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Draft A

Letter Report for Modeling Evaluation of N-Springs Barrier and Pump-and-Treat Systems

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Draft A

Letter Report for Modeling Evaluation of N-Springs Barrier and Pump-and-Treat Systems

Date Published
October 1994

United States
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EXECUTIVE SUMMARY

This report fulfills Milestone M-16-12C to supply "necessary documentation justifying barrier placement and location of extraction wells and discharge point(s)" (Part I) and to document the "results of pumping tests at three existing wells to evaluate strontium-90 (^{90}Sr) concentration response to pumping" (Part II).

Two models were used to analyze the hydraulic effects of a proposed barrier to flow located between N-Springs and the Columbia River. A linear barrier of sheet pile was located and its impact on reducing ^{90}Sr seepage under and around it were simulated. Results indicate that a 2,000-ft barrier would reduce the release of ^{90}Sr to the river to 22% to 26% of no-action, while a 3,800-ft barrier would reduce the release to 0% to 2% of no-action. Gaps in the wall's length would significantly degrade its performance, particularly if such gaps occur in the higher contamination zones. Simulations also demonstrated the need to anchor the sheet piling into or at the underlying clayey unit. Anchoring 2 ft above the underlying unit would degrade the overall performance of the wall by approximately 11%. Pump-and-treat options were not shown to significantly improve the protection of the river afforded by the barrier alone due to the affinity of ^{90}Sr for soil over water. The following table presents a summary of the model results.

Table ES-1. Summary of Model Results.

Percent Strontium-90 Released to the Columbia River Compared to No-Action				
RUN at Time	10 years	50 years	100 years	300 years
No wall (No-Action)	100.0%	100.0%	100.0%	100.0%
Wall length 2,000 ft	22.0%	25.2%	26.1%	25.8%
2000 ft w/ wells (50 gal/min)	23.3%	24.8%	25.5%	25.3%
2000 ft w/ wells (180 gal/min)	20.0%	21.7%	22.3%	22.2%
Wall length 3,000 ft	3.3%	5.4%	6.8%	7.8%
3000 ft w/ wells (50 gal/min)	3.3%	4.7%	5.6%	6.4%
3000 ft w/ wells (180 gal/min)	2.7%	3.8%	4.4%	4.7%
Wall length 3,800 ft	0.2%	1.4%	1.5%	2.1%
3800 ft w/ wells (50 gal/min)	0.0%	0.3%	0.6%	1.0%
3800 ft w/ wells (100 gal/min)	0.0%	0.3%	0.6%	0.8%
3800 ft w/ wells (180 gal/min)	0.0%	0.2%	0.4%	0.5%
Wall length 3800 ft w 10 ft gap	23.3%	45.2%	50.9%	51.0%

A rigorous calibration of the models was not possible because of the limited data on the geochemical and hydrologic properties of the unconfined aquifer. The most significant assumption affecting the results was how ^{90}Sr varied with depth. Contamination in the simulated aquifer reflected the levels observed in the top of the unconfined aquifer system. Additional data are needed to develop a profile of ^{90}Sr vs. depth in the area. The key elements of each model are considered valid. Design based on these predictions should be phased with data collection to refine the model.

All of the release for the vertical barrier reported in the N-Springs Expedited Response Action Proposal (DOE/RL 1994b) came from the volume of contaminated soil and ground water located between the barrier and the river. The mass of ^{90}Sr located between the river and the barrier is estimated to be between 2.5 and 6 ci, of which 1% is dissolved in the ground water and 99% is adsorbed into the soil. The release of this mass is unaffected by the proposed barrier and will continue to account for some release of ^{90}Sr to the river. This release is dependent upon how well the constant flushing of the Columbia River causes ^{90}Sr to be desorbed from these sediments. This is unknown at this time. To minimize the release of ^{90}Sr located between the river and barrier, the barrier should be located as close to the river as possible.

Part II provides the results from pumping at wells 199-N-3, 199-N-75, and 199-N-14. These results indicated that ^{90}Sr concentrations remained constant during extraction. The tests provided insufficient information to make generalizations on the response of dissolved ^{90}Sr to aquifer pumping. New extraction wells are recommended for any long-term pump-and-treat activities.

