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Draft A

N Springs Expedited Response Action Proposal

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United States
Department of Energy
Richland, Washington

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N Springs Expedited Response Action Proposal

Date Published
August 1993

United States
Department of Energy
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EXECUTIVE SUMMARY

The release of large volumes of water to 1301-N and 1325-N liquid waste disposal facilities (LWDF) at the 100 N Area caused contaminants, principally strontium-90 (Sr-90), to be carried toward the Columbia River through the groundwater. Since shutdown of the N Reactor, releases to the LWDF have been discontinued. The contamination is transported to the river as a result of the natural groundwater movement. The contaminated groundwater at N Springs flows into the river through seeps and springs along the river's edge. This expedited response action (ERA) is an interim action proposed to eliminate or significantly reduce the flux of Sr-90 to the river.

The principal objective of the N Springs ERA proposal is to evaluate alternatives and recommend an alternative that best meets the selection criteria as prescribed by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), including a demonstration of cost effectiveness. The methodology used for evaluation, cost analysis, and alternative recommendation is the engineering evaluation/cost analysis (EE/CA). Because final remediation of the contaminated groundwater beneath the 100 N Area is not a principal objective of the ERA, there is some flexibility in the scope of the ERA and the degree to which reduction of Sr-90 flux to the river is achieved. The objective of the EE/CA is to identify an ERA system which optimizes the degree of benefit produced for the costs incurred. The purpose of this ERA proposal is to document information concerning alternatives in sufficient detail to select an action for N Springs. Following selection of the alternative, a design phase will be conducted. This design phase will investigate design parameters and costs of the selected alternative in more detail. In addition, some field testing or treatability testing will be conducted to aid in the design of the ERA.

Results from groundwater monitoring programs indicate that the principal contaminants in the groundwater downgradient of the 1301-N and 1325-N cribs are Sr-90 and tritium. Other radionuclides are also present, but these are below release limits. The most recent N Springs monitoring data (1991) indicate that the maximum Sr-90 concentrations occur at well N-8T at levels ranging from 2,900 to 11,000 pCi/L with an average of 6,500 pCi/L. Tritium levels ranged from 4,000 to 400,000 pCi/L with an average of 50,000 pCi/L in this well for 1991 (Schmidt et al. 1992).

The primary objective of the N Springs ERA is to eliminate or significantly reduce the flux of Sr-90 to the Columbia River through the N Springs. For purposes of this evaluation, significant reduction is considered to be at least 50% of the Sr-90 concentration exceeding 1,000 pCi/L. A secondary objective of the ERA is to implement a removal action which will be compatible with future remedial actions planned for the operable unit and will contribute to the efficient performance of the remedial action to be taken.

For those alternatives which include extraction of contaminated groundwater, the objective is to treat the water to maximum contaminant levels (MCL) as prescribed in the Safe Drinking Water Act regulations (40 CFR 141) prior to disposal. Tritium is the exception because treatment for removal of tritium is currently unavailable. Disposal of

tritiated water may require a waiver of applicable or relevant and appropriate requirements (ARAR).

The screening of removal action technologies and process options eliminates technologies and process options which do not meet the ERA screening criteria. The following factors are used for this screening analysis (EPA 1987):

- protectiveness
- timeliness
- technical feasibility
- institutional considerations.

Based on screening against these criteria, technologies and process options that pass are assembled into four alternatives as follows:

Alternative 1 - No action (This alternative serves as a baseline for comparison with other alternatives.) Continued groundwater monitoring and access control.

Alternative 2 - Pump and treat (includes the following process options for water extraction, water treatment, and treated water disposal) (The purpose of this alternative is to intercept the groundwater plume.)

- Pumping Options:
  - five wells to intercept the majority of contaminated groundwater flowing into the river
  - three wells less closely spaced than the five well option.

- Treatment Options:
  - ion exchange to remove the principal contaminant Sr-90
  - reverse osmosis to remove the principal contaminant Sr-90
  - secondary treatments including filtration to remove suspended solids, evaporation to reduce the volume of secondary liquid wastes, solidification to prepare liquid wastes for disposal, and disposal of solid wastes to the low level waste burial grounds.

- Treated Water Disposal Options: (to dispose of treated water containing tritium)
  - river discharge
  - new N Area crib
  - N Area injection wells
  - new 200 Area crib.

Alternative 3 - Vertical barrier. Slurry wall (2,800 ft long), constructed by deep soil mixing method, to cut off Sr-90 contamination flux to the river

Alternative 4 - Hydraulic control. Upgradient pumping wells (11 wells total) to lower groundwater gradients in the plume thus reducing flux of contamination to the river.

All alternatives include continued groundwater monitoring and access control.

The assembled alternatives undergo a more detailed analysis to select the preferred removal action alternative. Each alternative is evaluated against the following selection criteria (EPA 1987):

- technical feasibility
- cost considerations
- institutional considerations
- environmental impacts.

For purposes of detailed analysis, a project life of 10 years is assumed because the removal action is an interim response until a final remedy is implemented for the 100 N Area operable units. At that point, the ERA system may become a part of the final remedy, although this is not a requirement of the ERA.

Detailed analysis includes hydrogeologic modeling of each alternative. All modeling is based on 1990 data. The no action, the five-well pump and treat, and the slurry wall were modeled using the three-dimensional groundwater flow and transport model PORFLO-3 (Runchal and Sagar 1989). In addition, a capture zone analysis for the three and five-well pump and treat options and hydraulic control alternatives was performed using FLOWPATH, a two-dimensional groundwater flow model. The capture zone analysis determines the percent of the area within the 1,000 pCi/L contour captured following one year of pumping. This analysis allows estimation of the benefit of each alternative in achieving the removal action objectives. Results of this analysis are summarized as follows:

Alternative	Estimated Percent Reduction in Sr-90 Flux to the River
Alternative 1 - No action	0 (Baseline)
Alternative 2 - Pump and treat	
Five pumping wells	75
Three pumping wells	55
Alternative 3 - Vertical barrier	100
Alternative 4 - Hydraulic control	50

The cost estimates that support the evaluations were based on historical Hanford costs for such items as well installation and crib construction and on quotations from vendors on

major systems such as treatment packages and pipelines. The cost estimates are considered to provide a level of accuracy of +50% to -30%. The general approach to costing assumes that remediation systems for N Springs are treated as environmental projects, not as installations of permanent nuclear facilities. In general, the costing assumes that the level of design and system complexity is minimized to provide systems that, while offering quality in construction and implementation, are consistent with the objectives of an ERA.

Present worth cost (capital plus operating and maintenance [O&M] costs for 10 years discounted at 5%) for each alternative is correlated to estimated percent reductions in Sr-90 flux. The result of this analysis is shown graphically in Figure 1. The no action, vertical barrier, and hydraulic control alternatives plot as a single point. However, the pump and treat alternative options plot as a range. Ranges are shown for the three-well and five-well extraction systems. The cost range for each of the pumping options reflects the cost differences in the treated water disposal options and in the treatment options.

Based on analysis of the cost-benefit relationship of Figure 1, several generalizations and conclusions can be reached.

- For the pump and treat options, river disposal appears to be the best choice among all treated water disposal options. The 100 N Area reinjection and the 100 N Area crib disposal option do not offer significant additional benefit for handling tritium but result in substantially greater costs. Further, the benefit of crib disposal and reinjection are considered negative, since either would result in contamination of additional aquifer sediments. Disposal at a 200 Area crib offers better protection of the river but results in further aquifer sediment contamination and greater expense.

- The slurry wall provides maximum reduction of Sr-90 flux; it offers the greatest benefit at the lowest cost. Although the pump and treat costs for the five-well system are comparable (reverse osmosis treatment with river disposal) to the slurry wall, the maximum reduction is lower with the five-well system. Increasing the number of wells or the pumping rates to achieve higher Sr-90 reductions results in greater waste disposal requirements and higher cost than both the proposed five-well system and the slurry wall.

- Hydraulic control offers the lowest cost; however, the uncertainties associated with the hydraulic control alternative are greater than the other alternatives. The modeling shows that upgradient hydraulic control could achieve at best a 50% reduction in Sr-90 flux without drawing the contamination into clean areas and requiring treatment of the extracted water. This reduction could be worse if hydraulic conductivity is higher or if significant flow channels are present.

The alternatives developed in this EE/CA are all technically feasible for use at N Springs. The alternative selected for the N Springs ERA should provide a high degree of protectiveness balanced with acceptable risks and reasonable costs. The slurry wall

alternative is selected because it offers the best tradeoffs of cost, benefit, and project risk for the following reasons:

- Although the slurry wall is not the lowest cost alternative, it is the most cost-effective alternative. For example, it offers complete reduction of the Sr-90 flux to the river for concentrations >1,000 pCi/L at a reasonable cost.

- It is not as sensitive as the other alternatives to the uncertainties associated with aquifer hydrologic properties.

- It offers long-term protection (even beyond the ERA time frame) without incurring O&M costs.

- Treatability studies are not required for a slurry wall although field testing of slurry formulations is required to support the design. A field scale test of the deep soil mixing technology may provide more certainty in the technical feasibility of this technology in the rocky soils of Hanford. Treatability studies would be required for either groundwater treatment option to define Sr-90 removal efficiency and secondary waste generation rates.

- Little or no secondary wastes are generated for the slurry wall using the deep soil mixing method, while the pump and treat alternative generates substantial quantities of wastes requiring disposal.

- Some reduction in tritium flux will be achieved as a result of the flow stagnation zone created behind the wall. In contrast, pump and treat results in accelerated movement of tritium, which must ultimately be disposed to the environment.

- The slurry wall alternative complies most fully with ARAR, while the no action, pump and treat, and hydraulic controls are uncertain.

- Based on performance of previous projects involving the deep soil mixing technology at analogous sites, the technology is considered implementable in Hanford soils for construction of an effective slurry wall.

Therefore, the preferred alternative for the ERA is the slurry wall installed by deep soil mixing method (Alternative 3). Installation requirements will be demonstrated in field testing. The length and location of the wall will be optimized during the design phase of the ERA.

While the slurry wall appears to be the best alternative for the N Springs ERA in terms of cost benefit, it should be noted that all the alternatives have associated uncertainties. These uncertainties include implementation in Hanford soil conditions, hydrogeologic properties, ability to comply with ARAR, and costs. Testing will be required for the slurry wall and pump and treat alternatives prior to more accurately predicting the performance and technical feasibility of the systems. The rocky soils pose an uncertainty in the slurry wall

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ACRONYMS

ALARA	as low as reasonably achievable
amsl	above mean sea level
ARAR	applicable or relevant and appropriate requirements
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
COPC	chemicals of potential concern
DOE	U.S. Department of Energy
DOE/RL	Department of Energy - Richland Operations
DST	double-shell tanks
Ecology	Washington Department of Ecology
EE/CA	engineering evaluation/cost analysis
EPA	U.S. Environmental Protection Agency
ERA	expedited response action
HCRC	Hanford Cultural Resources Clearance
HCRL	Hanford Cultural Resources Laboratory
IRM	interim response measure
FS	feasibility study
LWDF	liquid waste disposal facility
MCL	maximum contaminant level
NCP	National Contingency Plan
NERP	National Environmental Research Park
NPDES	National Pollutant Discharge Elimination System
O&M	operations and maintenance
ORNL	Oak Ridge National Laboratory
RAAS	Remedial Action Assessment System
RAO	removal action objective
RCRA	Resource Conservation and Recovery Act
R&D	research and development
RI	remedial investigation
ROD	Record of Decision
SARA	Superfund Amendments and Reauthorization Act
TBC	to-be-considered
WHC	Westinghouse Hanford Company

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1.0 INTRODUCTION

Since signing the *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) in 1989 (Ecology et al. 1989), the parties to the agreement have recognized the need to modify the approach to conducting investigations, studies, and cleanup actions at Hanford with a goal of maximizing efficiency, optimizing use of limited resources, and achieving cleanup in the earliest possible time frame. To implement this approach, the parties have jointly developed the *Hanford Past-Practice Strategy* (DOE/RL 1991a). The principles of the strategy are embodied in the *Hanford Federal Facility Agreement and Consent Order Change Package* (Ecology et al. 1991).

The strategy provides concepts for undertaking expedited response actions (ERA) and/or interim remedial measures (IRM), as appropriate, to either remove threats to human health and the environment or to reduce risk by reducing the toxicity, mobility, or volume of contaminants. In accordance with this strategy, the U.S. Department of Energy (DOE) proposes to conduct an ERA at the N Springs, located in the Hanford 100 N Area, to eliminate or substantially restrict the strontium-90 (Sr-90) transport into the river through the groundwater pathway.

The N Springs ERA is part of the Senior Executive Committee Agreement on resolution of the Tri-Party Agreement Milestone M-14 Change Request Dispute dated January 8, 1993 (Ecology et al. 1993). The N Springs ERA is a joint agreement by the parties to the Tri-Party Agreement. The purpose of this ERA proposal is to provide sufficient information to select a preferred alternative at N Springs. The nature of an ERA requires that alternatives developed for the ERA be field ready; therefore, all the technologies proposed for the ERA should be capable of addressing the circumstances at N Springs. A comparison of these alternatives is made based on protectiveness, cost, technical feasibility, and institutional considerations to arrive at a preferred alternative. Following the selection of an alternative, a design phase will be conducted; the design phase will include a detailed look at design parameters, performance specifications, and costs of the selected alternative. Testing will be conducted as required to generate design data.

1.1 BACKGROUND

Past practices in the 100 N Area have resulted in contamination of the soils and underlying groundwater in the reactor vicinity. The release of large volumes of water to the 1301-N and 1325-N liquid waste disposal facilities (LWDF) at the 100 N Area caused contaminants, principally Sr-90, to be carried toward the Columbia River through the groundwater. Since shutdown of the N Reactor, the releases to the LWDF have been discontinued. The contamination is transported to the river as a result of the natural groundwater movement. The contaminated groundwater at N Springs flows into the river through seeps and springs along the river's edge. Once in the river, the contamination is rapidly diluted to very low levels. Nevertheless, N Springs represents a significant pathway for Sr-90 releases into the river, and potential threats to human health and the environment exist as a result of exposure to the contaminated water in the immediate vicinity of the

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N Springs. The ERA is proposed to eliminate or substantially reduce the flux of Sr-90 migration into the river. This ERA meets the criteria as defined in the *Hanford Past-Practice Strategy* (DOE/RL 1991a) and as detailed in the *Site Selection Process for Expedited Response Actions at the Hanford Site* (Gustafson 1991). The ERA will be conducted as a non-time-critical removal action under the regulatory authority as defined in 40 CFR 300.415 and as described in the *N Springs Expedited Response Action Project Plan* (WHC 1992).

In accordance with the past practice strategy and the requirements of removal actions under 40 Code of Federal Regulations (CFR) 300.415, the ERA does not necessarily constitute the final remedial action for the 100 N Area operable unit(s), but will, to the extent practicable, contribute to the efficient performance of the final remedial actions with respect to the contaminant release(s). In accordance with 40 CFR 300.415(i), removal actions shall, to the extent practicable considering the exigencies of the situation, attain applicable or relevant and appropriate requirements (ARAR).

The principal objective of the N Springs ERA proposal is to evaluate alternatives and recommend a single alternative that best meets the selection criteria as prescribed by Comprehensive Environmental Response, Compensation, and Liability Act of (CERCLA), including a demonstration of cost effectiveness. The methodology used for evaluation, cost analysis, and alternative recommendation is referred to as an engineering evaluation/cost analysis (EE/CA). Because final remediation of the contaminated groundwater beneath the 100 N Area is not a principal objective of the ERA, there is some flexibility in the scope of the ERA and the degree to which reduction of Sr-90 contamination to the river is achieved. The EE/CA, which is conducted as part of the ERA proposal preparation, attempts to identify an ERA system which optimizes the degree of benefit produced for the costs incurred.

1.2 SCOPE

The scope of the ERA proposal is to identify, screen, and compare removal action alternatives that eliminate or substantially reduce the flux of Sr-90 to the river. The end product of the proposal is a recommended cost effective alternative that meets the ERA objectives. The proposal includes information sufficient to select an alternative. Additional information concerning costs and performance specifications will be collected during the design phase.

2.0 SITE DESCRIPTION

This section provides a background discussion of the 100 N Area physical setting and the nature and extent of contamination to be addressed by the N Springs ERA.

2.1 PHYSICAL SETTING

The Hanford Site lies within the semiarid Pasco Basin of the Columbia Plateau in southeastern Washington state. The Hanford Site occupies an area of about 560 mi^2 (1,450 km^2) north of the confluence of the Snake and Yakima Rivers with the Columbia River. The Columbia River flows through the northern part of the Site and, on turning south, forms the eastern Site boundary. Rattlesnake Mountain, the Yakima Ridge, and Umtanum Ridge form the southwestern and western boundaries while the Saddle Mountains form the northern boundary of the Hanford Site. Two small east-west trending ridges, Gable Mountain and Gable Butte, rise above the plateau of the central part of the Hanford Site. The cities of Richland, Pasco, and Kennewick (Tri-Cities) are the nearest population centers to the Hanford Site. (See Figure 2-1.)

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The subsections below describe the physical setting of the N Springs area, including both a discussion of the natural characteristics of the site and the human-induced influences on the site.

2.1.1 Location

The N Springs are a series of springs and seeps located along the southern edge of the Columbia River in and adjacent to the 100 N Area (Figure 2-2). The N Springs ERA site is located west and north of the 1301-N and 1325-N cribs and is bordered by the Columbia River, the 100 N Area, and the 600 Area. The N reactor (and associated support facilities), located in the 100 N Area, was operated as a dual production reactor (plutonium and by product steam for electricity generation) from 1963 until 1987. The city of Richland is approximately 27 air or 38 river mi (43 air or 61 river km) south of the 100 N Area. The N Springs are included in the 100-NR-2 Operable Unit.

2.1.2 Topography

Elevations within the N Springs ERA site range from approximately 387 ft (118 m) above mean sea level (amsl) along the river to approximately 490 ft (150 m) amsl in unimproved areas. The land surface surrounding the 1301-N and 1325-N LWDF is approximately 460 ft (140 m) amsl.

2.1.3 Meteorology and Air Quality

The Hanford Site weather is monitored at the Hanford Meteorology Station and at remote stations throughout the Site. Station 13 of the Hanford Telemetry Network is located in the 100 N Area.

The climate of the Hanford Site is semiarid and is greatly affected by the Cascade Mountains to the west. The Hanford Site receives an average of 6.3 in. (16 cm) of precipitation annually. The precipitation falls mainly in the winter months, with nearly half of the annual precipitation falling between November and February. Precipitation of 0.5 in. (1.3 cm) or more falling within a 24-hour period occurs only twice per year on the average. Instances of 1.0 in. (2.5 cm) or more of precipitation within a 24-hour period are infrequent, with only four occurrences between 1946 and 1980 (Cushing 1991).

Winter monthly average snowfall varies from 5.3 in. (13.5 cm) in January to 0.3 in. (0.8 cm) in March. The record snowfall of 24.4 in. (62 cm) occurred in February 1916. During the months of December through February, snowfall accounts for about 38% of all precipitation (Cushing 1991).

The average annual relative humidity between 1946 and 1980 was 54.4%. Humidity is higher in winter months than during the summer (Cushing 1991).

The Cascade mountains serve as a source of cold air drainage and have a considerable effect on the winds at Hanford. The gravity drainage, plus topographic channeling, results in northwest to west-northwest prevailing wind directions. The average mean monthly speed for the period 1945 to 1980 was 7.7 mi/h (12.4 km/h) with monthly means ranging from 6.1 mi/h (9.8 km/h) in December to 9.2 mi/h (14.8 km/h) in June (Stone et al. 1983). Peak gust speeds range from 63 to 80 mi/h (101 to 129 km/h) and are generally southwest to west-southwest winds (Stone et al. 1983).

Daily maximum and minimum temperatures range from an average of 36°F (2°C) in January to 95°F (35°C) in late July. There are, on average, 55 days during the summer months with maximum temperatures greater than 90°F (32°C). From mid-November through mid-March, minimum temperatures average less than 32°F (0°C) with the minimum in early January averaging 21°F (-6°C). The record maximum temperature is 115°F (46°C) and the record minimum is -27°F (-32.8°C) (Cushing 1991).

The actual annual evapotranspiration under current conditions for the Hanford Site is estimated to be 6.1 in. (15.5 cm) (Bauer and Vaccaro 1990).

2.1.4 Soils

Hajek (1966) lists and describes 15 different soil types on the Hanford Site, ranging from sand to silty sandy loam. Soils in the 100 N Area are described as either a sandy or stony loam. The sandy loam described by Hajek (1966) as surface soil is dark colored, while subsoil is dark-grayish-brown, medium textured, underlain by gravelly material. The

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stony loam is described as similar to the sandy loam; however, the stony loam contains gravel to boulder-sized debris released from melting glaciers.

2.1.5 Geology

The Hanford Site is located in the Pasco Basin which is within the Columbia-Snake River physiographic province (Hunt 1974). The following is a brief discussion of the geologic characteristics of the 100 N Area. More detailed discussions of the geologic characteristics of the Hanford Site and 100 N Area may be found in DOE/RL (1991b), DOE (1988), and WHC (1987a and b).

The stratigraphy of the 100 N Area is shown in Figure 2-3. Stratigraphically, the area is underlain by the Columbia River Basalt Group, the Ringold Formation, and the Hanford formation. Only the Ringold Formation and Hanford formation have direct relevance to this ERA proposal. The following geologic descriptions are taken from the *RCRA Facility Investigation/Corrective Measures Study Work Plan for the 100-NR-2 Operable Unit* (DOE/RL 1992b) and *Geology of the Hanford Site: An Outline of Data Sources and the Geologic Setting of the 100 Areas* (Lindsey 1992).

2.1.5.1 Ringold Formation. Regionally, the Ringold Formation is divided into five units, A through E (Lindsey 1992). Only units A, C, and E are present beneath the 100 N Area. The Ringold Formation unconformably overlies the Saddle Mountains Basalt of the Columbia River Basalt Group in the 100 N Area. The formation is approximately 470 to 480 ft (143 to 146 m) thick in the area. The Ringold Formation has been subdivided into three informal units in the 100 N Area. These units are designated Ringold units 1, 2, and 3 (DOE/RL 1992b).

The Ringold unit 3 is a relatively coarse-grained sandy pebbly gravel that may be weakly indurated with scattered pedogenic calcium carbonate zones. The unit is 18 to 65 ft (5.5 to 20 m) thick in the 100 N Area (DOE/RL 1992b).

The Ringold unit 2 overlies the Ringold unit 3 and is approximately 380 ft (115 m) thick. The Ringold unit 2 is further subdivided into subunits a, b, and c, which are differentiated based on lithologies and depositional environments. The Ringold unit 2c is composed of fine-grained material, such as clays, clayey silts, and silty clays. Ringold unit 2c is approximately 100 to 150 ft (30 to 46 m) thick in the 100 N Area. Ringold unit 2b consists of sandy silts and silty sands with interbedded clay-rich zones and rare gravelly zones. Ringold unit 2b is approximately 175 to 250 ft (53 to 76 m) thick in the 100 N Area. Ringold unit 2a is composed of clayey silts, silty clays, and silts that may also contain pedogenic calcium carbonate zones and horizons. Unit 2a ranges between 10 and 50 ft (3 and 15 m) thick in the 100 N Area (DOE/RL 1992b). In the recently drilled well 199-N-80, unit 2a is 16 ft thick.

The Ringold unit 1 consists of light-tan, interbedded sands and gravels. Lithologic logs indicate that a cemented horizon may be present in the upper portion of this unit; however this horizon does not appear to be laterally continuous in the 100 N Area. Within

the 100 N Area, the Ringold unit 1 is approximately 42 to 65 ft (13 to 20 m) thick. The contact between the Ringold Formation and the Hanford formation is at approximately 395 to 420 ft (120 to 128 m) elevation. Three cross sections were constructed across the 100 N Area and are shown in Figures 2-14, 2-15, and 2-16 in the 100-NR-2 work plan (DOE/RL 1992b). These cross sections show the degree of variability that can be found in the upper portion of the Ringold Formation and the Hanford formation. Ringold unit 1 can be distinguished from the overlying Hanford formation based on sand composition. Ringold unit 1 sands are tan and are derived primarily from metamorphic rocks and siliceous crystalline rocks; the Hanford sands are black and gray and derived from basaltic rocks.

2.1.5.2 Hanford Formation. The Hanford formation overlies the Ringold Formation and is composed of interbedded sands, gravels, and cobbles of the Pasco Gravels. The finer-grained Touchet beds are not present in this area. The Hanford formation is a poorly sorted gravelly sand to sandy gravel. Pedogenic calcium carbonate deposits are present in portions of this unit. Coarse-grained gravels appear to be present in the upper portions of the unit with sandy gravels and gravelly sands in the lower portion. Occasional calcium carbonate cemented zones occur within the gravels but do not appear to be laterally continuous. The Hanford formation is approximately 65 ft (20 m) thick in the 100 N Area. Surficial eolian deposits locally overlie the Hanford formation in the 100 N Area in areas undisturbed by construction activities (DOE/RL 1992b).

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2.1.6 Hydrogeology

2.1.6.1 Groundwater. The conceptual hydrogeologic column for the 100 N Area is shown in Figure 2-3. The figure correlates geologic unit designations with hydrogeologic units. The hydrogeologic system beneath the 100 N Area consists of underlying confined aquifers and associated confining layers within the Saddle Mountains Basalt and Ringold Formation; the unconfined aquifer, which is primarily within the Ringold unit 1, but may contain the lower portion of the Hanford formation; and the vadose zone. Detailed discussions of the regional hydrogeology may be found in DOE (1988); discussion of the 100 N Area hydrogeology is included in DOE/RL (1992b).

The primary regional recharge area for the hydrogeologic system is along the ridges surrounding the Pasco Basin. The primary regional discharge area is along the Columbia River (DOE 1988). The confined aquifer system has an upward vertical gradient which continues into the unconfined aquifer. However, locally this gradient may be reversed due to influences such as Columbia River stage changes and liquid waste disposal activities. Recently completed wells in the N Springs area suggest that the vertical gradient is variable due to Columbia River stage fluctuations affecting both the unconfined and upper confined aquifers. Over a 4-mo period in early 1993, the gradient changed from down to up and then back to down.

2.1.6.1.1 Ringold Confined Aquifers. The uppermost confined unit is the Ringold Confined Aquifer "B" (Figure 2-3). The unit corresponds to the Ringold Formation unit 2b. No site-specific hydrologic data are available for this unit. Reported hydraulic conductivity

values for the Ringold Formation range from 0.1 to 7,000 ft/day (3.0×10^{-2} to 2.2×10^{3} m/d) (DOE/RL 1992b).

The Ringold Confined Aquifer "B" is confined by the Ringold Confining Unit "B". The unit corresponds to Ringold Formation unit 2a and consists of fine-grained material including clayey silts, silty clays, and silts that may also contain carbonate cementation. The layer ranges in thickness from 10 to 50 ft (3 to 15 m). In recently drilled well 199-N-80 the unit is 16 ft (4.9 m) thick. No hydraulic data are available for this confining unit, but the clay and silt are expected to restrict both horizontal and vertical flow in the 100 N Area (DOE/RL 1992b). Although it appears that the Ringold Confining Layer "B" is present throughout the area, additional drilling may be necessary to determine its extent and thickness in the N Springs area.

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2.1.6.1.2 Unconfined Aquifer. The unconfined aquifer is located in the silt, sand, gravel, and cobbles of the Ringold unit 1. Locally, the lower portion of the Hanford formation may also be included. The contact between the Ringold and Hanford formations may be irregular due to erosion from catastrophic flooding that deposited the Hanford formation. The erosional areas and subsequent Hanford formation deposits may provide zones of higher conductivity and thus provide preferential pathways for groundwater and contaminant flow.

Regionally, the unconfined aquifer is recharged by infiltration of rainfall and runoff from the higher bordering elevations as well as infiltration from small ephemeral streams on the ridges to the south and west of the Hanford Site. The Columbia River recharges the unconfined aquifer along portions of the aquifer adjacent to the river during periods of high river stage. The unconfined aquifer is also recharged from the confined aquifer system where an upward gradient occurs. Artificial recharge at the Hanford Site occurs primarily from the LWDF. Observed natural recharge rates from precipitation vary from 0.4 to 4 in/yr (1 to 10 cm/yr) or more (Gee 1987).

The unconfined aquifer discharges to the Columbia River. The discharge rate is variable and is dependent on the river stage. During high river stage, bank storage occurs, resulting in either lowering of the gradient near the river or, at times, gradient reversal.

The liquid waste disposal activities to the 1301-N and 1325-N LWDF reportedly resulted in groundwater mounds beneath the facilities as much as ten feet above the natural groundwater levels (DOE/RL 1992b). Water levels in the unconfined aquifer have declined and returned to nearly natural levels since cessation of liquid waste disposal to the 1301-N and 1325-N LWDF. Water levels for the 100 N Area measured during June and October 1992, at high and low Columbia River stages, are shown in Figures 2-4 and 2-5. Water levels in the unconfined aquifer are influenced by daily and seasonal fluctuations in river level. Daily river level changes correlate with water level changes in wells 750 ft (230 m) from the shoreline and approximately 1,000 ft from the shoreline during seasonal river level changes (Gilmore et al. 1991). The hydraulic gradient in the area unaffected by river stage is approximately 0.001 ft/ft.

A number of aquifer tests have been completed in 100 N Area wells. Results of the tests are summarized in Table 2-4 in DOE/RL (1991b). Estimated transmissivities from wells near the two LWDF range from 6,770 to 27,000 ft^2/d (536 to 2,508 m^2/d). Estimates of hydraulic conductivities range from 290 to 1,300 ft/d (89 to 395 m/d) (Golder 1990). Connelly et al. (1991) developed a three-dimensional model for the N Springs area. The model calibration showed that a hydraulic conductivity of 220 ft/d (67 m/d) was the "best fit" average for the unconfined aquifer (Ringold/Hanford Producing Layer "A").

2.1.6.1.3 Vadose Zone. The vadose zone in the 100 N Area vicinity is within the Hanford formation. The vadose zone consists of poorly sorted boulders, cobbles, gravels, sands, and silts. Perched water was noted during drilling of one well near 116-N-3; no other perched water was encountered during drilling activities.

Connelly et al. (1991) collected soil samples from the unsaturated zone for estimating saturated hydraulic conductivities for the vadose zone. These estimates ranged from 1.4 to 170 ft/d (0.43 to 52 m/d). Connelly et al. (1991) compared these field test values with values obtained from Brown and Rowe (1960) and Pratt (1985). Connelly et al. (1991) determined that a vertical saturated hydraulic conductivity value of 3 ft/d (1 m/d) was representative of the vadose zone soils in the area surrounding the LWDF. Effective porosities were estimated to range from 9% to 44% (Connelly et al. 1991).

2.1.6.2 Surface Water Hydrology. The Columbia River forms the northwest border of the N Springs area. Flow in the Columbia River is relatively swift and straight in the vicinity of 100 N Area. While the Columbia River is free flowing over this reach, the flow is regulated upstream by Priest Rapids Dam. River levels may change as much as 5 ft (1.5 m) daily. A more complete description of the surface water hydrology is presented by Cushing (1991). Recorded flow rates of the Columbia River have ranged from approximately 158,000 to 635,600 ft^3/s (4,500 to 18,000 m^3/s) during spring and early summer runoff to approximately 35,300 to 158,900 ft^3/s (1,000 to 4,500 m^3/s) during the low flow period of late summer and fall. The average annual Columbia River flow in the Hanford Reach, based on 65 yr of record, is about 120,000 ft^3/s (3,400 m^3/s). A minimum flow of 36,000 ft^3/s (1,020 m^3/s) is maintained along the Hanford Site.

The maximum recent flood occurred in 1948 with an observed peak discharge of 706,280 ft^3/s (20,000 m^3/s). The Columbia River flood potential has been reduced along the Hanford Reach due to the construction of several water storage/flood control dams upstream of the site (Cushing 1991). There are no Federal Emergency Management Agency floodplain maps for the Hanford Reach. The opposite side of the Columbia River is the primary floodplain for the river. The 100 N Area is built approximately 60 ft (21 m) above the average river level, thereby reducing the potential for flooding in the area.

River stage changes affect groundwater levels and gradients. Gilmore et al. (1991) completed a study in the N Springs area in which seasonal river stage changes were identified as far as 1,000 ft (300 m) from the river shore. Short term, daily river-level fluctuations were correlated with water level changes in wells approximately 750 ft (230 m) from the river shore. Gilmore et al. (1991) also reported that during high-river stage, a

reversal in the groundwater gradient occurs. River shore springs and seeps are the visible groundwater discharge points.

2.1.7 Biological Resources

Biological resources that are likely to be present at the ERA site have been divided into the following categories: vegetation, wildlife, threatened and endangered species, and sensitive or critical habitats. Each of these is discussed below.

2.1.7.1 Vegetation. The Hanford Site has been botanically characterized as shrub-steppe (Daubenmire 1970). The characteristic plant communities present in the 100 Area are cheatgrass-tumble mustard, sagebrush/cheatgrass or Sandberg's bluegrass, sagebrush-bitterbrush/cheatgrass, and willow-riparian vegetation near the Columbia River shoreline (Cushing 1991). Cheatgrass is prevalent in the 100 Area because of the extensive perturbation of the soils in the area.

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Plants likely to be present in the 100 Area include gray rabbitbrush *(Chrysothamnus nauseosus)*, cheatgrass *(Bromus tectorum)*, tumbleweed *(Salsola kali)*, yarrow *(Achillea millefolium)*, yellow salsify *(Tragopogon dubius)*, false yarrow *(Chaenactis douglasii)*, and tumble mustard *(Sisymbrium altissimum)* (Cushing 1991; DOE/RL 1991b).

2.1.7.2 Wildlife. Of the approximately 39 species of mammals that have been recorded at the Hanford Site, most are small and nocturnal. The Great Basin pocket mouse *(Perognathus parvus)* is the most common. Muskrats *(Ondatra zibethicus)* and porcupines *(Erithizon dorsatum)* have been observed along the shorelines of streams, ponds, and ditches; beavers *(Castor canadensis)* occupy the sloughs along the Columbia River (Cushing 1991). Mule deer *(Odocoileus hemionus)* and raccoons *(Procyon lotor)* are also found or are likely to exist along the Columbia River.

Approximately 187 species of birds have been observed on the Hanford Site (Cushing 1991). The horned lark *(Eremophila alpestris)* and western meadowlark *(Sturnella neglecta)* are the most abundant nesting birds in the shrub-steppe vegetation type. Chinese ring-necked pheasants *(Phasianus colchicus)* and California quail *(Callipepla californicus)* are likely to be found near the Columbia River (Cushing 1991). The Columbia River provides a major nesting area for migrant waterfowl, such as ducks and geese. The most important resident waterfowl is the Canada goose *(Branta canadensis moffitti)*, which rests on the islands of the river. The Hanford Site is located in the Pacific Flyway for migrating bird species; in addition, a major sandhill crane flyway passes over the site (Cushing 1991).

Twelve species of reptiles and amphibians are known to occur on the Hanford Site (Cushing 1991). The side-blotched lizard *(Uta stansburiana)* is the most abundant reptile found at the site. Toads (family: *Bufonidae*) and frogs (family: *Ranidae*) are found along the Columbia River (DOE/RL 1991b).

