concentrations of anticipated contaminants of concern are generally below analytical detection limits (DOE-RL 1992d); however, no data are available to provide a characterization of the quality of the interstitial waters of the river sediments.

This activity will therefore consist of a focused characterization of the groundwater, sediment, interstitial water, and water column components of one of the major contaminated groundwater discharge zones in the 100 Area. It is recommended that the 100D-1 plume be selected, as the results of the preliminary impact assessment presented in this report indicates that the levels of Cr contamination within this plume have the potential to contribute significantly to any impact to the Hanford Reach environment. Using the 100D-1 plume to evaluate mixing will be efficient, because this same plume can be used for the Cr speciation investigation discussed below under Activity 1A-4, thus allowing for logistical consolidation of these two activities. If the 100D-1 plume is not practical, induced tracer studies with another plume will be considered.

Proposed data collection under this task will interface with the activities proposed for Milestone M-30-05, which is "Install all field instrumentation and initiate monitoring activities necessary to perform long-term evaluation of Columbia River and unconfined aquifer interaction, in accordance with tasks defined in operable unit work plans listed in M-30-03." Therefore, data collection planned under this activity should be a data compilation function to use information gathered during RI and RFI activities at the operable units.

Existing information indicates that analytical detection limits for Cr achievable with standard methods may not be adequate to provide the required information. During DOW development, various published methods should be evaluated to determine whether or not it is feasible to obtain lower detection limits. If this approach is not feasible, another more easily detectable contaminant, a tracer study, or perhaps another plume, should be sought for use. Radioactive substances are quite readily detectable; therefore, if a backup substance and plume are required, ^{90}Sr and the 100-N-1 plume are recommended. This recommendation is based on the findings of the preliminary impact assessment contained in this report.

<u>Activity 1A-4 — Cr Speciation.</u>

The results of the preliminary impact assessment presented in this report indicate that Cr is a 100 Area contaminant expected to be one of the most significant with respect to impact potential in the Hanford Reach. This conclusion, however, assumes that all hexavalent Cr in the groundwater remains in this valence state in the river water column. Hexavalent Cr is thermodynamically unstable under normal environmental conditions (Dragun 1988; Syracuse Research Corp. 1991), and is much more toxic than the reduced, trivalent form of the element. Therefore, investigation of the speciation of Cr in the various environmental media could possibly show that the impact potential attributable to Cr is either far less or non-existent.

It is recommended, based on the findings of the preliminary impact assessment, that this activity be focused on the 100D-1 plume, as this plume appears to have the greatest Cr flux. An activity-specific DOW will be developed to provide detailed guidance on sample collection and analysis, and on data evaluation. Efforts should encompass the groundwater, the river sediments, the interstitial waters of the river sediments, and the river water column. The importance of the 100 Area segment of the Hanford Reach as a salmonid spawning ground makes knowledge of Cr valence state in the sediments and interstitial waters essential, as hexavalent Cr has a corrosive effect on biological tissue.

In addition to sampling for total and hexavalent Cr, other relevant environmental parameters — such as pH, Eh, TOC, and DO — should be included. Sampling and analysis efforts should be accompanied by a literature review to document current understanding of the environmental behavior of Cr. If for some reason it is not practical to conduct the investigation on the 100D-1 plume, the 100H-1 or 100K-2 plumes should be considered as backup locations for the field effort, as the latter two plumes are estimated to have the second highest fluxes of Cr to the Reach.

There are five groundwater operable unit work plans currently under development for the 100 Area. The operable unit workplans show that groundwater characterization will not include any Cr speciation. Therefore, a DOW will need to be developed that will identify sampling techniques and analytical methods necessary to fulfill this data collection activity.

5.2.2.1.2 Subtask 1B — Characterization of Other Contaminant Inputs. If significant adverse impacts to human health or the environment are identified during the 100 Area impact assessment, additional work may be required to determine if contaminants are of Hanford or non-Hanford origin. Paragraph 5.2.1.1 establishes at least two objectives for this subtask: identification of other sources and characterization of contaminant fluxes. It may also be necessary to speciate certain contaminants identified; however, such a determination is contingent on the findings of the activity implemented to fulfill the contaminant identification objective. The subtask activities proposed to meet the two objectives are discussed below.

Activity 1B-1 — Identification of Other Contaminant Input Sources.

As indicated in Paragraph 5.2.1.1, sources of contaminant input to the Hanford Reach along the 100 Area other than groundwater affected by 100 Area operations exist. Examples of such other sources include groundwater and surface-water discharges affected by regional agricultural operations.

A long-term information compilation effort will be performed under this activity to identify other sources of potential contaminant input that affect Hanford Reach along the 100 Area, such as other agricultural discharges, irrigation return water, and contributions of designated hazardous substances from natural sources or from widespread anthropogenic activity (e.g., motor vehicle operation, past atmospheric nuclear testing, pesticide application, and fertilizer application).

If data collected during the information compilation effort are insufficient to conduct future 100 Area risk assessments, it is conceivable that this information compilation activity will identify a need to conduct a specific sampling, analysis, and data evaluation activity to support the identification of other contaminant sources. If such a need arises, a new activity will be defined and an activity-specific DOW will be developed to provide detailed guidance on such sample collection, analysis, and data evaluation. Any such DOW should address not only identification of sources, but identification of contaminants of potential concern in such sources and quantification of contaminant fluxes from such sources (see Activity 1B-2 below), as well.

Activity 1B-2 — Characterization of Contaminant Fluxes.

If implementation of Activity 1B-1 finds that insufficient data are available to identify contaminants of potential concern in non-Hanford-related sources having the potential to affect the Hanford Reach, a new sampling, analysis, and evaluation activity, supported by a DOW, will have to be developed for Subtask 1B, as mentioned above under Activity 1B-1.

As demonstrated in the discussion under Activity 1A-2, contaminant flux data are essential to allow for prediction or estimation of impacts to the Hanford Reach. The only way to quantify such fluxes through the groundwater medium is through characterization of groundwater flow and contaminant transport. Surface water sources, particularly in the form of irrigation return water, are expected to be a potentially significant contributor of hazardous substances to the Hanford Reach. As is the case with groundwater, both water quality as well as flow data are needed to quantify flux from this medium.

5.2.2.2 Task 2 — Characterization of Surface Water Pathways. Contaminants entering the Hanford Reach from discharging groundwater, that has been affected by 100 Area operations, have a high potential to enter and be transported by the flowing water column of the river. The surface water medium of the Hanford Reach is a highly valuable resource in the region for both human and non-human organisms. Therefore, a definitive characterization of this pathway is important.

Two activities are proposed under this task and are discussed below, one to define impacts to the water column through monitoring, the second to evaluate, select, and implement an appropriate surface water dispersion code or codes to allow for prediction of the magnitude and extent of contamination within the water column of the reach.

Activity 2-1 — Surface Water Monitoring.

The ongoing environmental monitoring program for the Hanford Site includes water quality monitoring for the Hanford Reach. This current program collects control samples from either Vernita Bridge or Priest Rapids Dam, and evaluates potential impacts from downstream samples collected at the City of Richland water intake. The current program also focuses primarily on radiological substances.

With relatively minor additions, the current program forms an excellent platform from which to collect data to assist in developing a cumulative impact assessment for the Hanford Reach, in addition to the program's long-term environmental monitoring function. In order to adapt the program for this purpose, this activity will include an evaluation of sampling locations, sampling frequencies, and analytes.

Current sampling frequencies are anticipated to be adequate for the purposes of cumulative impact evaluation. However, additional sampling locations should be considered. For example, a water intake, that supplies potable water to the 100 and 200 Areas, is located in the 100-B Area. A backup intake for this system is located in the 100-D Area. Data from samples at these locations should be consistent with and evaluated with the surface water monitoring program.

As the current program focuses on radionuclides, additional non-radiological parameters may have to be added to the analyte list to ensure that all contaminants of potential concern for the 100 Area are addressed. Specific analytes will need to be identified once groundwater characterization is completed in the 100 Area groundwater operable units. If contaminant inputs from non-Hanford-related operations are investigated under the modified program, it may be necessary to make the analyte list even broader. General water quality parameters, such as hardness and alkalinity, should be included in the monitoring program to assist in the evaluation of results.

It is not anticipated that a broad list of parameters will need to be analyzed for during each round of sampling. After initial analysis for the broad spectrum of analytes, a shorter list for routine monitoring can be developed, and it is anticipated that the short list will be similar to the current list. During the evaluation-of-sampling-frequencies component of this activity, consideration should be given to how often analyses are required for the broad spectrum of analytes that is to be developed.

Finally, once the current surface water monitoring program is modified and being implemented, this activity will serve to compile the information generated to allow for a definitive impact assessment.

Activity 2-2 — Surface Water Modeling.

Although the preliminary impact evaluation of this document does not show any adverse impacts to the overall river-water quality, there is the possibility for localized environmental effects. Investigation tasks have been proposed to collect data at specific sites regarding the interaction among groundwater, sediments, and river-water. Some of these proposed data collection activities are focused on specific locations or contaminants (see Activity 1A-3). To apply the data collected at one plume to another plume a groundwater and surface-water dispersion model is needed to predict contaminant concentrations in the Hanford Reach that originate in other plumes. The model can be useful to minimize the necessity of extensive characterization activities at all plumes. The implementation of this activity will be dependent on the nature and extent of groundwater contamination identified during previous tasks. Model development would be justified only if there is significant risk-based groundwater contamination.

It is expected that contaminant flux data generated under Task 1 will serve as inputs to a surface water dispersion model, and the output of the model will allow for an assessment of impacts associated with exposure to the water column of the Hanford Reach.

Before the modeling can be implemented, available models should be evaluated. It is recommended that the Hanford Site Risk Assessment Modeling Committee be tasked to implement the evaluation phase of this activity, and that they also be tasked to recommend an appropriate model (or models). Once this selection is made and input data are available, the surface water modeling necessary to support a cumulative impact assessment can proceed under this activity.

5.2.2.3 Task 3 — Characterization of River Sediment Pathways. Contaminants entering the Hanford Reach from discharging groundwater, that has been affected by 100 Area operations, are retained or deposited, to some extent, within the river sediments. The sediment medium of the Hanford Reach is highly valuable because of its use as a fish spawning bed, and its production of benthic organisms that in turn provide food to valued fish resources. The sediments of the reach may also be an important ultimate sink for many of the contaminants released from the 100 Area. Therefore, a definitive characterization of this pathway is important.