PART I:

MODELING EVALUATION OF N-SPRINGS BARRIER AND PUMP-AND-TREAT SYSTEM

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1.0 Introduction

As part of the Environmental Restoration Program at the Hanford Site, the U.S. Department of Energy (DOE) Richland Operations Office (RL) proposed a non-time-critical Expedited Response Action at N-Springs to substantially reduce the ^{90}Sr seeping into the Columbia River from past operations of N-Reactor. N-Springs is the local name for a site on the banks of the Columbia River within the Hanford Site that was contaminated by the 1301-N and 1325-N Liquid Waste Disposal Facilities (LWDF). Cote' (1994) provides an excellent historical description of N Reactor Operations.

The U.S. Environmental Protection Agency (EPA) and the Washington State Department of Ecology (Ecology) accepted this proposal, and it was made part of the Tri-Party Agreement Milestone Change Request Dispute Resolution dated January 8, 1993 (Ecology et al. 1993). The *N-Springs Expedited Response Action Proposal* (DOE/RL 1994b) evaluated a number of alternatives but was unable to select a preferred alternative. Subsequently, an independent technical review of the information recommended the selection of a "vertical barrier" (ASI 1994).

Since that time, RL has selected grouted interlocking sheet piles for the material to build the barrier. Ecology, EPA, and RL are currently negotiating milestones to guide the construction schedules.

1.1 Background

The operation of N-Reactor required the disposal of pass-through cooling water from the reactor's primary cooling loop, the spent fuel storage basins, and other reactor related sources. In 1963, the 1301-N LWDF, located approximately 800 ft from the Columbia River, was constructed for this purpose. Monitoring wells were installed between the LWDF and the Columbia River at the start of operations. Mobile contaminants were observed almost immediately at N-Springs. The 1301-N LWDF received approximately 2,100 gal/min of radiologically contaminated water, creating a 20-ft high ground-water mound. The near field flow system was radial away from the LWDF with all streamlines ultimately discharging into the river. In 1980, ^{90}Sr near the river was detected by the monitoring system. To partially alleviate the ^{90}Sr releases, a second LWDF, the 1325-N LWDF, located farther from the river, was placed into service in 1983. However, it did not go into full service until 1985. The flow rates to this crib were ~400 gal/min (1983-1985), ~1,400 gal/min (1986), 350 gal/min (after 1986). Discharges to the 1301-N LWDF ceased in 1985, and to 1325-N LWDF in 1991.

The total discharge of ^{90}Sr discharged to the 1301-N and 1325-N LWDFs is 2100 Ci (Connelly 1990). Greater quantities of ^{60}Co and ^{137}Cs also exist in the LWDFs, as well as in the Hanford gravels above the water table. Due to its much longer operational life, the majority of the radiological inventory is found in and under the 1301-N LWDF. Other nonradiological contaminants were also discharged to both LWDFs. Hartman (1992) contains a complete listing of contaminants disposed to the LWDFs and monitored in the ground water.

Current ground-water contamination caused by the past LWDF operations consists primarily of tritium and ^{90}Sr. Of the total 2100 Ci of ^{90}Sr released to the LWDF, the *Hanford Sitewide Groundwater Remediation Strategy* (DOE/RL 1994a) estimated the unconfined aquifer to contain 75.5 Ci of ^{90}Sr, of which 75 Ci are estimated to be adsorbed onto the sediments within the unconfined

aquifer and 0.5 Ci are dissolved in the ground water. The amount of ^{90}Sr released to the Columbia River is estimated to be 46.1 Ci. This value was derived by summing the releases to the Columbia River for N-Springs reported in UNC's yearly Liquid Effluent Release Reports and WHC's Environmental Release for Calendar Year () from 1974-1993. These numbers suggest the remaining curies (1978.4) are located in the LWDF or contained within the vadose zone directly below the LWDFs.

1.2 Purpose

This report refines the analyses conducted in previous studies (DOE/RL 1994b) to incorporate additional information and to examine barrier designs and pump-and-treat alternatives. For this phase of the modeling, the barrier and the pump-and-treat system have the following goals:

Vertical Barrier:

- Extend the travel path for strontium-90
- Reduce the contaminant migration to take advantage of ^{90}Sr's slow movement (approximately 1/100th the rate of water) and to allow for natural decay
- Dampen the effects of Columbia River diurnal river level changes for the pump-and-treat system.

Pump-and-treat System:

- Remove ^{90}Sr from the unconfined aquifer
- Test treatment technologies for ^{90}Sr.