Of the 44 species of fish that have been identified in the Hanford Reach of the Columbia River, four species use the river as a migration route to and from upstream

spawning areas: the chinook salmon *(Oncorhyncus tshawytscha)*, sockeye salmon *(oncorhyncus nerka)*, coho salmon *(Oncorhyncus kisutch)*, and steelhead trout *(Oncorhyncus mykiss)*. A fifth anadromous species, the shad *(Alosa sapidissima)*, may also use the Hanford Reach to spawn (Cushing 1991).

2.1.7.3 Threatened and Endangered Species. Four species of plants that are listed by the federal government as candidate threatened or endangered species and by the state of Washington as either threatened or endangered could be present in the 100 Area:

- Persistentsepal yellowcress (*Rorippa columbiae*): endangered (state), candidate (federal)
- Northern Wormwood (*Artemisia campestris* ssp. *borealis* var. *wormskioldii*): endangered (State), candidate (federal)
- Columbia milk-vetch (*Astragalus columbianus*): threatened (state), candidate (federal)
- Hoover's desert parsley (*Lomatium tuberosum*): threatened (state), candidate (federal).

To date, none of these species has been reported as occurring in the 100 N Area (Cushing 1991; Sackschewsky 1992; DOE/RL 1992a).

There are several species of birds that are listed by either the federal government or the state of Washington as threatened or endangered that could occur as migrants within the 100 Area:

- Aleutian Canada goose *(Branta canadensis leucopareia)*: endangered (federal and state)
- Peregrine falcon *(Falco peregrinus)*: endangered (federal and state)
- Bald eagle *(Haliaeetus leucocephalus)*: threatened (federal and state)
- White pelican *(Pelecanus erythrorhychos)*: endangered (state)
- Sandhill crane *(Grus canadensis)*: threatened (state)
- Ferruginous hawk *(Buteo regalis)*: threatened (state).

None of these species is known to nest or roost in the 100 N Area (Cushing, 1991). However, bald eagle roosting locations exist at the 100-D and 100-K Areas, and nesting sites have been observed near the 100-F Area (Fitzner and Weiss 1992).

One threatened mammal species, the pygmy rabbit (*Sylvilagus idahoensis*), was once known to exist west of the 200 Area but has not been observed in the 100 Area (DOE/RL 1992a).

2.1.7.4 Sensitive or Critical Habitat. Biological surveys conducted in 1991 and 1992 did not identify any sensitive or critical habitat (habitat that is essential to the support or continuance of a threatened or endangered species) in the area of the proposed ERA (Sackschewsky 1992).

Wetlands habitat exists in the riparian zone that borders the Columbia River. The riparian zone supports stands of willows, grasses, aquatic macrophytes, and other plants. The wetlands along the river are impacted by seasonal and dam-controlled fluctuations in water level.

Alternatives developed as part of this ERA have assumed placement of the alternative to avoid impact to the 100-yr floodplain. The 100-yr floodplain was estimated using a discharge for the river of 440,000 ft^3/s (12,500 m^3/s). This is the most recent Corps of Engineers estimate for events in the Hanford Reach. This flow rate would result in a zone of flooding to approximately 392 ft (120 m) amsl. The actual placement of the removal system affects both the effectiveness and the cost of the alternative. Factors to be considered include the topography and subsequent surface preparation for system installation, depth to the confining layer, equipment mobility and stability, as low as reasonably achievable (ALARA) practices (area near the river is designated as a radiation zone), legal considerations, and amount of residual contamination in the zone between the removal system and the river. These factors will be more fully analyzed in the design phase of the ERA. Figure 2-6 is a cross-sectional view of the riverbank at the N Springs ERA site.

2.1.8 Cultural Resources

The Hanford Site contains numerous, well-preserved archaeological sites representing both the prehistoric and historic periods. The Hanford Reach has been occupied by Native Americans for more than 10,000 yr. The river shores contain extensive archaeological deposits (Chatters 1989).

The following Indian tribes have dwelt along or utilized the Hanford Reach for fishing:

- Wanapum and Chamnapum band of the Yakima tribe
- Palus
- Walla Walla
- Umatilla.

Certain landmarks on the Hanford Site, including sites and cemeteries along the Columbia River, are sacred to the Native Americans. Also, certain plant resources that are used in ceremonial activities may be present on the Hanford Site.

Historic resources dating from the 1860's and later at the Hanford Site are represented by remains of homesteads, farm fields, ranches, abandoned U.S. Army installations, gold mine tailings, and the following recorded historic locations (Cushing 1991):

- Allard Pumping Station at Coyote Rapids
- Hanford Irrigation Ditch
- Hanford townsite
- Wahluke Ferry
- White Bluffs townsite
- Richmond Ferry
- Arrowsmith townsite
- East White Bluffs ferry landing
- White Bluffs road
- Old Hanford High School
- Cobblestone Warehouse at Riverland.

The most recent historic sites are the defense reactors and materials processing facilities that have been constructed since World War II.

The 100 N Area is situated on an archaeologically rich segment of the Columbia River shoreline. Within 1.2 mi (2 km) of the area perimeter on the south bank are five recorded sites. Two pithouse village sites and a cemetery comprise the Ryegrass Archaeological District. A fourth site is part of the Hanford Generating Plant Site. All of the sites are either listed in or considered eligible for inclusion in the National Register of Historic Places (Chatters et al. 1990). In addition, two other cairn (or rock pile) sites have been recorded in the upland area east of N Springs. These two sites are considered to be at risk from CERCLA characterization studies (Chatters et al. 1992).

The double-fenced compound of the 100 N Area has been investigated and cleared of cultural resources concerns (Cushing 1991). This means that no known sites of Native American religious or ceremonial significance, or sites included in the National Register of Historic Places, exist within the compound itself. No sites have been recorded along the stretch of riverbank adjacent to the N Springs.

In preparation for this ERA, a cultural resources review was conducted for the N Springs area. The Hanford Cultural Resources Laboratory (HCRL) found no cultural resources in the proposed project area and gave the site a clearance number (HCRC #92-100-032).

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2.1.9 Visual Resources

The landscape in the vicinity of the Hanford Site is generally flat with little relief. Rattlesnake Mountain, Gable Mountain, and Gable Butte are the highest landforms within the site. The White Bluffs above the northern boundary of the river are a striking feature of the landscape. The Columbia River, flowing adjacent to the 100 N Area, provides a visual source of enjoyment to people. Also, desert flowers blooming in the spring provide an aesthetically pleasing resource (Cushing 1991).

The ERA site is adjacent to the Columbia River. The terrace slopes to the east of the N Springs range up to 460 ft (140 m) high. While the 100 N compound itself might not be considered a pleasing visual resource, the combined aspects of river and plateau downstream from the compound could be considered a source of visual enjoyment.

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2.1.10 Land and Water Use

The entire Hanford Site has been designated a National Environmental Research Park (NERP) (Cushing 1991). The 100 Area in general, and particularly the 100 N Area, are not open for use by the public. Land use at the N Springs site along the river is negligible. The majority of any current land use would probably be associated with 100 N Area operations and with environmental monitoring and characterization activities.

The Columbia River is a source of recreational opportunity, especially on the lakes formed by the dams. Because the reach adjacent to the 100 N Area is free-flowing and relatively swift, the recreational use of the river would be limited to adequate power boating, hunting, and fishing, where permitted.

2.2 NATURE AND EXTENT OF CONTAMINATION

A detailed description of the sources, occurrence, and concentration of contaminants at the N Springs ERA site is presented below.

2.2.1 Sources

The two major sources for the contamination released in the N Springs area are the 1301-N and 1325-N LWDF, consisting of cribs and their associated trenches. These cribs are discussed below.

2.2.1.1 1301-N (116-N-1) Liquid Waste Disposal Facility. The 1301-N crib and trench were used between 1964 and 1985 for disposal of liquids from the operation of the 100 N Reactor. The facility made use of the natural filtration and adsorptive properties of the soil to remove the radioactive constituents from the discharged water. The crib is 290 ft (88 m) long, 125 ft (38 m) wide, and approximately 12 ft (3.7 m) deep. The walls of the crib are sloped and covered with soil and gravel. A 3-ft (1-m) layer of boulders was placed

in the crib. The zig-zag shaped extension trench extends for 1,600 ft (490 m) and is 50 ft (15 m) wide and 12 ft (3.7 m) deep. Precast concrete panels were placed over the crib and trench to minimize wildlife access and airborne contamination (DOE/RL 1992b).

The liquid wastes disposed to the 1301-N crib and trench were generated from the reactor coolant system, spent fuel storage basin, periphery coolant systems, laboratories, and radioactive drain systems in the reactor facility. The average flow rate to the facility was 2,100 gal/min (7,900 L/min) during reactor operations (DOE/RL 1992b).

The cumulative inventory (accounting for decay as of January 1988) of selected radionuclides disposed to the crib and trench is presented in Table 2-1. Table 2-1 also lists the dangerous wastes disposed to the facility. Strontium-90 discharges to the 1301-N LWDF through 1990 are listed on Table 2-2. Tritium, a product of the nuclear reaction, was a major contaminant released to the LWDF.

The 1301-N crib and trench is currently classified as a Resource Conservation and Recovery Act (RCRA) interim status dangerous waste disposal facility. The DOE prepared a draft closure and post-closure plan (WHC 1987a) for submittal to the Washington Department of Ecology (Ecology). A new closure and post-closure plan is to be submitted on May 1994, in accordance with milestone M-20-31 of the Tri-Party Agreement (Ecology et al. 1990).

The EPA issued a National Pollutant Discharge Elimination System (NPDES) permit for the 1301-N facility. The permit requires routine monitoring of discharges to the Columbia River by way of N Springs.

2.2.1.2 1325-N (116-N-3) Liquid Waste Disposal Facility. The 1325-N LWDF was constructed as a replacement for the 1301-N LWDF and first received liquid wastes from N Reactor in 1983. Between 1983 and September 1985, both facilities received N Reactor wastes. In September 1985, all flow was diverted to the 1325-N facility. The crib is 250 ft (76 m) long, 240 ft (73 m) wide, and provides 60,000 ft^2 (5,600 m^2) of percolation area. A 3,000-ft (910-m) extension trench was constructed to provide additional operating capacity. The trench is 55 ft (17 m) wide and 7 ft (2 m) deep, and is covered by precast concrete panels to prevent access by wildlife (DOE/RL 1992b).

The liquid wastes disposed to the 1325-N crib and trench were the same as those disposed to 1301-N. The average flow rate to the 1325-N facility was 450 gal/min (1,700 L/min) (Connelly et al. 1991).

The cumulative inventory disposed to the 1325-N facility, accounting for decay through September 1985, is listed on Table 2-3. This table also lists an estimate of dangerous wastes disposed to the facility. Strontium-90 discharges to the 1325-N LWDF through 1990 are listed on Table 2-2. Major discharges were discontinued to this facility in January 1987 when the N Reactor was placed on standby. Small discharges continued until 1991. The crib and trench are not currently receiving any liquid wastes.

The 1325-N LWDF is a RCRA interim status waste disposal facility. As with the 1301-N LWDF, a closure and post-closure plan was prepared by DOE (WHC 1987b) and submitted to Ecology. A new closure and post-closure plan is to be submitted in May 1994, according to the Tri-Party Agreement Milestone M-20-31 (Ecology et al. 1990).

2.2.2 Soil Contaminants

Soil contamination resulted from N Reactor liquids being disposed to the 1301-N and 1325-N LWDF. As the liquids traveled through the vadose zone, radioactive contaminants sorbed onto the soils beneath the LWDF. Retention of radionuclides in the soils is highly variable, ranging from nearly complete retention for cesium-137 (Cs-137) to no retention for tritium. Strontium-90 retention is intermediate between these two.

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Robertson et al. (1984) conducted a study to determine the migration of radionuclides from the 1301-N LWDF to the N Springs. In this study, wells 199-N-9, 199-N-12, and 199-N-13 were installed to the water table, north of the 1301-N LWDF at distances of approximately 100, 150, and 240 ft (30, 46, and 73 m). Drill cuttings were collected and analyzed for radionuclides. In addition, gamma-ray logging tools were run in the wells. Results of the study showed that very low concentrations of radionuclides, such as cobalt-60 (Co-60), Cs-137, antimony-125 (Sb-125), and ruthenium-106 (Ru-106), were present in well N-9 above the water table. The concentrations increased markedly at the water table. Wells 199-N-12 and 199-N-13 had lower concentrations in the unsaturated zone, but also had higher concentrations at the water table. This study indicates that extensive lateral migration of radionuclides from the LWDF within the vadose zone did not occur during the liquid disposal period. This study, which also addresses the selective removal of radionuclides in the soil column, concludes that the cationic and particulate species are retained in the soil column and the anionic and nonionic species are transported more freely to and within the groundwater. While this study did not address Sr-90 specifically, the results should also be indicative of Sr-90 concentrations in the area. With the cessation of liquid disposal, it is estimated that very high concentrations of radionuclides remain in the soil column between the surface and the groundwater. These contaminants are sorbed onto the soil and the only transport medium for these contaminants is the small amount of precipitation recharge which is occurring from 0.4 to 4 in/yr (1 to 10 cm/yr) (Gee 1987)

Additional discussions of soil contamination can be found in the *RCRA Facility Investigation/Corrective Measures Study Work Plan for the 100-NR-1 Operable Unit* (DOE/RL 1991b).

2.2.3 Groundwater Contaminants

Groundwater contamination within the N Springs area is primarily the result of liquid waste disposal to the 1301-N and 1325-N LWDF. Neither LWDF is in use any longer; discharges to 1301-N and 1325-N were halted in 1985 and 1991, respectively. As stated in Section 2.2.1, many of the radionuclides disposed to these facilities have remained adsorbed to the soils and are found only in low concentrations in the groundwater. An example of this

is Cs-137, where a combined inventory of 2,650 ci (decayed to 1985) have been disposed to the two LWDF and the maximum concentration in groundwater (6.68 pCi/L, well 199-N-8S) is significantly below the DOE release limit of 120 pCi/L. Adsorption and desorption of radionuclides to the soil particles and groundwater has not been specifically studied for the N Springs area, but certainly occurs. Concentrations of radionuclide in the groundwater are also affected by radioactive decay. Radioactive decay halflives for Sr-90 and tritium are 28.1 and 12.3 yr respectively.

Representative groundwater analyses are listed in Table 2-4. Samples from these wells were collected during December 1991 and January 1992 as a part of the 1301-N and 1325-N RCRA groundwater monitoring programs.

The 1301-N and 1325-N LWDF are currently under RCRA indicator evaluation monitoring (detection monitoring) programs (Hartman 1993). Results from these monitoring programs indicate that no hazardous chemical constituents are present in the groundwater. Radionuclides, primarily Sr-90 and tritium, are present in the groundwater at significant concentrations. Lesser amounts of other radionuclides are also present, but are below regulatory and DOE release limits. Concentration maps for Sr-90 and tritium are presented on Figures 2-7 through 2-10. Figures 2-7 and 2-8 are based on groundwater sampling conducted in February 1990. Figures 2-9 and 2-10 are based on sampling conducted in February 1993. Comparisons of Figures 2-7 and 2-9 indicate that Sr-90 concentrations have declined near the 1325-N LWDF and have remained steady in the groundwater beneath the 1301-N LWDF and N Springs. Two new wells, N-75 and N-76 were installed in 1992 between the 1301-N LWDF and the Columbia River to supplement the RCRA groundwater monitoring program. It should be noted that there is approximately one order of magnitude difference in concentrations between these two wells. Both wells have been sampled three times and results are consistent. The reason for this is unknown but may be related to localized differences in the adsorptive and desorptive characteristics of the soils in the area. Tritium values for these wells do not show this large difference (Figure 2-10). The declining Sr-90 concentrations in the vicinity of the 1325-N LWDF may be due to the flushing of the saturated soils with noncontaminated groundwater, an overall lower inventory of Sr-90 in the soils, and, to a lesser extent, radioactive decay.

Figures 2-8 and 2-10 show that tritium concentrations have declined in the vicinity of the 1325-N LWDF, have remained steady near the 1301-N LWDF, and have increased near wells N-14 and N-41. Tritium is a nonretarded radionuclide and travels at the same rate as the groundwater. The groundwater flow direction is northerly except near the river as shown on Figures 2-4 and 2-5.

A sulfate plume is present along the western edge of the area. This plume is the result of discharge to the 1324-NA percolation pond. Sulfate is a non-regulated constituent. Elevated concentrations of sulfate are present in samples collected from well 199-N-3 (DOE/RL 1992b).

Discharges of radioactively contaminated groundwater into the Columbia River occur from small springs and seeps along the riverbank. Water samples have been collected

annually from wells placed in adjacent springs and seeps which discharge to the river. Average results of these analyses for the period from 1985 to 1991 are shown on Figure 2-11.

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Figure 2-1. Hanford Site

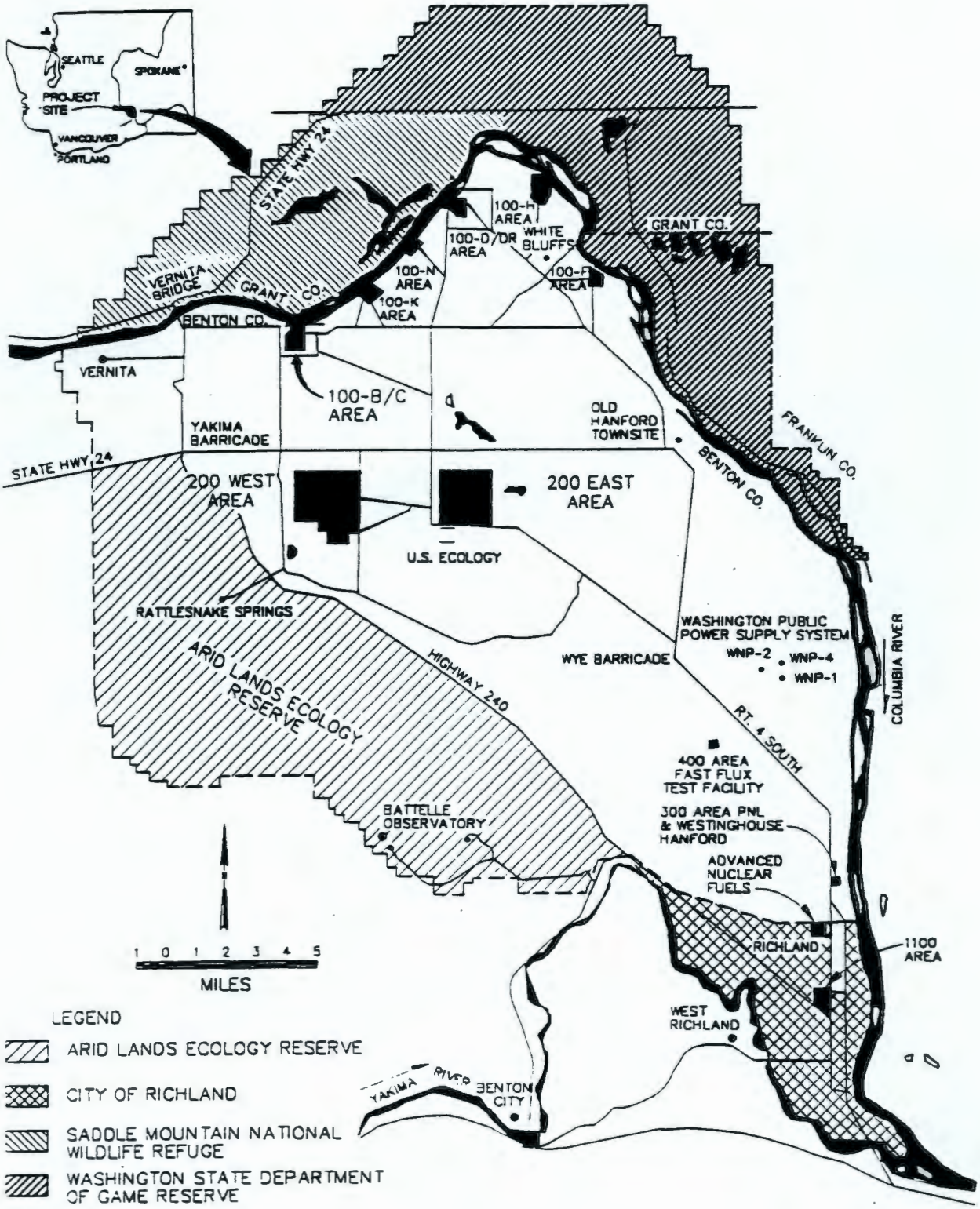

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Figure 2-2. N Springs ERA Site Location

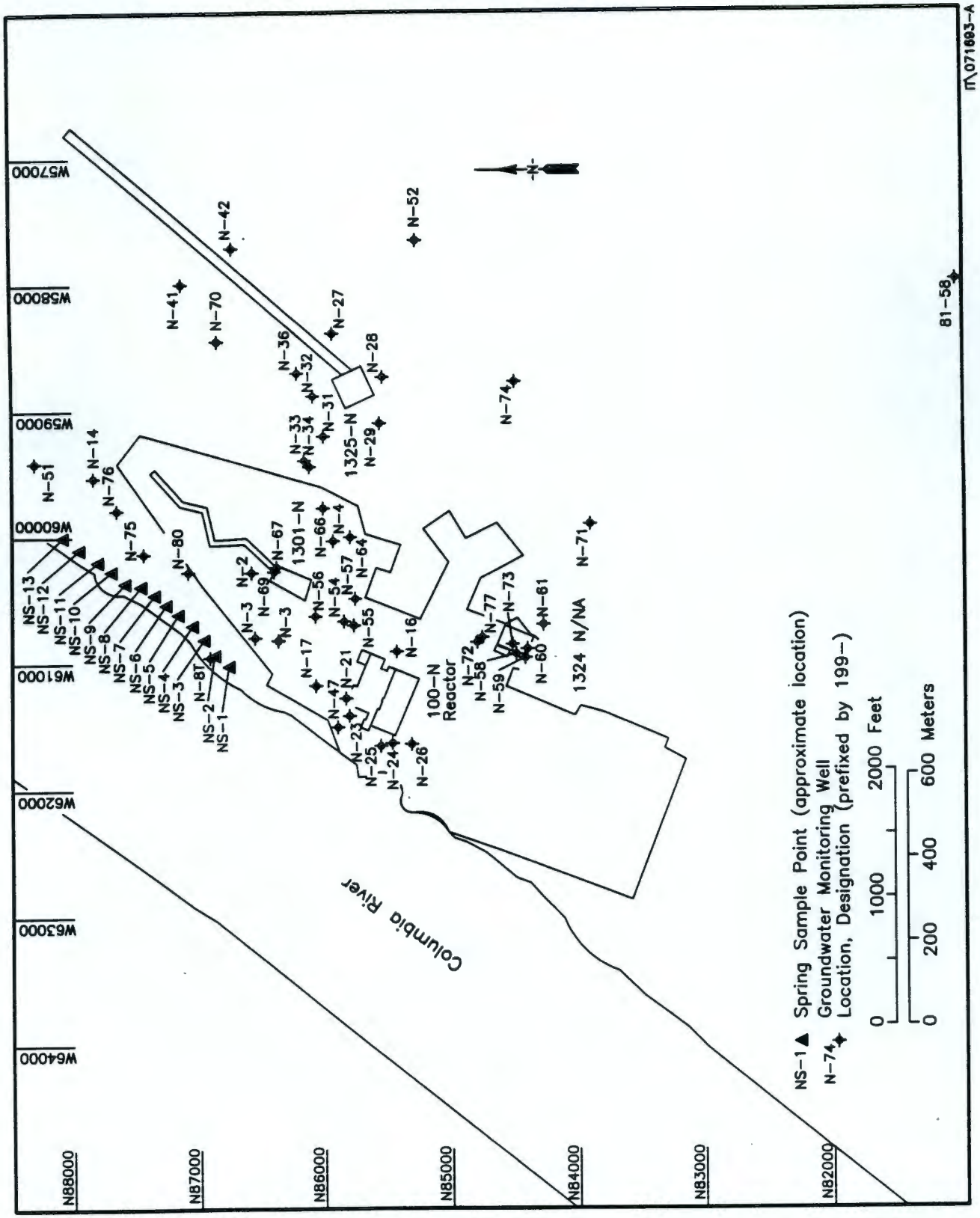

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Figure 2-3. Conceptual Geologic and Hydrogeologic Column

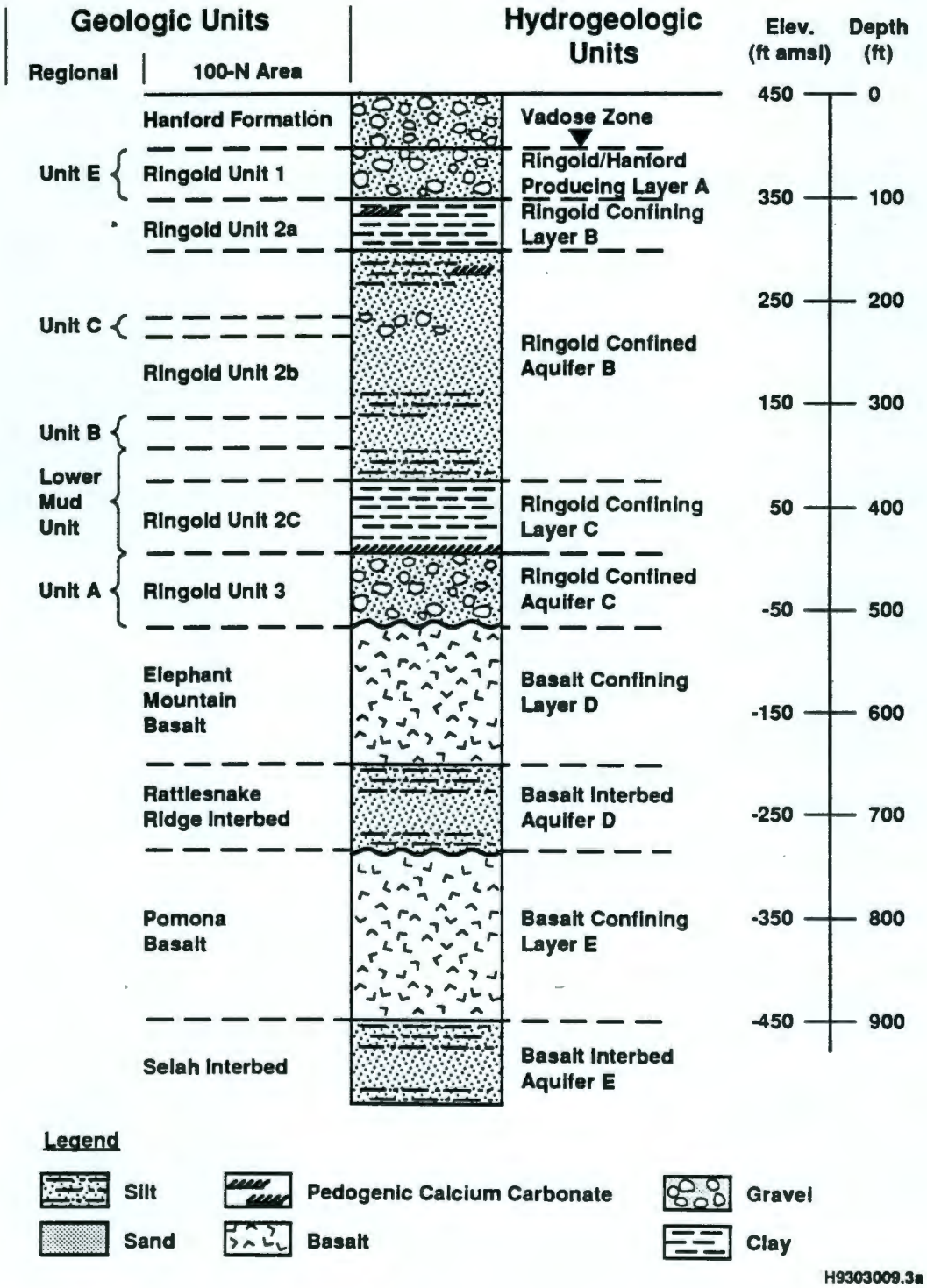

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Figure 2-4. 100 N Area Water Table - June 1992

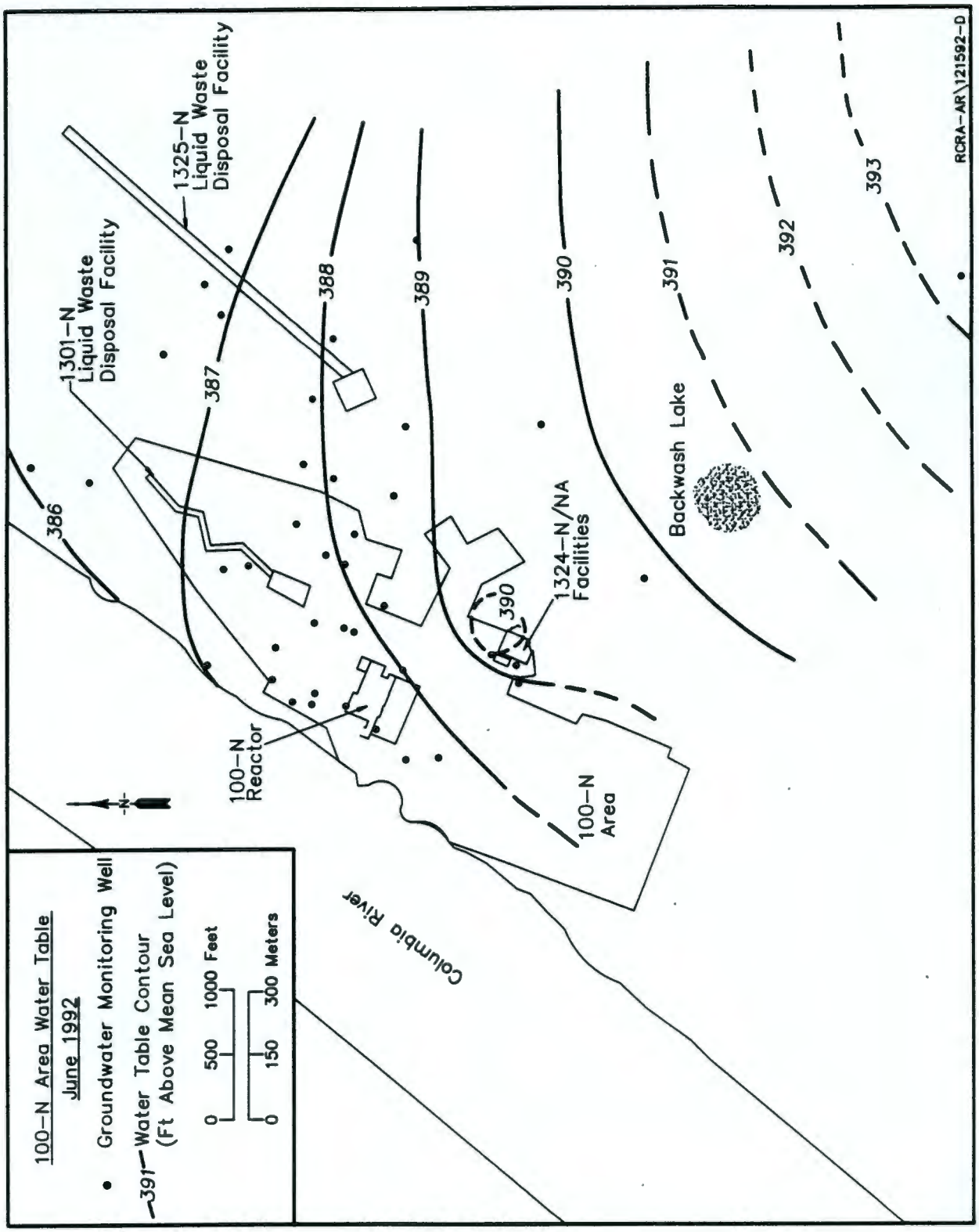

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Figure 2-5. 100 N Area Water Table - October 1992

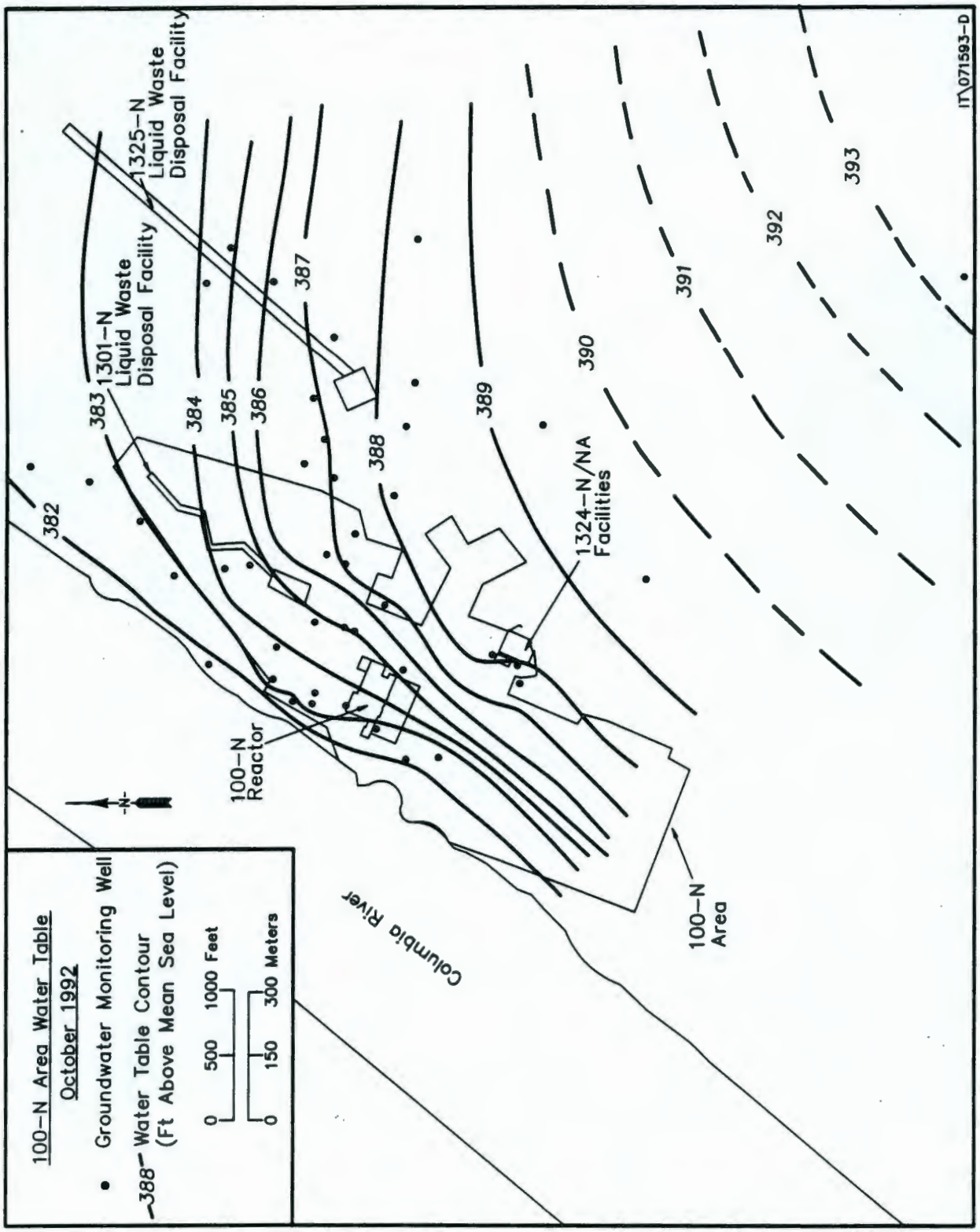

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Figure 2-6. N Springs Riverbank Cross Section