The one activity proposed under this task is to define impacts to the sediments through monitoring.

Activity 3-1 — River Sediment Monitoring.

While sediment monitoring has been conducted for the Hanford Reach, it has not been conducted as comprehensively as is the ongoing Hanford Site surface water monitoring program. A lack of sediment quality criteria and difficulty in sampling sediments from an armored substrate in a swift current provide at least a partial explanation for the absence of a comprehensive sediment monitoring program. However, given the importance of this medium, as noted above, it is essential that a comprehensive program be developed and implemented.

A DOW for sediment sampling in the 100 Area segment of the Hanford Reach has been developed. The implementation of this DOW consisted of the first phase in the development of an appropriate and comprehensive river sediment monitoring program. The sediment DOW focussed on sampling in likely areas of contaminant deposition, such as the production reactor outfall pipelines, islands, and within backwater slough areas between B Reactor and the Hanford Town Site. Control samples upstream of the 100-BC Area were also be obtained to allow for determination of the presence of contamination. Sampling was completed in November, 1992.

Contaminants of concern were based on contaminants known to be present in the effluent from the pipelines and the springs/seeps. Other non-contaminant parameters, such as total organic carbon and mineralogy, were also be considered for inclusion as they may be important in the overall characterization of the nature, extent, and effect of river sediment contamination. An attempt to determine particle-size/concentration relationships will also be made.

Sediment sampling efforts were restricted to depositional zones, where contaminants are expected to accumulate. If adverse impacts are encountered, additional zone of sediment disposition within the channel will be identified and targeted for additional sampling.

If a long-term sediment monitoring program is developed and implemented, this activity will serve to compile the information generated to allow for a definitive impact assessment.

Another and highly significant data gap identified during the course of developing the preliminary impact assessment is the lack of sediment quality criteria, including even the lack of a generally accepted approach from which surrogate criteria can be developed. Without such an ability, one can not determine whether contaminant levels encountered within the river sediments have the potential to result in a significant adverse impact to organisms. The EPA and Ecology are currently in the process of developing freshwater sediment quality criteria. Therefore, these agencies should be consulted during the implementation of this activity.

5.2.2.4 Task 4 — Characterization of Biological Pathways. A wide variety of human and non-human receptors have a potential of being exposed to contaminants entering the Hanford Reach from discharging groundwater that has been affected by 100 Area operations. Because the ecology of the Hanford Reach has been extensively studied for almost five decades, there are relatively few data needs required to allow for a cumulative impact assessment.

Three activities are proposed under this task and are discussed below, one to compile ecotoxicological data specific to 100 Area contaminants, the second to compile the results of ongoing biocontaminant monitoring efforts, and the third to compile information on the locations and species composition of sensitive and critical habitats within and along the Hanford Reach.

Activity 4-1 — Compilation of Ecotoxicological Data.

The purposes of this activity are to conduct a literature review to obtain valid ecotoxicological data for 100 Area contaminants, and to obtain recommendations on approaches for developing sediment quality criteria.

In the course of developing the preliminary impact assessment presented in this report, no aquatic ecotoxicological data for ^{99}Tc were found. In addition, the ecotoxicological information for U indicates that this element has a very low aquatic toxicity; however, the values found in the literature may be a reflection of the insolubility and density of U. In other words, the aquatic bioassays performed may show a low toxicity due to the fact that U is not highly soluble, which, in combination with its high density, results in rapid deposition from the water column and virtually no actual exposure to the experimental organisms.

Activity 4-2 — Compilation of Biocontaminant Monitoring Data.

Biocontaminant monitoring of various populations within the Hanford Reach is undertaken annually as part of the Site-wide environmental monitoring program. This activity will include the compilation of the results of this annual program. In addition, this activity will include the compilation of the results of further biocontaminant monitoring efforts that are being conducted under the 100 Area groundwater operable unit work plans under development. These efforts are detailed in Appendix D to groundwater operable unit work plans (e.g. DOE-RL 1992e); therefore, they are briefly summarized below.

The three main objectives of the biocontaminant monitoring effort being undertaken in the 100 Area segment of the Hanford Reach are:

- To determine the aquatic species of interest and the composition of the aquatic community;
- To identify and evaluate potential aquatic biocontamination transport pathways; and
- To evaluate existing biocontaminant concentrations within representative populations.

This biocontaminant monitoring effort will provide the information needed to refine the conceptual understanding of environmental and human exposures to 100 Area contaminants. The information of species composition and species of interest can be used to identify appropriate ecological receptors for consideration in subsequent baseline environmental evaluations. It can also be used to assess potential impacts to biota that may be part of the human food chain. The evaluation of the existing levels of contaminants and the biotic pathways for transport of contaminants provides information to identify appropriate environmental endpoints for use in assessing impacts to ecological receptors and may be useful in estimating human exposures.

Activity 4-3 — Compilation of Sensitive and Critical Habitat Information.

The NCP [40 CFR 300.430(e)(2)(i)(G)] requires that a baseline risk assessment contain an environmental evaluation that focuses on critical habitats and sensitive habitats. In order to conduct a cumulative impact assessment on the Hanford Reach information on the location, nature, and species composition of such habitats within and along the reach needs to be compiled. This compilation will be undertaken in accordance with the guidance provided in the HSBRAM (DOE-RL 1992c).

To assist in evaluating potential human exposures to aquatic biological organisms that may be contaminated from 100 Area operations, this activity will also include the compilation of the types, locations, and uses of species, particularly riparian species, that are known to be utilized by humans.

Activity 4-4 Data Evaluation.

Data compiled during other activities will be evaluated against the needs of the risk assessment to determine if further data gaps are identified. If data gaps are present, then additional sampling programs may be recommended.

5.2.3 Proposed Schedule

A proposed schedule for initiation of the tasks included in this document is attached (Table 5-1). This table indicates either start of activity (assuming models are approved, if applicable, or dependent data are available) or date DOW is due to regulators for review. A meeting will be held with the EPA and Ecology to define the scope of all the work tasks (except sediment sampling; the DOW for that project was submitted in June 92 to allow sufficient time for planning field work).

Table 5-1. Proposed Activity Schedule.

Activity	Start
1) 1A-1 ID Contaminants of Concern	Dec 92
2) 1A-2 Characterize Groundwater Flux to the River	Oct 92
3) 1A-3 Characterize Flux Mixing in River	Nov 93
4) 1A-4 Cr Speciation	Oct 92
5) 1B-1 ID Non-Hanford Sources	March 94
6) 1B-2 Characterize Non-Hanford Sources	Sept 94
7) 2-1 Surface Water Monitoring	Jul 93
8) 2-2 Model Surface-Water Dispersion	Jul 94
9) 3-1a Sediment Sampling	Nov 92
10) 3-1b Identify Additional Depositional Areas	Sept 93
11) 4-1 Compile Ecotoxicological Data	Jan 93
12) 4-2 Compile Biocontaminant Data	Oct 92
13) 4-3 Compile Habitat Information	Oct 92

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APPENDIX A

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APPENDIX B

DESCRIPTION OF HYDROGEOLOGY AND GROUNDWATER CONTAMINATION AT THE 100 AREA OF THE HANFORD SITE

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CONTENTS

FIGURES:

TABLES:

ACRONYMS

TCE	trichloroethylene
PUREX	plutonium and uranium extraction

B.1 GENERAL HANFORD SITE HYDROGEOLOGY

B.1.1 Stratigraphy

The stratigraphy of Pasco Basin geology is provided in Figure B-1. Bedrock in the Pasco Basin is the Columbia River Basalt Group, which consists of numerous basalt flows and interbedded sediments, with maximum accumulations of more than 10,000 feet (DOE 1988). The uppermost basalt unit is the Elephant Mountain Flow.

Overlying the Columbia River Basalt Group are unconsolidated deposits of sand, silt, clay, and gravels, referred to as the Ringold Formation (DOE 1988). The Ringold Formation has been divided into four subunits: the gravelly sand of the Basal Ringold, the silts and fine sands of the Lower Ringold, the sands and gravels of the Middle Ringold, and the fine sands and silts of the Upper Ringold. Generally, the Ringold sediments are characterized as main channel and overbank fluvial deposits. The subunits are not continuous throughout the Hanford Site.

Two minor units overlie the Ringold Formation in the western Pasco Basin: the Plio-Pleistocene unit, a basaltic gravel or caliche-rich paleosol, and the early "Palouse" soil, a fine-grained eolian sand to silt. The predominate upper stratigraphic unit in the Pasco Basin is the Hanford formation. The Hanford formation is composed primarily of sands and gravels deposited during catastrophic ice-age flooding associated with failures of ice dams in western Montana and Northern Idaho (DOE 1988). Surficial deposits of sand, alluvium, loess, and colluvium overlie the Hanford formation in places, although these deposits rarely exceed 10 feet in thickness (DOE 1988).

B.1.2 Groundwater Hydrology

Aquifers within the Pasco Basin occur both in the underlying basalt sequences and the unconsolidated deposits. Confined aquifers in the basalt are associated with interbeds, basalt flow tops and basalt flow bottoms of the basalt. The uppermost aquifer in the basalt is the Rattlesnake Ridge interbed aquifer (DOE 1988).

Groundwater flow in the unconsolidated deposits is predominately controlled by the Columbia River, influx from Cold Creek and Dry Creek Valleys, and effluent discharge from Hanford facilities. Contours of water table elevations before effluent discharge began in the 1940's are shown in Figure B-2. Flow is primarily from west to east, with influx from Cold Creek and Dry Creek Valleys, and discharge to the Columbia River. Since operations began at the Hanford Site, effluent discharge in the 200 Areas has resulted in significant groundwater mounding. A map of recent groundwater contours is provided in Figure B-3. Comparison of Figures B-2 and B-3 indicates that groundwater levels have increased approximately 50-70 feet in the 200 West Area and 10-20 feet in the 200 East Area. These increases are attributed to effluent discharge in the 200 Areas and an increase in irrigation up-gradient of the Hanford Site. The difference in mounding between the two areas reflects the lower hydraulic conductivity of the sediments underlying the 200 West Area.