1.3 Scope

This study quantifies the effect of the linear barrier on reducing ^{90}Sr contamination entering the Columbia River. The barrier is located between the 1301 LWDF and the Columbia River, approximately 30 ft from the river. The study also examines the interaction of a pump-and-treat system and the barrier. Other studies (Engineering Evaluation/Cost Analysis [EE/CA]) have evaluated the effects of a pump-and-treat system without the barrier.

The following alternatives were analyzed:

Two-Dimensional Plan View Model

Wall Length	No Wells	50 gal/min	100 gal/min	180 gal/min
0 ft (No-Action)	x			
2,000 ft	x	x		x
3,000 ft	x	x		x
3,800 ft	x	x	x	x
3,800 ft w/ 10 ft gap	x			

The 50 gal/min system used one pumping well and one injection well; the 100 gal/min system used two pumping wells and two injection wells; and the 180 gal/min system used three pumping wells and two injection wells.

Heterogeneity was not considered in this phase of the modeling because of the lack of data describing how the hydraulic conductivity and retardation varies spatially. In particular, this report does not address the possibility of preferential pathways. Heterogeneity will be introduced as this data becomes available through the sampling and monitoring programs that are currently being implemented.

Figure 1-1 shows the conceptual model with location of the vertical barriers and pumping-and-injection wells together with ^{90}Sr concentrations in ground water. The springs shown in this figure are located on the river side of the barrier. The ^{90}Sr concentrations are a modification of the Hartman and Lindsey (1993) plume map (Figure 1-2), taking into account additional information from well 199-N-46/199-N-8T. Figure 1-3 shows the wells, facilities, and vertical barrier, and is provided to orient the reader to the monitoring network within the 100-N Area.

Two Dimensional Cross-Section Model

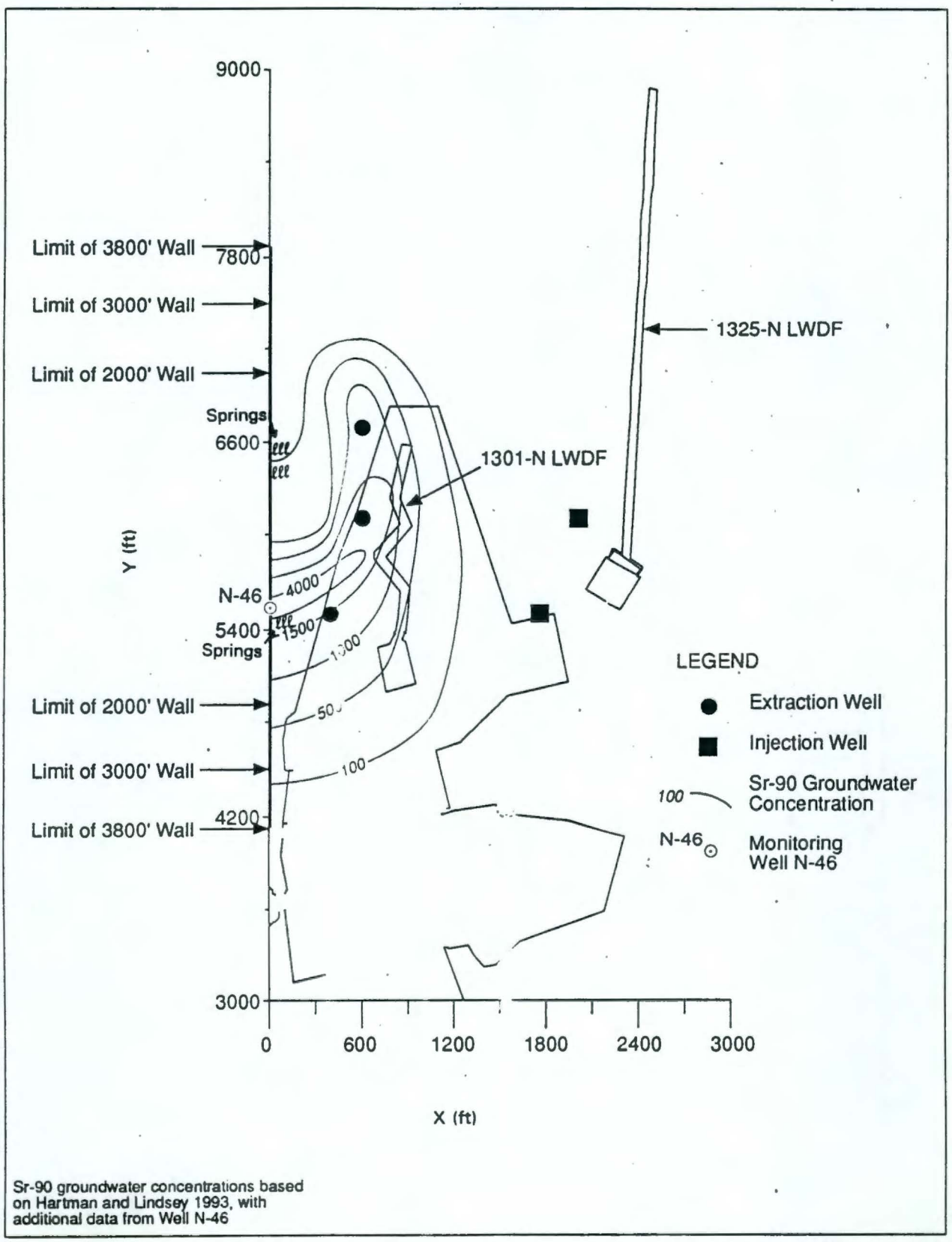
- No-Action
- Barrier anchored 4 ft into underlying silts
- Barrier anchored at the underlying silts
- Barrier anchored 2 ft above underlying silts
- Horizontal hydraulic conductivity for underlying silts increased a factor of 10 over previous alternatives