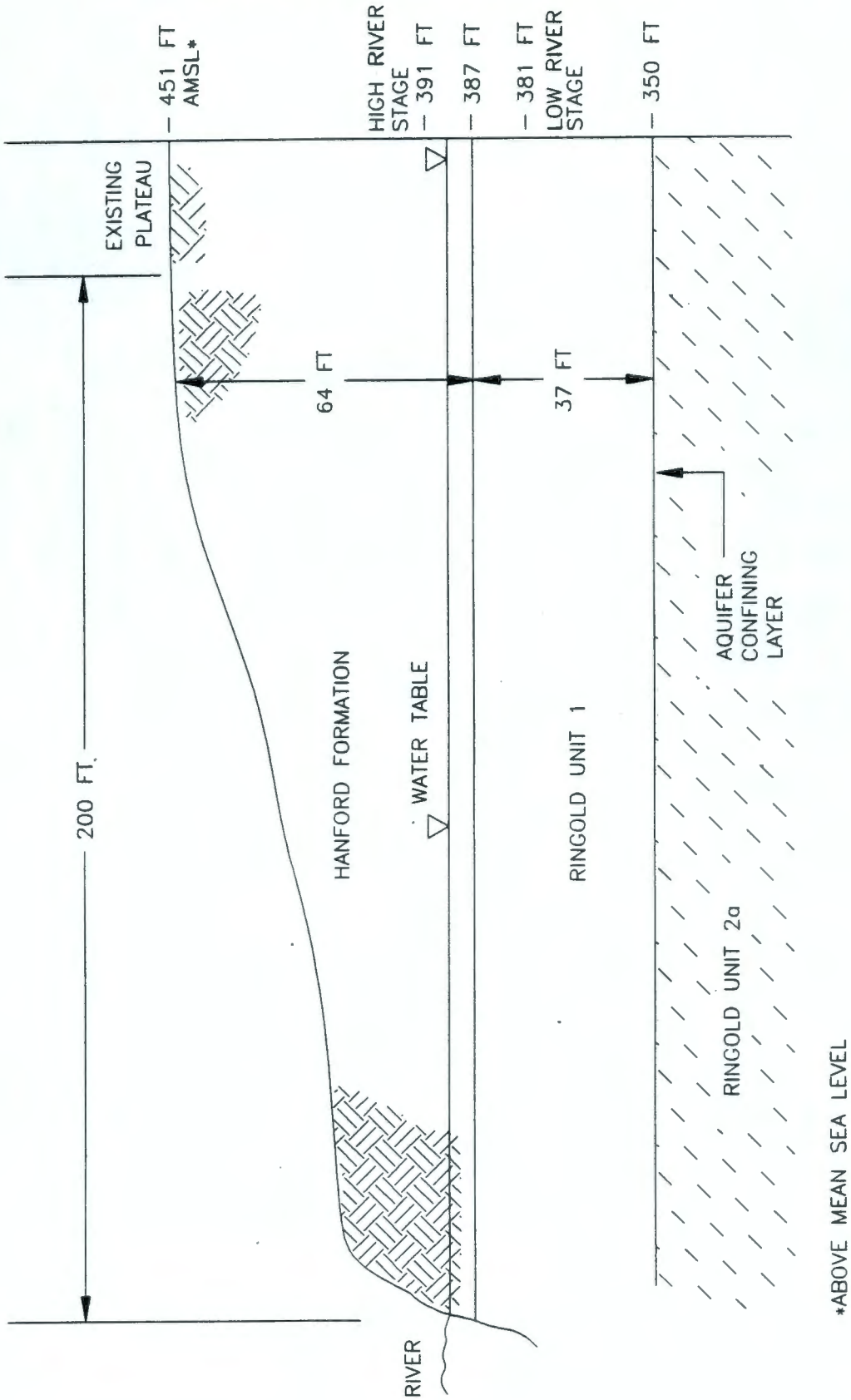

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Figure 2-7. Strontium-90 Activity in 100 N Area Groundwater During February 1990

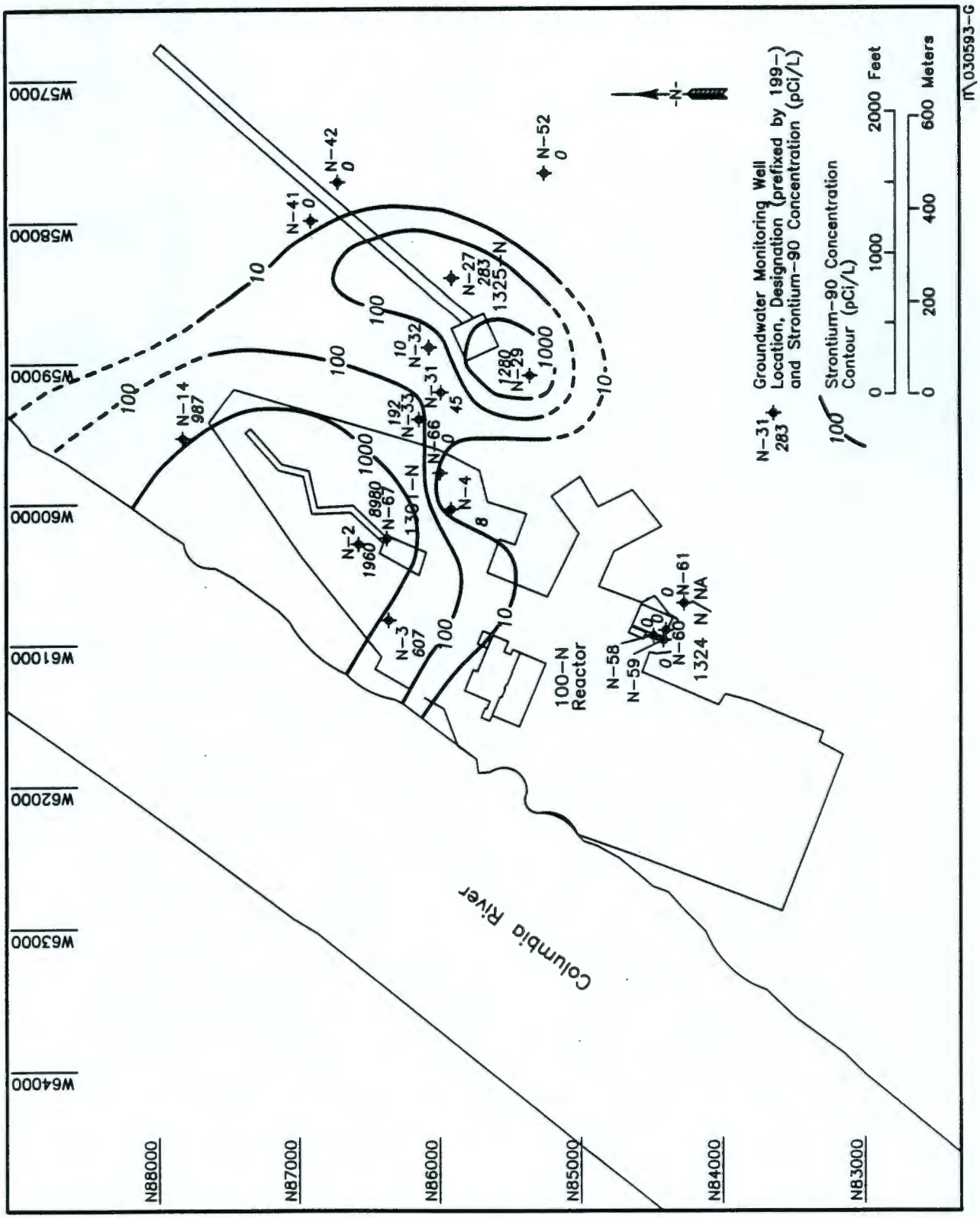

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Figure 2-8. Tritium Activity in 100 N Area Groundwater During February 1990

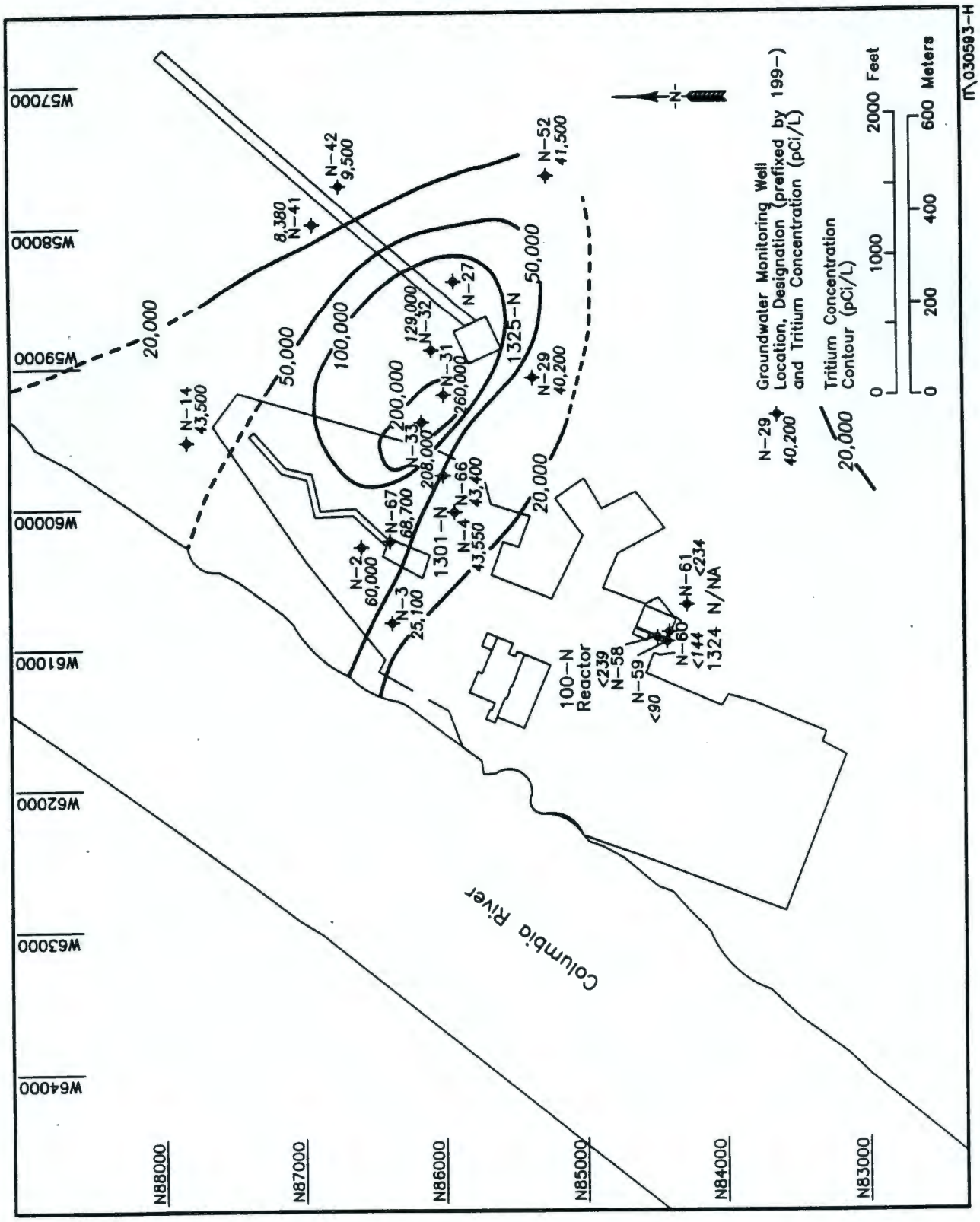

Figure 2-9. Strontium-90 Activity in the 100 N Area Groundwater During February 1993

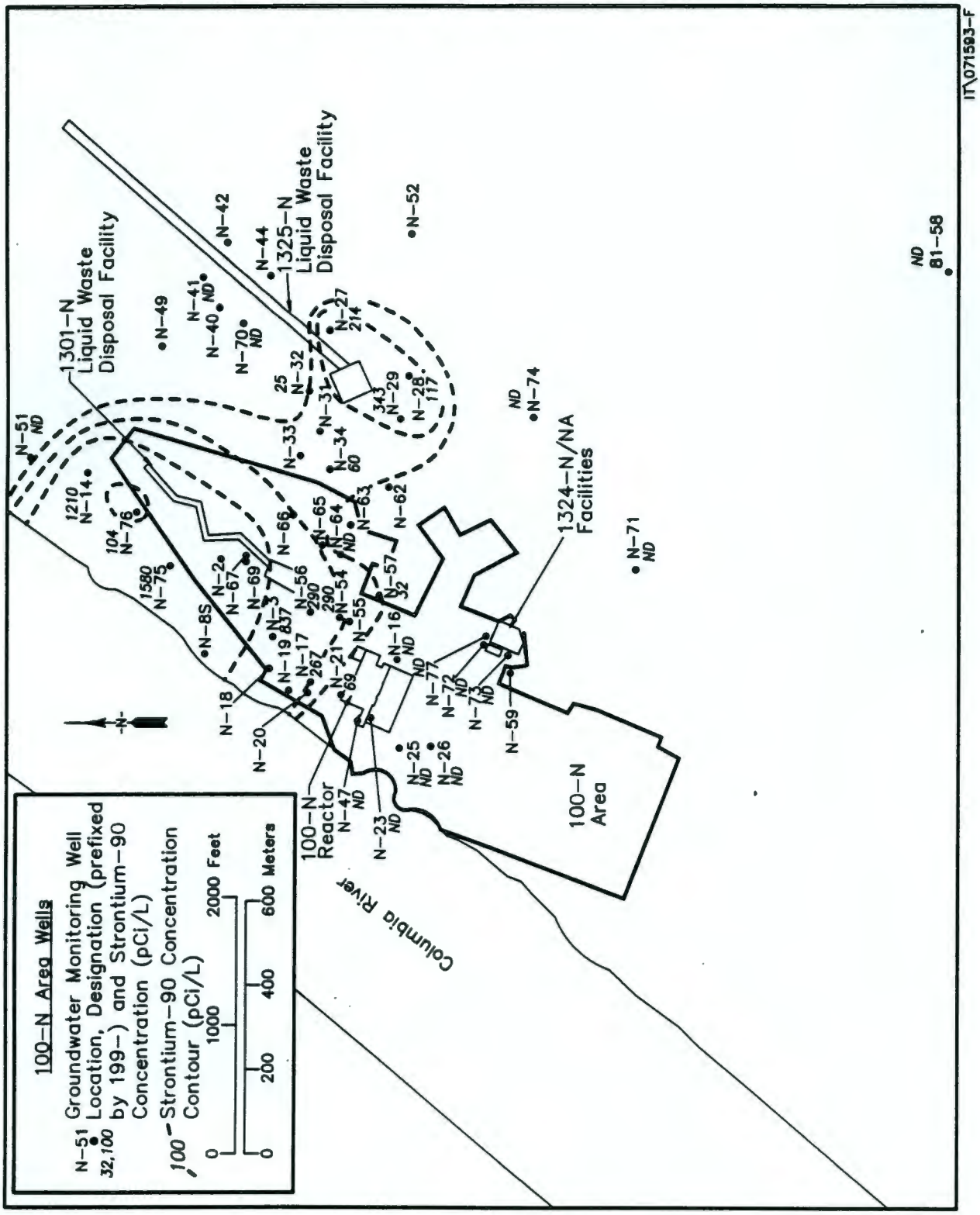

Figure 2-10. Tritium Activity in the 100 N Area Groundwater During February 1993

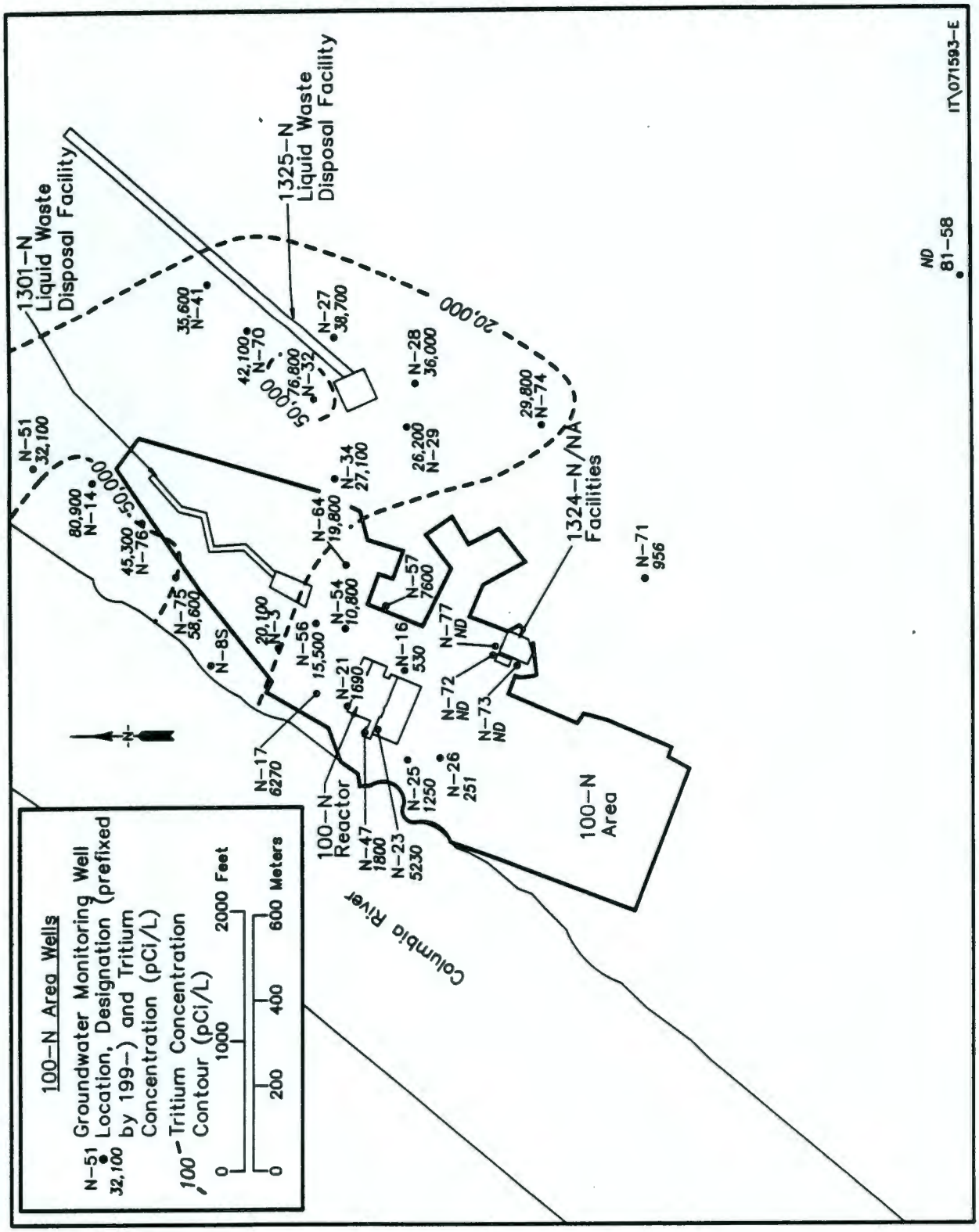

Figure 2-11. Average Strontium-90 Concentrations in the N Springs from 1985 to 1991

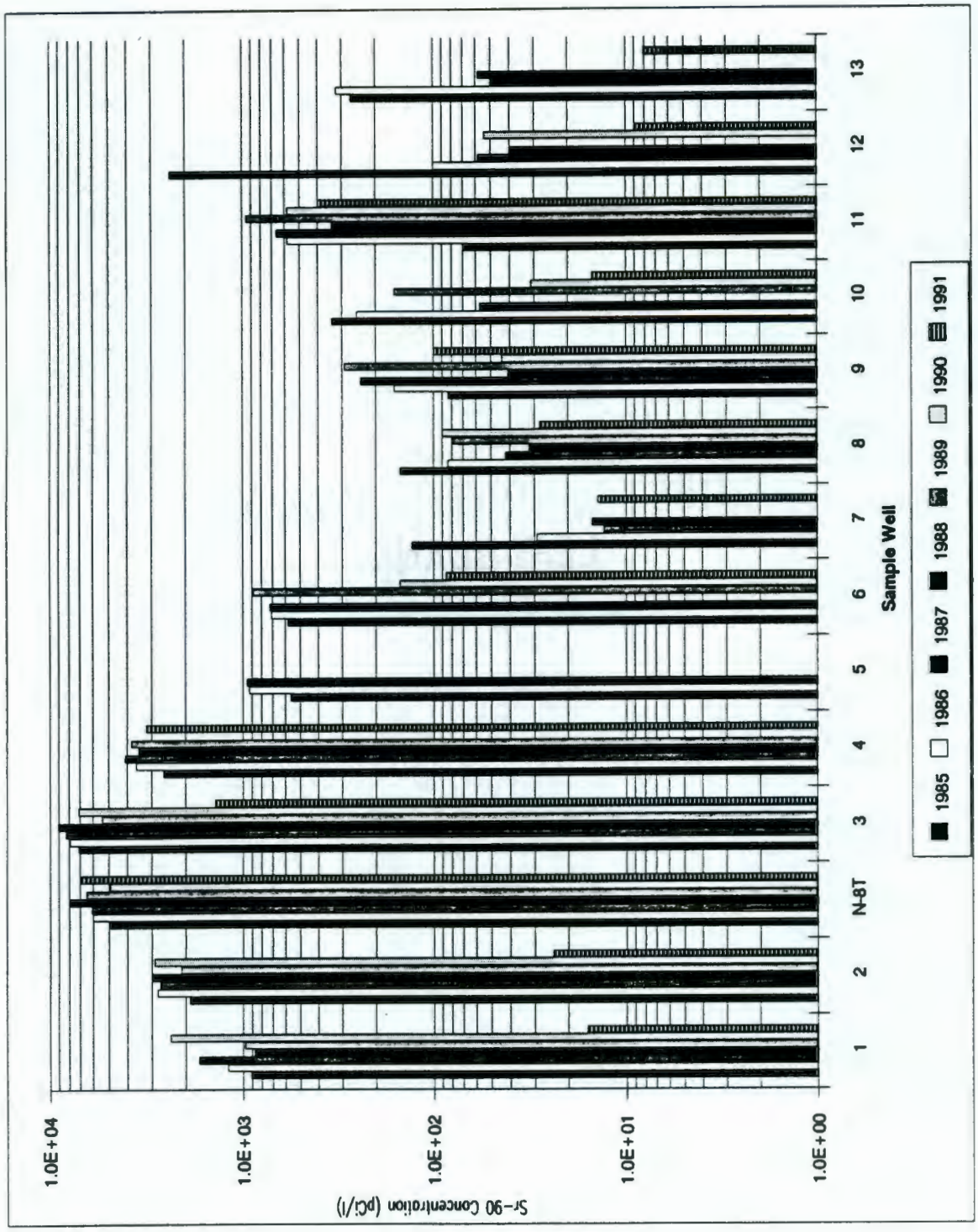

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Table 2-1. Radionuclides/Chemical Wastes Disposed to 1301-N Liquid Waste Disposal Facility

Radionuclide	Cumulative Inventory[a] (Ci)
Cobalt-60	3,800
Strontium-90	1,800
Ruthenium-106	120
Cesium-134	51
Cesium-137	2,300
Plutonium-239	18
Chemical Waste	**Disposal Rate (lb/yr)**
Hydrazine Test Solution	6,100
Ammonia Test Solution	6,100
Chloride Test Solution	7,800
Fluoride Test Solution	3,900
Lead-Acetate Battery Fluid	630[b]
Nickel-Cadmium Battery Fluid	270[b]
Hydrazine (Injection System)	350

[a]Accounting for decay to September 1985
[b]Actual amount is not available, but amount shown is possible because of common floor drains.
Source: DOE/RL 1991b

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Table 2-2. Water Flow Rates and Strontium-90 Discharges to 1301-N and 1325-N Liquid Waste Disposal Facilities

Year	Water Flow to 1301-N LWDF L/d	Water Flow to 1325-N LWDF L/d	Average Sr-90 Concentration in Discharges pCi/L	Annual Sr-90 Discharge Ci/yr	Annual Sr-90 Discharge Accounting for Decay Ci/yr*
1964	9,462,500	0	20,000**	69	35
1965	9,462,500	0	20,000**	69	36
1966	9,462,500	0	20,000**	69	37
1967	9,462,500	0	20,000**	69	38
1968	9,462,500	0	20,000**	69	39
1969	9,462,500	0	20,000**	69	40
1970	9,462,500	0	20,000**	69	41
1971	9,462,500	0	20,000**	69	42
1972	9,462,500	0	20,000**	69	43
1973	8,702,000	0	4,700	15	9
1974	9,500,000	0	18,100	63	41
1975	9,500,000	0	26,800	93	62
1976	9,900,000	0	30,400	110	75
1977	14,500,500	0	22,700	120	84
1978	12,500,000	0	26,300	120	85
1979	13,500,000	0	26,400	130	95
1980	12,500,000	0	35,000	160	119
1981	10,500,000	0	21,900	84	64
1982	10,500,000	0	36,500	140	110
1983	6,942,000	1,960,000	43,500	141	114
1984	8,100,000	1,900,000	84,800	310	255
1985	7,200,000	2,800,000	65,700	240	202
1986	0	7,250,000	13,600	36	31
1987	0	2,100,000	19,600	15	13
1988	0	1,660,000	24,700	15	14
1989	0	1,660,000	64,300	39	36
1990	0	500	64,300	<1	<1
Total				2,451	1,757

Source: Adapted from Connelly et al. 1991

* Decay was accounted for through 1992 using the equation:
Concentration = C exp (-0.693*T/t1/2)
where C = initial activity (Ci), T = number of years since discharge,
t1/2 = the half life of Sr-90 = 28.6 years, exp = exponential function

** No reliable data for average flow rates and average concentrations of effluents. Rough estimates based on discharge volumes from 1973 to 1976 were used. Data for 1973 through 1989 are from annual effluent release report.

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Table 2-3. Radionuclides and Chemical Wastes Disposed to 1325-N Liquid Waste Disposal Facility

Radionuclide	Cumulative Inventory[a] (Ci)
Cobalt-60	1,300
Strontium-90	200
Ruthenium-106	66
Cesium-134	14
Cesium-137	350
Plutonium-239	2.6
Chemical Waste	**Disposal Rate (lb/yr)**
Hydrazine Test Solution	6,100
Ammonia Test Solution	6,100
Chloride Test Solution	7,800
Fluoride Test Solution	3,900
Lead-Acetate Battery Fluid	120[b]
Nickel-Cadmium Battery Fluid	80[b]
Hydrazine (Injection System)	10

[a]Accounting for decay to September 1985
[b]Actual amount is not available, but amount shown is possible because of common floor drains.
Source: DOE/RL 1991b

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Table 2-4. Groundwater Quality in the Vicinity of the N Springs ERA Site (Page 1 of 3)

Constituent	Units	Well 199-N-2		Well 199-N-3	
		Result	Error	Result	Error
Ammonium ion	ppb	40 U		100 U	
Antimony	ppb	200 U			
Antimony, filtered	ppb	200 U		200 U	
Arsenic	ppb	5 U,H		5 U,H	
Arsenic, filtered	ppb	5 U,H		5 U,H	
Barium	ppb	29			
Barium, filtered	ppb	20 U		47	
Beryllium	ppb	3 U			
Beryllium, filtered	ppb	3 U		3 U	
Bromide	ppb	500 U		500 U	
Cadmium	ppb	10 U			
Cadmium, filtered	ppb	10 U		10 U	
Calcium	ppb	27000			
Calcium, filtered	ppb	24000		53000	
Chloride	ppb	1500		5500	
Chromium	ppb	20 U			
Chromium, filtered	ppb	20 U		20 U	
Cobalt	ppb	20 U			
Cobalt, filtered	ppb	20 U		20 U	
Coliform bacteria	MPN	1 U		1 U	
Copper	ppb	20 U			
Copper, filtered	ppb	20 U		20 U	
Fluoride	ppb	100		600	
Iron	ppb	1400			
Iron, filtered	ppb	20 U		24	
Lead (graphite furnace)	ppb	5 U,H		5.7 H	

Table 2-4. Groundwater Quality in the Vicinity of the N Springs ERA Site (Page 2 of 3)

Constituent	Units	Well 199-N-2		Well 199-N-3	
		Result	Error	Result	Error
Lead, filtered	ppb	5 U,H		5 U,H	
Magnesium	ppb	5100			
Magnesium, filtered	ppb	4400		8900	
Manganese	ppb	43			
Manganese, filtered	ppb	10 U		10 U	
Mercury	ppb	0.2 U		0.2 U	
Mercury, filtered	ppb	0.2 U		0.2 U	
Nickel	ppb	30 U			
Nickel, filtered	ppb	30 U		30 U	
Nitrate	ppb	3400		15500	
Nitrite	ppb	200 U		200 U	
pH, Field Measurement		7.92		7.54	
Phosphate	ppb	400 U		400 U	
Potassium	ppb	2200			
Potassium, filtered	ppb	1300		2700	
Selenium	ppb	10 U		10 U	
Selenium, filtered	ppb	10 U		10 U	
Silver	ppb	20 U			
Silver, filtered	ppb	20 U		20 U	
Sodium	ppb	2700			
Sodium, filtered	ppb	2500		9600	
Specific conductance	μmho/cm	167		365	
Sulfate	ppb	14000		35000	
Temperature, field	DEG-C	21.8		20.9	
Tin	ppb	100 U			
Tin, filtered	ppb	100 U		100 U	

Table 2-4. Groundwater Quality in the Vicinity of the N Springs ERA Site (Page 3 of 3)

Constituent	Units	Well 199-N-2		Well 199-N-3	
		Result	Error	Result	Error
Total organic carbon	ppb	1000 U		2000	
Total Organic Halogen, Low Detection Level	ppb	10 U		10 U	
Turbidity	NTU	2.1		0.6	
Uranium, chemical	μg/L			1.66	0.5692
Vanadium	ppb	30 U			
Vanadium, filtered	ppb	30 U		30 U	
Zinc	ppb	10 U			
Zinc, filtered	ppb	10 U		10 U	
Cobalt-60	pCi/L	12.4	6.304	4.8 U	9.644
Cesium-137	pCi/L	0 U	0.000001	-7.34 U	8.58
Ruthenium-106	pCi/L	-40.7 U	53.06	-22.3 U	61.66
Antimony-125	pCi/L	13.8 U	15.95	4.12 U	17.23
Tritium	pCi/L	30100	2362	21300	1760
Gross beta	pCi/L	637	50.04	1170	97.4
Strontium-90	pCi/L	336	64.42	557	98.07
Radium	pCi/L	0.00867 U	0.08794	0.0131 U	0.1716
Gross alpha	pCi/L	0.202 U	0.5426	0.622 U	0.7956

U Result is less than the contract required quantitation limit (CRQL); reported value is the CRQL. For radionuclides the value is less than the error.
H Recommended holding time was exceeded.

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3.0 REMOVAL ACTION OBJECTIVES DEVELOPMENT

Removal action objectives (RAO) define the "why," "what," and "when" of a removal action. Within the scope of an EE/CA study, the RAO delineate the limits of acceptable technical performance and institutional factors. RAO are developed by first identifying the chemicals of potential concern (COPC) and ARAR.

3.1 CHEMICALS OF POTENTIAL CONCERN

Strontium-90 is the principal COPC at N Springs. The release of Sr-90 to the Columbia River through springs located along the river's edge is considered significant enough by the parties to the Tri-Party Agreement to warrant an expedited response. While Sr-90 is the COPC driving this removal action, other constituents in the groundwater must be considered in the evaluation of alternatives. Tritium, for example, is elevated above Safe Drinking Water Act of 1974 MCL in the 100 N Area and will be a significant consideration for disposal of treated groundwater. One other radionuclide, Co-60, while present at levels in groundwater samples below regulatory limits, needs to be considered in the design of any treatment system. Table 2-4 presents the most recent analysis of the groundwater as sampled from Wells 199-N-2 and 199-N-3.

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3.2 POTENTIAL APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS

Section 121(d) of CERCLA, as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA), requires that fund-financed, enforcement, and federal facility remedial actions comply with ARAR of federal environmental laws and more stringent, promulgated state environmental or facility siting laws. While these requirements generally apply as a matter of law to remedial actions, ARAR for removal actions should be identified and complied with to the extent practicable.

CERCLA defines applicable requirements as those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site.

Relevant and appropriate requirements are those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that, while not "applicable" to a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site, address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is well suited to the particular site.

In addition to ARAR, CERCLA provides for the consideration of to-be-considered (TBC) guidance, nonpromulgated advisories or guidance documents issued by federal or state

governments that do not have the status of potential ARAR but which may be considered in determining necessary levels of protection of health or the environment.

ARAR requirements may be further subdivided into the following categories:

- *Chemical-specific requirements* - health- or risk-based numerical values or methodologies that, when applied to site-specific conditions, result in the establishment of numerical values. If a chemical has more than one such requirement that is applicable or relevant and appropriate, compliance should generally be with the most stringent requirement.

- *Location-specific requirements* - restrictions placed on the concentration of hazardous substances or the conduct of activities solely because they are in specific locations, such as wetlands or historic places.

- *Action-specific requirements* - technology- or activity-based requirements or limitations on actions taken with respect to hazardous wastes. These requirements are triggered by the particular remedial activities that are selected to accomplish a remedy.

Potential ARAR identified in the *100 Area Feasibility Study, Phases 1 and 2* (DOE/RL 1992a) were reviewed and refined for appropriateness to the N Springs ERA. Potential chemical-specific ARAR and TBC identified for the N Springs ERA are listed in Tables 3-1 through 3-3. Potential action- and location-specific ARAR and TBC are presented in Tables 3-4 through 3-9.

3.3 REMOVAL ACTION OBJECTIVES

The primary objective of the N Springs ERA is to eliminate or significantly reduce the flux of Sr-90 to the Columbia River through the N Springs. For purposes of this evaluation, significant reduction was considered to be at least 50% of the Sr-90 concentrations >1,000 pCi/L. Currently, Sr-90 is being discharged to the river via the N Springs at concentrations that exceed the drinking water MCL of 8 pCi/L for Sr-90. A secondary objective of the ERA is to implement a removal action that will be compatible with future remedial actions planned for the operable unit and will contribute to the efficient performance of the final remedial action to be taken.

For those alternatives that include extraction of contaminated groundwater, the objective is to treat the water to MCL prior to disposal. Tritium is the exception because treatment for tritium removal is currently unavailable. Disposal of tritiated water may require a waiver of ARAR.