In the eastern half of the Hanford Site, an upward hydraulic gradient exists between the uppermost basalt interbed aquifer (the Rattlesnake Ridge Aquifer) and the

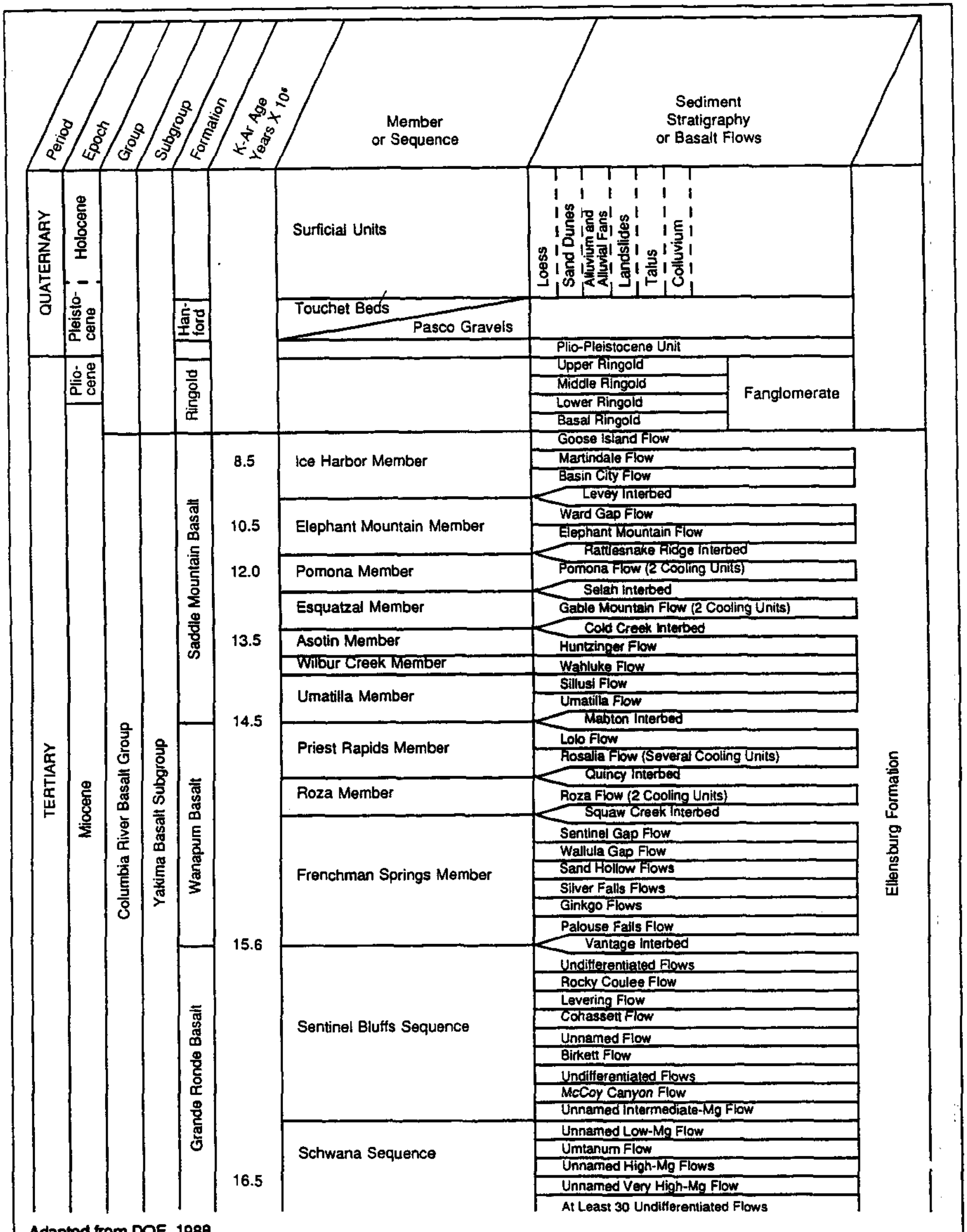

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Figure B-1. Generalized Pasco Basin Stratigraphy.

9 3 1 2 7 5 3 1 7 3 3

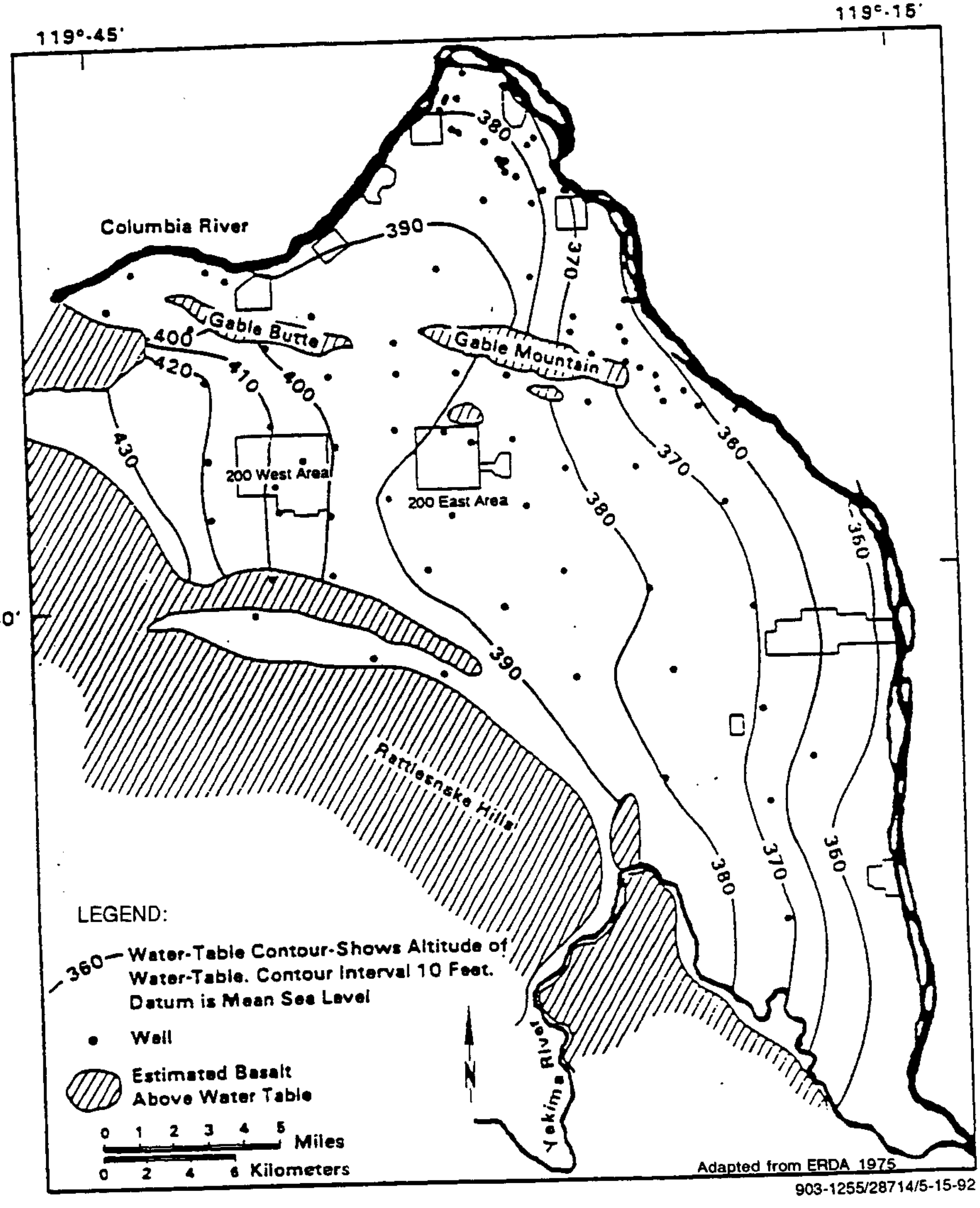

Figure B-2. 1944 Water Table Elevations at the Hanford Site.

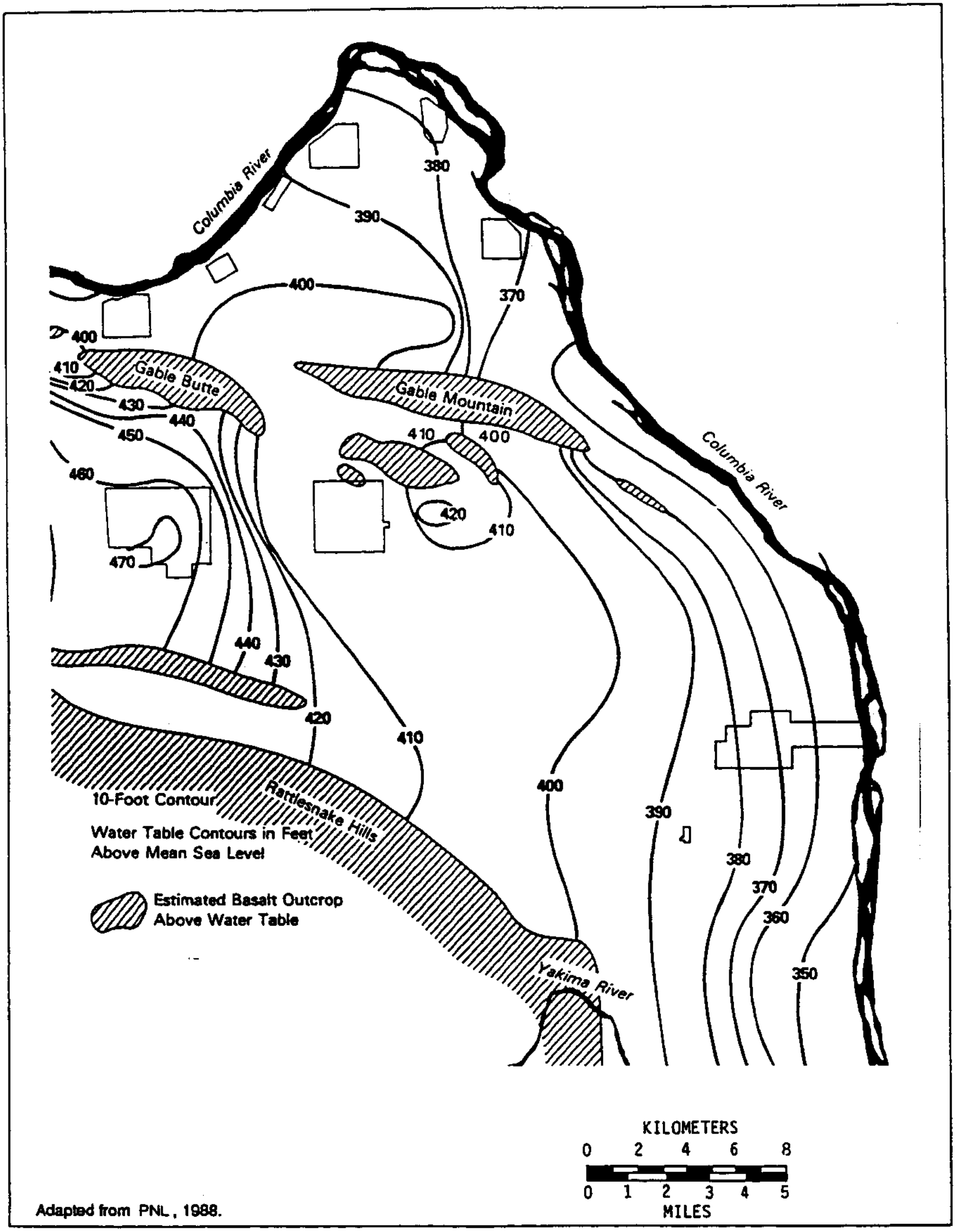

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Figure B-3. Recent (1987) Water Table Elevations at the Hanford Site.