Figures 1-4a and 1-4b are diagrammatic depictions of this conceptual model showing the numerical grid, boundary conditions, initial conditions, and the location of the wall for both the flow equation (a) and transport equation (b).

Several attempts were made to examine the release of ^{90}Sr from between the river and the vertical barrier. For these attempts, the model simulated both ground-water flow and contaminant transport in a transient mode. However, the code was not able to maintain mass balance, and this case was therefore dropped from the analysis. The total mass of ^{90}Sr from between the river and the vertical barrier is estimated to be between 2.5 and 6 Ci.

Appendix A presents a brief description of the hydrogeology of the 100-N Area. Appendix B is a description of the conceptual model used to construct the numerical models. Included in Appendix B is a description of the modeling parameters and how they were chosen.

Figure 1-1. Typical Plan-View Model Arrangement for Barrier Walls and Pump-and Treat System.



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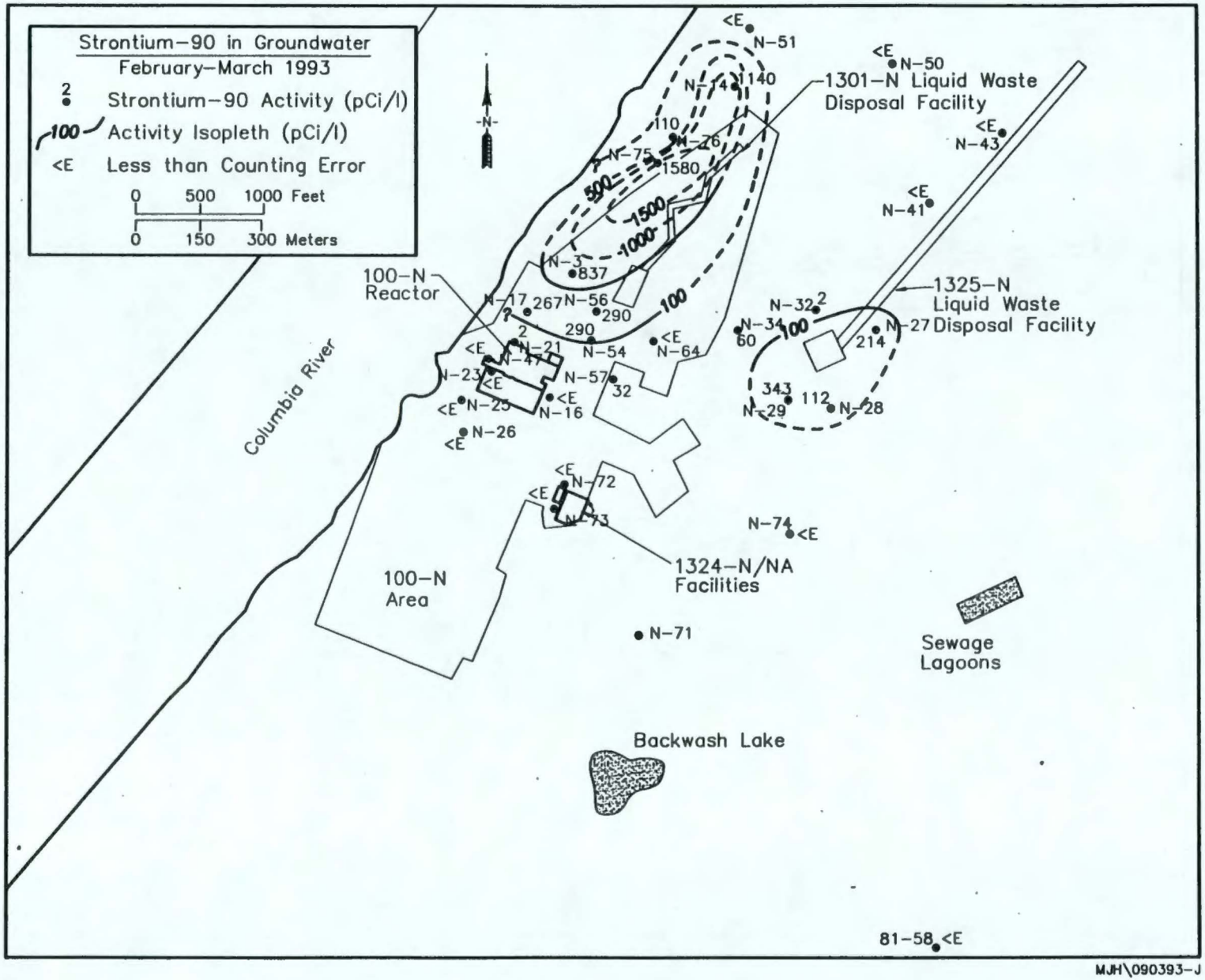