Table 3-1. Potential Federal Chemical-Specific ARAR (Page 1 of 2)

Description	Citation	Requirements	Remarks
Clean Air Act, as amended	42 U.S.C. 7401 et seq.	A comprehensive environmental law designed to regulate any activities that affect air quality, providing the national framework for controlling air pollution.	
National Primary and Secondary Ambient Air Quality Standards	40 CFR Part 50	Sets National Ambient Air Quality Standards for ambient pollutants which are regulated within a region.	
Air Standards for Particulates	40 CFR §50.6	Prohibits average concentrations of particulate emissions in excess of 50 micrograms/m^3 annually or 150 micrograms/m^3 per 24-hour period.	A potential for particulate emissions exists during excavation for vertical barrier installation.
National Emissions Standards for Hazardous Air Pollutants (NESHAP)	40 CFR Part 61	Establishes numerical standards for hazardous air pollutants.	
Radionuclide Emissions from DOE Facilities (except Airborne Radon-222)	40 CFR §61.92	Prohibits emissions of radionuclides to the ambient air exceeding an effective dose equivalent of 10 mrem per year.	Applicable to removal technologies where air emissions may occur.
Federal Water Pollution Control Act, as amended by the Clean Water Act of 1977	33 U.S.C. 1251 et seq.	Creates the basic national framework for water pollution control and water quality management.	
National Pollutant Discharge Elimination System (NPDES)	40 CFR Part 122	Establishes permitting requirements, technology-based limitations and standards, control of toxic pollutants, and monitoring of effluents to assure permit conditions and limits are not exceeded.	Permit may not be required for CERCLA actions; however, substantive requirements must be met.
Permit Conditions	40 CFR §122.41-122.50	Establishes conditions that apply to NPDES permits including effluent limitations and monitoring requirements.	Applicable to direct discharges of wastewaters to waters of the U.S. Treatment of process waters that will be discharged to waters of the U.S. will be required to meet all applicable effluent limitations, quality standards, and toxic pollutant discharge standards as determined by the state, and/or federal discharge permitting authority.

Table 3-1. Potential Federal Chemical-Specific ARAR (Page 2 of 2)

Description	Citation	Requirements	Remarks
Safe Drinking Water Act	42 U.S.C. 300f et seq.	Creates a comprehensive national framework to ensure the quality and safety of drinking water.	
National Primary Drinking Water Regulations	40 CFR Part 141	Establishes maximum contaminant levels (MCL) and maximum contaminant level goals (MCLG) for organic, inorganic, and radioactive constituents. The MCL for Sr-90 is 8 pCi/L. The average annual concentration of beta particle and photon radioactivity from manmade radionuclides in drinking water shall not produce an annual dose equivalent to total body or any internal organ in excess of 4 mrem/year.	Pertains to public drinking water supplies. Chemicals of potential concern are being discharged to the river which serves as a drinking water supply downstream.
National Secondary Drinking Water Regulations	40 CFR Part 143	Controls contaminants in drinking water that primarily affect the aesthetic qualities relating to the public acceptance of drinking water.	Although federal secondary drinking water standards are not enforceable, they are potential ARARs under the Washington State Model Toxics Control Act when more stringent than other standards. See state ARARs.

Table 3-2. Potential State Chemical-Specific ARAR

Description	Citation	Requirements	Remarks
Nuclear Energy and Radiation	RCW 70.98		
Radiation Protection - Air Emissions	WAC 246-247	Requires that emissions of radionuclides to the air shall not cause a dose equivalent of more than 25 mrem/year to the whole body or 75 mrem/year to a critical organ of any member of the public.	
Model Toxics Control Act (MTCA)	70.105D RCW	Requires remedial actions to attain a degree of cleanup protective of human health and the environment.	
Cleanup Regulations	WAC 173-340	Establishes cleanup levels and prescribes methods to calculate cleanup levels for groundwater.	
Groundwater Cleanup Standards	WAC 173-340-720	Requires that where the groundwater is a potential source of drinking water, cleanup levels under Method B must be at least as stringent as concentrations established under applicable state and federal laws, including the following: (A) Maximum contaminant levels established under the Safe Drinking Water Act and published in 40 CFR 141, as amended; (B) Maximum contaminant level goals for noncarcinogens established under the Safe Drinking Water Act and published in 40 CFR 141, as amended; (C) Secondary maximum contaminant levels established under the Safe Drinking Water Act and published in 40 CFR 143, as amended; and (D) Maximum contaminant levels established by the state board of health and published in Chapter 248-54 WAC, as amended.	Federal maximum contaminant level goals for drinking water (40 CFR Part 141) and federal secondary drinking water regulation standards (40 CFR Part 143) are potential ARARs under MTCA when they are more stringent than other standards.

Table 3-3. Chemical-Specific TBCs

Description	Citation	Requirements	Remarks
Safe Drinking Water Act	42 U.S.C. 300f et seq.		
National Primary Drinking Water Regulations; Radionuclides - Proposed Rules	FR Vol. 56, No. 138, July 18, 1991	Provides numerical standards for radionuclides corresponding to 4 mrem/yr dose through drinking water as follows (pCi/L): Tritium 69,040 Strontium-90 42	When promulgated, these proposed rules will replace sections in 40 CFR 141 and 142
U.S. Department of Energy Orders			
Radiation Protection of the Public and the Environment	DOE 5400.5	Establishes radiation protection standards for the public and environment.	
Radiation Dose Limit (All Pathways)	DOE 5400.5, Chapter II, Section 1a	The exposure of the public to radiation sources as a consequence of all routine DOE activities shall not cause, in a year, an effective dose equivalent greater than 100 mrem from all exposure pathways, except under specified circumstances.	Pertinent if remedial activities are "routine DOE activities."
Radiation Dose Limit (Drinking Water Pathway)	DOE 5400.5, Chapter II, Section 1d	Provides a level of protection for persons consuming water from a public drinking water supply operated by DOE so that persons consuming water from the supply shall not receive an effective dose equivalent greater than 4 mrem per year. Combined radium-226 and radium-228 shall not exceed 5×10^{-9} μCi/mL and gross alpha activity (including radium-226 but excluding radon and uranium) shall not exceed 1.5×10^{-8} μCi/mL.	Pertinent if radionuclides may be released during remediation.

Table 3-4. Potential Federal Action-Specific ARAR

Description	Citation	Requirements	Remarks
Federal Water Pollution Control Act (FWPCA), as amended by the Clean Water Act of 1977 (CWA)	33 U.S.C. 1251 et seq.	Creates the basic national framework for water pollution control and water quality management in the United States.	
The National Pollutant Discharge Elimination System (NPDES)	40 CFR Part 122	Part 122 covers establishing technology-based limitations and standards, control of toxic pollutants, and monitoring of effluent to assure limits are not exceeded.	Applicable to river discharge option for treated groundwater disposal; also applies to storm water runoff associated with industrial activities.
NPDES Criteria and Standards	40 CFR §125.104	Best management practices program shall be developed in accordance with good engineering practice.	
Safe Drinking Water Act (SDWA), as amended			
Underground Injection Control (UIC) Program	40 CFR Part 144	Identifies the minimum requirements for UIC programs.	Applicable for the reinjection option of treated groundwater disposal.
Criteria and Standards for the Underground Injection Control Program	40 CFR Part 146	Establishes siting, construction, operating, monitoring, and closure requirements for all classes of injection wells.	Applicable for the reinjection option of treated groundwater disposal.

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Table 3-5. Potential State Action-Specific ARAR (Page 1 of 2)

Description	Citation	Requirements	Remarks
Department of Ecology	43.21A RCW	Vests the Washington Department of Ecology with the authority to undertake the state air regulation and management program.	
Air Pollution Regulations	WAC 173-400	Establishes requirements for the control and/or prevention of the emission of air contaminants.	Applicable if emission sources are created during remedial action.
Standards for Maximum Emissions	WAC 173-400-040	Requires best available control technology be used to control fugitive emissions of dust from materials handling, construction, demolition, or any other activities that are sources of fugitive emissions. Restricts emitted particulates from being deposited beyond Hanford. Requires control of odors emitted from the source. Prohibits masking or concealing prohibited emissions. Requires measures to prevent fugitive dust from becoming airborne.	Applicable to dust emissions from cutting of concrete and metal and vehicular traffic during remediation.
Emission Limits for Radionuclides	WAC 173-480	Controls air emissions of radionuclides from specific sources.	Applicable to remedial activities that result in air emissions.
New and Modified Emission Units	WAC 173-480-060	Requires the best available radionuclide control technology be utilized in planning construction, installation, or establishing a new emission unit.	Applicable to remedial actions that result in air emissions.
Model Toxics Control Act	70.105D RCW	Authorizes the state to investigate releases of hazardous substances, conduct remedial actions, carry out state programs authorized by federal cleanup laws, and to take other actions.	
Hazardous Waste Cleanup Regulations	WAC 173-340	Addresses releases of hazardous substances caused by past activities, and potential and ongoing releases from current activities.	Applicable to facilities where hazardous substances have been released, or there is a threatened release that may pose a threat to human health or the environment.
Selection of Cleanup Actions	WAC 173-340-360	Establishes cleanup requirements to include in cleanup plans. Identifies technologies to be considered for remediation of hazardous substances.	
Cleanup Actions	WAC 173-340-400	Ensures that the cleanup action is designed, constructed, and operated in accordance with the cleanup plan and other specified requirements.	
Institutional Controls	WAC 173-340-440	Requires physical measures such as fences and signs to limit interference with cleanup, and legal and administrative mechanisms to enforce them.	

Table 3-5. Potential State Action-Specific ARAR (Page 2 of 2)

Description	Citation	Requirements	Remarks
Water Pollution Control Act	90.48 RCW	Prohibits discharge of polluting matter in waters.	
Underground Injection Control Program	WAC 173-218	Establishes permitting requirements for injection of fluids through wells. Prohibits injection of any dangerous or radioactive waste fluids. Prohibits injection of industrial or commercial waste fluids beneath the lowermost formation containing, within 1/4 mile of the well, an underground source of drinking water.	Federal Criteria and Standards for the Underground Injection Control Program (40 CFR 146) are reserved at this time.
State Waste Discharge Permit Program	WAC 173-216		
Permit terms and conditions	WAC 173-216-110	Requires all known, available, and reasonable methods of prevention, control, and treatment be used as a condition of the permit to discharge to the waters of the state.	While a permit is not required under CERCLA actions, the substantive requirements of that permit must be met.
Water Well Construction Act	18.104 RCW		
Standards for Construction and Maintenance of Wells	WAC 173-160	Establishes minimum standards for design, construction, capping, and sealing of all wells. Sets additional requirements including disinfection of equipment, abandonment of wells, and quality of drilling water.	Applicable if water supply wells, monitoring wells, or other wells are utilized during remediation.

Table 3-6. Action-Specific TBCs

Description	Citation	Requirements	Remarks
Residual Radioactive Material as Surface Contamination	U.S. NRC Regulatory Guide 1.86	Sets contamination guidelines for release of equipment and building components for unrestricted use, and if buildings are demolished, shall not be exceeded for contamination in the ground.	
U.S. Department of Energy Orders			
Radiation Protection of the Public and the Environment	DOE 5400.5	Establishes standards and requirements for operations of DOE and DOE contractors respecting protection of the public and the environment against undue risk of radiation.	
Discharge of Treatment System Effluent	DOE 5400.xy	Treatment systems shall be designed to allow operators to detect and quantify unplanned releases of radionuclides, consistent with the potential for off-property impact.	Required of all DOE-controlled facilities where radionuclides might be released as a consequence of an unplanned event.
Radiation Protection for Occupational Workers	DOE 5480.11 Section 9a	Establishes radiation protection standards and program requirements to protect workers from ionizing radiation.	
Radioactive Waste Management	DOE 5820.2A Chapters III and IV	Establishes policies and guidelines by which DOE manages radioactive waste, waste by-products, and radioactive contaminated surplus facilities. Disposal shall be on the site at which it was generated, if practical, or at another DOE facility. DOE waste containing byproduct material shall be stored, stabilized in place, and/or disposed of consistent with the requirements of the residual radioactive material guidelines contained in 40 CFR 192.	

Table 3-7. Potential Federal Location-Specific ARAR

Description	Citation	Requirements	Remarks
Archaeological and Historical Preservation Act of 1974	16 U.S.C. 469	Requires action to recover and preserve artifacts in areas where activity may cause irreparable harm, loss, or destruction of significant artifacts.	Applicable because of the presence of significant scientific, prehistorical, historical, or archeological data in the N Area.
Endangered Species Act of 1973	16 U.S.C. 1531 et seq.	Prohibits federal agencies from jeopardizing threatened or endangered species or adversely modifying habitats essential to their survival.	
Fish and Wildlife Services List of Endangered and Threatened Wildlife and Plants	50 CFR Parts 17, 222, 225, 226, 227, 402, 424	Requires identification of activities that may affect listed species. Actions must not threaten the continued existence of a listed species or destroy critical habitat.	Requires consultation with the Fish and Wildlife Service to determine if threatened or endangered species could be impacted by activity.
Historic Sites, Buildings, and Antiquities Act	16 U.S.C. 461	Establishes requirements for preservation of historic sites, buildings, or objects of national significance. Undesirable impacts to such resources must be mitigated.	Applicable because of the presence of
National Historic Preservation Act of 1966, as amended.	16 U.S.C. 470 et seq.	Prohibits impacts on cultural resources. Where impacts are unavoidable, requires impact mitigation through design and data recovery.	Applicable to properties listed in the National Register of Historic Places, or eligible for such listing.
Wild and Scenic Rivers Act	16 U.S.C. 1271	Prohibits federal agencies from recommending authorization of any water resource project that would have a direct and adverse effect on the values for which a river was designated as a wild and scenic river or included as a study area.	The Hanford Reach of the Columbia River is under study for inclusion as a wild and scenic river.

Table 3-8. Potential State Location-Specific ARAR

Description	Citation	Requirements	Remarks
Habitat Buffer Zone for Bald Eagle Rules	RCW 77.12.655		
Bald Eagle Protection Rules	WAC 232-12-292	Prescribes action to protect bald eagle habitat, such as nesting or roost sites, through the development of a site management plan.	Applicable if the areas of remedial activities includes bald eagle habitat.
Regulating the Taking or Possessing of Game	RCW 77.12.040		
Endangered, Threatened, or Sensitive Wildlife Species Classification	WAC 232-12-297	Prescribes action to protect wildlife classified as endangered, threatened, or sensitive, through development of a site management plan.	Applicable if wildlife classified as endangered, threatened, or sensitive are present in areas impacted by remedial activities.

Table 3-9. Location-Specific TBCs

Description	Citation	Requirements	Remarks
Floodplains/Wetlands Environmental Review	10 CFR Part 1022	Requires federal agencies to avoid, to the extent possible, adverse effects associated with the development of a floodplain or the destruction or loss of wetlands.	Pertinent if remedial activities take place in a floodplain or wetlands.
Protection and Enhancement of the Cultural Environment	Executive Order 11593	Provides direction to federal agencies to preserve, restore, and maintain cultural resources.	Pertains to sites, structures, and objects of historical, archeological, or architectural significance.
Hanford Reach Study Act	PL 100-605	Provides for a comprehensive river conservation study. Prohibits the construction of any dam, channel, or navigation project by a federal agency for 8 years after enactment. New federal and non-federal projects and activities are required, to the extent practicable, to minimize direct and adverse effects on the values for which the river is under study and to utilize existing structures.	This law was enacted November 4, 1988.

4.0 IDENTIFICATION OF REMOVAL ACTION TECHNOLOGIES

The *100 Area Feasibility Study Phases 1 and 2* (DOE/RL 1992a) serves as a basis for defining technologies and process options considered for this ERA. Technology types are general groups of operations with common characteristics or results, such as physical treatment. Process options are specific operations within a technology type, such as ion exchange. The process options defined in the feasibility study (FS) for vertical barriers, hydraulic control, and groundwater physical, biological, and chemical treatment technology types are screened for applicability to the circumstances at N Springs. Table 4-1 identifies those technologies and process options relevant to the proposed action at N Springs that were considered in the FS. Some of these technologies are eliminated from further consideration because they do not specifically address the type of contamination at N Springs; that is, they are not applicable. The rationale for the elimination of technologies and process options is indicated in the table. Descriptions of the technologies that are eliminated are given in the FS (DOE/RL 1992a).

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Table 4-1. Technology Identification (Page 1 of 2)

Technology	Is technology applicable to N Springs?
Vertical Barriers	
Slurry Wall	Yes
Grout Curtain	Yes
Sheet Pilings	Yes
Freeze Wall	Yes
Biological Barriers	No; difficult to maintain stable barrier and potential to mobilize contaminants
Permeable Treatment Beds	Yes
Pump and Treat	
Extraction Wells	Yes
Ion Exchange	Yes
Media Filtration	Yes; consider for water pretreatment to remove suspended solids
Flocculation/Precipitation	Yes
Carbon Adsorption	No; used for volatile organic compounds
Air Stripping	No; used for volatile organic compounds
Reverse Osmosis	Yes
Ultrafiltration	No; used for higher molecular weight contaminants
Electrodialysis	No; has not been proven for radionuclides
Dissolved Air Flotation	No; used for removing fine solids with densities close to water
Sedimentation	Yes; consider for pretreatment to remove larger sediment particles in suspension (in conjunction with media filtration)
Steam Stripping	No; used for organics
Forced Evaporation	Yes; as a secondary treatment for treatment of waste liquids to reduce volume
Freeze Crystallization	No; used for heavy metals and partially soluble organics

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Table 4-1. Technology Identification (Page 2 of 2)

Technology	Is technology applicable to N Springs?
Supported Liquid Membrane	Yes
Chemical Oxidation	No; used for organics
Wet-Air Oxidation	No; used for organics
Chemical Reduction	No; used for hexavalent chromium
Solidification/Stabilization	Yes; consider as secondary treatment for treatment residues
Hydraulic Control	
Extraction Wells	Yes
Extraction Trenches	Yes
Treated Water Disposal	
Crib Disposal	Yes
River Discharge	Yes
Reinjection	Yes
Passive solar evaporation	Yes
Double Shell Tanks	No; capacity not available; volume increase of high level waste
242-A Evaporator	No; capacity not available
Grout Facility	No; volume exceeds capacity; costs excessive

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5.0 SCREENING OF REMOVAL ACTION TECHNOLOGIES

The screening of removal action technologies and process options is conducted to eliminate technologies and process options that do not meet the ERA screening criteria. The following factors are used for this screening analysis:

- protectiveness
- timeliness
- technical feasibility
- institutional considerations.

The list of technologies and process options that were retained from Section 4.0 for analysis in the screening includes the following:

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- Pump and Treat - Extraction
  - extraction wells.

- Pump and Treat - Treatment
  - ion exchange
  - reverse osmosis
  - selective liquid membrane
  - flocculation
  - sedimentation
  - media filtration
  - forced evaporation
  - solidification/stabilization.

- Pump and Treat- Treated Water Disposal
  - river discharge
  - crib disposal
  - reinjection
  - passive solar evaporator.

- Vertical Barriers
  - slurry wall
  - grout curtain
  - sheet pilings
  - freeze wall
  - permeable treatment beds.

- Hydraulic Control
  - extraction wells
  - extraction trenches.

In addition to these technologies, at the request of U. S. Department of Energy, Richland Operations (RL), two innovative technologies are considered in screening: strontium biosorption and strontium solvent extraction with ionizable crown ethers. In their comments to the ERA project plan, the U. S. Environmental Protection Agency (EPA) also requested that wetlands bioassimilation be considered.

5.1 SCREENING CRITERIA

Criteria for screening removal action technologies and process options are derived from the draft EPA guidance document *Draft Engineering Evaluation/Cost Analysis Guidance for Non-Time-Critical Removal Actions* (EPA 1987). The criteria are described briefly as follows:

- Protectiveness
  - Does the technology protect human health and the environment?
  - Will the technology provide ultimate long-term mitigation of threats to human health and the environment?
  - Are there any potential long-term threats posed by the technology? What is the severity of these threats?

- Timeliness
  - Can approval processes, contracting, mobilization, testing, and storage capacity be obtained on a timely basis?
  - Are site specific factors conducive to timely implementation?

- Technical feasibility
  - Has the technology been proven in large, field-scale applications?
  - Has the technology been used on similar site conditions, media, and contaminants?

- Institutional considerations
  - Will the public accept the technology?
  - Does the technology require acquisition of permits?
  - Is the technology able to comply with essential chemical and location specific ARAR?
  - Does the technology require the cooperation of other agencies or organizations?

5.2 TECHNOLOGY SCREENING

This section documents the screening process for determining which technologies and process options should be developed into alternatives for detailed analysis. Each subsection provides a brief description of the technology or process option. The rationale for retaining or eliminating technologies and process options, based on evaluation against the screening criteria, is provided in Table 5-1.

5.2.1 Pump and Treat - Extraction Wells

Groundwater extraction wells are used to withdraw and isolate contaminated groundwater by manipulation of the hydraulic gradient (RAAS 1991). The extraction system may include a single well or multiple wells. The complexity of the design depends on the nature of the transporting medium, the depth of penetration of the contaminants, and the complexity of the geologic stratigraphy. The extraction process is used in conjunction with groundwater treatment and disposal.

5.2.2 Pump and Treat - Treatment Process Options

A wide range of primary and secondary treatment process options is considered for treating extracted contaminated water at the N Springs. Brief descriptions are provided below.

5.2.2.1 Ion Exchange. The ion exchange process adsorbs ionic contaminants in exchange for mobile ions of similar charge that are contained on organic resin beads or on inorganic materials such as zeolites. Both anions and cations, including radionuclides, can be removed from water by use of appropriate ion exchange media. The process involves pumping the contaminated water through vessels containing beds of ion exchange media. Configurations and combinations of ion exchangers containing either cation or anion media, or mixtures of the two, may be specified to operate either in series or parallel based on the volume of contaminated water to be treated. Media are chemically regenerated using concentrated salt or acid solutions that result in substantial volumes of secondary waste requiring treatment, usually by evaporation. Some media, such as synthetic zeolites, are used without regeneration. That is, the spent media are disposed of as solid waste after they become fully loaded with contaminants. The advantage of this type of media is that secondary liquid wastes are not generated.

Ion exchange is commercially available and proven. It is commonly used in DOE facilities and in the nuclear industry for a wide variety of processing and wastewater treatment applications (RAAS 1991).

5.2.2.2 Reverse Osmosis. The reverse osmosis process purifies contaminated water by application of high pressure which forces pure water through a semipermeable membrane but leaves the contaminants in a concentrated waste stream (EPA 1987). The process is commercially available and highly effective for purifying water containing dissolved ions and radionuclides. However, a chief disadvantage is the generation of a substantial volume of secondary liquid waste that must be volume reduced and solidified prior to disposal.

5.2.2.3 Selective Liquid Membrane. The supported liquid membrane process is a variation of reverse osmosis. A liquid membrane consists of a micro-porous membrane containing an organic carrier held in place by capillary forces. Carriers are used to increase the selectivity of the membrane for specific constituents, potentially reducing the volume of secondary

waste generated relative to reverse osmosis. Supported liquid membrane technology is currently in the experimental development phase. No commercial applications are known.

5.2.2.4 Flocculation. Flocculation is a proven physical process where inorganic contaminants are coagulated by the addition of chemicals (Freeman 1989). Flocculation is effective in removing suspended solids and is used in conjunction with sedimentation and/or filtration to remove the particles from water (DOE 1990).

5.2.2.5 Sedimentation. Sedimentation is a proven physical separation process whereby particles entrained in a liquid are separated by induced settling with gravitational or inertial forces (NRC 1981). For N Springs, it would be considered as a pretreatment step for removal of suspended particulates in the raw groundwater. Sedimentation produces a wet sludge as a secondary waste that must be dewatered and disposed.

5.2.2.6 Media Filtration. Media filtration is a common pretreatment step to remove solids from suspension by using media, such as diatomaceous earth or beds of sand (EPA 1987). Depending on particle sizes and quantities to be removed, cartridge-type filters containing fabric bags or porous metallic elements can also be used for filtration. Filtration produces secondary solid waste requiring disposal.

5.2.2.7 Forced Evaporation. Forced evaporation is a proven process for reducing the volume of aqueous wastes. Forced evaporation would be considered for use in reducing the volume of secondary liquid wastes from reverse osmosis or ion exchange treatment. Vaporization of water is induced by raising the temperature of the waste stream mechanically by vapor recompression or in a heated evaporator. Vapor is then separated, condensed, and discharged. The concentrate requires further processing to render it a solid waste. This can be accomplished by drying or solidifying with cement or other solidification materials.

5.2.2.8 Solidification/Stabilization. This process is used to eliminate free liquids and immobilize contaminants so that the waste material can be land-disposed. The waste liquids or wet sludges are mixed with cement, fly ash, polymers or other suitable solidification material. The technology is well developed and commercially practiced for use in radioactive waste disposal. The technology would be considered for use in solidifying secondary wastes from reverse osmosis, ion exchange, filtration, and/or evaporation.

5.2.3 Pump and Treat - Treated Water Disposal Options

No practical treatment process is available for removing tritium from the N Springs groundwater. Thus several disposal options are considered for comparison to river discharge. Each is described briefly below.

5.2.3.1 River Discharge. This option provides a baseline for evaluation. Treated water containing tritium is discharged directly into the river via a pipeline and river outfall.

5.2.3.2 Crib Disposal. Crib disposal is a subsurface water discharge method whereby water is allowed to percolate through the porous soil column into groundwater. The particles of the soil column essentially act as filters by adsorbing contaminants. Two crib disposal

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options are considered for N Springs: disposal at the N Area and disposal at the 200 Area. Crib disposal at the 200 Area allows sufficient travel time of tritiated water to the river so that the tritium would decay to very low levels by the time it reached the river. However, the chief disadvantage of this option is that a long and costly pipeline would have to be constructed to allow pumping the water to the 200 Area. Crib disposal to the N Area does not allow sufficient travel time for tritium decay. Both options would require a waiver of Tri-Party Agreement Milestone M-17, which requires the cessation of liquid effluent releases.

5.2.3.3 Reinjection. In this option, treated water is reinjected directly into the aquifer using conventional screened injection wells. Injected water would flow through the aquifer and into the river. Water would be injected at a location in the N Area that does not impact contaminated plume movement. The advantage of this option is that clean vadose zone soil is not contaminated with injected water.

5.2.3.4 Passive Solar Evaporation. Passive solar evaporation is a proven technology that uses large shallow surface impoundments or open tanks to evaporate water using solar radiation. The impoundments must be lined to prevent the water from percolating into the soil. Nets or other protection are also required to prevent animal access. The release of tritium to the air is a potential concern with passive evaporation. At present, treatment options for tritium in air are unavailable. Also, capture of emissions from a passive solar evaporator would be impracticable.

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5.2.4 Vertical Barriers

Vertical barriers act as an obstruction to the groundwater pathway of contaminant migration. Because the flow of contaminants at N Springs is generally from the 1301-N and 1325-N cribs toward the river, a vertical barrier placed between these contaminant sources and the river may eliminate or substantially restrict the movement of contaminants to the river by leveling the groundwater flow gradient behind the wall. Strontium-90 has a tendency to bind to the soils. This tendency, combined with the decrease in the flow gradient, results in a decrease of Sr-90 movement and thus a reduction in the flux to the river.

5.2.4.1 Slurry Wall. A slurry wall is a vertical barrier formed by emplacement of slurry in a vertical trench or boring. Conventional trench excavation uses backhoes or clamshell excavators; the slurry is used to shore the trench as excavation proceeds. New techniques for slurry wall construction have been commercialized whereby walls are built using deep soil mixing. In deep soil mixing, large-diameter augers are used to simultaneously drill, inject slurry, and mix slurry with soil materials. Slurry materials can include soil-bentonite or cement-bentonite mixes (slurry recipe would be determined through field testing). Slurry walls are typically designed for permeabilities of 10^{-7} cm/s, but performance can be greater or less depending on the type of slurry used, soil conditions, and placement techniques. The slurry wall technology has been proven on large, field-scale applications under similar circumstances and is commercially available.

5.2.4.2 Grout Curtain. A grout curtain is a vertical barrier used to reduce or contain groundwater flow. Grout curtains are formed by pressure injection of grout through pipes, augers, or beams that are inserted into the ground using a drill rig. The curtain is developed one "post" at a time along the containment boundary. Grout curtains are implementable and effective at waste sites. However, the presence of very coarse-grained and non-uniform materials in the Hanford formation increases the uncertainty in the proper positioning of the grout posts and in the integrity of grout penetration and coverage. The high permeability soils would inhibit the formation of a grout curtain by reducing the ability to control continuity of grout placement.

5.2.4.3 Sheet Pilings. Sheet pilings are vertical barriers constructed of materials such as wood, precast concrete, or steel. The walls, or sheets, are typically assembled at the surface and then driven into the ground a few feet at a time over the entire length of the wall with a vibratory or drop hammer.

Sheet pilings are not feasible at N Springs because of the presence of large boulders and rocky soils that would cause damage or deflection of the walls. This damage or deflection would result in unpredictable wall integrity.

5.2.4.4 Freeze Wall. A freeze wall, or cryogenic wall, is a vertical barrier formed by freezing interstitial water within the soils. The freeze wall is formed by circulating coolant through steel pipes installed in the ground. Pipes are installed using conventional drilling techniques. To facilitate an effective frozen wall, the pipes must be installed on a relatively close spacing (6 to 7 ft). Freeze walls have been used successfully in special construction applications where temporary groundwater barriers were necessary. However, this technology is considered innovative for use in hazardous waste management as it has not yet been applied in site remediation (Dash 1991, EPA 1990).

The implementability of the freeze wall is very difficult and costly because of the need for a large number of holes. A vendor estimated that approximately 800 holes, 120 ft deep, would be required for a 2,800-ft wall at N Springs. Using cable tool or sonic drilling would require over 40 rig-years for installation and would incur costs over $80M. Thus this technology is neither technically feasible nor cost effective for Hanford application.

5.2.4.5 Permeable Treatment Beds. Permeable treatment beds are excavated trenches placed perpendicular to groundwater flow and filled with an appropriate material to treat the plume of contamination as it flows through the material (EPA 1985). Permeable treatment beds are also referred to as permeable barriers (EPA 1990). The technology category is also referred to as in situ sorption (RAAS 1991). Possible treatment materials or adsorbents include activated carbon, agricultural residues, clays, zeolites, glauconitic greensand, and limestone (RAAS 1991). In the case of N Springs, zeolites and glauconitic greensands, which are high surface area cation exchange materials, would probably be the most appropriate materials for removing Sr-90.

The technology is applicable to relatively shallow groundwater tables containing a plume. The application of permeable treatment beds at hazardous waste sites has not been performed (EPA 1985, EPA 1990), although bench- and pilot-scale testing for specific

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applications have been undertaken (EPA 1990). The DOE Office of Technology Development has proposed that research and development programs on permeable barriers be included in the In Situ Remediation Integrated Program (Peterson 1992).

A major drawback in using permeable treatment beds is that the materials may become fully loaded with contaminants and other adsorbed constituents and may lose their adsorption characteristics (RAAS 1991). In addition, permeable barriers may become clogged with precipitates necessitating periodic removal, treatment and/or disposal as hazardous/radioactive waste. Therefore, this technology should be considered only as a temporary containment measure (RAAS 1991).

Because permeable treatment beds have not been proven in hazardous waste field applications, and therefore no performance data exist, the degree of protectiveness and the technical feasibility of this technology at N Springs are uncertain.

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5.2.5 Hydraulic Control

5.2.5.1 Extraction Wells. Extraction wells, described in Section 5.2.1, are used for hydraulic control by placement upgradient from the contaminated plume. By pumping groundwater upgradient from the contaminated plume, the natural flow is intercepted so that the gradient in the area of the contamination is lowered and the flow of groundwater towards the river is slowed. This reduction in flow reduces the rate of contaminant transport into the river. The hydraulic control wells are placed sufficiently upgradient from the plume so the contaminated water is outside the radius of influence of the wells. Thus the water pumped by upgradient control wells is not contaminated and can be discharged to the river without treatment.

5.2.5.2 Extraction Trenches. Extraction trenches are sometimes used for hydraulic control instead of a line of extraction wells. The trench, which is constructed with permeable material, provides a subsurface drain by which the flow of groundwater can be intercepted. Pumps are used to remove the groundwater that flows into the trench. Trenches are more beneficial than wells where the groundwater and the contamination are shallow or where the geologic conditions would require a large number of closely spaced wells. Neither is the case for N Springs, because the N Area groundwater is deep and the aquifer is porous so that wells would not be closely spaced.

5.2.6 Miscellaneous Technologies

At the request of DOE-RL, selected innovative technologies were evaluated for their potential application in the N Springs ERA.

5.2.6.1 Strontium Biosorption. Laboratory-scale studies have been performed at Oak Ridge National Laboratory (ORNL) on the adsorption of strontium from wastewater using immobilized microorganisms (Faison et al. 1990, Watson et al. 1990, Watson et al. 1989). The experiments were performed using laboratory glass packed-columns containing microbial

cells (bacteria) immobilized on beads of a gelatin matrix. The experiments concluded that microbial cells can adsorb strontium from dilute solutions.

While the laboratory studies performed to date show promise, this innovative technology is in the very early stages of development. The potential advantage of this technology relative to conventional ion exchange media is that the microbial media may be less expensive, more selective for strontium, and have higher loading capacities; however, these advantages have yet to be demonstrated.

Because this technology is not yet sufficiently developed, it cannot be shown to meet the ERA selection criteria of timeliness, protectiveness, and technical feasibility. Therefore, this technology will not be considered further for the N Springs ERA.

5.2.6.2 Solvent Extraction With Ionizable Crown Ethers. Laboratory experiments have been performed by researchers at University of Idaho on the extraction of Sr-90 and other radionuclides from aqueous phase into chloroform using a new class of selective chelating agents called ionizable crown ethers (Wai and Du 1990, Tang and Wai 1989, Tang and Wai 1988). The published papers discuss results of work aimed at understanding the chemistry of the process and do not delve into applications.

From the information available, it is apparent that the technique is in the very early research stage. Much more research and development remain to demonstrate practical application. Thus, because this technology does not meet the ERA selection criteria, it will not be considered further for N Springs.

5.2.6.3 Wetlands Bioassimilation. Wetlands bioassimilation refers to the utilization of wetlands plants to uptake and accumulate contaminants such as metals and radionuclides contained in wastewater. This innovative technology would be used in combination with groundwater extraction; the water would be pumped from the aquifer and discharged to artificial wetlands onsite in which plants would be grown and harvested. Harvested plants containing metals and radionuclides would then be permanently disposed by compaction and burial as solid waste.

Wetlands have been used for control of urban runoff. There is evidence that some metals are biologically accumulated in plants grown where contaminants exist. However, no performance data exist on effectiveness or secondary effects of this technique. While the concept may have merit, more research is needed before the concept could be considered for hazardous site remediation.