9 3 1 2 7 5 3 1 7 3 5

unconsolidated deposits (DOE 1988). Downward gradients have been observed near the 200 Areas due to mounding associated with effluent discharge to B-Pond and U-Pond (Graham et al. 1984). Significant discharge from the Rattlesnake Ridge Aquifer to the unconsolidated deposits appears to be occurring in the region of West Lake where some of the basalt aquitards have been eroded away (Graham et al. 1984). Although this connection does not have an observed impact on hydraulic head contours in the unconsolidated deposits, it does appear to result in a significant drawdown cone in the Rattlesnake Ridge Aquifer (Graham et al. 1984).

B.2 100 AREAS

The 100 Areas include 100-BC, 100-K, 100-N, 100-D, 100-H, and 100-F. As shown in Figure B-4, the 100 Areas are located along the Columbia River in the northern end of the Hanford Site. These areas are primarily nuclear reactor sites dating back to the 1940's.

The following sub-sections include a general discussion of the hydrogeology in the 100 Areas, as well as area-specific discussions of soil and groundwater contamination, and groundwater discharge analyses.

B.2.1 Hydrogeology in the 100 Areas

Hydrostratigraphy

The 100 Areas are located within the Wahluke Syncline. The thickness of unconsolidated deposits (includes the Hanford and Ringold Formations) range from 600 feet near the 100-BC Area, to 350 feet near the 100-H and 100-D Areas. In general, the unconfined aquifer in the 100 Areas is contained within permeable zones of the Hanford formation or Middle Ringold Formation. Near the 100-BC Area the unconfined aquifer is contained within permeable zones of the Middle Ringold Formation; the base of the unconfined aquifer in this region is defined by the top of the Lower Ringold Formation, or "Blue Clay", found at a depth of 350 feet below the ground surface (DOE 1990). In contrast, the unconfined aquifer near the 100-H and 100-D Areas is contained within the Hanford formation, and the base of the unconfined aquifer is defined by the relatively impermeable Upper Ringold Formation (DOE 1989a). The thickness of the unconfined aquifer in this region of the 100 Areas ranges from 0 to 40 feet due to undulations in the upper surface of the Ringold Formation.

Groundwater Elevations

Contours of groundwater elevations in the 100 Areas are shown in Figure B-5. These contours are uncertain near the Columbia River since groundwater elevations change in response to water-level fluctuations in the river. A study conducted in the 100-H Area concluded that groundwater levels near the river were most affected by river-level fluctuations, but that effects could be observed up to 3,000 feet inland of the river.

9 3 1 2 7 5 3 1 7 3 7

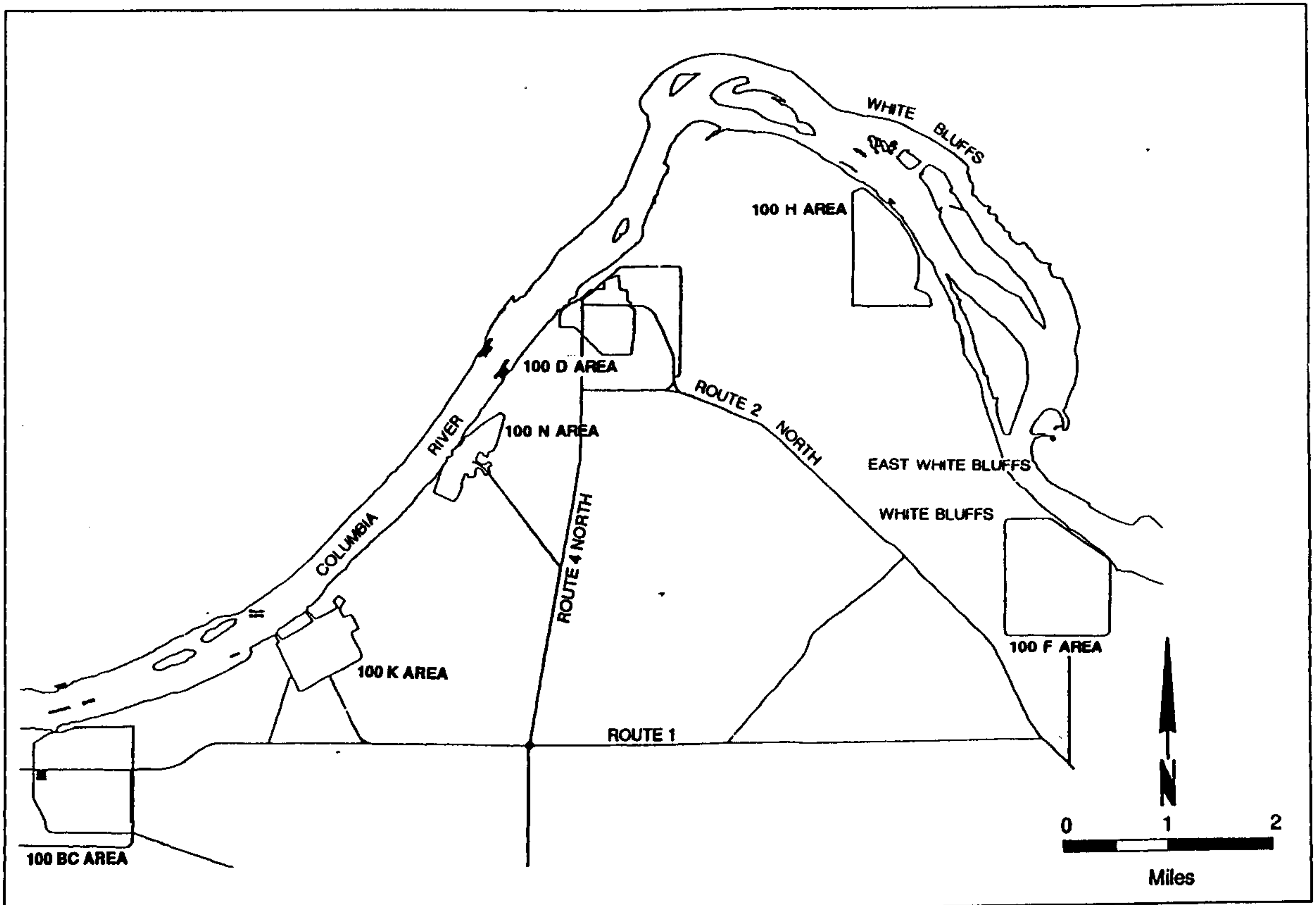

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Figure B-4. Site Map of the 100 Areas.

Hydraulic Conductivity

Hydraulic conductivity data specific to the 100 Areas are available for the 100-H and 100-N Areas. As reported in Liikala et al. (1988), pump test data from the 100-H Area provided estimates of hydraulic conductivity in the Hanford formation ranging from 49 to 5,940 ft/d, with a mean value of 760 ft/d. Transmissivity estimates for the 100-N Area range from 5,200 to 26,000 ft^2/d, with a mean of 13,000 ft^2/day (Hartman, 1991). Assuming an average screen length of 20 feet and no vertical flow, the hydraulic conductivity is estimated to equal 650 ft/day. Given the similarity in values between the 100-H and 100-N Areas, it was decided to assume a hydraulic conductivity of 700 ft/day for all the 100 Areas.

Groundwater Discharge Analyses

The specific discharge rate for a specific plume is essentially the amount of water that passes through a section of aquifer equal to the width of the plume, which is the specific discharge of contaminated groundwater as calculated using Darcy' Law. Therefore, the only information required to estimate the groundwater flow rate is the hydraulic conductivity, the impacted aquifer thickness (assumed 30 feet), the hydraulic gradient, and the plume width.

As discussed above, a generic hydraulic conductivity of 700 ft/d was used for all the 100 Areas. In addition, since groundwater contamination in the 100 Areas is likely contained near the water table, it was assumed that only the upper region of the aquifer would be pumped, not the entire aquifer thickness. Therefore, the aquifer thickness used for the analyses was assumed to equal 30 feet. The hydraulic gradient and the width were specific to each of the 100 Area groundwater plumes, and are discussed below and also presented in Table B-1.

Identification of Groundwater Contaminants

Because of the potential for significant adverse impacts associated with groundwater discharge from the 100 Area to the Hanford Reach, water quality criteria were used to identify contaminants of potential concern. These water quality criteria used to identify contaminants of potential concern were based on the more stringent concentrations from either drinking water standards, chronic freshwater quality criteria, or groundwater concentrations (calculated by either method A, B, or C) in Model Toxics Control Act (WAC 173-340). The concentrations are shown in Table B-2.

B.2.2 Groundwater Contamination in the 100 Areas

100 BC

A site plan for the 100-BC Area is shown in Figure B-6. Eight wells are located within the 100-BC Area. The depth from ground surface to groundwater in the 100-BC Area is approximately 65 to 95 feet.

Groundwater contaminants that exceed the water quality standards in the 100-BC Area include strontium-90, tritium, nitrate, and chromium (Evans et al. 1990).