Figure 1-2. 1993 Strontium-90 Plume Map.

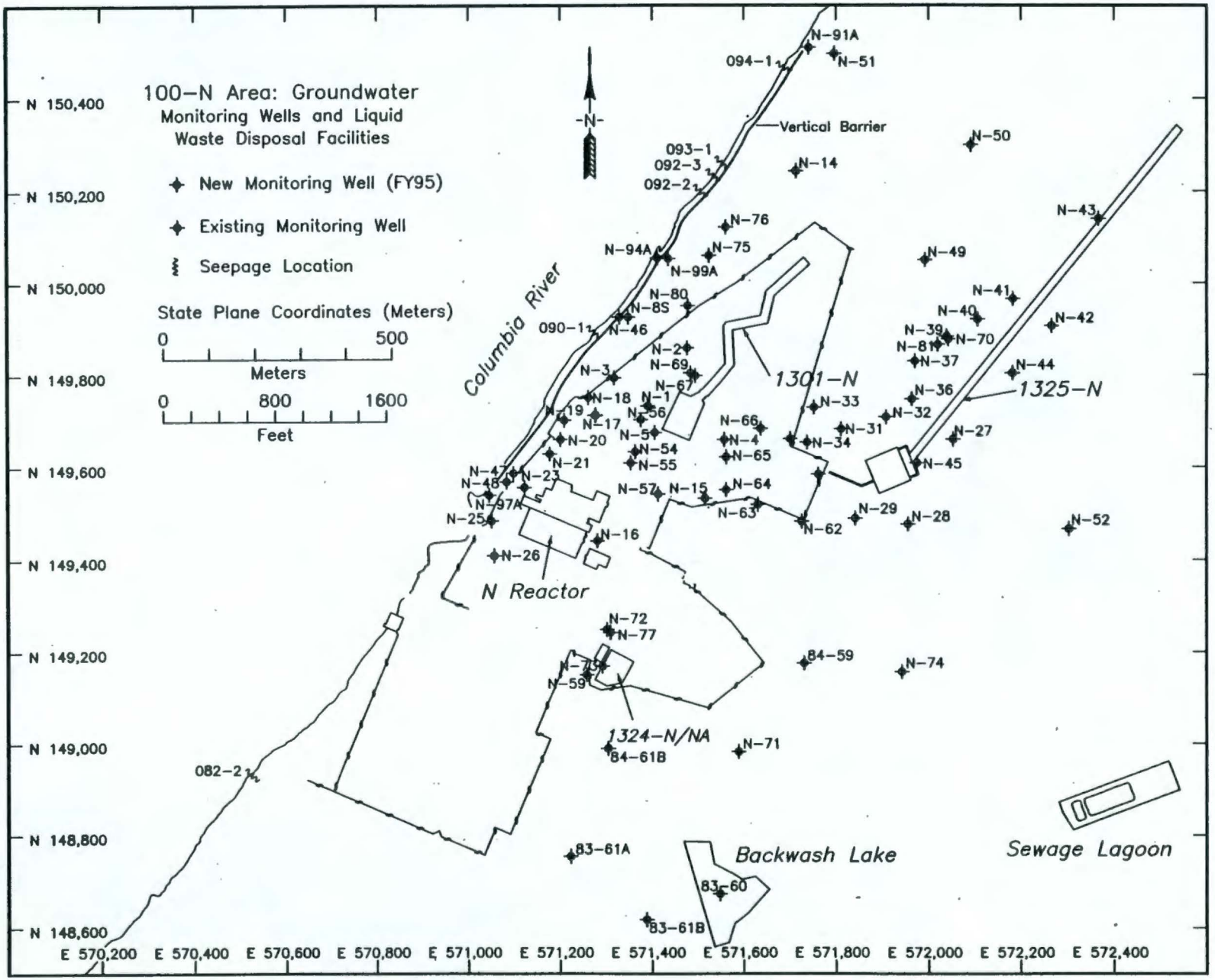

Figure 1-3. Monitoring Well Locations.