Table 5-1. Screening of Technologies and Process Options (Page 1 of 3)

Process Option	Technical Feasibility, Timeliness	Technical Feasibility	Protectiveness	Technical Feasibility, Institutional Considerations	Retain Process Option for Detailed Analysis?
	Is Process Option Commercially Available?	Has Process Option Been Used in Similar Circumstances?	Is Process Option Sufficiently Effective?	Is Process Option Implementable?	
Pump and Treat - Extraction					
Extraction Wells	Yes	Yes	Yes	Yes	Yes
Pump and Treat - Treatment					
Ion Exchange	Yes	Yes	Yes	Yes	Yes
Reverse Osmosis	Yes	Yes	Yes	Yes	Yes
Selective Liquid Membrane	No	No	Uncertain	Uncertain	No
Flocculation	Yes	Yes; for pretreatment	Yes; for pretreatment	Yes	Yes(1)
Sedimentation	Yes	Yes	Yes	Yes	Yes(1)
Media Filtration	Yes	Yes; for pretreatment	Yes; for pretreatment	Yes	Yes(1)
Forced Evaporation	Yes	Yes; for secondary waste treatment	Yes; for secondary waste treatment; potential for tritium release to air*	Yes	Yes(2)
Solidification/ Stabilization	Yes	Yes	Yes	Yes	Yes(3)
Pump and Treat - Disposal Options					
Crib Disposal	Yes	Yes	Yes	Yes	Yes
River Discharge	Yes	Yes	Yes	Yes	Yes
Reinjection	Yes	Yes	Yes	Yes	Yes

Table 5-1. Screening of Technologies and Process Options (Page 2 of 3)

Process Option	Technical Feasibility, Timeliness	Technical Feasibility	Protectiveness	Technical Feasibility, Institutional Considerations	Retain Process Option for Detailed Analysis?
	Is Process Option Commercially Available?	Has Process Option Been Used in Similar Circumstances?	Is Process Option Sufficiently Effective?	Is Process Option Implementable?	
Passive Evaporation	Yes	Unknown	Tritium in groundwater would be released to air*; potential leaks to soil; control of animal exposure uncertain	Yes	No
Vertical Barriers					
Slurry Wall	Yes	Yes	Yes	Yes	Yes
Grout Curtain	Yes	Yes	Could be significantly less than slurry walls because of Hanford porous soil	Ability to control grout placement is limited	No
Sheet Pilings	Yes	Yes	Uncertain; panels are difficult to seal and often leak	Unlikely ability to install in Hanford rocky soils	No
Freeze Wall	Yes	Has not been used in hazardous waste site remediation	Uncertain; technology has not been applied to similar situations	Technology requires installation of 800 holes, 120 feet deep; drilling would require over 40 rig years; not cost effective	No
Permeable Treatment Beds	Yes	Has not been demonstrated at field-scale	Uncertain due to lack of performance data	Limited to shallow depths	No

Table 5-1. Screening of Technologies and Process Options (Page 3 of 3)

Process Option	Technical Feasibility, Timeliness	Technical Feasibility	Protectiveness	Technical Feasibility, Institutional Considerations	Retain Process Option for Detailed Analysis?
	Is Process Option Commercially Available?	Has Process Option Been Used in Similar Circumstances?	Is Process Option Sufficiently Effective?	Is Process Option Implementable?	
Hydraulic Control					
Extraction Wells	Yes	Yes	Yes	Yes	Yes
Extraction Trenches	Yes	Used in shallow applications	Yes	Depth to groundwater makes this impracticable	No
Miscellaneous					
Strontium biosorption	No	No	Unknown; no performance data available	Unknown; no performance data available	No
Solvent extraction with ionizable crown ethers	No	No	Unknown; no performance data available	Unknown; no performance data available	No
Wetlands bioassimilation	No	No	Unknown; no performance data available	Unknown; no performance data available	No

Notes: 1. Consider as an option for ion exchange or reverse osmosis pretreatment to remove suspended solids
2. Consider as an option for ion exchange or reverse osmosis liquid waste treatment for volume reduction
3. Consider as an option for ion exchange or reverse osmosis liquid waste solidification treatment
* No current treatment options for practicable removal of tritium from air are available.

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6.0 DETAILED ANALYSIS OF REMOVAL ACTION ALTERNATIVES

The alternative technologies that have passed the initial screening must undergo a more detailed analysis to select the removal action alternative to be implemented. Each alternative is evaluated with respect to the four selection criteria: (1) technical feasibility; (2) cost considerations; (3) institutional considerations; and (4) environmental impacts.

Each of these criteria is described briefly as follows (EPA 1987).

Technical feasibility:

- ability to comply with ARAR
- effectiveness in reducing toxicity, mobility, or volume of contamination
- demonstrated performance and reliability under similar conditions
- useful life
- constructability
- operating and maintenance requirements
- environmental effects on performance
- sensitivities and uncertainties.

Cost considerations:

- capital costs
- operating and maintenance costs
- present worth
- cost uncertainties.

Institutional considerations:

- ability to achieve removal action objectives
- regulatory concerns about the technology
- permitting requirements
- safety
- timeliness.

Environmental Impacts:

- impacts of the removal action on
  - topography and surface drainage
  - geology
  - soils
  - surface water hydrology and quality
  - groundwater hydrology and quality
  - meteorology and air quality
  - biological resources
  - cultural resources

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- land and water use
- visual resources.

Removal action technologies that passed screening (Section 5.0) are assembled into alternatives for evaluation and comparative analysis. The alternatives are assembled into major technology types (e.g., pump and treat, vertical barriers). The pump and treat alternative includes numerous suboptions for number and location of pumping wells, treatment processes, and treated water disposal schemes. Not all possible combinations of extraction, treatment, and disposal options are evaluated because of the cumbersome nature of the process and lack of benefit of examining all permutations. Instead, the pump and treat technology options are evaluated in three modules: pumping options, treatment options, and treated water disposal options. Specific options from each module are then combined in such a way as to allow evaluation of alternatives that span the full range of benefits and cost. Once alternatives are compared, selection of a preferred alternative is made by assessing the advantages, disadvantages, uncertainties, and sensitivities of each option and arriving at a selection that is cost-effective for the benefit achieved.

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The list of alternatives evaluated in detail is given as follows:

Alternative 1 - No Action. Continued groundwater monitoring and access control.

Alternative 2 - Pump and Treat

- Pumping Options:
  - five wells
  - three wells.

- Treatment Options:
  - ion exchange
  - reverse osmosis.

- Treated Water Disposal Options:
  - river discharge
  - new N Area crib
  - N Area injection wells
  - new 200 Area crib.

Alternative 3 - Vertical barrier (slurry wall).

Alternative 4 - Hydraulic control (upgradient pumping wells).

All alternatives include continued groundwater monitoring and access control. For purposes of detailed analysis, a 10-yr project life is assumed because the removal action is considered an interim response until a final remedy is implemented for the 100 N Area operable units. An objective of this ERA is to implement an alternative that contributes to the efficient performance of the final remedial action.

The cost estimates that support the evaluations provide a level of accuracy of +50% to -30%, which is typical of the types of estimates performed for CERCLA feasibility studies. Wherever possible, common assumptions are used for estimates and all costs are given in 1993 dollars. Cost estimating details, including assumptions and sources of costs, are provided in Appendix A. Caution should be used in interpreting the estimates, because the intent at this stage of evaluation is to assess costs in relative terms as opposed to absolute terms. That is, the costs should not be considered for their absolute accuracy because more definition and design are needed, especially in assigning indirect costs associated with Hanford installations. However, in relative terms, the costs are sufficiently accurate to make comparisons and judgements regarding the cost-effectiveness of alternatives. The cost uncertainties associated with each alternative or option are discussed in the specific sections where sufficient information is available to evaluate uncertainties.

The general approach to cost estimation assumes that removal systems for N Springs are treated as environmental projects, not as installations of permanent nuclear facilities. Where noted, Hanford labor rates have been used in the labor cost estimate, and additional costs associated with handling radioactively contaminated materials have been considered, where appropriate. In general, the cost estimates reflect an assumption that the level of design and system complexity are minimized to provide systems which, while offering quality in construction and implementation, are consistent with the objectives of an expedited response action.

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6.1 ALTERNATIVE 1 - NO ACTION

6.1.1 Description

The no action alternative implies no removal action: however, groundwater monitoring and institutional access/administrative controls would continue through the assumed period of performance (10-yr project life). This alternative will not reduce the flow of contaminants to the river through the springs. However, because the principal contaminants are radionuclides, the contaminations will eventually attenuate through radioactive decay. Soil adsorption is also a factor in the eventual release of Sr-90 to the river. As Sr-90 contaminated groundwater travels through the soils, the contaminant is adsorbed and desorbed in the soil. The net effect will be long term slow release of Sr-90 to the groundwater.

Connelly et al. (1991) developed a simulation of the groundwater flow and Sr-90 transport in the N Springs area. The PORFLO-3 (Runchal and Sagar 1989) groundwater flow and transport model was used for this modeling effort. This model simulates the groundwater flow system and contaminant transport utilizing user inputs for groundwater flow and contaminant transport parameters (e.g. hydraulic conductivity, groundwater gradient, contaminant sorption coefficient, etc). As with all models, this model was an approximation of the groundwater flow system and contaminant transport at N Springs. Assumptions regarding the geometry of model, such as source dimensions, were generalized due to internal model constraints. The model was initially calibrated to pre-disposal

groundwater conditions (July 1965). The transport portion of the model was calibrated to match the Sr-90 concentrations observed at the N Springs. Additional details of the model setup, calibration, and results are found in Connelly et al. (1991). Following calibration, the model was run to predict Sr-90 concentrations in the future. Using 1990 as the base case, Sr-90 gradually decreases from 6,200 pCi/L in 1990 to about 1,000 pCi/L in 2002. A plot of groundwater levels and Sr-90 concentrations between the 1301-N LWDF and the N Springs is shown on Figure 6-1. The Sr-90 distribution shown on Figure 6-1 does not exactly match what would be expected based on the groundwater levels shown on the same figure. This is because the very large volumes of water discharged from 1964 to 1991 created an artificial groundwater mound that distributed the Sr-90 radially around the disposal facility. The figure reflects this distribution. Over the 12-yr period, the model predicts the total Sr-90 flow to the river, with no abatement action taken, to be 10.7 Ci.

The monitoring program presently in place will continue. The program consists of the following elements:

- yearly monitoring of the N Springs
- quarterly groundwater well monitoring
- bi-weekly radionuclide effluent analysis of N Springs discharges to the river
- continuous dosimeter surveys along the perimeter fences and ropes
- quarterly radiation surveys along the outer perimeter fences of the cribs/trenches
- annual radiation surveys around the inner perimeter rope of both trenches
- continuous air sampling with monthly analysis.

The monitoring program discussed for the no-action alternative is also assumed to apply to the other alternatives being evaluated. The monitoring program may be expanded to include new wells to monitor the performance of the ERA. Specification of changes to the current monitoring program would be made in the ERA design phase.

Inclusion of this option in the evaluation satisfies the National Contingency Plan (NCP) requirement that a no action alternative be evaluated as a baseline to which all other alternatives are compared.

6.1.2 Technical Feasibility

Existing administrative and institutional controls in the 100 N Area include site security and access restrictions designed to minimize human exposure to contamination. Currently, the only potential human exposure to contaminated groundwater is in the immediate vicinity of the seeps and springs along the riverbank. While access controls may

be effective in reducing human exposure, the level of security is not sufficient to prevent members of the public from intentionally entering the area. Institutional controls also do not prevent exposure to environmental receptors, such as wildlife. The existing monitoring program is considered effective in continually assessing potential human health and environmental effects. Evaluation of the no-action alternative against other technical feasibility criteria is given in Table 6-1.

6.1.3 Cost Considerations

Costs associated with institutional controls and continued groundwater monitoring are not included in this analysis because these programs are already in place and because these are common to all the alternatives being evaluated. Thus this alternative is considered to have a zero baseline cost for comparative evaluation purposes.

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6.1.4 Institutional Considerations

The evaluation of institutional considerations for the no action alternative is summarized in Table 6-2.

6.1.5 Environmental Impacts

The evaluation of environmental impacts for the no action alternative is summarized in Table 6-3.

6.2 ALTERNATIVE 2 - PUMP AND TREAT

6.2.1 Description

The pump and treat alternative consists of two groundwater extraction options, two treatment process options, and four treated water disposal options. Each of these options is described in the subsections below. An overall process flow diagram for the pump and treat system is presented in Figure 6-2. Capture zone analysis was performed for the three-well, five-well, and hydraulic control alternatives using FLOWPATH (Franz and Guiguer 1989), a two-dimensional groundwater flow model. In addition, the five-well system was modeled using PORFLO-3. Both models used the same hydraulic properties and both were calibrated. Results of each model were similar for the five-well system.

6.2.1.1 Pumping Options. Three- and five-well systems are considered for the pump and treat alternative to optimize the cost-benefit. The evaluation determines the relative effectiveness of each pumping option in reducing the contaminant flux to the river. The pumping options were chosen because they represent a reasonable estimate of the system requirements. It is recognized that other options of well numbers and locations may also

prove effective. This optimization will be addressed in the design phase if pump and treat is the chosen alternative.

6.2.1.1.1 General Modeling Approach. In both pumping options, the wells are placed approximately 200 ft (60 m) from the river and groundwater is extracted at a rate of 60 gal/min per well (330 m^3/day). The choice of the 200-ft (60-m) setback from the river is based on a need to minimize the flow of river water into the wells which will result in increased water treatment needs.

The effectiveness of each pumping case is evaluated through capture zone analysis. The numerical groundwater flow model FLOWPATH was used. FLOWPATH assumes two-dimensional, steady-state flow, in heterogeneous, anisotropic, saturated, porous media. The application of the model for the N Springs assumes that the unconfined aquifer system is homogeneous and isotropic.

Aquifer properties used in the model are the same as those used by Connelly et al. (1991) to model the no action alternative and the five-well pumping option using PORFLO-3.

In the FLOWPATH modeling, capture zones are calculated by introducing particles at the wells and reverse tracking to their original location. Capture zones were calculated for 1-, 2-, and 5-yr durations and for steady state conditions. The 1-yr capture zone analysis was used for the determination of the relative near-term effectiveness of each pumping case. This allows for a determination of the timeliness of each case. Each well system was centered directly upgradient from the N Springs showing the highest levels of contamination (near well N-8T) allowing for capture of the Sr-90 within the 1,000 pCi/L contour. All wells were assumed to be fully penetrating, with horizontal and radial flow.

Three pumping rates, 60 gal/min per well (330 m^3/d), 100 gal/min per well (545 m^3/d), and 200 gal/min per well (1,090 m^3/d), were initially modeled for each case. The 60 gal/min rate resulted in the best balance between performance of the well and river water contribution. The other pumping rates generated significantly higher river water contributions which result in higher costs for treatment and in increased difficulty in handling secondary wastes (both tritiated water and treatment wastes).

The calculated one-year capture zones (Figures 6-3 and 6-4) are superimposed on a Sr-90 contaminant distribution map. The percent of Sr-90 capture represents the ratio of the 1-yr well capture area to the area of the 1,000 pCi/L contour interval adjacent to the river. The Sr-90 distribution map was developed from data collected during February 1990 (see Section 2.2.3).

6.2.1.1.2 Three-Well Pumping Option. The one-year capture zone for the three-well system is shown on Figure 6-3. The well spacing for these wells is 710 ft (216 m). The 1-year capture percentage for the three-well system is estimated to be 55%.

6.2.1.1.3 Five-Well Pumping Option. The one-yr capture zone for the five-well system is shown in Figure 6-4. The well spacing for these wells is 350 ft (108 m). The 1-yr capture percentage for the five-well system is estimated to be 75%.

6.2.1.1.4 Pumping Option Comparison. The results of the capture zone analysis show that, based on the 1990 contaminant distribution, Sr-90 capture increases significantly with increasing number of wells. The three-well system slightly exceeds the 50% reduction objective; the five-well system captures more of the Sr-90. Additional wells or pumping rates will increase the Sr-90 capture but also significantly increase the cost due to increased water treatment requirements. Pumping well locations and extraction rates will be optimized in the design phase if this alternative is chosen.

6.2.1.1.5 Uncertainties. The percent of capture analysis is qualitative and is sensitive to several key factors. The first is the uncertainty in the distribution of Sr-90 at levels >1,000 pCi/L. This will affect the Sr-90 capture percentage; the smaller the area of Sr-90 concentrations >1,000 pCi/L, the higher the percent capture.

A second factor which affects the percent capture is the uncertainty in the hydrologic representation of the model. The model assumes the aquifer is homogeneous and isotropic while the aquifer is most likely neither homogeneous nor isotropic. There may be zones of higher or lower hydraulic conductivity. The hydraulic conductivity used in this model, 220 ft/d (67 m/d), was determined through the calibration process in the three-dimensional model completed by Connelly et al. (1991). Reported aquifer test values from near the 1325-N LWDF range from 290 to 1,300 ft/d (89 to 395 m/d) with a mean of 800 ft/d (245 m/d) (Golder 1990). Zones of higher hydraulic conductivity would result in preferential pathways for contaminant transport that may or may not be captured by a three-well system. If the hydraulic conductivities are higher than those used in the model, higher pumping rates would be required. Additional wells or refinement of pumping rates may counter these uncertainties; however, these changes result in higher costs for treatment and disposal of the water and solid wastes.

6.2.1.2 Treatment Options. Two treatment options are evaluated in detail for application to treatment of contaminated N Springs groundwater: ion exchange and reverse osmosis. Each treatment option is described in the following paragraphs.

6.2.1.2.1 Ion Exchange. A conceptual process flow diagram of an ion exchange system for treatment of N Springs groundwater is given in Figure 6-5. A brief discussion is presented in the following paragraphs.

Groundwater pumped from the extraction well system is collected in a flow equalization tank, which is used to ensure uniform contaminant concentrations in the water fed to the ion exchange system and to provide surge capacity. The water from the tank is pumped to a pretreatment filtration system to remove particulates and suspended solids. These solids must be removed to prevent fouling of the ion exchange beds. The filters are precoat type, which generate small volumes of low-level radioactive solid waste requiring disposal.

Three ion exchange columns in parallel (two active columns and a maintenance backup) are used to remove the Sr-90. Each column contains two types of exchange media: an organic resin for removal of anionic species such as cobalt colloids and a chabazite zeolite for removal of the Sr-90. The zeolite media will also remove calcium, non-radioactive

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strontium, magnesium, and other minerals in the groundwater. Alkali metals such as sodium and potassium, however, are not significantly adsorbed on either media. The ion exchange media are not regenerated but are periodically removed from the exchange columns and replaced with fresh media. The media are removed hydraulically into a dewatering tank followed by load-out into disposal containers, such as drums or disposal boxes. Fresh media are pneumatically transferred into the ion exchange vessel. The treated water then flows to the disposal system (see Section 6.2.1.3). Spent media and filter wastes are estimated to be about 8,000 ft^3/yr (225 m^3/yr) for a system treating 300 gal/min (1,135 L/m) of groundwater (the five-well system). Solid wastes would be disposed as low-level radioactive solid wastes.

The type of system described above has been used in nuclear power plant applications and has been recently pilot tested at ORNL (Robinson et al. 1990) for treatment of a wastewater that is very similar in composition to the N Springs groundwater. Oak Ridge National Laboratory presently treats a 150-gal/min wastewater stream with a regenerative ion exchange system. However, they have found that evaporation of the secondary waste is costly (about $0.5M/yr total disposal cost) (Robinson et al. 1990). The pilot tests using non-regenerative chabazite zeolites showed potential disposal cost savings of about 80%. Oak Ridge National Laboratory plans to install the zeolite-based system at their facility in the future.

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The ORNL system was designed to remove the Sr-90 to 300 pCi/L to meet the requirements of DOE Order 5400.5; the pilot testing verified that those levels could be met. However, the N Springs target performance level is the Sr-90 MCL of 8 pCi/L. The vendor of the proposed system was unwilling to state that the ion exchange system could meet the desired performance level without treatability testing. The vendor stated that the proposed system could produce water less than 270 pCi/L. Therefore, the ion exchange system performance remains a technical uncertainty at this point.

Because essentially all of the dissolved material removed in the ion exchange columns is other than the target contaminant Sr-90, the size of the treatment system and the generation of secondary waste will vary proportionately to the volume of groundwater treated. For example, the treatment system for the three-well pumping scenario (180 gal/min) is 60% the size of the five-well treatment system (300 gal/min) and generates correspondingly less secondary waste.

6.2.1.2.2 Reverse Osmosis. A conceptual process flow diagram for a reverse osmosis groundwater treatment system is shown in Figure 6-6.

A flow equalization/surge tank receives groundwater from the pumping wells. The water is pretreated by filtration using 5- and 0.5-μ cartridge filters in series to remove suspended solids. The pH of the groundwater is then adjusted to 5.0 using acid, which prevents precipitation of salts as the concentration of carbonates is increased in the reject stream. Formation of carbonate and sulfate salts will clog the membranes and greatly reduce operating efficiency. Sodium hexametaphosphate is also added to inhibit crystallization of other types of salts that may form as concentration increases in the reject stream.

The chemically treated groundwater is pumped at high pressure into a reverse osmosis unit where processing will produce a concentrated waste stream containing the bulk of the dissolved solids and a stream consisting of demineralized water. The membranes are typically either spiral wound into a cylindrical configuration or are fabricated into hollow fibers. The membranes provide a pore size in the range of 1 to 10 A (0.0001 to 0.001 μ).

The purified water stream (permeate) is discharged via the disposal system while the concentrate must be processed further for volume reduction. The concentrated waste stream represents about 10% of the feed stream, although the exact quantity of waste is subject to determination in a treatability study. It is also uncertain whether the reverse osmosis system can meet the treatment performance requirement of 8 pCi/L. This is subject to determination in a treatability study.

The concentrated waste stream is volume-reduced by evaporation. A single vapor recompression evaporator (electrically heated) is specified for this application (this evaporator is assumed here because of energy efficiency; the actual type of evaporator and power source would be determined in the design phase). The clean condensed vapor from the evaporator is discharged with the reverse osmosis permeate. The evaporator-bottoms stream, which is about 50% solids, is solidified in a Portland cement grout and is disposed as a low-level radioactive solid waste. For a 300-gal/min groundwater treatment system, the volume of grouted waste is estimated to be about 8,000 ft^3/yr.

The options of disposing liquid wastes to the existing double-shell tanks (DST), the 242-A evaporator, or both were considered but rejected. The volume of liquid waste would result in an unacceptably large increase in DST wastes. The 242-A evaporator is not currently operating and is considered unavailable for processing any wastes other than the existing tank farm wastes.

6.2.1.3 Treated Water Disposal Options. Treated groundwater from the processes described in Section 6.2.1.2 above will still contain levels of tritium that exceed ARAR (the drinking water MCL for tritium is 20,000 pCi/L). The tritium levels in the groundwater are not reduced by either treatment process. Currently, there is no known treatment process for removing tritium that can be practically applied to groundwater.

Based on 1991 data, the average tritium concentration in the area of the pumping wells is about 51,000 pCi/L (Schmidt et al. 1992). Upon pumping, the tritium concentrations would likely increase because the center of mass of the tritium plume is still upgradient of the proposed pumping well location(s). Based on 1993 data, the maximum observed concentration of tritium was 80,000 pCi/L, located just downgradient of the 1325-N crib. This could be considered as a conservative maximum concentration that may be expected in an extraction well.

Four options are evaluated for disposal of the treated water containing tritium:

- river discharge
- new crib in the N-Area
- new injection well(s) in the N-Area
- new crib in the 200 Area.

Each of these options is described in the following paragraphs.

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6.2.1.3.1 River discharge. Treated water from the treatment unit is collected in a tank, providing a surge capacity of 15 min prior to discharge to the river. The effluent is continuously monitored for Sr-90 using an on-line beta counting instrument. The energy of beta particle emissions from Sr-90 is sufficiently different relative to tritium that discrimination of Sr-90 is readily achieved. Exceeding pre-set limits for Sr-90 as detected by the monitor would alert the system operator and automatically shut down the system. Once the problem is corrected, the surge tank contents would be reprocessed through the treatment system.

Treated water from the surge tank flows into the river via a buried gravity flow pipeline. The pipeline would be double-wall construction with leak detection systems. It is assumed that the flow would be routed via the existing river outfall (009) or a new outfall. This study assumes use of the existing outfall.

River discharge may require an NPDES permit. Although N Reactor has been operated under an existing NPDES permit since 1980, additional permitting requirements, if any, have not yet been established for river disposal of N Springs treated water. Establishing permitting requirements would require discussions with regulators. In addition, the Tri-Party Agreement Milestone M-17 requires the cessation of liquid effluent discharges by 1995 and may affect the treated water disposal options.

6.2.1.3.2 New Crib in the 100 N Area. Collection and monitoring of treated water is achieved in the same manner as described for the river discharge option.

Treated water from the surge tank would be pumped to a new crib located in the 100 N Area. The crib would be a standard Hanford design located so the discharged water would not affect existing contaminant plumes or contaminant sources. Water discharged to the crib would percolate to groundwater and flow into the river. The travel time of the water to the river would not be sufficient to allow depreciable decay of the tritium.

6.2.1.3.3 New injection wells in the N Area. Collection and monitoring of treated water is achieved in the same manner as described for the river discharge system.

Treated water from the surge tank is pumped to a series of injection wells located in the 100 N Area. The injection wells would be screened over the entire thickness of the Ringold unit 1 aquifer and would be located so that the discharge water would not affect existing contaminant plumes. Water discharged to injection wells would eventually flow into the river. The travel time of the water to the river would not be sufficient to allow appreciable decay of the tritium.

6.2.1.3.4 New crib in the 200 Area. Collection and monitoring of treated water is achieved in the same manner as described for the river discharge option.

Treated water from the surge tank is pumped via a cross-country pipeline approximately 9 miles to a new crib located in the 200 West Area. This crib is assumed to be in the same vicinity as the one planned for discharging treated wastewater from the 242-A evaporator condensate treatment facility. The crib would be a standard Hanford design. The

water would percolate through the soil column and eventually flow to the river through the groundwater system. However, since the travel time to the river is long (model estimates at 105 yr), the tritium would decay to well below drinking water limits by the time it reached the river. The estimated travel time of 105 yr is about 8.5 half-lives of tritium. At the maximum expected concentration of 80,000 pCi/L, only about two half-lives of decay would actually be required to meet the drinking water MCL for tritium. While the new crib could be located somewhat closer to the river to achieve a travel time of about 50 yr, the basis for this study assumes the 200 West Area location.

6.2.2 Technical Feasibility

Technical feasibility of each of the pump and treat pumping options, treatment options, and disposal options are discussed in the following subsections.

6.2.2.1 Pumping Options. Technical feasibility for each of the three pumping options are summarized in Table 6-4.

6.2.2.2 Treatment Options. Both ion exchange and reverse osmosis are considered to be implementable and effective for removing the Sr-90 from N Springs groundwater. However, with either process, the ability to meet the stringent 8 pCi/L discharge limit cannot be determined without performing treatability studies on samples of actual groundwater. It is likely that both processes could be made to meet the discharge limit, although perhaps at the expense of greater operating severity and cost. The reverse osmosis system is much more complex than the ion exchange system because of the need for chemical pretreatment, secondary volume reduction by evaporation, and waste solidification. Table 6-5 summarizes the evaluation against the technical feasibility criteria.

6.2.2.3 Treated Water Disposal Options. The evaluation of technical feasibility of all four treated water disposal options is summarized in Table 6-6.

6.2.3 Cost Considerations

Cost estimates for all of the options evaluated in this alternative are summarized in the Tables 6-7 through 6-13. Cost estimate assumptions, sources, and details are documented in Appendix A. All present worth values are based on a discount factor of 5% and a project life of 10 yr.

6.2.3.1 Pumping Options. Costs for the extraction system associated with the pump and treat alternative are given in Table 6-7.

6.2.3.2 Treatment Options. Costs for the treatment system options associated with the pump and treat alternative are given in Tables 6-8 and 6-9.

6.2.3.2.1 Uncertainties. Cost estimates for both the ion exchange and reverse osmosis systems were based on vendor quotations. The ion exchange costs are based on

knowledge gained in pilot testing at ORNL. Uncertainty exists for ion exchange in the consumption of media and associated waste generation rate.

Both capital and operating costs for the reverse osmosis system are more uncertain than for ion exchange, especially the operating costs. The vendor operating cost quotes span a wide range. One vendor quoted the total system O&M costs at $0.03 to $0.05/gal for a system which uses an evaporator and vacuum drier. Based on the high value, the annual O&M cost would be nearly $8 million for the five-well system. This is almost an order of magnitude higher than the costs developed by different vendors. The discrepancy is not resolved and is indicative of substantial cost uncertainty for the reverse osmosis system at this conceptual level of design.

6.2.3.3 Treated Water Disposal Options. Costs for the treated water disposal options associated with the pump and treat alternative are given in Tables 6-10 through 6-13.

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6.2.4 Institutional Considerations

Evaluation of institutional considerations for the pumping, treatment, and disposal options are discussed in the subsections below.

6.2.4.1 Pumping Options. The evaluation of institutional considerations for the two pumping options is summarized in Table 6-14.

6.2.4.2 Treatment Options. The evaluation of institutional considerations for the two treatment options is summarized in Table 6-15.

6.2.4.3 Disposal Options. The evaluation of institutional considerations for all four treated water disposal options is summarized in Table 6-16.

6.2.5 Environmental Impacts

Environmental impacts for the pumping, treatment, and treated water disposal options are discussed in the subsection below.

6.2.5.1 Pumping Options. The evaluation of environmental impacts for the pump and treat pumping options is summarized in Table 6-17.

6.2.5.2 Treatment Options. Neither treatment option is considered to have significant environmental impact. Ion exchange does not produce air emissions; the reverse osmosis system has the potential to release tritium to the air from the evaporator. Secondary waste is produced from both which is solidified, packaged, and buried as low level radioactive waste.

6.2.5.3 Disposal Options. The evaluation of environmental impacts for the pump and treat disposal options is summarized in Table 6-18.

6.3 ALTERNATIVE 3 - VERTICAL BARRIERS

Slurry walls were retained as the single process option for consideration in the vertical barrier alternative.

6.3.1 Description

The vertical barrier option for N Springs was modeled using the PORFLO-3 groundwater flow and transport model. This model is the same as discussed in the no action alternative with the barrier wall added to this base case. The modeled barrier is a 2,800-ft long wall spanning the width of the Sr-90 plume where it intersects the river. The model assumes a slurry wall permeability of 10^{-6} cm/s and a retardation coefficient of 43.3. The wall causes a reduction in the groundwater gradient behind it. Strontium-90 tends to bind with the soil and, when combined with the decreased gradient, transport of Sr-90 to the river is reduced. The wall does not completely prevent Sr-90 transport to the river; however, modeling results indicate that Sr-90 flux to the river is significantly reduced (0.001 Ci/yr with the wall as compared to 0.67 Ci/yr in the same year without the wall). The wall meets the objective of 50% reduction of the Sr-90 in the greater than 1,000 pCi/L contour. Results of the modeling for the year 2002 are shown on Figure 6-7. The figure illustrates the water level configuration and contaminant distribution. It should be noted that the contaminant distribution does not completely match the groundwater flow direction because the model considers not only groundwater Sr-90 concentrations but also Sr-90 which is tied to the soils. The radial Sr-90 distribution is due to the original liquid waste disposal patterns at the 1301 LWDF.

The wall modeled with PORFLO-3 was retained for detailed analysis, except that the location of the wall is assumed to be 200 ft from the river instead of 100 ft. This was done to avoid placing the wall in the 100-yr floodplain which would trigger wetlands analysis and to allow for easier construction in the more level terrain at 200 ft back from the river (100 ft from the river is on a steep slope). Locating the wall further back should not affect the ability to reduce Sr-90 flux from the area of the cribs but would result in slightly more contamination (between the wall and the river) being flushed into the river from already contaminated sediments as a result of fluctuating river stages. Actual wall placement would be considered in the design phase. Placement of the wall closer to the river has several advantages including:

- lower depth to the confining layer resulting in lower costs
- reduced risk of drilling difficulties from boulders
- increased production rates during construction.

From a technical and cost point of view, location of the wall closer to the river (in the floodplain) is advantageous but risks administrative delays in assessing wetlands impacts. The approximate location of the wall for this proposal is shown in Figure 6-8. At its base, the wall would be keyed approximately 3 ft into the Ringold unit 2a as shown in Figure 6-9. The wall would be designed to provide a permeability of 10^{-7} cm/s which would severely restrict the movement of contaminant-laden groundwater through the wall. At the proposed

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location, the total depth from ground surface is estimated to average about 104 ft. Placement of the wall in the floodplain would reduce its depth to about 50 ft (15 m).

Two types of construction are considered for installation of a slurry wall at N Springs, conventional excavation and deep soil mixing. Each type of installation is discussed in the following paragraphs.

6.3.1.1 Excavated slurry wall. Conventional slurry wall installation involves the excavation of a trench to a confining layer using a thickened bentonite slurry for excavation support. The trench is sequentially backfilled with a mixture of excavated soils and bentonite or a combination of soil, bentonite, and cement in the case of a plastic concrete wall.

Soil is excavated using a backhoe or an excavator, such as a clamshell or dragline, depending upon the depth required. The N Springs slurry wall would require the latter because the total depth is beyond the maximum 70-ft reach of backhoes.

As excavated soil is removed from the trench, it is placed on the adjacent ground surface. Bentonite is added to these backfill soils in both dry form and as slurry for moisture conditioning; the bentonite and soils are mixed by plowing with a bulldozer or in a pugmill. Upon completion of mixing, backfill material is pushed into the trench displacing the bentonite slurry mixture and forming a contiguous mass of low permeability wall. Excess soil is generated that may require disposal; approximately 33% of the total excavated volume for a soil-bentonite wall and up to 60% for a soil-bentonite-cement wall is excess soil (Spooner et al. 1985). To minimize the volume of contaminated soil produced, materials could be segregated so that the uncontaminated vadose zone soil would make up most of the soil not returned to the trench.

To make a suitable slurry, the fines content of the soil must be in the range of 10% to 20%. Hanford formation and Ringold Formation soils are lower in fines than required; therefore, some import of fine soil materials or an increase in the amount of bentonite in the slurry mixture is needed to construct the wall. This will likely increase the volume of excess soil requiring disposal. Contaminated soil will have to be disposed as a low level radioactive waste in accordance with DOE Order 5820.2A. In addition, saturated soils excavated from below the water table will require dewatering; the contaminated water fraction will also require suitable disposal.

6.3.1.2 Deep soil mixing. Deep soil mixing is a relatively new technique and is available commercially for construction of vertical barriers with properties similar to slurry walls. The equipment used for deep soil mixing consists of a kelly bar and a specially designed large diameter (e.g., 5 to 8 ft) auger containing injection nozzles. The assembly is mounted on a crane and is initially driven into the soil mechanically to the depth required. The tool is then withdrawn partially (to approximately half the depth of the wall), slurry material injection is initiated as the auger is again driven downward, and slurry injection continues through withdrawal of the auger. The auger mixes the slurry with the soil as it is driven downward and pulled upward. This method of operation ensures thorough mixing of the soil with slurry materials, such as bentonite or combinations of bentonite and cement.

The slurry wall is completed by auguring and mixing a series of overlapping holes. For the N Springs application, the completed wall would be 3 to 5 ft thick. A tool which measures 5 ft in diameter is specified for the purposes of costing the N Springs application. According to a vendor, tools of this diameter are capable of operation in Hanford's rocky soils and should meet the minimum requirement of 10^{-6} cm/s permeability. While Hanford soils are rocky, they are also unconsolidated, which is an advantage to the auguring approach. Also, according to the vendor, the probability of achieving a permeability of 10^{-7} cm/s is excellent, because a slurry mix with a high percentage of bentonite and imported fines may be designed to fill the interstitial pores, even in coarse, gravelly soils. The mix would require testing, however.