Table B-1. Groundwater Discharge Analysis Summary.

Hanford Area	Number of Plumes	Hydraulic Gradient (ft/ft)	Hydraulic Conductivity (ft/day)	Aquifer Thickness (ft)	Plume Width (ft)	Groundwater Discharge Rate[1] (gpm)
100 BC	2	$1x10^{-3}$	700	30	3000	400
100 K	3	$3x10^{-3}$	700	30	6000	2000
100 N	1	$2x10^{-3}$	700	30	3000	700
100 D	1	$1.5x10^{-3}$	700	30	4000	800
Between 100 N & 100 D	1	$1.5x10^{-3}$	700	30	6000	1000
100 H	2	$7x10^{-4}$	700	30	3000	260
100 F	2	$2x10^{-3}$	700	30	2000	600

[1]Flow rates obtained using Darcy's Law have been rounded up to account for potential error in hydraulic parameter assumptions and approximations that were necessarily made due to lack of actual field test data.

Table B-2. Draft Clean-up Levels (Sheet 1 of 4)

Contaminants	Drinking water mg/L	Chronic aquatic mg/L	Groundwater mg/L
Gross Alpha (*)	15 pCi/L 1		15 pCi/L A
Gross Beta (*)	50 pCi/L 1		4 mrem/yr A
pH	6.5-8.5 2	6.5-8.5 E	6.5-8.5 D
Total Coliform	>10% tests 1	org/100 ml	org/100 ml
Total Organic Carbon	1.0		
Total Organic Halogen	0.32		
Aluminum		.087 T	5 T
Antimony		1.6 E	0.146 T
Arsenic (*)	0.05 2	0.048 E	0.05 A
Barium	1 1	1 S	1.0 A
Beryllium (*)		0.0053 E	0.005 A
Cadmium (*)	0.005 1	0.0011 E	0.005 A
Calcium			<500 D
Chromium total	0.1 1	0.21 E	0.050 A
Copper	1 2	0.012 E	1 A
Iron	0.3 2	1 E	10
Lead (*)	0.05 1	0.0032 E	.005 A
Magnesium			<400 D
Manganese	0.05 2		<400 D
Mercury	0.002 1	0.000012 E	0.002 A
Nickel (*)		0.160 E	0.7 X
Potassium			5 D
Selenium	0.01 1	0.035 E	0.01 A
Silver	0.05 1	0.00012 E	0.05 A
Sodium			100 D
Strontium	8 pci/L 1		
Thallium	.013 A	.013 T	0.0002 F
Vanadium			.02 F
Zinc	5 2	0.110 E	.48 F
Ammonium		.05 H	.1 H
Chloride	250 2		<1000 D
Fluoride	4 1		4 E
Nitrate	10 1		20 E

Table B-2. Draft Clean-up Levels. (Sheet 2 of 4)

Contaminants	Drinking water mg/L	Chronic aquatic mg/L	Groundwater mg/L
Nitrite			20 C
Sulfate	250 2		<2000 D
Phosphate			<1000 D
Arochlor 1260 (*)		0.00002 E	0.01 x (1/100)
Arochlor 1248 (*)		.00002 E	0.01 x (1/100)
Chloroform (*)	0.10 1	1.2 E	0.023 F
Dichloroethene (*)	0.007 1	1.2 E	0.020 F
Methanol		100 S	1.142 F
Methyl Isobutyl Ketone		9 H	0.114 F
Methylene Chloride (*)		10 S	0.005 A
Tetrachloroethene (*)		0.84 E	0.005 A
Trichloroethene (*)	0.005 1	21.9 E	0.005 A
Carbon Tetrachloride (*)	0.005 1	3.5 E	0.002 F
Trichloroethane	0.2 1	1.80 E	0.2 A
Benzene (*)	0.005 1	0.053 E	0.005 E
Ethyl Benzene (*)		3.2 E	0.03 A
Total Xylenes		0.36 E	0.02 A
Toluene		1.75 E	0.04 A
Acetone			.22 F
Boron			.21 F
Bis-2-ethyl hexyl Phthalate (*)		3 E	.0009 F
Chromium (IV) (*)	0.1 1	0.011	0.05 A
Chlorobenzene		50 E	0.0003 F
Cyclotetrasiloxane - octomethyl			1 S
Cyanide		5 E	0.0003 F
Diesel Fuel			
Hexane			100 H
Hydrazine (*)			4 x 10-6
Herbicides (*)			.010 E
Lillium			70 D
Morpholine		100 S	7 (1/10)
4 Methyl 2 Pentanone (Methyl Isobutyl Ketone)		9 H	0.114 F
Oxalate			20 H

Table B-2. Draft Clean-up Levels. (Sheet 3 of 4)

Contaminants	Drinking water mg/L	Chronic aquatic mg/L	Groundwater mg/L
Sulfamate			2000 C
Tetraethylpyrophosphate			0.001 F
Tetrahydrofuran			0.5 H
Thiourea (*)			5 x 10 -6 E
VOCs	0.1 1		

Contaminants	Drinking water pCi/L	Chronic aquatic pCi/L	Groundwater** pCi/L
^{60}Co			200
^{99}Tc	900		4000
^{147}Pm			4 x 10-6
^{235}U	20		24
^{238}U	20		24
^{3}H	20000		80000
^{137}Cs	10		120
^{90}Sr	8		40
^{241}Am			1.2
^{242}Am			1.2
^{243}Am			1.2
^{238}Pu			1.6
^{239}Pu			1.2
^{240}Pu			1.2
^{106}Ru	30		240
^{129}I	1		20
^{241}Pu			80
^{226}Ra			3 A
^{152}Eu			8×10^{2}
^{154}Eu			8×10^{2}
^{155}Eu			4×10^{3}
^{151}Sm			16×10^{3}
^{134}Cs			80
^{125}Sb			2×10^{3}
^{113}Cd			32
^{103}Ru			2×10^{3}

Table B-2. Draft Clean-up Levels. (Sheet 4 of 4)

Contaminants	Drinking water pCi/L	Chronic aquatic pCi/L	Groundwater** pCi/L
^{107}Pd			4×10^4
^{94}Nb			12×10^2
^{93}Zr			36×10^2
^{63}Ni			12×10^3
^{79}Se			8×10^2
^{14}C			7×10^3
^{41}Ca			4×10^3
^{51}Cr			4×10^4

[1]Primary Drinking Water Standards
[2]Secondary Drinking Water Standards
[3]BG = Background
A State of Washington
S Dangerous Properties of Industrial Materials, Sax
C By Comparison
D Soil Chemistry of Hazardous Materials, Dragun
H Handbook of Environmental Data on Organic Chemicals, Verschueren
T Toxicology Profiles; Agency for Toxic Substance and Disease Registry
F By Ecology Formulae
X Proposed Action Level
E EPA Reference Dose

(*) Carcinogen
** 0.04 of Derived Concentration Guide for Public Exposure Approximate 4 mrem Exposure

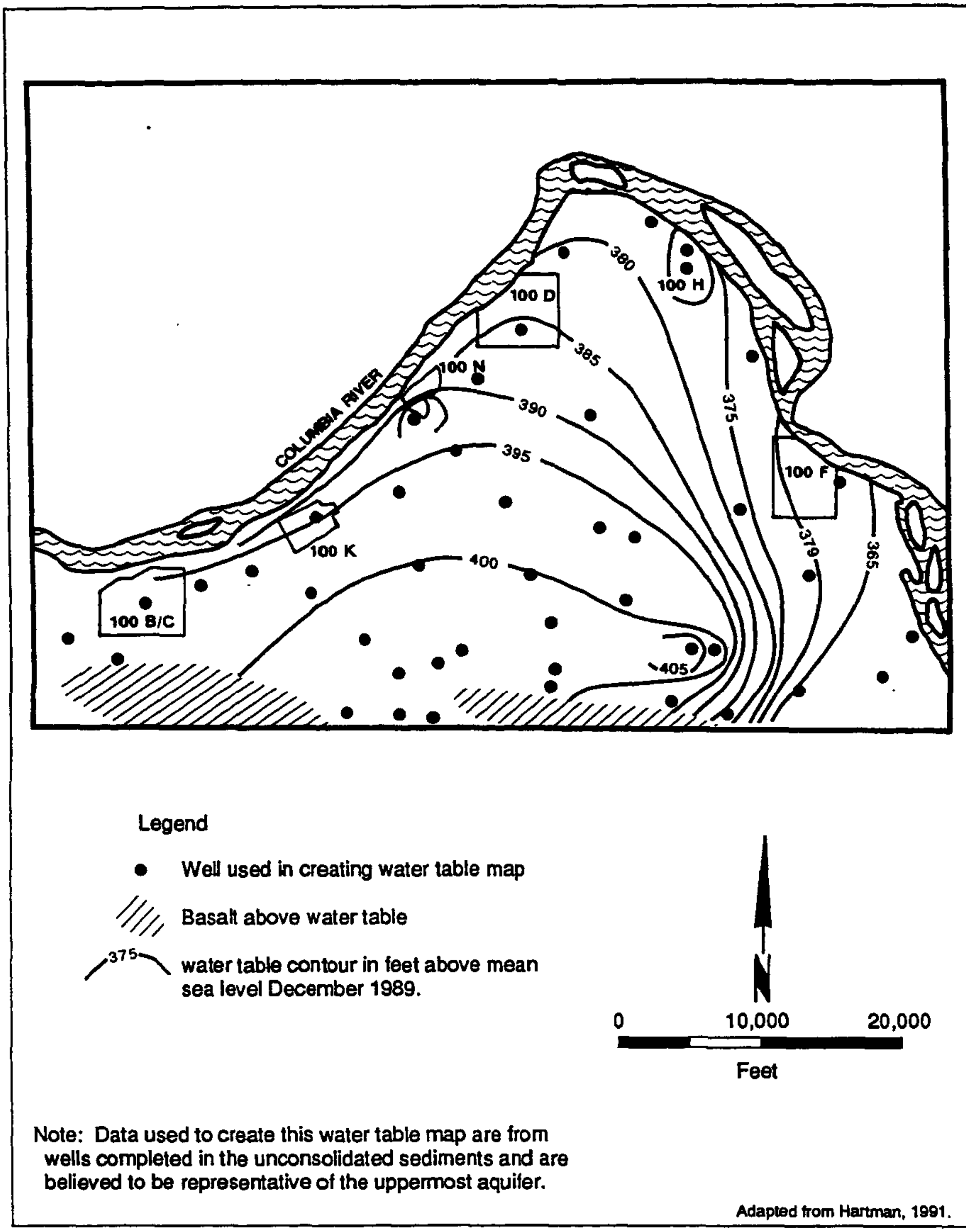

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Figure B-5. Contours of Groundwater Elevations in the 100 Areas.