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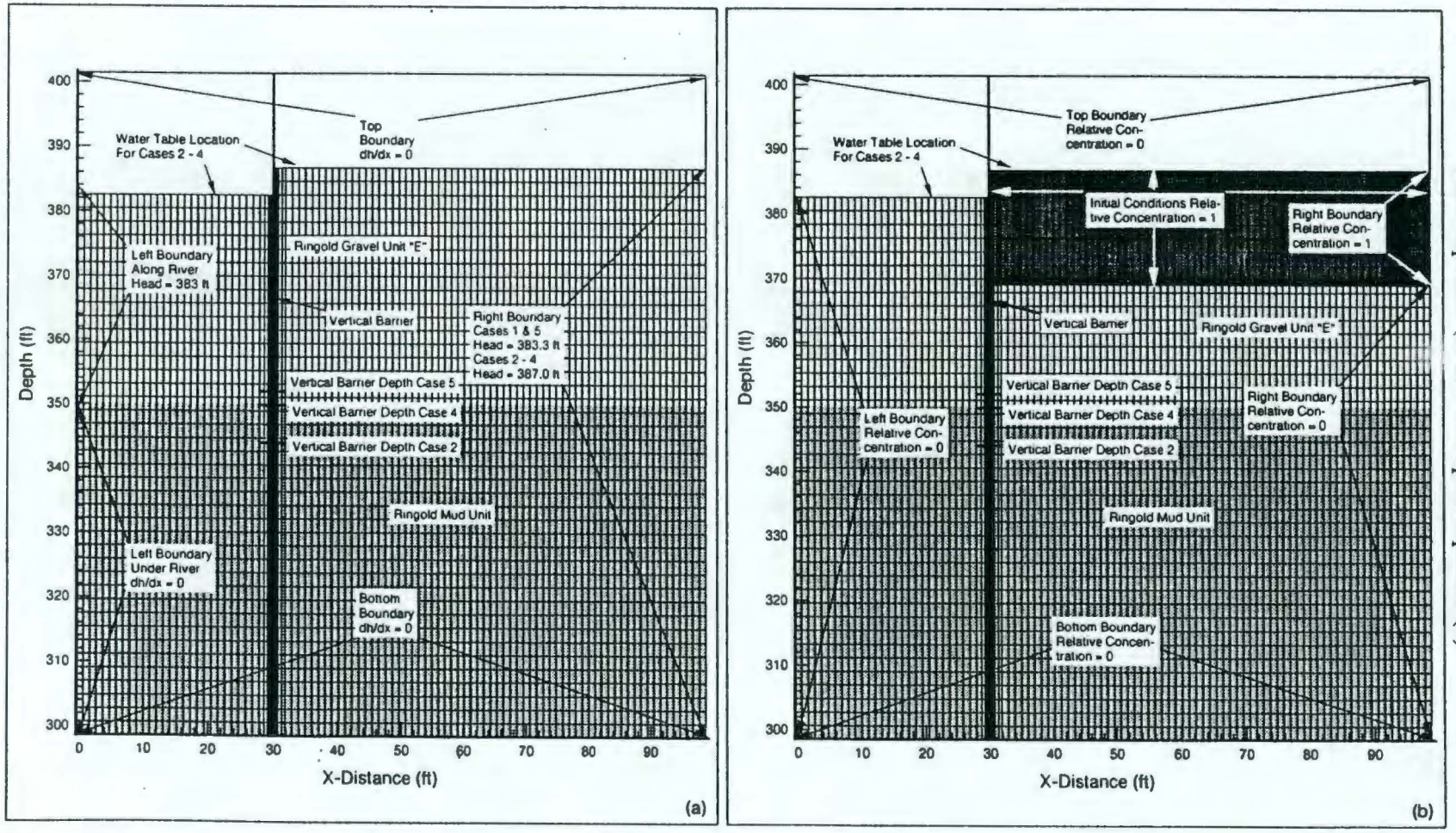