The chief advantage to deep soil mixing is that it does not require removal of contaminated soil, thereby eliminating contaminated soil or water disposal problems. Construction costs are comparable to conventional excavation, but potentially much lower when soil and water disposal costs are taken into account. For this reason, further analysis, including cost analysis, will be conducted under the assumption that deep soil mixing will be used for constructing a slurry wall at N Springs.

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6.3.2 Technical Feasibility

Deep soil mixing appears to be a preferred slurry wall construction method for Hanford application because it does not require contaminated soil removal and disposal. Field trials prior to actual installation may be required to demonstrate a 10^{-6} cm/s permeability. In addition, full-scale field testing could be done to demonstrate the viability of deep soil mixing in Hanford soils. Table 6-19 presents a technical feasibility evaluation of a slurry wall installed by deep soil mixing.

6.3.3 Cost Considerations

Cost estimates for all of the options evaluated in this alternative are summarized in Table 6-20. Cost estimate assumptions, sources and details are documented in Appendix A. All present worth values are based on a discount factor of 5% and a project life of 10 yr.

6.3.4 Institutional Considerations

The evaluation of institutional considerations for slurry wall option is summarized in Table 6-21.

6.3.5 Environmental Impacts

The environmental impacts for the slurry wall option are summarized in Table 6-22.

6.4 ALTERNATIVE 4 - HYDRAULIC CONTROL

Only one process option was considered for hydraulic control: extraction wells located upgradient from the contaminated groundwater plume. The evaluation of this option is documented in the subsections below.

6.4.1 Description

The upgradient hydrologic control option is analyzed to determine its relative effectiveness in reducing contaminant flux to the river by reducing the flow of water from the contaminated portion of the aquifer. This can be accomplished by reducing the hydraulic gradient.

Upgradient hydraulic control is implemented by placing a series of pumping wells upgradient from the contaminant sources to capture the water flowing into the area. A properly designed pumping system results in lowering of the water table at the pumping wells. The wells are placed sufficiently upgradient so that the pumped water is uncontaminated and, therefore, secondary water treatment would not be required. There is, however, a potential to induce groundwater flow from the area of contamination and increase the area of contamination beyond the current upgradient boundary.

Upgradient hydraulic control is assessed with the aid of the FLOWPATH two-dimensional numerical groundwater flow model. The model conditions are the same as those used in the pump and treat option except that the southern model boundary is extended approximately 1,640 ft (500 m) to allow for well placement away from areas of contamination.

The goal of upgradient hydraulic control is to reduce the groundwater flow to the river by at least 50% without causing spread of Sr-90 contamination upgradient toward the pumping wells. Several different upgradient well placement and pumping rate scenarios were modeled to determine the optimum well placement within the constraints of the model. The resulting well configuration and pumping rates are shown on Figure 6-10. The configuration consists of 11 pumping wells set in a radial pattern upgradient from the 1325-N facility. Pumping rates vary from 75 to 150 gal/min. The total flow of all wells is 1,100 gal/min. All pumped water is monitored and discharged directly to the river through a new outfall.

This scenario resulted in a reduction in groundwater flow to the river of approximately 50% within the 1,000 pCi/L concentration contour for the 1990 concentration data. The hydraulic gradients are altered gradually before reaching steady-state. Steady-state conditions would probably be reached in a matter of months; however, more comprehensive modeling is required to precisely determine the time to reach steady-state conditions.

As discussed for the pump and treat options, because the model assumes that the unconfined aquifer is both homogeneous and isotropic, there is some uncertainty in the validity of the final results. The aquifer may have zones of higher or lower conductivity that

may have a directional component. This could serve as preferred pathways for groundwater and contaminant flow and could affect the capture zone of individual pumping wells. In the actual system operation, these effects could be mitigated to some extent by varying the pumping rates from individual wells to balance out the hydrogeologic uncertainties.

6.4.2 Technical Feasibility

Table 6-23 presents a technical feasibility evaluation of upgradient hydraulic control.

6.4.3 Cost Considerations

Cost estimates for all of the options evaluated in this alternative are summarized in Table 6-24. Cost estimate assumptions, sources, and details are documented in Appendix A. All present worth values are based on a discount factor of 5% and a project life of 10 yr.

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6.4.4 Institutional Considerations

The evaluation of institutional considerations for the hydraulic control option is summarized in Table 6-25.

6.4.5 Environmental Impacts

The environmental impacts for the hydraulic control are summarized in Table 6-26.

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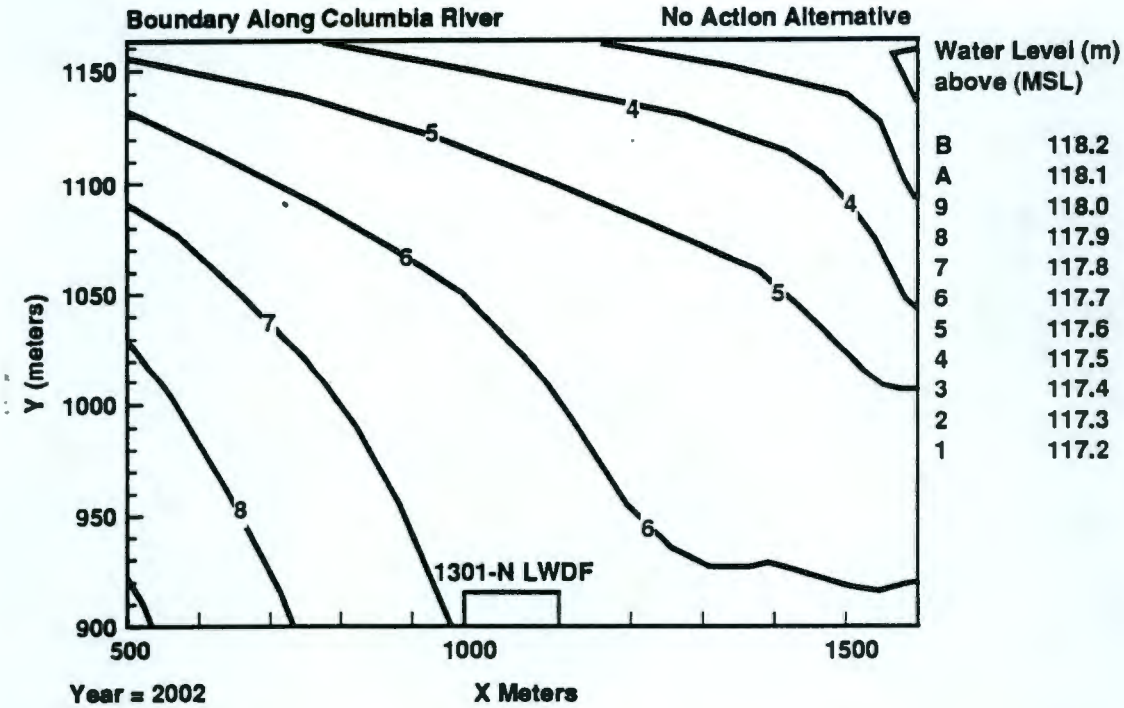
Figure 6-1. Groundwater Levels and Sr-90 Concentration Estimates Based on Groundwater Modeling for the Year 2002 - No Action Alternative



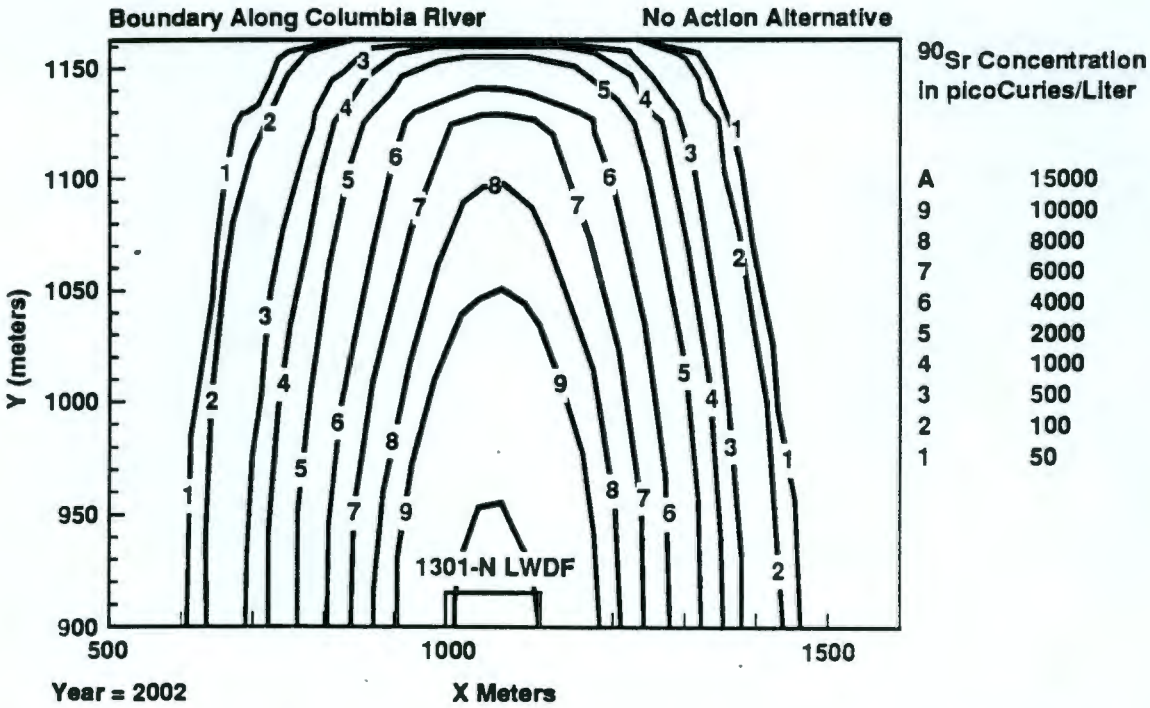


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Figure 6-2. Alternative 2 - Pump and Treat Overall Process Flow Diagram

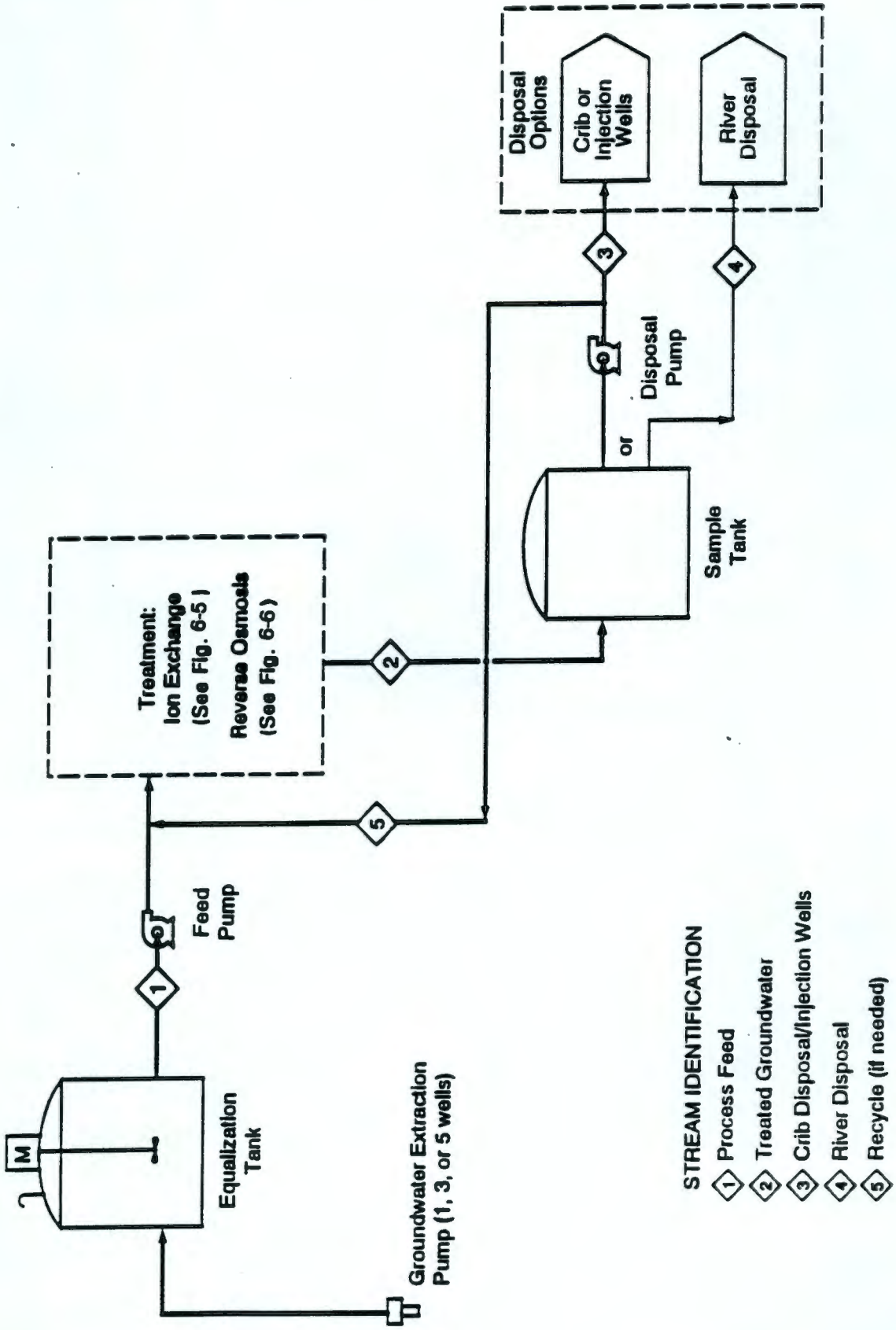

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Figure 6-3. Three-Well Capture Zone Analysis

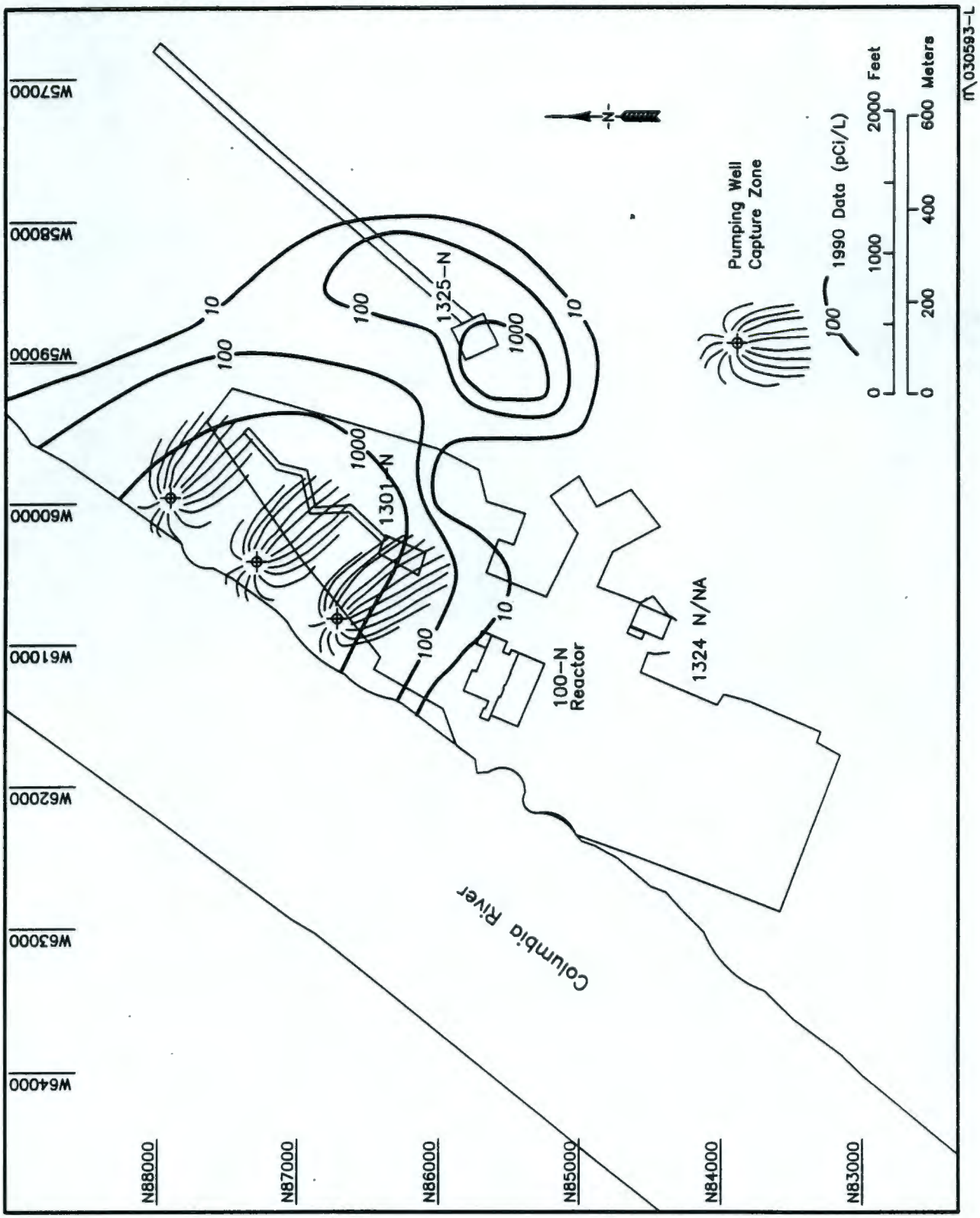

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Figure 6-4. Five-Well Capture Zone Analysis

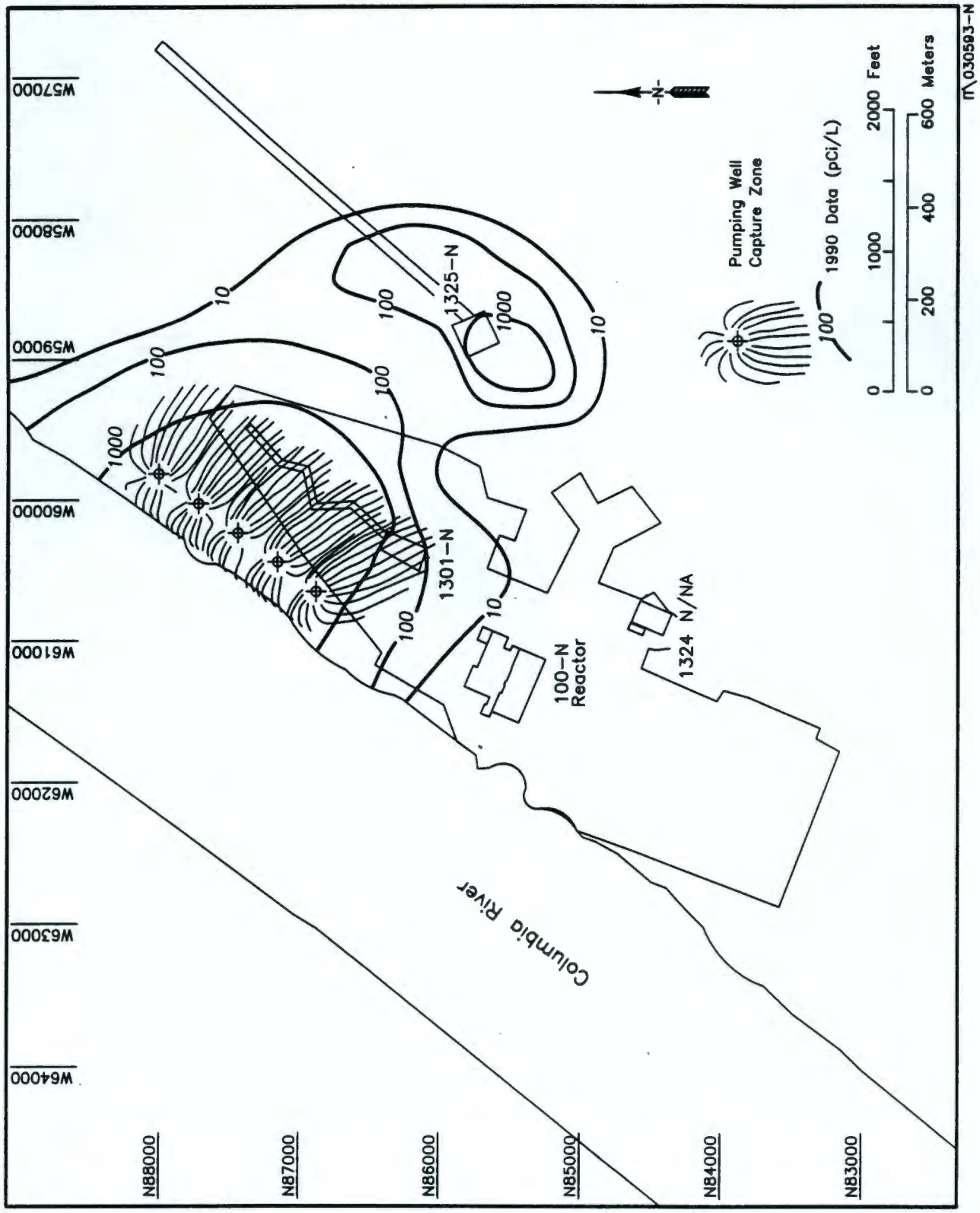

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Figure 6-5. Alternative 2 - Pump and Treat, Ion Exchange Treatment Process Flow Diagram

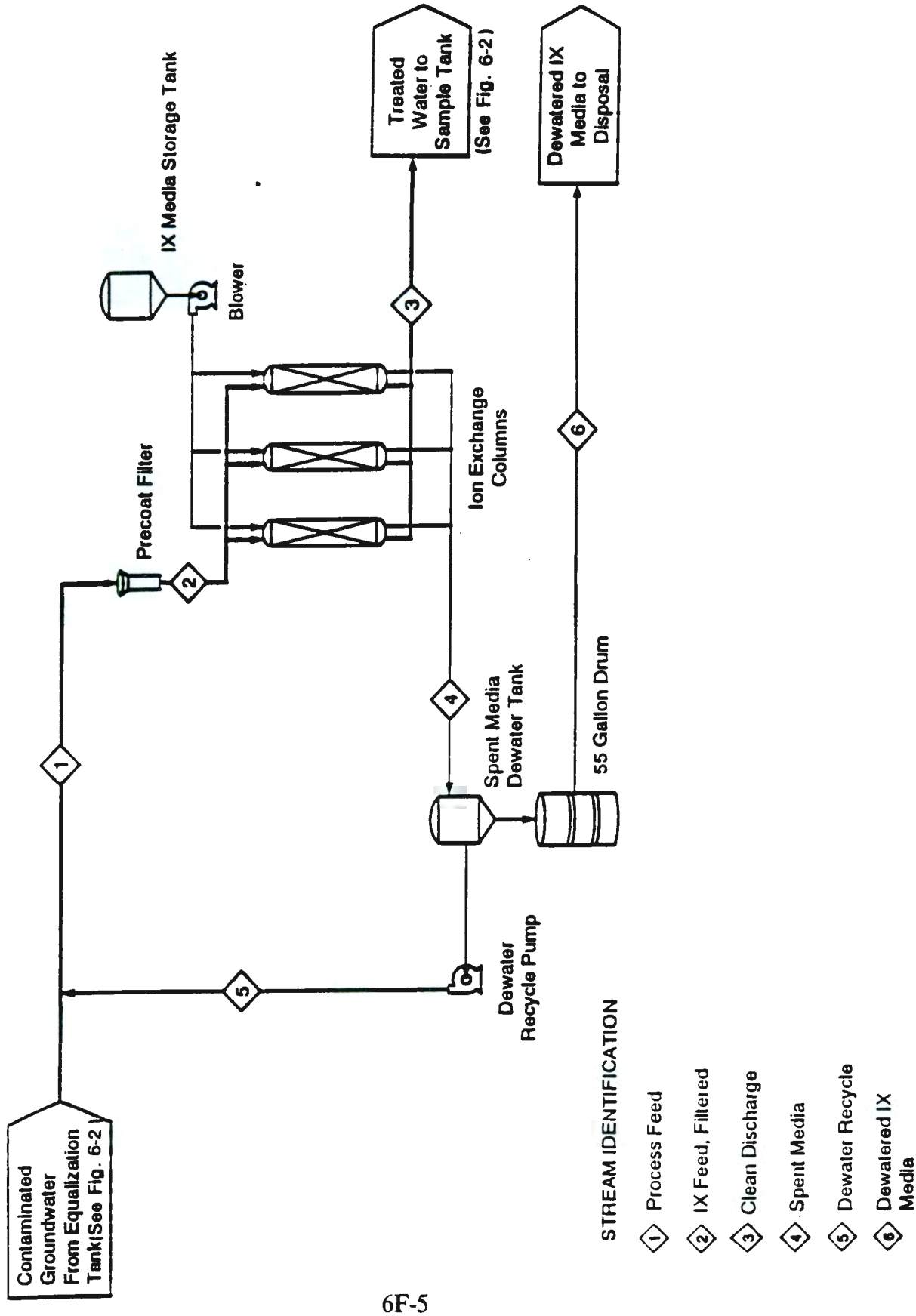


Figure 6-6. Alternative 2 - Pump and Treat, Reverse Osmosis Treatment Process Flow Diagram

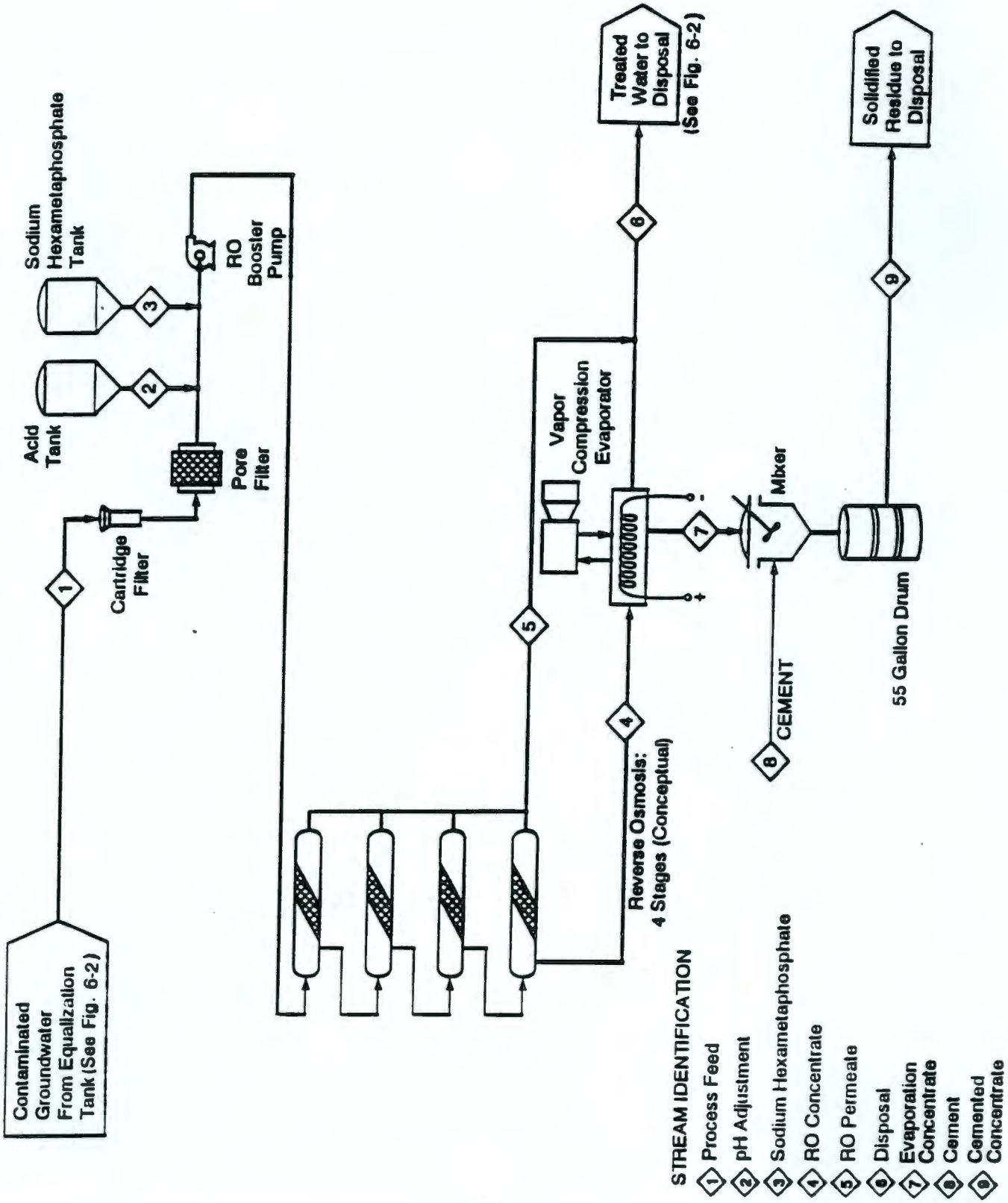
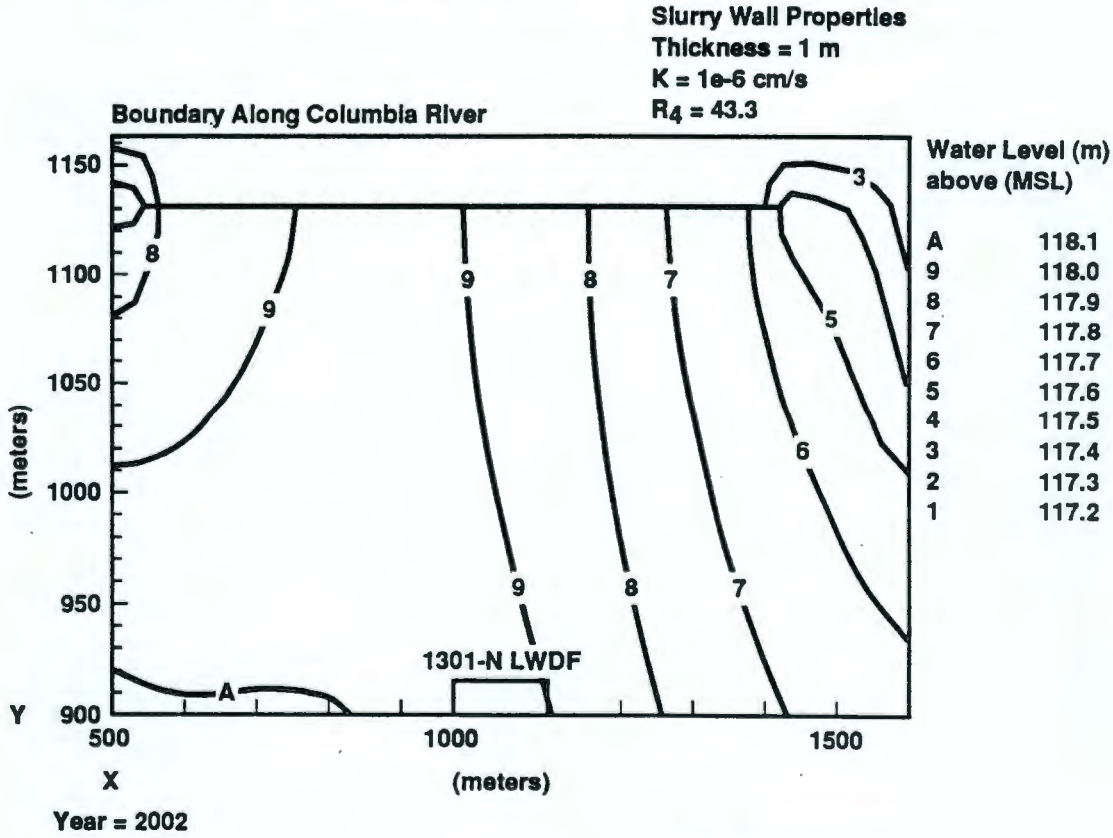


Figure 6-7. Groundwater Levels and Sr-90 Concentration Estimates Based on Groundwater Modeling for the Year 2002 - Slurry Wall Alternative



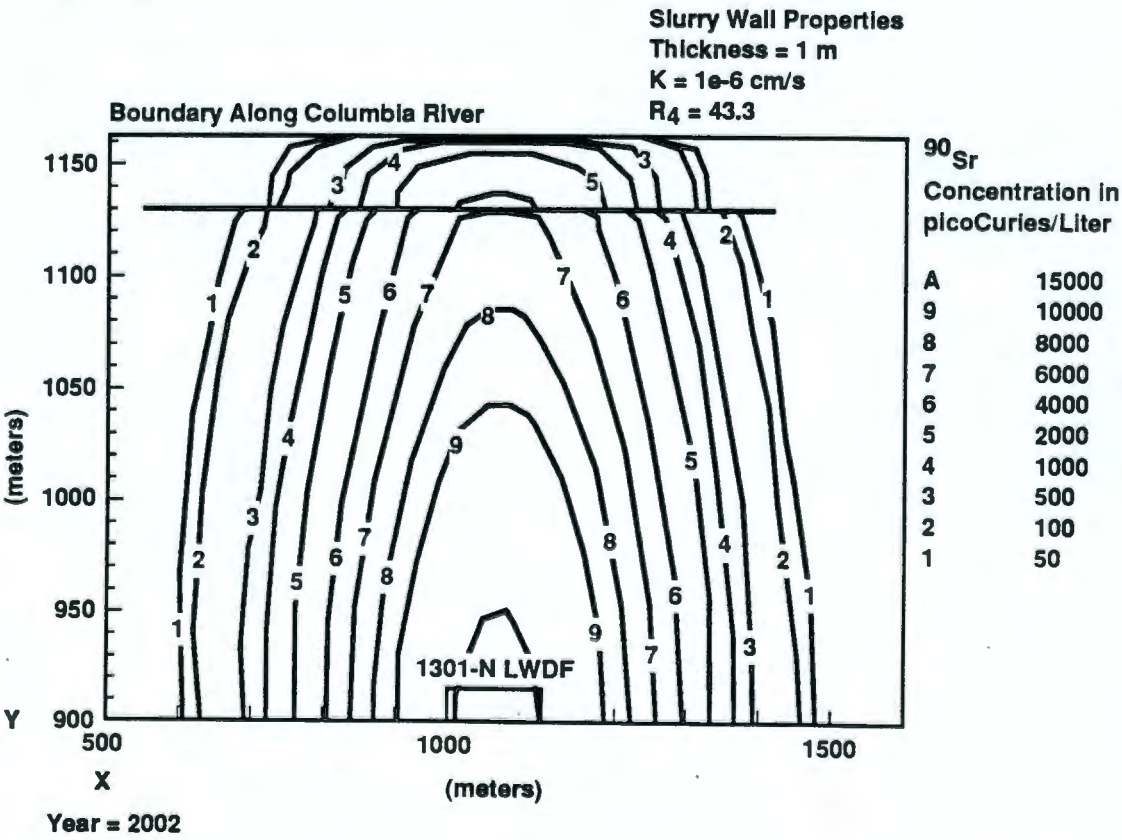


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Figure 6-8. Approximate Location of Slurry Wall