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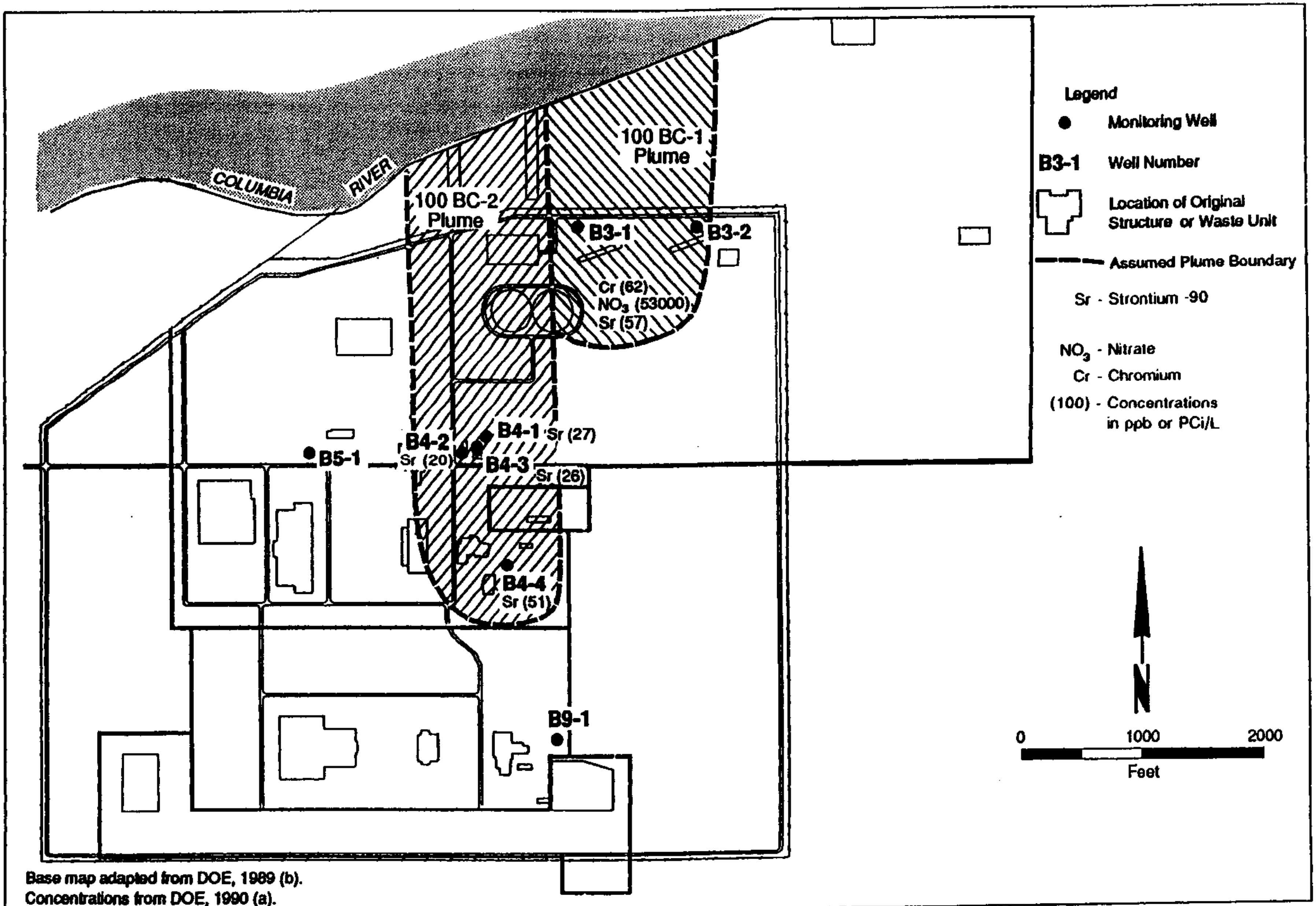

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Figure B-6. 100-BC Area Facilities and Groundwater Plumes.

Ruthenium-106 was detected above drinking water standards, but concentrations are comparable to detection limits, and should be regarded with high uncertainty. Since concentrations are low enough (less than 140 pCi/L) that they may reflect natural background levels, ruthenium-106 was not considered a contaminant of concern for this study. Wells that exceed water quality standards for constituents other than ruthenium-106 are indicated on Figure B-6. The approximate boundaries of the plumes shown on Figure B-6 are poorly defined due to the sparsity of wells in the 100-BC Area.

The hydraulic gradient across the 100-BC Area has been estimated to range from 10^{-4} to 10^{-3} (DOE, 1990a); a conservative value of 10^{-3} and a plume width of 3,000 feet was used for the capture-zone analysis. A plume flow rate of 330 gpm was derived from the groundwater discharge analysis. The flow rate was rounded up to 400 gpm for this assessment.

Nitrate and chromium levels above the water quality standards are only found in Well B3-1, suggesting that it may be possible to divide the plume into a portion that contains nitrate and chromium, and a portion that does not. For the purpose of this assessment, it was assumed that half of the plume contains nitrate and chromium (referred to as plume 100BC-1), and half of the plume (plume 100BC-2) does not.

100 K Area

A site plan for the 100-K Area is shown in Figure B-7. Eight wells are located in and near the 100-K Area. The depth from ground surface to groundwater in the 100-K Area is approximately 70 to 100 feet.

Groundwater contaminants that exceed the water quality standards in the 100-K Area include tritium, nitrate, and chromium (Evans et al. 1990). Wells which exceed water quality standards are indicated on Figure B-7. The approximate boundaries of the plumes shown on Figure B-7 are poorly defined due to the sparsity of wells in the 100-K Area.

From Figure B-5, the hydraulic gradient across the 100-K Area was estimated to equal $3x10^{-3}$ and the width of the plume was assumed to be approximately 6,000 feet. The estimated plume flow rate determined by the groundwater discharge analysis was approximately 2,000 gpm.

As shown in Figure B-7, it is apparent that nitrate and tritium are confined to the south end of the plume, and chromium is confined to the north end of the plume, although both nitrate and chromium are above the water quality standards in Well 1-K-19. Given this distribution of chemicals, it is possible to divide the plume into a chromium-only portion (55 percent, 100K-3), a nitrate and chromium portion (25 percent, plume 100K-2), and a nitrate and tritium portion (25 percent, plume 100K-1). It was assumed that the plume could be segregated into these separate streams for purposes of assessing impacts to the Columbia River due to spring discharge.

100 N Area

A site plan for the 100-N Area is shown in Figure B-8. Over 40 wells are used to monitor groundwater in and near the 100-N Area. The depth from ground surface to groundwater in the 100-N Area is approximately 65 feet.

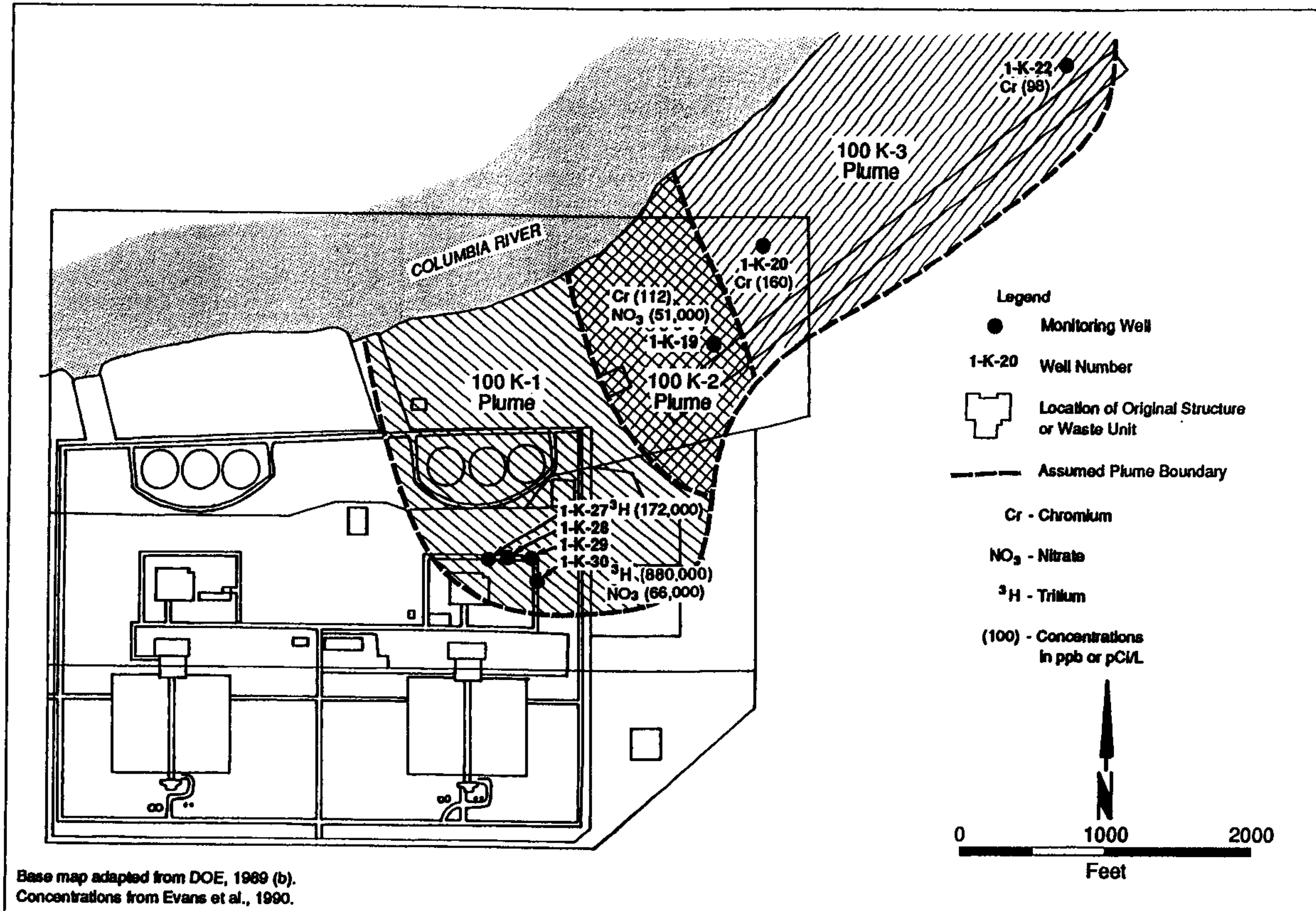

Figure B-7. 100-K Area Facilities and Groundwater Plumes.