Figure 1-4. Two-Dimensional Cross Section Model Showing Grid, Boundary Conditions, Location of Barrier, and Initial Conditions for Both the Flow Equation (a) and Transport Equation (b).

2.0 Model Results

Results from numerical models provided estimates on the effectiveness of remedial actions to reduce the ^{90}Sr flux at N-Springs. These remedial actions are a pump-and-treat system and a vertical barrier. The pump-and-treat system will remove ^{90}Sr and test treatment technologies, while the vertical barrier reduces ground water velocities in the zone of highest contamination and extends travel path of strontium-90 to the river. Two models in two-dimensional format were developed. The first model simulated a two-dimensional horizontal section of the unconfined aquifer. This model assessed the impacts that various vertical barrier lengths (2,000, 3,000, and 3,800 ft) along with 50, 100, and 180 gal/min pump-and-injection system will have on the unconfined aquifer. For each of the different barrier lengths and well locations, the release of ^{90}Sr to the river is calculated from stream tubes and compared to a no-action case. The second model simulated a cross section of the vertical barrier to evaluate the impact on wall depth and penetration into the lower mud unit.

2.1 Location of the Vertical Barrier; Pumping and Injection Wells

The goal of the vertical barrier is to reduce the release of ^{90}Sr to the Columbia River. Therefore, the location of the barrier wall in the model was determined by observing the concentration of ^{90}Sr in the ground water. The 1000 ρCi/L ^{90}Sr contour close to the Columbia River is bounded on the south by well 199-N-3 and to the north by well 199-N-14 (Figure 1-3). The highest concentrations of ^{90}Sr occur at wells 199-N-8T/199-N-46 ($\sim$6,000 ρCi/L) and well 199-N-67 ($\sim$4,000 ρCi/L), which are located between 199-N-3 and 199-N-14. The distance separating wells 199-N-3 and 199-N-14 is approximately 2,000 ft. This is in the center of the ^{90}Sr plume and is how the 2,000-ft wall length was chosen. The 3,000-ft wall length was chosen by the 100 ρCi/L isopleth (Figure 1-3), which is estimated to lie halfway between 199-N-18 and 199-N-19 on the south to two-thirds of the way between 199-N-14 and 199-N-51 to the north. The 3800-ft wall was chosen by adding 200 ft to the distance between non-detect well 199-N-21 in the south and 199-N-51 in the north. The actual coordinates for the starting and ending locations should be surveyed in.

The goal of the pump-and-treat system is to remove ^{90}Sr from the aquifer and to test treatment technologies. This directed placement of any pumping wells to areas of high ^{90}Sr concentrations. The locations for the pumping and injection wells were further refined by placing the wells to prevent a streamline from passing through the center of the plume, which would add to the release of ^{90}Sr around the edges of the barrier. The 50 gal/min pumping well was placed approximately at the 571600 W and 150000 N Lambert Coordinates. The 50 gal/min injection well was placed at 571775 W and 149600 N Lambert Coordinates. These locations are within 200 ft of wells 199-N-75 and 199-N-34. However, the actual locations of these pumping and injection wells could change with the collection of additional data. Only after observing the response of the aquifer for the 50 gal/min system should the wells for higher pumping rates be located.