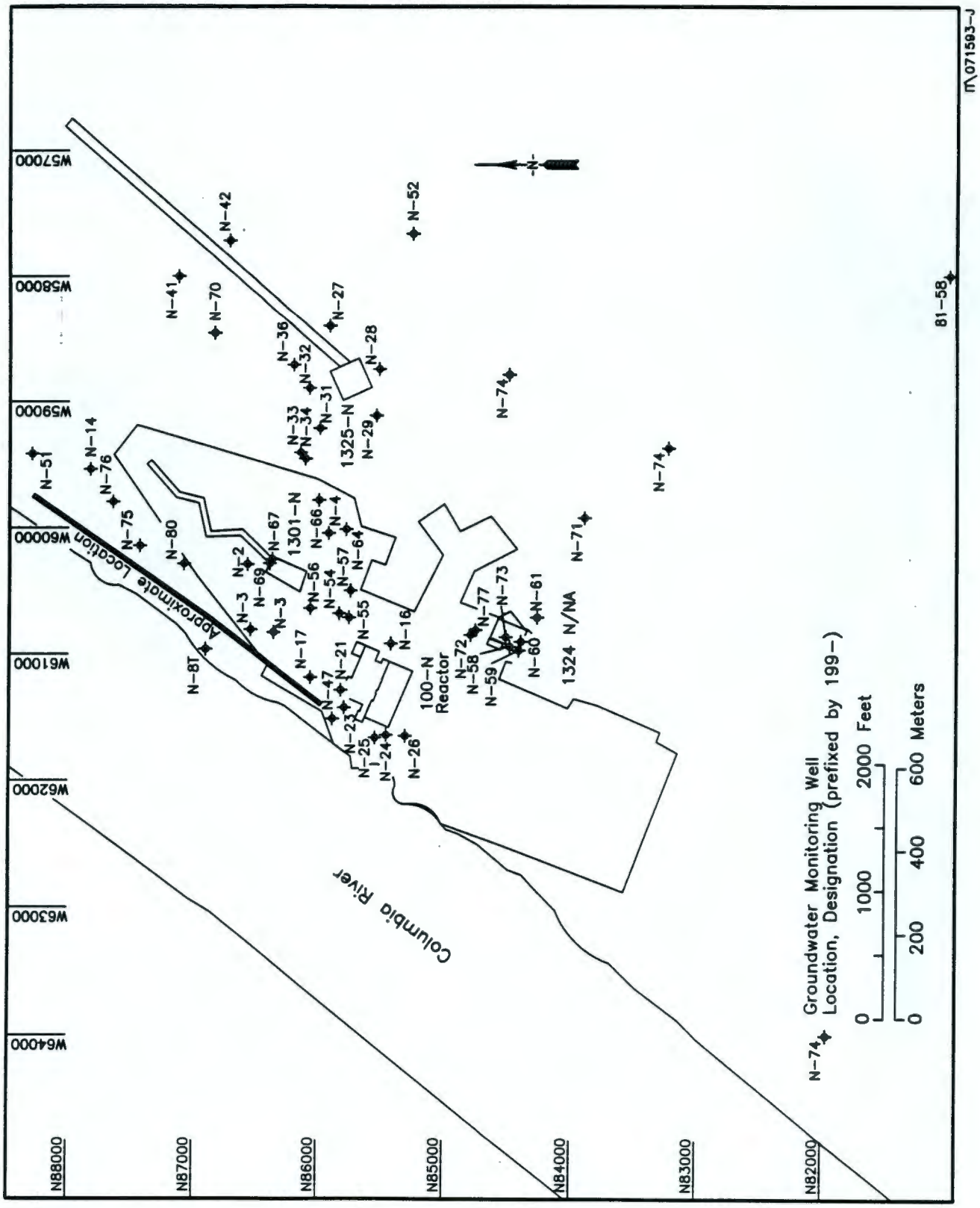

Figure 6-9. Side View, Slurry Wall

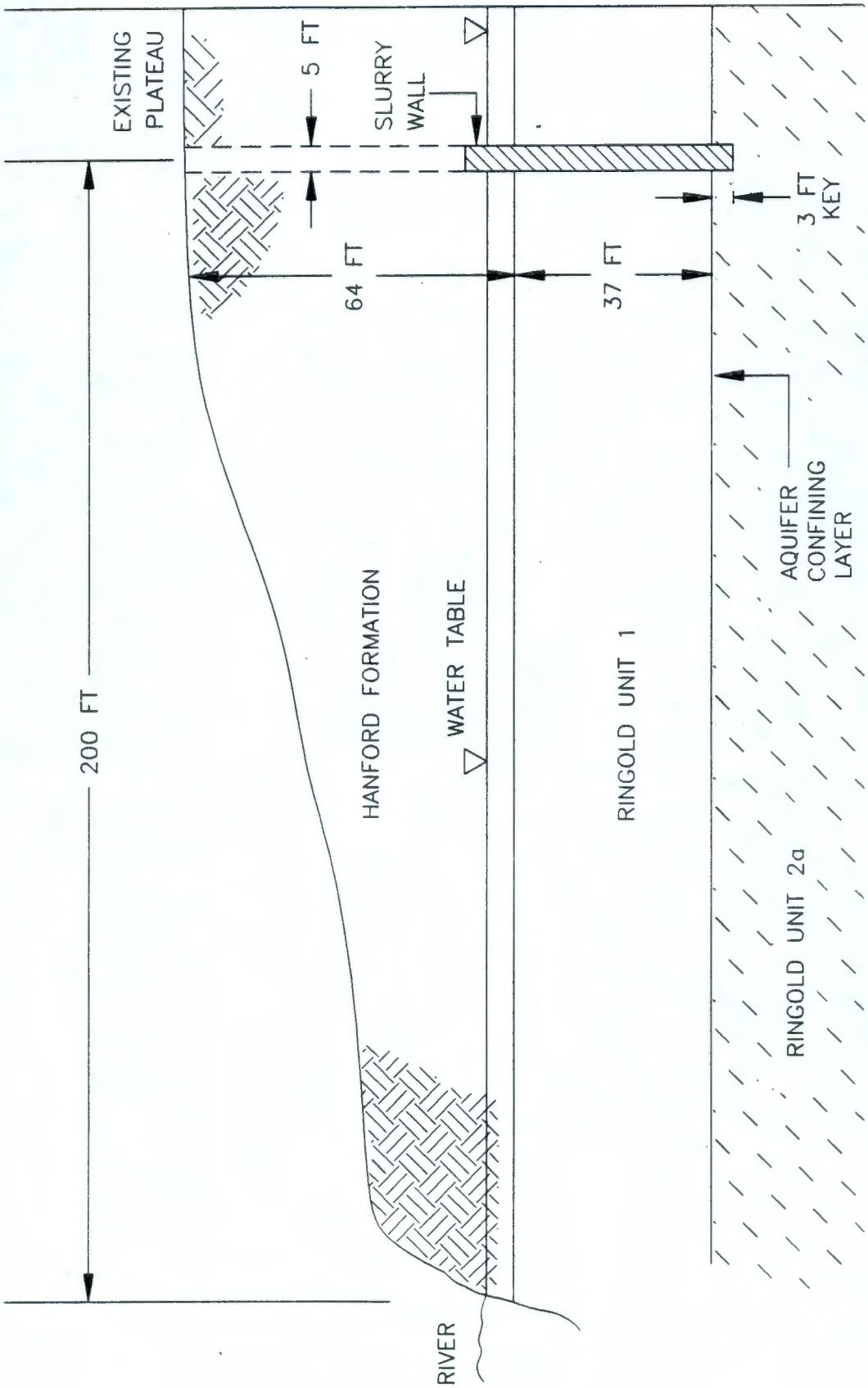

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Figure 6-10. Upgradient Hydraulic Control Steady State Hydraulic Head Distribution and Individual Well Pumping Rates

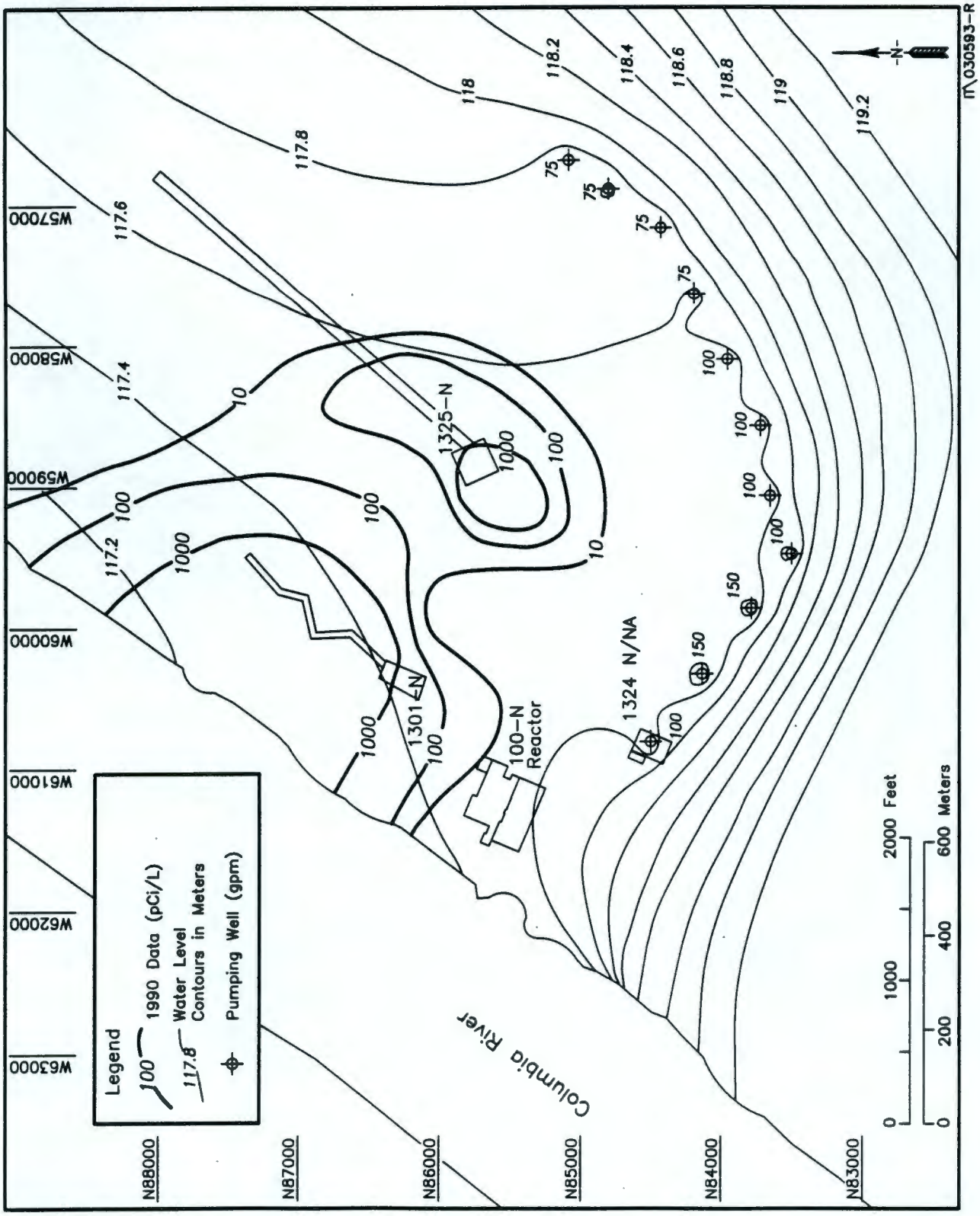

Table 6-1. Technical Feasibility Evaluation for No Action Alternative

Criteria	Evaluation
Ability to comply with ARAR	Does not comply with chemical-specific ARAR such as the drinking water MCL
Effectiveness in reducing toxicity, mobility, or volume of contamination	None is attained except that achieved through natural attenuation, primarily through radioactive decay
Demonstrated performance and reliability under similar conditions	No action - not applicable
Useful life	No action - not applicable
Constructability	No action - not applicable
Operation and maintenance requirements	No incremental requirements beyond existing controls and monitoring
Environmental effects on performance	None
Sensitivities and uncertainties	Some uncertainties exist in the data with regard to plume concentration profiles; some uncertainty associated with modeling parameters and modeling predictions, however these uncertainties do not affect this alternative because no actions are taken

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Table 6-2. Institutional Considerations Evaluation for No Action Alternative

Criteria	Evaluation
Ability to achieve removal action objectives	Does not achieve objectives
Regulatory concerns about the technology	Likely unfavorable because ERA objectives are not achieved
Permitting requirements	None
Safety	No action - not applicable
Timeliness	Contamination reduction achievable by natural attenuation only in the long term

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Table 6-3. Environmental Impacts Evaluation of No Action Alternative

Criteria	Evaluation
Environmental impacts on: Topography and surface drainage	No impact
Geology	No impact
Soils	Riverbank sediments will continue to be contaminated
Surface water hydrology and quality	Flow of contamination into the river will continue to impact the near-shore surface water quality
Groundwater hydrology and quality	Contamination will continue to impact local groundwater quality
Meteorology and air quality	No impact
Biological resources	Contamination from springs will continue to potentially impact riparian and aquatic biota
Cultural resources	No impact
Land and water use	Local groundwater and land use will continue to require restriction
Visual resources	No impact

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Table 6-4. Technical Feasibility Evaluation for Groundwater Extraction Options

Criteria	Evaluation	
	Five-Well System	Three-Well System
Ability to comply with ARAR	Removes contaminated water but does not meet chemical-specific ARAR	Same as five-well system; less contaminated water is removed
Effectiveness in reducing toxicity, mobility, or volume of contamination	Contaminated water flow to the river is greatly restricted (potentially 100% of the >1,000 pCi/L plume)	Contaminated water flow is restricted to a lesser extent than the five-well system
Useful life	Meets requirements	Meets requirements
Constructability	Pumping wells are readily constructable	Same as five-well system; constructability somewhat easier because of fewer wells
O&M requirements	Operation is not complex; moderate maintenance required for pumps	Same as five-well system; lower O&M due to less wells
Environmental effects on performance	None anticipated	None anticipated
Sensitivities and uncertainties	Uncertainties in plume concentration distribution and hydrologic properties; this option is less vulnerable to uncertainties since it uses five pumping wells	Same uncertainties as five-well system, but more vulnerable to uncertainties since fewer wells are used

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Table 6-5. Technical Feasibility Evaluation of Groundwater Treatment Options

Criteria	Evaluation	
	Ion Exchange	Reverse Osmosis
Ability to comply with ARAR	Tritium not removed; ability to meet Sr-90 MCL is uncertain; treatability studies are needed	Same as ion exchange
Effectiveness in reducing toxicity, mobility, or volume of contamination	Effective in removing Sr-90 from extracted groundwater; not effective in tritium removal	Same as ion exchange
Demonstrated performance and reliability under similar conditions	ion exchange has been used extensively for radioactive wastewater treatment	Application for radioactive wastewater is more limited but has been proven
Useful life	Meets requirements	Meets requirements
Constructability	Commercially available systems are designed and constructed as package units by multiple vendors	Commercially available but not to the same extent as ion exchange
O&M requirements	System is designed to operate automatically; periodic need for ion exchange media replacement and disposal of spent media	O&M are more complex due to evaporator and residue solidification
Environmental effects on performance	System in enclosed building; none anticipated	Same as ion exchange
Sensitivities and uncertainties	Treatability studies required to optimize media selection, determine waste generation rate, and treatment performance	Treatability studies required to determine waste generation rate, membrane life, and treatment performance

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Table 6-6. Technical Feasibility Evaluation of Treated Water Disposal Options (Page 1 of 2)

Criteria	Evaluation			
	River Discharge	N Area Crib	N Area Injection	200 Area Crib
Ability to comply with ARAR	Does not meet tritium MCL	Does not meet tritium MCL	Does not meet tritium MCL	Meets tritium MCL
Effectiveness in reducing, toxicity, mobility or volume of contamination	Effective except for tritium	Effective except for tritium	Effective except for tritium	Effective for all contaminants
Demonstrated performance and reliability under similar conditions	The discharge system is simple and expected to perform reliably	Slightly more complex than river discharge but performance is well established at Hanford	Injection wells are subject to plugging and therefore reliability is somewhat less than other options	Crib performance is reliable; long pipeline to 200 Area is more vulnerable to leaks and other operating problems
Useful life	Meets project goals	Meets project goals	Meets project goals	Meets project goals
Constructability	Easily constructable	Easily constructable	Easily constructable	More difficult constructability because of long pipeline
O&M requirements	Very low since it is a gravity flow system	Low since pumping requirements are not high	Low since pumping requirements are not high	High cost for pump operation and maintenance of long pipeline
Environmental effects on performance	None anticipated	None anticipated	None anticipated	Long pipeline more vulnerable to earthquake effects

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Table 6-6. Technical Feasibility Evaluation of Treated Water Disposal Options (Page 2 of 2)

Criteria	Evaluation			
	River Discharge	N Area Crib	N Area Injection	200 Area Crib
Sensitivities and uncertainties	Some uncertainties exist in the data with regard to tritium plume concentration profiles; discharge levels will probably be somewhat lower than assumed for this study	Same as river discharge	Same as river discharge	Pipeline may be undersized if flow rates have to be increased beyond design capacity

Table 6-7. Cost Evaluation for Groundwater Extraction Options

Cost in Millions of 1993 Dollars	Extraction System	
	Five-Well System	Three-Well System
Capital	1.53	1.01
Annual O&M	0.03	0.02
Present Worth	1.77	1.17

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Table 6-8. Cost Evaluation for Ion Exchange System

Cost in Millions of 1993 Dollars	Five-Well System	Three-Well System
Capital	2.97	2.11
Annual O&M	1.29	0.78
Present Worth	12.94	8.14

Table 6-9. Cost Evaluation for Reverse Osmosis System

Cost in Millions of 1993 Dollars	Five-Well System	Three-Well System
Capital	2.26	1.58
Annual O&M	0.83	0.50
Present Worth	8.70	5.45

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Table 6-10. Cost Evaluation for River Disposal

Cost in Millions of 1993 Dollars	Five-Well System	Three-Well System
Capital	0.06	0.05
Annual O&M	<0.01	<0.01
Present Worth	0.07	0.06

Table 6-11. Cost Evaluation for N Area Crib Disposal

Cost in Millions of 1993 Dollars	Five-Well System	Three-Well System
Capital	2.85	2.05
Annual O&M	<0.01	<0.01
Present Worth	2.92	2.09

Table 6-12. Cost Evaluation for N Area Reinjection

Cost in Millions of 1993 Dollars	Five-Well System	Three-Well System
Capital	1.13	0.85
Annual O&M	<0.01	<0.01
Present Worth	1.20	0.89

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Table 6-13. Cost Evaluation for 200 Area Crib Disposal

Cost in Millions of 1993 Dollars	Five-Well System	Three-Well System
Capital	8.98	8.23
Annual O&M	0.13	0.08
Present Worth	10.02	8.85

Table 6-14. Institutional Considerations Evaluation for Groundwater Extraction Options

Criteria	Evaluation	
	Five-Well System	Three-Well System
Ability to achieve removal action objectives	Achieves objectives; Sr-90 flux above 1,000 pCi/L is potentially completely eliminated	Achieves objectives; Sr-90 flux is restricted to a lesser extent than five-well system
Regulatory concerns about the technology	Concern should be low since technology is well proven for containment	Same as five-well system
Permitting requirements	None required	None required
Safety	Meets ALARA with engineering controls applied	Same as five-well system
Timeliness	Meets requirements	Meets requirements

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Table 6-15. Institutional Considerations Evaluation for Groundwater Treatment Options

Criteria	Evaluation	
	Ion Exchange	Reverse Osmosis
Ability to achieve removal action objectives	Uncertain; treatability studies required	Uncertain; treatability studies required
Regulatory concerns about the technology	Concern should be low since technology is well proven	Same as ion exchange
Permitting requirements	None required	None required
Safety	Meets ALARA	Meets ALARA
Timeliness	Meets requirements	Meets requirements

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Table 6-16. Institutional Considerations Evaluation for Treated Water Disposal Options

Criteria	Evaluation			
	River Discharge	N Area Crib	N Area Injection	200 Area Crib
Ability to achieve removal action objectives	Achieves removal objectives for all contaminants except tritium	Same as river discharge option	Same as river discharge option	Achieves all objectives
Regulatory concerns about the technology	Tritium above drinking water standards	Same as river discharge but soil column acts as buffer	Same as river discharge; state not likely to favor injection	Same as river discharge but soil column acts as buffer
Permitting requirements	NPDES	WAC 173-216	WAC 173-218	WAC 173-216
Safety	Meets ALARA	Meets ALARA	Meets ALARA	Meets ALARA
Timeliness	Meets requirements	Meets requirements	Meets requirements	Meets requirements

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Table 6-17. Environmental Impacts Evaluation for Groundwater Extraction Options

Criteria	Evaluation	
	Five-well System	Three-well System
Environmental impacts on: Topography and surface drainage	No impact	No impact
Geology	No impact	No impact
Soils	No impact	No impact
Surface water hydrology and quality	Some surface water will flow into the pumping wells; surface water quality will increase through removal of Sr-90	Same as five-well system but with a lesser increase in surface water quality
Groundwater hydrology and quality	Hydrology will be impacted by increasing gradients in the capture zone; flow of contamination toward the well will be accelerated due to the pumping effect	Same as five-well system but to a lesser extent
Meteorology and air quality	No impact	No impact
Biological resources	No impact	No impact
Cultural resources	No impact	No impact
Land and water use	Water use restrictions will continue; same as no action	Same as five-well system
Visual resources	No impact	No impact

Table 6-18. Environmental Impacts Evaluation for Treated Water Disposal Options

Criteria	Evaluation			
	River Discharge	N Area Crib	N Area Injection	200 Area Crib
Environmental impacts on: Topography and surface drainage	No impact	Potential slight topography changes from crib excavation	No impact	Potential slight topography changes from crib excavation
Geology	No impact	No impact	No impact	No impact
Soils	No impact	Tritium will increase in disposal crib soils and underlying groundwater aquifer sediments	Contamination of currently clean aquifer sediments with tritium	Same as N Area crib
Surface water hydrology and quality	Discharge of tritiated water into the river could impact the surface water in the immediate vicinity	Tritiated water could impact near-shore surface water quality	Same as N Area crib	Elimination of contamination impact to river
Groundwater hydrology and quality	No impact	Local groundwater hydrology impacted	Same as N Area crib	200 Area groundwater hydrology impacted;
Meteorology and air quality	No impact	No impact	No impact	No impact
Biological resources	Minimal impact in immediate vicinity of discharge point	No impact except at river flow interface	Same as N Area crib	No impact
Cultural resources	No impact	Minimal or no impact	Minimal or no impact	Minimal or no impact
Land and water use	Water use restricted at discharge point	Same as river discharge	Same as river discharge	Same as river discharge
Visual resources	No impact	No impact	No impact	No impact

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Table 6-19. Technical Feasibility Evaluation for Slurry Wall Alternative

Criteria	Evaluation
Ability to comply with ARAR	Source to receptor pathway is restricted; therefore alternative complies with ARAR
Effectiveness in reducing toxicity, mobility, or volume of contamination	Restricts the flow of water containing both Sr-90 and tritium although tritiated water will flow around the wall because it is not retarded by the soil
Demonstrated performance and reliability under similar conditions	Slurry walls have been used effectively for containment actions at RCRA/CERCLA sites throughout the country
Useful life	Exceeds requirements
Constructability	Readily constructable but rocky soils will make construction more difficult
O&M requirements	Vegetative cap required to prevent dehydration of bentonite; continued spring and groundwater monitoring after installation
Environmental effects on performance	Natural flow of groundwater has the potential to deteriorate the performance of the barrier over time
Sensitivities and uncertainties	Soil testing is needed to provide data on design of slurry formulations including compatibility with the injection system equipment

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Table 6-20. Cost Evaluation for Slurry Wall Alternative

Cost in Millions of 1993 Dollars	Deep Soil Mixing
Capital	10.01
Annual O&M	0
Present Worth	10.01

Table 6-21. Institutional Considerations Evaluation for Slurry Wall Alternative

Criteria	Evaluation
Ability to achieve removal action objectives	Sr-90 flux is restricted; achieves objectives
Regulatory concerns about the technology	Concern should be low since technology is well proven
Permitting requirements	None required
Safety	Meets ALARA
Timeliness	Meets requirements

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Table 6-22. Environmental Impacts Evaluation for Slurry Wall Alternative

Criteria	Evaluation
Environmental impacts on: Topography and surface drainage	No impact
Geology	No impact
Soils	Reduced contamination in riverbank soils
Surface water hydrology and quality	Improved surface water quality as a result of restricting flow of contaminants into the river
Groundwater hydrology and quality	Groundwater hydrology in the N Area is altered
Meteorology and air quality	No impact
Biological resources	Less threat to riparian and aquatic biota
Cultural resources	No impact
Land and water use	No impact.
Visual resources	No impact

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Table 6-23. Technical Feasibility Evaluation for Hydraulic Control Alternative

Criteria	Evaluation
Ability to comply with ARAR	Flow of contamination to river is restricted but alternative does not meet any final cleanup ARAR
Effectiveness in reducing toxicity, mobility, or volume of contamination	Restricts the flow of water containing Sr-90 and tritium
Demonstrated performance and reliability under similar conditions	Hydraulic control has been used effectively for containment actions at RCRA/CERCLA sites
Useful life	Meets requirements
Constructability	Readily constructable
Operation and maintenance requirements	System is not complex and easy to operate; some maintenance required for pumps
Environmental effects on performance	Changing hydrologic conditions could affect system performance
Sensitivities and uncertainties	Uncertainties in hydrologic properties and heterogeneities of the flow system

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Table 6-24. Cost Evaluation for Hydraulic Control Alternative

Cost in Millions of 1993 Dollars	Hydraulic Control System
Capital	2.30
Annual O&M	0.07
Present Worth	2.85

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Table 6-25. Institutional Considerations Evaluation for Hydraulic Control Alternative

Criteria	Evaluation
Ability to achieve removal action objectives	Sr-90 flux is restricted; achieves objectives
Regulatory concerns about the technology	Concern should be low since technology is proven in the field
Permitting requirements	None required
Safety	No contaminated water is pumped
Timeliness	Meets requirements

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Table 6-26. Environmental Impacts Evaluation for Hydraulic Control Alternative

Criteria	Evaluation
Environmental impacts on: Topography and surface drainage	No impact
Geology	No impact
Soils	Reduced contamination in riverbank soils
Surface water hydrology and quality	Improved surface water quality as a result of restricting flow of contaminants into the river
Groundwater hydrology and quality	Groundwater hydrology in the N Area is altered, groundwater quality remains the same
Meteorology and air quality	No impact
Biological resources	Less threat to riparian and aquatic biota as a result of reducing contamination flux to the river
Cultural resources	No impact
Land and water use	No impact
Visual resources	Minimal impact; wells are visible but not intrusive

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7.0 COMPARATIVE ANALYSIS OF REMOVAL ACTION ALTERNATIVES

This section provides comparisons of the four alternatives evaluated in Section 6.0. Each alternative is compared against the others in relation to the evaluation criteria. Cost benefits of the alternatives are compared based on correlation of cost with the estimated percentages of Sr-90 reductions achieved by each alternative.

7.1 ALTERNATIVE COMPARISONS

Comparisons of the alternatives based on the evaluation criteria are summarized below.

7.1.1 Technical Feasibility

7.1.1.1 Ability to Comply with ARAR. Ability to comply with MCL is uncertain for all the alternatives. All alternatives, except for no action, reduce the flux of contamination to the river to some degree. The vertical barrier has the greatest potential to meet the 8 pCi/L MCL for Sr-90; the five-well pump and treat system has the second best flux reduction potential; the hydraulic control alternative reduces the flux the least.

None of the alternatives meet the tritium MCL for surface or groundwater discharge. While the 200 Area crib disposal option for pump and treat prevents tritium discharge to surface water above the MCL, discharging the water to groundwater at the 200 Area would require an ARAR waiver. The slurry wall potentially reduces the level of tritium reaching the river through the lowered groundwater gradient.

Location- and action-specific ARAR are generally met by all the alternatives.

7.1.1.2 Effectiveness in Reducing Toxicity, Mobility, or Volume of Contamination. All alternatives except no action reduce the flux of Sr-90 to the river, but to a different extent depending on the technology or process option. Based on the modeling, the vertical barrier is the most effective, while hydraulic control is the least effective. However, all alternatives, except no action, meet the removal action objective of eliminating or substantially reducing the flux of Sr-90 to the river.

Of the pump and treat options, the five-well system has the most certain effectiveness because more of the plume is intercepted.

7.1.1.3 Demonstrated Performance and Reliability under Similar Conditions. All technologies have been proven in field applications that are similar to the proposed application. Reliability of all removal action technologies is considered good, although the vertical barrier is the least complex and therefore the most reliable. The pump and treat

alternative is the most complex because it involves extraction, treatment, and disposal operations; therefore, reliability may be less than the other alternatives.

7.1.1.4 Useful Life. All alternatives meet the requirement of the ERA for a 10-yr useful life. All the alternatives can be easily incorporated into future remedial actions for the operable unit.

7.1.1.5 Constructability. All alternative systems are readily constructable. Constructability of the vertical barrier is less certain than the others because of Hanford's rocky soils.

7.1.1.6 Operating and Maintenance Requirements. The pump and treat alternative requires the most O&M; the vertical barrier requires the least. Hydraulic control O&M requirements are low. For pump and treat, river disposal requires the least O&M, while 200 Area crib disposal requires the most.

7.1.1.7 Environmental Effects on Performance. None of the alternatives are sensitive to environmental effects such as weather or terrain.

7.1.1.8 Sensitivities and Uncertainties. With the exception of the no action alternative, all the alternatives are feasible for application at N Springs. However, because none of the technologies has been applied at Hanford Site conditions, the technical feasibility has some uncertainties. For the slurry wall, the uncertainty of installation in the rocky soils is a concern. Field testing is recommended to assess the impacts of the gravels and boulders on the deep soil mixing slurry wall. For pump and treat, uncertainties lie in the ability to treat the groundwater to meet ARAR. Treatability testing is necessary before performance factors can be confidently assessed. Both ion exchange and reverse osmosis treatment options generate substantial volumes of secondary waste. In the case of ion exchange, the volume of solid zeolite resins requiring disposal as low-level waste depends upon the media loading capacity. This loading capacity is sensitive to influent concentrations, including content of non-contaminants, such as calcium and non-radioactive strontium, and to the decontamination factors required. Disposal of tritiated water is another uncertainty associated with the pump and treat alternative, both in terms of institutional considerations and cost. The hydraulic control option has uncertainties associated with efficiency and the potential for increased contamination of clean areas.

While all the alternatives are somewhat affected by the uncertainties in the hydrogeologic setting of the area, the slurry wall is least affected. Capture effectiveness for the pump and treat will be influenced by hydraulic conductivity. If conductivities are higher than modeled, higher pumping rates would be required for effective capture which directly affects treatment system size and design. Heterogeneities in the aquifer sediments could also produce adverse effects on contaminant capture.

Hydraulic control is very sensitive to hydrologic properties and aquifer heterogeneities. If hydraulic conductivities are higher than modeled, pumping rates would have to be increased to maintain the same effect on downgradient water levels. However, higher pumping rates present a greater risk of drawing contamination further upgradient.

Aquifer heterogeneities in the form of flow channels could also result in upgradient flow of contamination and lower effectiveness in controlling gradients in the intended portion of the plume.

7.1.2 Cost Considerations

The present worths of the alternatives, including options within the pump and treat alternative, are compared in Table 7-1. As indicated in the table, present worth (excluding no action) ranges from a low of about $2.85 million for the hydraulic control alternative to a high of over $24 million for a five-well pump and treat using ion exchange treatment and 200 Area crib disposal.

The cost analysis indicates that among the pump and treat options, cost is most sensitive to the system size in terms of flowrate from the wells, followed by the type of water disposal, and finally to the type of treatment. Cost differentials between a five-well and three-well system are on the order of $4 to $7 million. Cost differentials between river disposal and 200 Area crib disposal are on the order of $6 to $10 million. Cost differentials between ion exchange and reverse osmosis treatment are on the order of $2 to $4 million (reverse osmosis is less costly). Cost uncertainties, especially operating costs, are greatest for treatment technologies. The true differential between ion exchange and reverse osmosis may not be significant, but costs cannot be refined further without treatability studies. Costs for extraction wells are fairly certain because they are based on well-defined, historical drilling costs at Hanford. Costs for treated water disposal carry moderate uncertainties in that, even though the systems are straightforward, costs for pipelines and cribs are subject to further refinement with greater design definition.

Costs for slurry wall installation are based solely on estimates provided by vendors, although two vendors provided estimates that were on the same order of magnitude. Both vendors state that field testing is required to determine optimum slurry mixes. Costs for the slurry wall will likely change as site-specific design is performed. The major cost uncertainties associated with slurry wall installation are those that relate to unexpected field conditions, e.g., encountering large boulders that interfere with augering. Placement of the wall closer to the river would result in significant cost savings because the wall depth would be reduced approximately 50%. However, placing the wall closer to the river presents potential impacts to the 100-year floodplain. This issue can be more fully addressed in the design phase of the ERA.

Costs for hydraulic control are fairly certain because they are based primarily on historical well installation costs. There is more uncertainty in the costs of installing a water pipeline to the river.

7.1.3 Institutional Considerations

7.1.3.1 Ability to Achieve Removal Action Objectives. All alternatives, except no action, meet the removal action objective of eliminating or substantially reducing Sr-90 flux to the

river. The five-well pump and treat and the vertical barrier are potentially more effective in reducing the flux relative to the other alternatives.

7.1.3.2 Regulatory Concerns about the Technology. All technologies are proven for site remediation and thus should not raise concern among the regulators.

7.1.3.3 Permitting Requirements. The pump and treat alternative will require that substantive requirements of permitting regulations be met for disposal of the treated water. For example, river discharge requires meeting NPDES requirements. The vertical barrier and hydraulic control alternatives should not trigger any permit requirements.

7.1.3.4 Safety. All alternatives will meet ALARA requirements through application of standard control for construction and operation. Pump and treat will require appropriate controls for handling treatment residues. Some shielding may be required on vessels where Sr-90 is concentrated, although shielding will be modest because there are no significant concentrations of gamma emitters.

7.1.3.5 Timeliness. All alternatives can be implemented within a time frame that meets ERA objectives. Pump and treat will require treatability studies prior to design of treatment systems. The slurry wall will require field testing of slurry formulations and a demonstration of implementability in Hanford soils. Hydraulic control can be implemented in the shortest time frame.

7.1.4 Environmental Impacts

All alternatives, except no action, will impact the river positively by reducing the flux of Sr-90 in the riverbank springs. This will benefit riparian biota and downstream water users. All alternatives except for no action will alter groundwater hydrology in the area of the plume; however, this will not cause impacts to human health or the environment. All alternatives will continue to require land use restrictions and restrictions on use of water from the contaminated portions of the aquifer.

7.2 COST-BENEFIT ANALYSIS

Cost benefit of each alternative is analyzed by correlating present worth costs to estimated reductions in Sr-90 flux as a percentage of no action (benefit). The result of this analysis is shown graphically in Figure 7-1. In this figure, the estimated percent reduction in Sr-90 flux to the river is plotted as the abscissa against the present worth cost as the ordinate.

Note that in the figure the no action, vertical barrier, and hydraulic control alternatives plot as a single point. However, the pump and treat alternative options plot as a range. Ranges are shown for the three-well and five-well extraction systems. The cost range for each of the pumping options reflects the cost differences in the treated water disposal options and in the treatment options. The figure reflects those parameters which

could be quantified for this ERA. However, uncertainties may lie in both the costs and effectiveness of the alternatives. For example, the slurry wall may actually restrict only 95% of the Sr-90 to the river. Likewise the pump and treat costs may be slightly higher or lower. However, these uncertainties cannot be quantified with existing data. The information shown on the figure represents the modeling results, professional judgement, and current data available for the N Spring area. Further analysis at this stage would require unsupportable assumptions which would not decrease the level of uncertainty.