Groundwater contaminants that exceed the water quality standards in the 100-N Area include strontium-90, tritium, and nitrate (Evans et al. 1990). Wells that exceed water quality standards are indicated on Figure B-8. Only one well, 199-N-55, exceeds water quality standards for nitrate. The strontium-90 plume is approximately 3,000 feet wide, while the tritium plume includes the strontium-90 plume and extends up to the 100-D Area. Elevated sulfate concentrations, up to 300 mg/L, appear to be associated with the 100-N plume.

From Figure B-5, the hydraulic gradient across the 100-N Area was estimated to equal $2x10^{-3}$ and the width of the plume was assumed to be approximately 3,000 feet. From the groundwater discharge analysis the estimated plume flow rate was 656 gpm. However, due to uncertainties in the hydraulic parameters a rounded-up value of 700 gpm was used for this assessment.

100-D Area

A site plan for the 100-D Area is shown in Figure B-9. Only three wells are located in the 100-D Area. The depth from ground surface to groundwater in the 100-D Area is approximately 60-70 feet.

Groundwater contaminants that exceed the water quality standards in the 100-D Area include strontium-90, tritium, nitrate, and chromium (DOE 1989a). Wells that exceed water quality standards are indicated on Figure B-9. Only one well, 199-D5-12, exceeds water quality standards for strontium-90. The width of the chromium plume indicated on Figure B-9 is approximately 4,000 feet wide, although their are no wells to define the limits of this plume and its dimensions are uncertain.

From Figure B-5, the hydraulic gradient across the 100-D Area was estimated to equal $1.5x10^{-3}$ and the width of the plume was assumed to be approximately 4,000 feet. From the groundwater discharge analysis, the estimated plume flow rate was 738 gpm. A rounded-up value of 800 gpm was used for this assessment.

Levels of tritium higher than water quality standards are found in both the 100-N and 100-D Areas, and apparently the region in between these areas. The tritium plume that extends between the 100-N and the 100-D Areas (plume 100D-2) covers an additional 6,000 feet not already included in other plumes. Assuming the parameters in the previous paragraph, a flow rate of 984 gpm was calculated. A conservative value of 1,000 gpm was assumed for this assessment.

100-H Area

A site plan for the 100-H Area is shown in Figure B-10. Over 20 wells are located on or near this area. Depth from ground surface to groundwater in the 100-H Area is approximately 40 feet.

Groundwater contaminants that exceed the water quality standards in the 100-H Area include chromium, uranium, technetium-99, and nitrate (DOE 1989a; and Evans et al. 1990). Wells that exceed water quality standards are indicated on Figure B-10. The width of the 100-H Area plume indicated on Figure B-10 is approximately 3,000 feet.

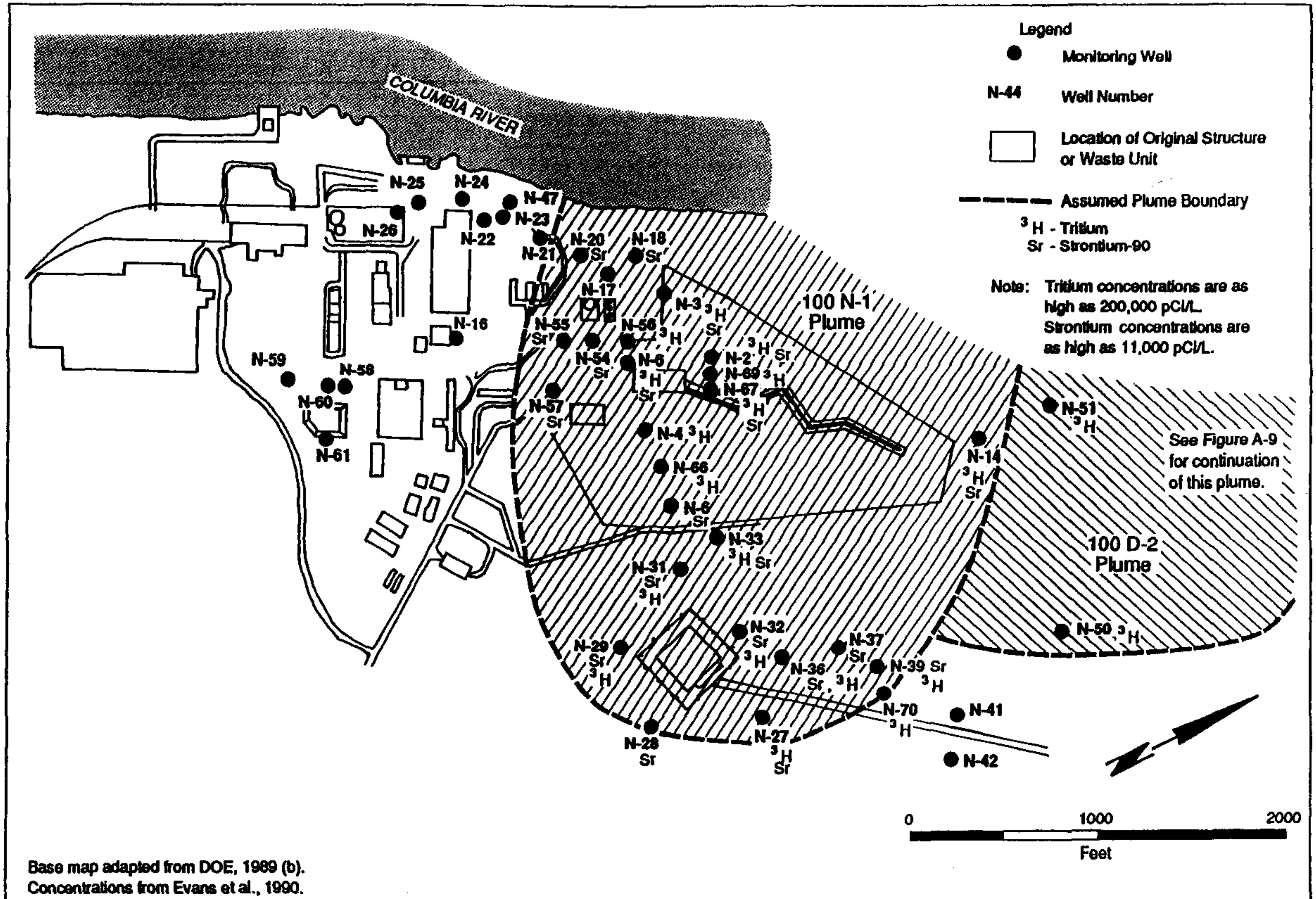

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Figure B-8. 100-N Area Facilities and Groundwater Plumes.

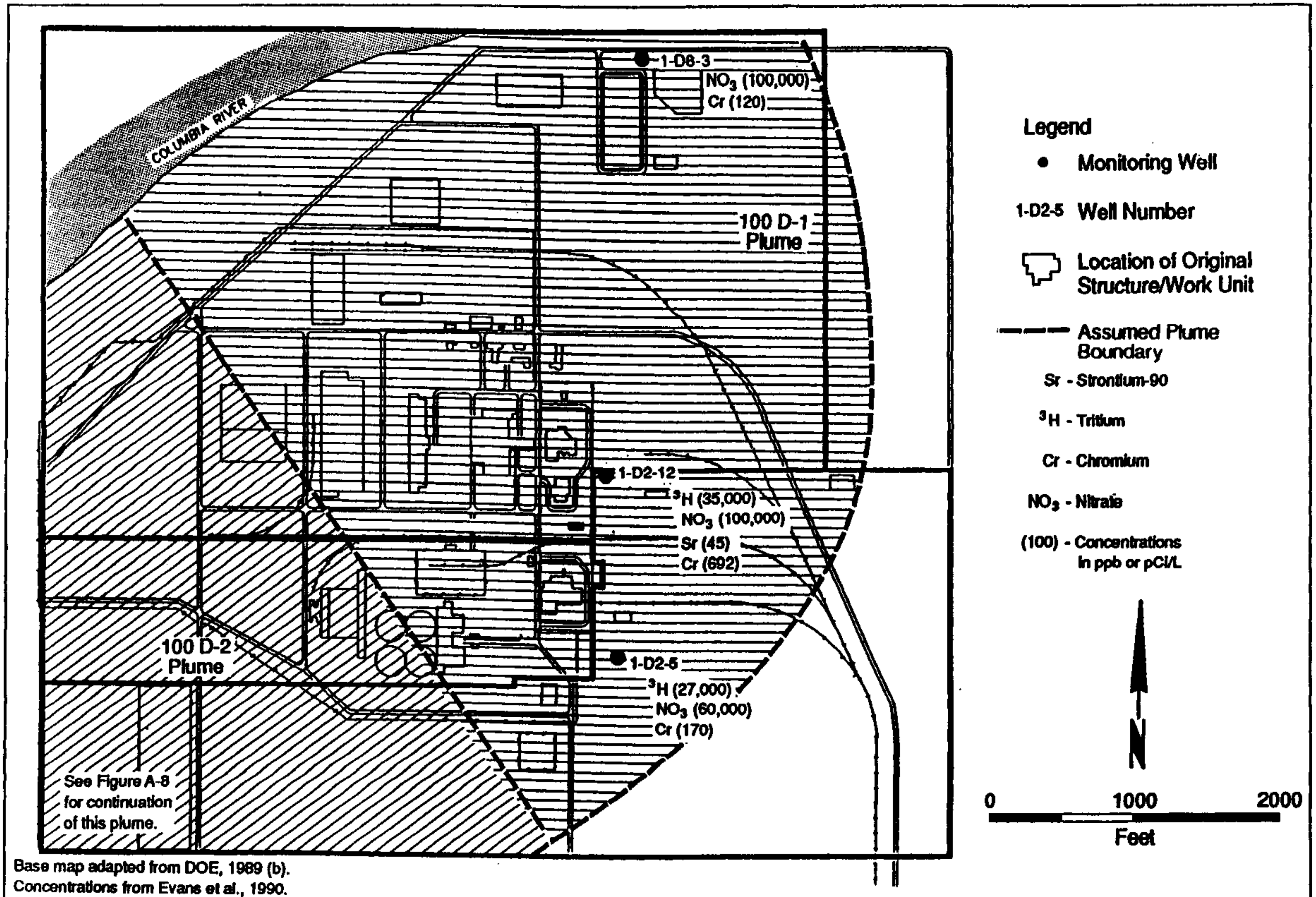

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Figure B-9. 100-D Area Facilities and Groundwater Plumes.