Based on analysis of the cost-benefit relationship of Figure 7-1, several generalizations and conclusions can be reached. These are discussed as follows:

- For the pump and treat options, river disposal appears to be the best choice among all treated water disposal options. The 100 N Area reinjection and the 100 N Area crib disposal option do not offer significant additional benefit for handling tritium but result in substantially greater costs. Further, the benefit of crib disposal and reinjection are considered negative, since either would result in contamination of additional aquifer sediments. Disposal at a 200 Area crib offers better protection of the river but results in further aquifer sediment contamination and greater expense.

- The slurry wall provides maximum reduction of Sr-90 flux; it offers the greatest benefit at the lowest cost. Although the pump and treat costs for the five-well system are comparable (reverse osmosis treatment with river disposal) to the slurry wall, the maximum reduction is lower with the five-well system. Increasing the number of wells or the pumping rates to achieve higher Sr-90 reductions results in greater waste disposal requirements and higher cost than both the proposed five-well system and the slurry wall.

- Hydraulic control offers the lowest cost; however, the uncertainties associated with the hydraulic control alternative are greater than the other alternatives. The modeling shows that upgradient hydraulic control could achieve at best a 50% reduction in Sr-90 flux without drawing the contamination into clean areas and requiring treatment of the extracted water. This reduction could be worse if hydraulic conductivity is higher or if significant flow channels are present.

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Figure 7-1. Cost Benefit Analysis of Alternatives

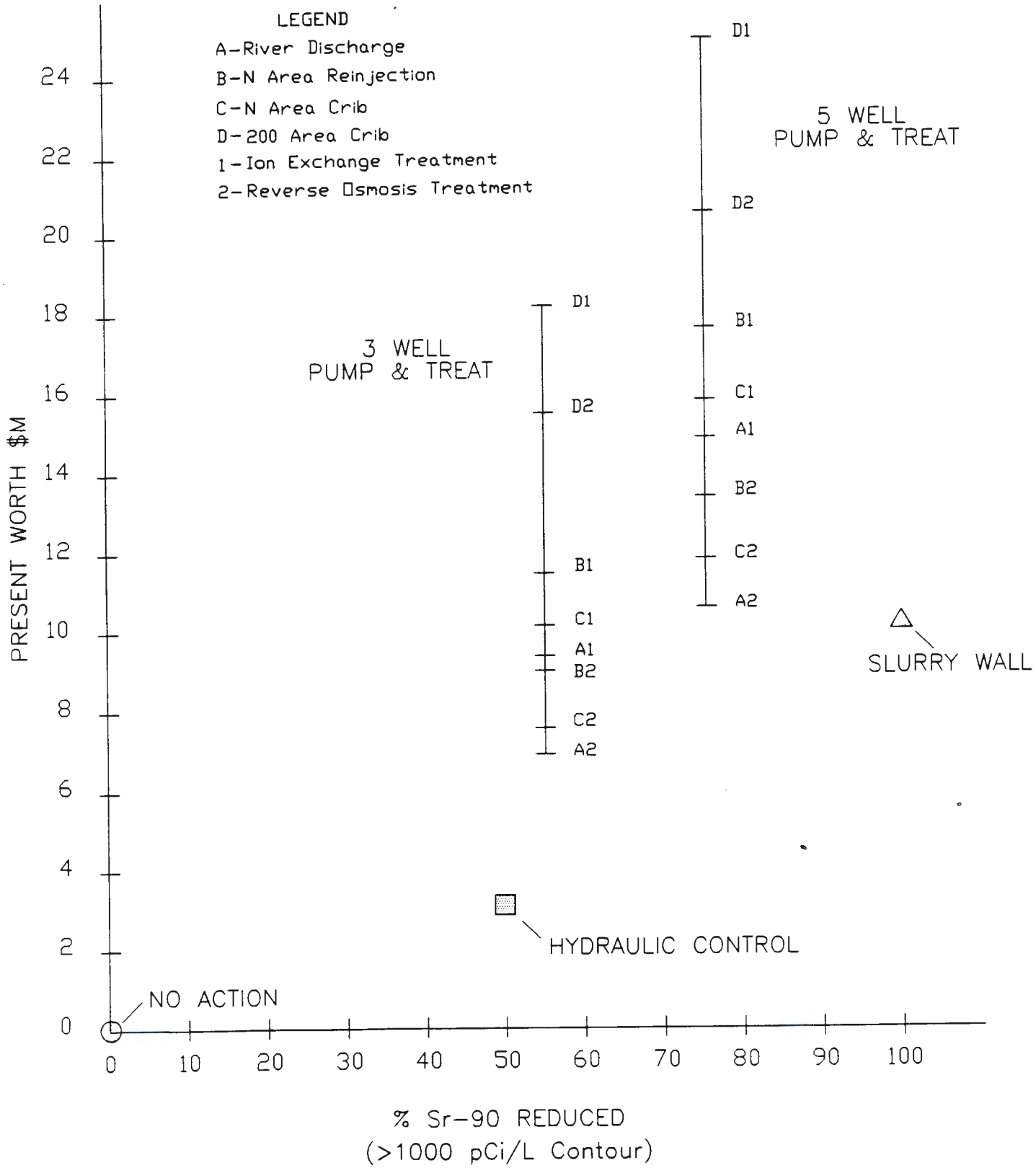

Table 7-1. Cost Comparison of Alternatives

Table 7-1 Alternative Present Worth Comparisons (In Millions of $)		
Alternative 1	**No Action** **$0**	
Alternative 2	**Five Well**	**Three Well**
Ion Exchange:		
River Disposal	$14.78	$9.36
N Area Crib	$17.56	$11.36
N Reinjection	$15.91	$10.19
200 Area Crib	$24.73	$18.16
Reverse Osmosis:		
River Disposal	$10.54	$6.68
N Area Crib	$13.39	$8.71
N Reinjection	$11.67	$7.51
200 Area Crib	$20.49	$15.47
Alternative 3	**Slurry Wall** $10.01	
Alternative 4	**Hydraulic Control** $2.85	

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8.0 PREFERRED ALTERNATIVE

The preferred alternative action should provide a high degree of protectiveness balanced with acceptable risks and reasonable costs. The slurry wall alternative offers the best tradeoffs of cost, benefit, and project risk for the following reasons:

- Although the slurry wall is not the lowest cost alternative, it is the most cost effective alternative. For example, it offers complete reduction of the Sr-90 flux to the river for concentrations greater than 1,000 pCi/L at a reasonable cost.

- It is not as sensitive as the other alternatives to the uncertainties associated with aquifer hydrologic properties.

- It offers long-term protection (even beyond the ERA time frame) without incurring O&M costs.

- Treatability studies are not required for a slurry wall although field testing of slurry formulations is required to support the design. A field scale test of the deep soil mixing technology may provide more certainty in the technical feasibility of this technology in the rocky soils of Hanford. Treatability studies would be required for either groundwater treatment option to define Sr-90 removal efficiency and secondary waste generation rates.

- Little or no secondary wastes are generated for the slurry wall using the deep soil mixing method, while the pump and treat alternative generates substantial quantities of wastes requiring disposal.

- Some reduction in tritium flux will be achieved as a result of the flow stagnation zone created behind the wall. In contrast, pump and treat results in accelerated movement of tritium, which must ultimately be disposed to the environment.

- The slurry wall alternative complies most fully with ARAR, while the no action, pump and treat, and hydraulic controls are uncertain.

- Based on performance of previous projects involving the deep soil mixing technology at analogous sites, the technology is considered implementable in Hanford soils for construction of an effective slurry wall.

Therefore, the preferred alternative for the ERA is the slurry wall installed by deep soil mixing method (Alternative 3). The length and location of the wall will be optimized during the design phase of the ERA.

While the slurry wall appears to be the best alternative for the N Springs ERA in terms of cost benefit, it should be noted that all the alternatives have associated uncertainties.

These uncertainties include implementation in Hanford soil conditions, hydrogeologic properties, ability to comply with ARAR, and costs. Testing is recommended for the slurry wall and pump and treat alternatives prior to implementation to more accurately predict the performance and technical feasibility of the systems. The rocky soils pose an uncertainty in the slurry wall installation which may be reconciled with a field test. The potential for large boulders may increase the cost of the wall if step outs to avoid these obstructions are required. Treatability testing for the pump and treat is required to obtain more precise cost estimates, to predict secondary waste volumes, and to ascertain the ability to meet ARAR for release of treated water. The hydraulic control is greatly influenced by hydrogeologic factors.

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APPENDIX A

COST ESTIMATES

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Cost Estimate Assumptions and Estimating Sources
N Springs ERA

Assumptions:

1. Westinghouse in-house crafts install all individual pieces such as pumps, tanks, mixers, and pipe; perform site preparation; use WHC labor rates ($53.64/hr from WHC Program Office)

2. Subcontractors install all skid-mounted packages and construct large items such as the transfer pipe to the 200 Area; also assumes that subcontractors erect buildings, install concrete floors and foundations, and perform all trenching/backfilling ($95.87/hr from WHC Program Office)

Sources:

1. Based on actual costs of cable tool drilling of monitoring wells by Kaiser Engineers; per foot cost from WHC Program Office; contact K. Popham

2. Richardson Cost Engineering Services, Richardson Rapid System, Process Plant Construction Estimating Standards

3. Cost quotation from Familian Northwest, Inc. (Goulds Pumps); Portland, Oregon; contact Randy Mather (503-283-3333)

4. Cost quotation from Corr Tech, Inc; Houston Texas; contact Brian Mause (713-674-7242)

5. Vatavuk, William M., *Estimating Costs of Air Pollution Control*, Lewis Publishers, 1990

6. Electric power rate from Benton County PUD; cpmmercial rate for usage in the range of 2500-17500 kw

7. Cost quotation from Babcock and Wilcox; contact Dr. Billy Bingham (804-385-3267)

Cost Estimate Assumptions and Estimating Sources
N Springs ERA

Sources (Continued)

8. WHC LLW disposal cost; contact Frank Gustavson

9. Cost quotation from Polymetrics, Inc.; contact Les Bell (719-570-7507)

10. Cost quotation from Licon, Inc.; contact Edgar Steindal (904-434-5088)

11. Cost quotation from WHC stores

12. Based on calculation brief by IT Corp.

13. Best professional judgement assumption; contact Joe Alvarez, IT Corp. (303-694-0044)

14. Based on KEH cost estimate for Project C018H crib; contact Frank Gustavson

15. Based on actual costs of Odex drilling of monitoring wells in uncontaminated areas by Kaiser Engineers; per foot cost from WHC Program Office; contact K. Popham

16. Based on cost quotation from Millgard Environmental Corp.; contact Jeff Jacobs (313-261-9760)

Alternative Present Worth Comparisons
(In Millions of $)

Alternative 1	**No Action**	
	$0	
Alternative 2	**Five Well**	**Three Well**
Ion Exchange:		
River Disposal	$14.78	$9.36
N Area Crib	$17.56	$11.36
N Reinjection	$15.91	$10.19
200 Area Crib	$24.73	$18.16
Reverse Osmosis:		
River Disposal	$10.54	$6.68
N Area Crib	$13.39	$8.71
N Reinjection	$11.67	$7.51
200 Area Crib	$20.49	$15.47
Alternative 3	**Slurry Wall**	
	$10.01	
Alternative 4	**Hydraulic Control**	
	$2.85	

Alternative Capital Cost Comparisons (In Millions of $)

Alternative 1	**No Action**	
	$0	
Alternative 2	**Five Well**	**Three Well**
Ion Exchange:		
River Disposal	$4.56	$3.17
N Area Crib	$7.35	$5.17
N Reinjection	$5.63	$3.97
200 Area Crib	$13.49	$11.35
Reverse Osmosis:		
River Disposal	$3.85	$2.64
N Area Crib	$6.63	$4.64
N Reinjection	$4.91	$3.44
200 Area Crib	$12.77	$10.83
Alternative 3	**Slurry Wall**	
	$10.01	
Alternative 4	**Hydraulic Control**	
	$2.30	

Alternative O&M
Cost Comparisons
(In Millions of $)

Alternative 1	**No Action**	
	$0	
Alternative 2	**Five Well**	**Three Well**
Ion Exchange:		
River Disposal	$1.32	$0.80
N Area Crib	$1.33	$0.81
N Reinjection	$1.33	$0.81
200 Area Crib	$1.46	$0.88
Reverse Osmosis:		
River Disposal	$0.87	$0.52
N Area Crib	$0.88	$0.53
N Reinjection	$0.88	$0.53
200 Area Crib	$1.00	$0.60
Alternative 3	**Slurry Wall**	
	$0.00	
Alternative 4	**Hydraulic Control**	
	$0.07	

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Alternative 2
Pump and Treat - Extraction System

	Five Well System	Three Well System
Capital Cost:		
Wells	$793,936	$476,362
Pumps	$16,299	$9,779
Transfer Piping	$161,989	$155,253
Subtotal	$972,224	$641,394
Engineering @ 10%	$97,222	$64,139
Project Management @11%	$106,945	$70,553
Subtotal	$1,176,391	$776,087
Contingency @30%	$352,917	$232,826
Total Capital Cost	**$1,529,308**	**$1,008,913**
O&M Cost: (Annual)		
Operating Labor	*	*
Maintenance	$29,167	$19,242
Utilities	$2,083	$1,086
Total O&M Cost	**$31,250**	**$20,328**
Present Worth	**$1,770,613**	**$1,165,880**

*Included in treatment plant

Pump and Treat

System Module: Groundwater Extraction

Option: Five Well System

Cost Type	Component	Description	Quantity	Unit Cost	Total, $	Assumption	Source
Capital	Pumping Wells	6-inch diameter, 104 ft total depth, stainless steel, install by cable tool drilling; costs include all materials, mob/demob, drilling labor, logging, well development, waste disposal, equipment decon	520 ft	$1526.8/ft	793,936	--	1
	Pumps	5 hp, 100 gpm at 100 ft head, submersible, stainless steel; costs include materials and installation	5	--	16,299	1	3
	Transfer piping (transfer to treatment plant)	6-inch diameter, double wall PVC, buried below frost line; costs include pipe materials, valves, valve boxes and fittings, trenching, installation	2250 ft	--	147,263	1,2	4
	Piping leak detection	Materials and installation	--	10% of piping	14,726	--	5
O&M	Maintenance	System maintenance cost	--	3% of capital	29,167/ yr	--	5
	Operating Labor	(*Include in treatement system costs)	--		*	--	--
	Elect. Power	Power for pumps; annual cost	62,000 kwh/yr	$0.0336/kwh	2,083/yr	--	6

Pump and Treat

System Module: Groundwater Extraction

Option: Three Well System

Cost Type	Component	Description	Quantity	Unit Cost	Total, $	Assumption	Source
Capital	Pumping Wells	6-inch diameter, 104 ft total depth, stainless steel, install by cable tool drilling; costs include all materials, mob/demob, drilling labor, logging, well development, waste disposal, equipment decon	312 ft	$1526.80/ft	476,362	--	1
	Pumps	5 hp, 100 gpm at 100 ft head, submersible, stainless steel; costs include materials and installation	3	--	9,779	1	3
	Transfer piping (transfer to treatment plant)	6-inch diameter, double wall PVC, buried below frost line; costs include pipe materials, valves, valve boxes and fittings, trenching, installation	2150 ft	--	141,139	1,2	4
	Leak detection	Materials and installation	--	10% of piping	14,114	--	5
O&M	Maintenance	System maintenance cost		3% of capital	19,242/ yr	--	5
	Operating labor	(*Include in treatment system costs)	--	--	*	--	--
	Elect. Power	Power for pumps; annual cost	32,300 kwh/yr	$0.0336/kwh	1,086/yr	--	6

Alternative 2
Pump and Treat - Treatment System
Ion Exchange

	Five Well System	Three Well System
Capital Cost: (Installed)		
Tanks and mixers	$21,962	$19,622
Feed pumps	$10,959	$9,755
IX package unit	$1,772,000	$1,239,500
IX pilot test by vendor	$45,000	$45,000
Site preparation	$8,429	$6,757
Treatment building	$28,323	$18,934
Building utilities and tie-ins	$2,823	$1,893
Subtotal	$1,889,496	$1,341,461
Engineering @ 10%	$188,950	$134,146
Project Management @11%	$207,845	$147,561
Subtotal	$2,286,290	$1,623,168
Contingency @30%	$685,887	$486,950
Total Capital Cost	**$2,972,177**	**$2,110,118**
O&M Cost: (Annual)		
Operating	$748,980	$449,445
Maintenance	$56,699	$40,233
Waste Dipsosal	$485,100	$291,060
Total O&M Cost	**$1,290,779**	**$780,738**
Present Worth	**$12,939,230**	**$8,138,770**

Pump and Treat

System Module: Treatment
Description: Ion Exchange - Five Well System

Cost Type	Component	Description	Quantity	Unit Cost	Total	Assumption	Source
Capital	Flow Equalization Tank	6000 gal, carbon steel/w epoxy lining, vertical	1	--	14,259	1	2
	Equalization Tank Mixer	6 hp, vertical/impeller type, carbon steel	1	--	7,703	1	2
	Influent Feed Pump	10 hp, 500 gpm at 40 ft head, centrifugal, carbon steel	2	--	10,959	1	2
	Ion Exchange Package Unit	Vendor engineered and constructed, zeolite, non-regenerative, skid-mounted, package unit, 300 gpm incluing pre- and post-filter units, ion exchange vessels, resin storage tank, resin load-in system, resin load-out	1	--	1,295,000	--	7
	IX Package Installation	Freight, install package, process piping; include materials and labo 45,000	2	7			
	Site Preparation	Clear and grub site, level and compact, 2000 ft2 area	1	--	8,429	1	2
	Treatment Building	1000 ft2 x 20 ft high metal building, (Butler-type); include concrete slab on grade, insulated with HVAC; include materials and installation	1	--	28,323	2	2
	Utilities and tie-ins	Building and process electrical, building plumbing and sewer/water tie-ins	1	10% of building cost	2,823	2	5
O&M	Operating	All materials and labor, excluding waste disposal	157.7 M gal/yr	$4.75/kgal	748,980/yr	--	7
	Maintenance	Materials and labor		3% of capital	56,699/yr	--	5
	Waste Disposal	Treatment residuals disposal as solid LLW; spent zeolite and filter wastes	7700 ft3/yr	$63/ft3	485,100/yr	--	8

Pump and Treat

System Module: Treatment
Description: Ion Exchange - Three Well System

Cost Type	Component	Description	Quantity	Unit Cost	Total	Assumption	Source
Capital	Flow Equalization Tank	4000 gal, carbon steel/w epoxy lining, vertical	1	--	11,919	1	2
	Equalization Tank Mixer	4 hp, vertical/impeller type, carbon steel	1	--	7,703	1	2
	Influent Feed Pump	7.5 hp, 300 gpm at 40 ft head, centrifugal, carbon steel	2	--	9,755	1	2
	Ion Exchange Package Unit	Vendor engineered and constructed, zeolite, non-regenerative, skid-mounted, package unit, 180 gpm incluing pre- and post-filter units, ion exchange vessels, resin storage tank, resin load-in system, resin load-out	1	--	905,500	--	7
	IX Package Unit Installation	Freight, install package, process piping; include materials and labor	1	--	334,000	2	7
	IX Pilot Test	Vendor pilot test	1	--	45,000	--	7
	Site Preparation	Clear and grub site, level and compact, 1500 ft2 area	1	--	6,757	1	2
	Treatment Building	600 ft2 x 20 ft high metal building, (Butler-type); include concrete slab on grade, insulated with HVAC; include materials and installation.	1	--	18,934	2	2
	Utilities and Tie-ins	Building and process electrical, building plumbing and sewer/water tie-ins	1	10% of building	1,893	2	5
O&M	Operating	All materials and labor; excluding waste disposal	94.6Mgal/yr	$4.75/kgal	449,445/yr	--	7
	Maintenance	All materials and labor		3% of capital	40,233/yr	--	5
	Waste Disposal	Treatment residuals disposal as solid LLW; spent zeolite and filter wastes	4620 ft3/yr	$63/ft3	291,060/yr	--	8

Alternative 2
Pump and Treat - Treatment System
Reverse Osmosis

	Five Well System	Three Well System
Capital Cost: (Installed)		
Tanks and mixers	$22,935	$16,040
Feed pumps	$10,959	$7,664
RO package unit	$624,900	$437,035
RO pilot test by vendor	$14,000	$14,000
Waste evaporator	$720,000	$503,545
Waste solidification	$2,191	$1,532
Site preparation	$8,429	$5,895
Treatment building	$28,323	$19,808
Building utilities and tie-ins	$2,823	$1,974
Subtotal	$1,434,560	$1,007,494
Engineering @ 10%	$143,456	$100,749
Project Management @11%	$157,802	$110,824
Subtotal	$1,735,818	$1,219,068
Contingency @30%	$520,745	$365,720
Total Capital Cost	**$2,256,563**	**$1,584,789**
O&M Cost: (Annual)		
Chemicals	$23,863	$14,318
Operating and Maintenance	$168,800	$101,280
Electric Power	$99,474	$59,684
Waste disposal	$542,790	$325,674
Total O&M Cost	**$834,927**	**$500,956**
Present Worth	**$8,703,648**	**$5,453,040**

Pump and Treat

System Module: Treatment
Description: Reverse Osmosis - Five Well System

Cost Type	Component	Description	Quantity	Unit Cost	Total	Assumption	Source
Capital	Flow Equalization Tank	6000 gal, carbon steel/w epoxy lining, vertical	1	--	14,259	1	2
	Equalization Tank Mixer	7.5 hp, vertical/impeller type, carbon steel	1	--	8,676	1	2
	Influent Feed Pump	10 hp, 500 gpm at 40 ft head, centrifugal, carbon steel	2	--	10,959	1	2
	Reverse Osmosis Package Unit	Vendor engineered and constructed, multi-stage, skid-mounted, package unit, 300 gpm incluing pre-filter units, high pressure pumps, RO membranes and vessels, chemical supply and metering systems	1	--	624,900	2	9
	Pilot Test	RO pilot test by vendor; complete	1	--	14,000	2	9
	Waste Evaporator	30 gpm vapor compression evaporator	1	--	720,000	2	10
	Waste Solidification	Mixing equipment for cement solidification of evaporator bottoms; 25 ft3/day	1	--	2,191	2	2
	Site Preparation	Clear and grub site, level and compact, 2000 ft2 area	1	--	8,429	1	2
	Treatment Building	1000 ft2 x 20 ft high metal building, (Butler-type); include concrete slab on grade, insulated with HVAC; include materials and installation.	1	--	28,323	2	2
	Utilities and tie-ins	Building and process electrical, building plumbing and sewer/water tie-ins	1	10% of building	2,823	2	5

	System Module: Treatment Description: Reverse Osmosis - Five Well System						
Cost Type	**Component**	**Description**	**Quantity**	**Unit Cost**	**Total**	**Assumption**	**Source**
O&M	O&M for RO Unit	Operating, maintenance and electrical	1	108,000/yr	108,000/ yr	--	9
	Chemical for RO	Acid for pH control, hexametaphosphate for scale control	1	23,863/yr	23,863/ yr	--	12
	Operating for evaporator	Operating labor; 2 man-hours/day	730 hours/yr	$53.64/mh	39,200/ yr	1	--
	Maintenance for evaporator	Maintenance cost	1	3% of evap. capital	21,600/yr	--	5
	Electric power for evaporator	338 kw connected load	2.96 M kwh/yr	$0.0336/kwh	99,400/yr	--	10,6
	Evaporator waste disposal	Evaporator bottoms solidified with cement	7,990 ft3/yr	$63/ft3	503,370/ yr	--	8
	Drums for solid waste	Drums for containing the solidified evaporator bottoms	1,460/yr	$27/drum	39,420/yr	--	11
	Electric power for solidification mixer	1 hp motor	2,178 kwh/yr	$0.0336/kwh	74/yr	--	6

Alternative 2
Pump and Treat - Treated Water Disposal System
River Discharge

	Five Well System	Three Well System
Capital Cost: (Installed)		
Tanks	$14,259	$9,972
Transfer piping/leak detection	$14,661	$12,578
Effluent monitoring	$10,000	$10,000
Subtotal	$38,920	$32,550
Engineering @ 10%	$3,892	$3,255
Project Management @11%	$4,281	$3,581
Subtotal	$47,093	$39,386
Contingency @30%	$14,128	$11,816
Total Capital Cost	**$61,221**	**$51,201**
O&M Cost: (Annual)		
Operating labor	*	*
Maintenance	$1,167	$700
Total O&M Cost	**$1,167**	**$700**
Present Worth	**$70,232**	**$56,608**

* Included in treatment plant

Pump and Treat

System Module: Treated Water Disposal

Description: River Discharge - Five Well System

Cost Type	Component	Description	Quantity	Unit Cost	Total	Assumption	Source
Capital	Treated water sampling and collection tank	5000 gal, carbon steel/w epoxy lining, vertical; include level detection and control system	1	--	14,259	1	2
	Transfer piping (to river)	6-inch diameter, PVC, buried, double pipe, gravity flow; include valves, fittings, leak detection; include materials and installation	200 ft	--	13,328	1	4
	Piping leak detection	Materials and installation	--	10% of piping	1,333	--	5
	Instrumentation/Sr-90 monitoring	Materials and installation	--	Allowance	10,000	--	13
O&M	Operating labor	(*Included in treatment unit)	--	--	*	--	--
	Maintenance	Materials and labor	--	3% of capital	1,167/yr	--	5

Alternative 2
Pump and Treat - Treated Water Disposal System
N Area Crib

	Five Well System	Three Well System
Capital Cost: (Installed)		
Tanks	$14,259	$9,972
Transfer piping/leak detection	$215,985	$185,297
Pumps	$10,958	$7,664
Effluent monitoring	$10,000	$10,000
Disposal Crib (includes engin.)	$1,700,000	$1,188,926
Subtotal	$1,951,202	$1,401,859
Engineering @ 10%	$25,120	$21,293
Project Management @11%	$214,632	$154,205
Subtotal	$2,190,954	$1,577,357
Contingency @30%	$657,286	$473,207
Total Capital Cost	**$2,848,241**	**$2,050,564**
O&M Cost: (Annual)		
Operating labor	*	*
Maintenance	$7,535	$4,521
Electric Power	$1,388	$833
Total O&M Cost	**$8,923**	**$5,354**
Present Worth	**$2,917,142**	**$2,091,905**

* Included in treatment plant

Pump and Treat

System Module: Treated Water Disposal

Description: N Area Crib - Five Well System

Cost Type	Component	Description	Quantity	Unit Cost	Total	Assumption	Source
Capital	Treated water sampling and collection tank	6000 gal, carbon steel/w epoxy lining, vertical; include level detection and control system	1	--	14,259	1	2
	Transfer piping (to crib)	6-inch diameter, Sch 40 PVC, buried, double pipe; include valves, fittings, leak detection; include materials and installation	3000 ft	--	215,985	1	4
	Transfer pump	10 hp, 500 gpm at 40 ft head, centrifugal, carbon steel; include materials, installation and electrical	2	--	10,958	1	2
	Instrumentation/Sr-90 monitoring	Materials and installation	1	Allowance	10,000	1	13
	Disposal Crib	Crib, 300 gpm; include design, materials, and construction	1	--	1,700,000	2	14
O&M	Operating labor	(*Included in treatment plant)	--	--	*	--	--
	Maintenance	Materials and labor	--	3% of capital (excluding crib)	7,536/yr	--	5
	Power	Electric power for pump	41,300 kwh/yr	$0.0336/kwh	1,388/yr	--	6

Alternative 2
Pump and Treat - Treated Water Disposal System
N Area Injection Wells

	Five Well System	Three Well System
Capital Cost: (Installed)		
Tanks	$14,259	$9,972
Transfer piping/leak detection	$215,985	$185,297
Pumps	$10,959	$7,664
Effluent monitoring	$10,000	$10,000
Injection Wells	$466,440	$326,213
Subtotal	$717,643	$539,147
Engineering @ 10%	$71,764	$53,915
Project Management @11%	$78,941	$59,306
Subtotal	$868,348	$652,368
Contingency @30%	$260,504	$195,710
Total Capital Cost	**$1,128,852**	**$848,079**
O&M Cost: (Annual)		
Operating labor	*	*
Maintenance	$7,536	$4,522
Electric Power	$1,388	$833
Total O&M Cost	**$8,924**	**$5,354**
Present Worth	**$1,197,761**	**$889,424**

* Included in treatment plant

Pump and Treat

System Module: Treated Water Disposal

Description: N Area Reinjection - Five Well System

Cost Type	Component	Description	Quantity	Unit Cost	Total	Assumption	Source
Capital	Treated water sampling and collection tank	6000 gal, carbon steel/w epoxy lining, vertical; include level detection and control system	1	--	14,259	1	2
	Transfer piping (to injection wells	6-inch diameter, Sch 40 PVC, buried, double pipe; include valves, fittings, leak detection; include materials and installation	3000 ft	--	215,985	1	4
	Transfer pump	10 hp, 500 gpm at 40 ft head, centrifugal, carbon steel; include materials, installation and electrical	2	--	10,959	1	2
	Instrumentation/Sr-90 monitoring	Materials and installation	--	Allowance	10,000	1	13
	Injection Wells	6-inch diameter, 104 ft total depth, stainless steel, install by cable tool drilling; costs include all materials, mob/demob, drilling labor, logging, well development, waste disposal, equipment decon	312 ft	$1495/ft	466,440	--	1
O&M	Operating labor	(*Included in treatment plant)	--	--	*	--	--
	Maintenance	Materials and labor	--	3% of capital (excluding injection wells)	7,535/yr	--	5
	Power	Electric power for pump	41,300 kwh/yr	$0.0336/kwh	1,388/yr	--	6

Alternative 2
Pump and Treat - Treated Water Disposal System
200 Area Crib

	Five Well System	Three Well System
Capital Cost: (Installed)		
Tanks	$14,259	$9,972
Transfer piping/leak detection	$4,116,596	$4,116,596
Pumps	$10,959	$7,664
Effluent monitoring	$10,000	$10,000
Disposal Crib (includes engin.)	$1,700,000	$1,188,926
Subtotal	$5,851,814	$5,333,159
Engineering @ 10%	$415,181	$414,423
Project Management @11%	$643,700	$586,647
Subtotal	$6,910,695	$6,334,229
Contingency @30%	$2,073,208	$1,900,269
Total Capital Cost	**$8,983,903**	**$8,234,498**
O&M Cost: (Annual)		
Operating labor	*	*
Maintenance	$124,554	$74,732
Electric Power	$9,095	$5,457
Total O&M Cost	**$133,649**	**$80,189**
Present Worth	**$10,015,906**	**$8,853,699**

* Included in treatment plant

Pump and Treat

System Module: Treated Water Disposal

Description: 200 Area Crib - Five Well System

Cost Type	Component	Description	Quantity	Unit Cost	Total	Assumption	Source
Capital	Treated water sampling and collection tank	6000 gal, carbon steel/w epoxy lining, vertical; include level detection and control system	1	--	14,259	1	2
	Transfer piping (to 200 Area)	8-inch diameter, Sch 40 carbon steel, buried, double pipe; include valves, fittings, leak detection; include materials and installation	48,000 ft	--	4,116,596	2	4
	Transfer pump	40 hp, 300 gpm at 350 ft head, centrifugal, carbon steel; include materials, installation and electrical	2	--	10,959	1	2
	Instrumentation/Sr-90 monitoring	Materials and installation	--	Allowance	10,000	1	13
	Disposal Crib (at 200 Area)	Crib, 300 gpm; include design, materials and construction	1	--	1,700,000	2	14
O&M	Operating labor	(*Included in treatment plant)	--	--	*	--	--
	Maintenance	Materials and labor	--	3% of capital (excluding crib)	124,554/ yr	--	5
	Power	Electric power for pump	270,700 kwh/yr	$0.0336/kwh	9,095/yr	--	6

Alternative 3
Vertical Barrier
Slurry Wall

Capital Cost: (Installed)	
Slurry wall, subcontractor installed by deep soil mixing	$6,200,000
Testing (incl. engineering)	$200,000
Engineering @10%	$620,000
Project Management @11%	$682,000
Subtotal	$7,702,000
Contingency @30%	$2,310,600
Total Capital Cost	**$10,012,600**
O&M Cost: (Annual)	
Operating labor	0
Maintenance	0
Electric Power	0
Total O&M Cost	**$0**
Present Worth	**$10,012,600**

Vertical Barrier

System Module: Slurry Wall
Description: Install By Deep Soil Mixing

Cost Type	Component	Description	Quantity	Unit Cost	Total	Assumption	Source
Capital	Slurry wall installed by deep soil mixing	Vendor engineered and constructed, 2800 ft long, average 104 ft depth, includes materials and installation	291,200 ft2	$20.60/ft2	6,000,000	2	16
	Auger replacement	Replace contaminated/broken augers	--	Allowance	200,000	2	--
	Field testing	Develop appropriate slurry mixtures and demonstrate constructability in Hanford soils	--	--	200,000	2	16

Alternative 2
Hydraulic Control
Extraction Wells

Capital Cost: (Installed)	
Pumping Wells	$716,034
Transfer piping	$698,087
Pumps	$39,778
Effluent monitoring	$10,000
Subtotal	$1,463,899
Engineering @ 10%	$146,390
Project Management @11%	$161,029
Subtotal	$1,771,318
Contingency @30%	$531,395
Total Capital Cost	**$2,302,713**
O&M Cost: (Annual)	
Operating labor	$39,157
Maintenance	$22,436
Electric Power	$9,510
Total O&M Cost	**$71,103**
Present Worth	**$2,851,752**

Hydraulic Control

System Module Groundwater Extraction
Description Hydraulic Control

Cost Type	Component	Description	Quantity	Unit Cost	Total	Assumption	Source
Capital	Pumping Wells	11 wells, 8-inch diameter, 114 ft total depth, stainless steel, install by cable tool drilling; costs include all materials, mob/demob, drilling labor, logging, well development, waste disposal, equipment decon	1254 ft	$571/ft	716,034		
	Pumps	5 hp, 75 gpm at 100 ft head, submersible, stainless steel; costs include materials and installation	4	--	14,283		
	Pumps	5 hp, 100 gpm at 100 ft head, submersible, stainless steel; costs include materials and installation	5	--	17,853		
	Pumps	7.5 hp, 150 gpm at 100 ft head, submersible, stainless steel; costs include materials and installation	2	--	7,642		
	Transfer piping to river	16-inch, single wall PVC, buried below frost line; costs include pipe materials, valves, valve boxes and fittings, trenching, installation	8000 ft	--	698,087		
	Instrumentation/Sr-90 monitoring	Materials and installation	--	Allowance	10,000		
O&M	Operating	Assume 2 man-hours/day	730 mh/yr	$53.64/mh	39,157/yr		
	Labor	Materials and labor	--	3% of capital (excluding wells)	22,436/yr		
	Elect. Power	Power for pumps; annual cost	283,054 kwh/yr	$0.0336/kwh	9,510/yr		