The hydraulic gradient across the 100-H Area has been estimated to range from $4x10^{-4}$ to $1x10^{-3}$ (DOE 1989a). A value of $7x10^{-4}$ and a plume width of approximately 3,000 feet was used for the groundwater discharge analysis. The estimated flow rate was 230 gpm. A rounded-up value of 260 gpm was used for this assessment.

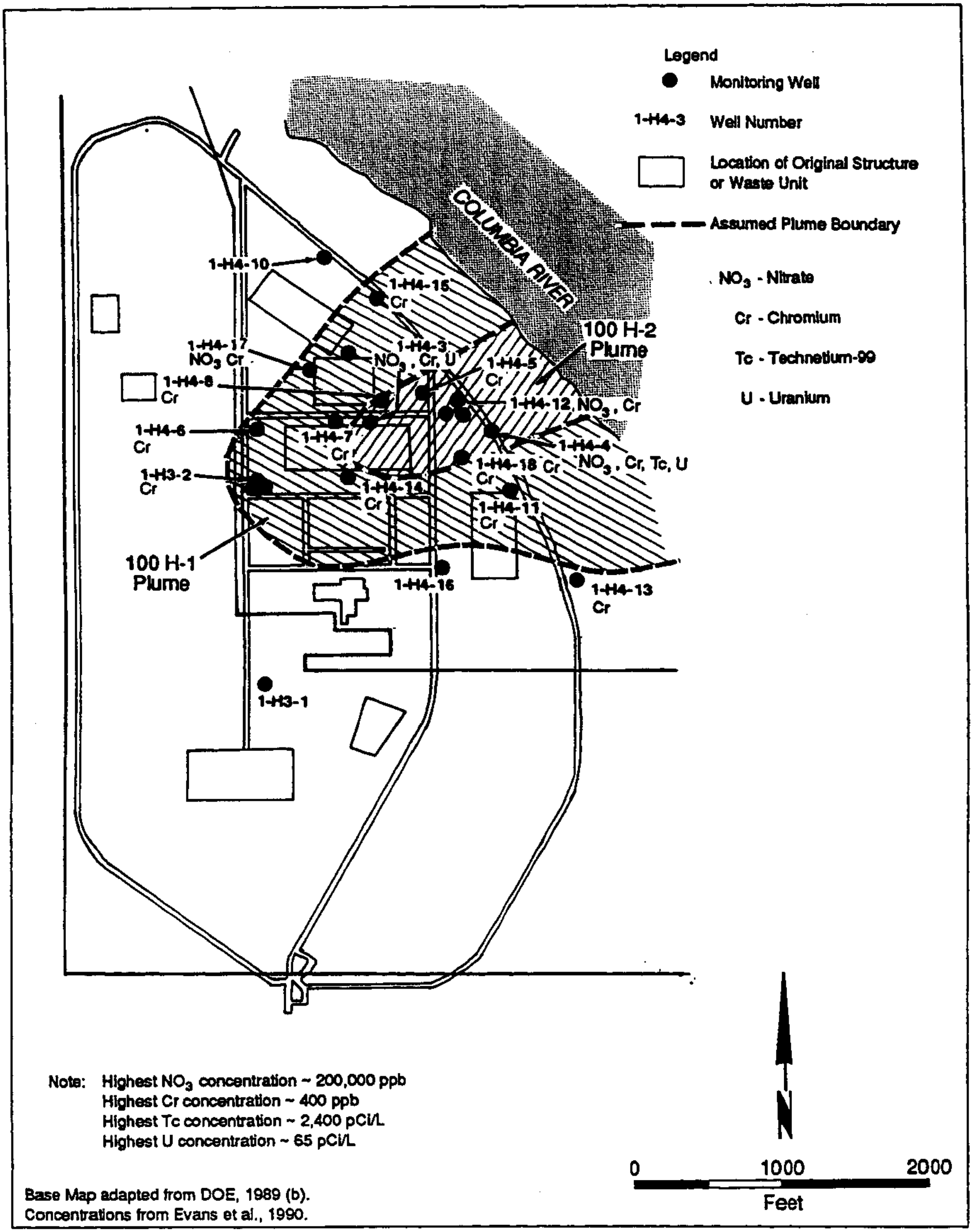
As noted on Figure B-10, only a portion of the 100-H plume contains technetium-99 and uranium. Assuming that the technetium-uranium plume is 700 feet wide, only 54 gpm of the plume will require treatment for these constituents. Conservative values of 60 gpm for the technetium/uranium plume (plume 100H-2) and 200 gpm for the remainder of the nitrate/chromium plume (plume 100H-1) were assumed.

100-F Area

A site plan for the 100-F Area is shown in Figure B-11. Seven wells are located in the 100-F Area. Depth from the ground surface to groundwater beneath the 100-F Area is approximately 40 feet.

Groundwater contaminants that exceed the water quality standards in the 100-F Area include strontium, uranium, and nitrate. (Evans et al. 1990) Wells that exceed water quality standards are indicated on Figure B-11. It is apparent from Figure B-11 that the uranium-nitrate plume (plume 100F-2) is distinct from the strontium plume (plume 100F-1). Although poorly defined due to the lack of wells, the width of both plumes appears to be approximately 1,000 feet.

From Figure B-5 the hydraulic gradient across the 100-F Area was estimated to equal $2x10^{-3}$. Assuming the combined width of both plume was 2,500 feet, the estimated total flow rate was 550 gpm. Rounded-up flow rates of 300 gpm were used for both plumes.



9 3 1 2 7 5 3 1 7 5 2

Figure B-10. 100-H Area Facilities and Groundwater Plumes.

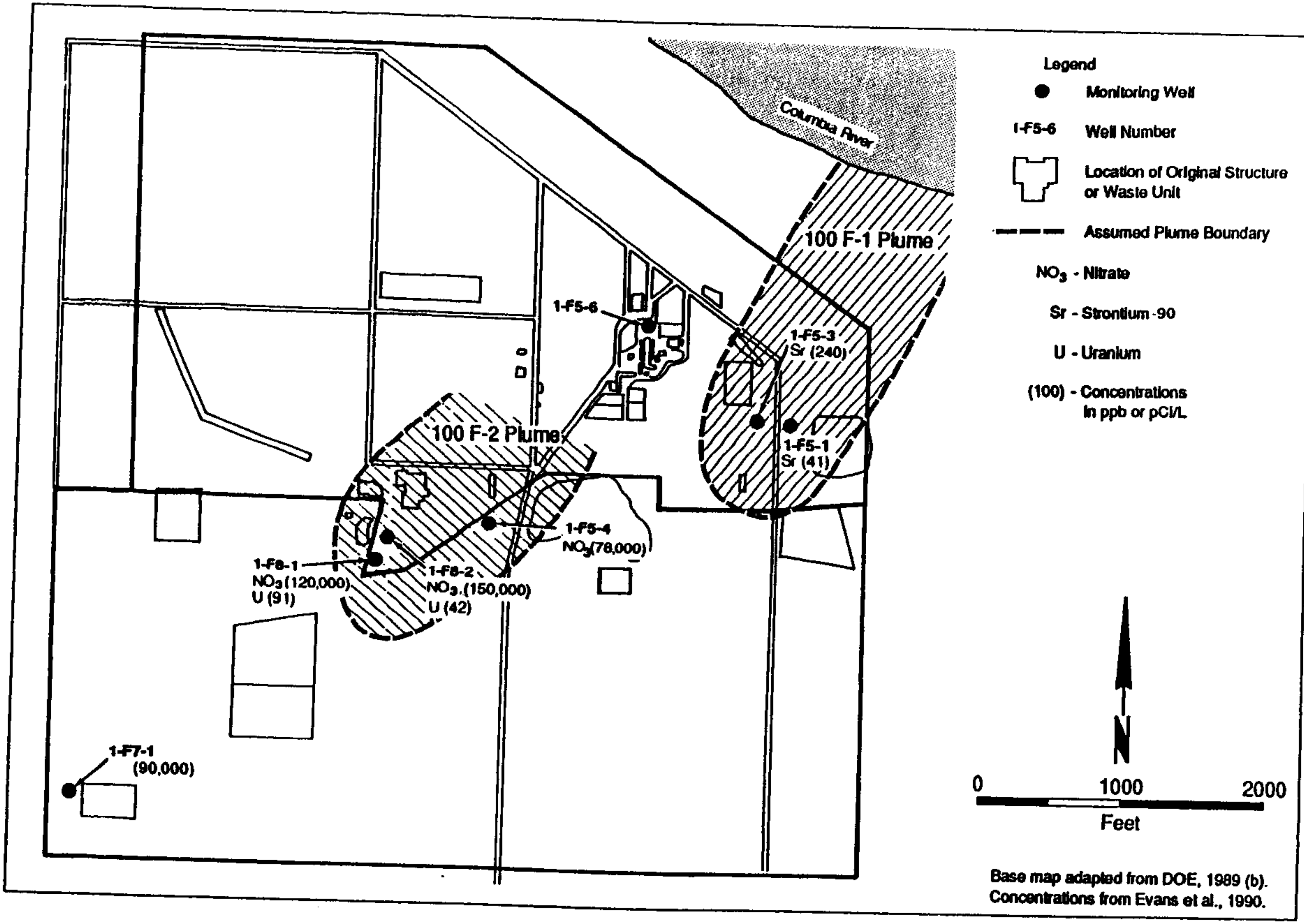


Figure B-11. 100 F Area Facilities and Groundwater Plumes.

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