2.2 2-D Plan View

From the FLOWPATH model, the ground water travel time to the river from specific locations within the modeled area can be estimated using the particle tracking feature. The average contaminant travel time from these locations to the river can therefore be computed by multiplying the ground water travel time by the retardation coefficient. Knowing the initial concentration of ^{90}Sr in the ground

water (measured concentrations in monitoring wells), the concentration at the discharge point can be calculated, allowing for radioactive decay during the period of migration. The effect of radioactive decay is to reduce the source concentration. The concentration at the river is estimated by applying the following equation:

$$C_{river}=C_{source}*e^{-1*(\frac{0.693}{29\ (y)}*Time(y))}$$

where 29 y refers to the half life of ^{90}Sr in years and time refers to the number of years it took ^{90}Sr to move from the source to the river.

The total loading of ^{90}Sr to the river at a specific time is calculated by integrating the ^{90}Sr fluxes (discharge concentration multiplied by ground-water flux) along the Columbia River boundary.

The source concentration will change with time as ^{90}Sr decays and is advected by the ground-water flow. Since the distribution coefficient is high, only a small proportion of the inventory is removed by advection. For these analyses, the reduction in source concentration because of advection has been ignored. This results in a conservative (high) estimate of the discharge of strontium to the river.

The methodology for determining the ^{90}Sr releases involves initially running the FLOWPATH model for a particular barrier wall and pump-and-treat arrangement. Boundary flux data from the FLOWPATH model are then imported into an Excel spreadsheet. Maximum ^{90}Sr concentrations along individual particle pathlines at different ground-water travel times are estimated by overlying the particle pathlines with ^{90}Sr ground-water concentrations. The ^{90}Sr travel times, estimated by multiplying the ground-water travel times by the retardation factor for ^{90}Sr, are used to calculate the decayed ^{90}Sr concentrations at the points of discharge to the Columbia River. The ^{90}Sr flux for each pathline can then be calculated by multiplying the discharge concentration by the ground-water flux, and the total mass loading by summing the individual ^{90}Sr fluxes along the river.

Since the hydraulic conductivity is constant throughout the modeled area, the ground-water flow pattern does not change when the value for hydraulic conductivity is changed. However, the discharge flux and ground-water travel times will change in direct proportion to the change in hydraulic conductivity. These parameter sensitivity analyses are therefore performed in the spread sheet, without the need to re-run the FLOWPATH model. The results from the analyses are included in Figures 2-10, 2-11, and 2-12. Only the high and low hydraulic conductivities found in the 100-N Area are included in this study.

2.2.1 Existing Conditions (NOWALL)

The effectiveness of each model case is evaluated by comparison to the case in which no barrier wall exists (FLOWPATH file NOWALL). For this case, all boundary nodes were set to constant head boundary conditions.

The equipotentials and steady-state pathlines for existing conditions are shown in Figures 2-1 and 2-2. (In all figures, the barrier has been moved inland from its actual location to distinguish it from the boundary line.) Based on the ^{90}Sr concentrations in ground water shown on Figure 1-1 and a hydraulic conductivity of 261 ft/d, it is estimated that the current discharge to the Columbia River is

0.36 Ci/y. The ^{90}Sr loading to the river as a function of time is shown on Figure 2-3 for a hydraulic conductivity of 261 ft/d and results in total releases over a period of about 300 years of 20 Ci.

2.2.2 Barrier Walls

In the baseline barrier wall case (FLOWPATH file NSPRINGS), the barrier wall length was 3,800 ft. Constant head boundary conditions based on observed ground-water and river elevations were used, except for the barrier wall, which was represented as a no-flow boundary. The mid point of the barrier was located midway along the river boundary. No pumping or injection wells were included in the baseline model case.

Two runs were performed in which the wall length was changed to 2,000 ft and 3,000 ft (FLOWPATH files 2000FT and 3000FT, respectively) in order to evaluate the effects of different length barriers. This was modeled by assigning no-flow boundary conditions to the appropriate nodes over a 2,000 or 3,000 ft interval. All other parameters remained the same as in the baseline case.

The equipotentials and steady-state pathlines for barrier walls of 2,000-, 3,000-, and 3,800-ft length are shown in Figures 2-4 through 2-9. The variations with time of the discharge of ^{90}Sr to the Columbia River are shown in Figures 2-10 to 2-12 for hydraulic conductivities of 100, 261 and 500 ft/d. For some of the graphs (for example, 3,800-ft wall, Figure 2-10) the discharge of ^{90}Sr to the river does not take place immediately. In these cases, the barrier wall extends upstream and downstream beyond the area of elevated ^{90}Sr concentrations. After installation of the barrier wall, the ground-water flowlines are redirected around the wall, lengthening the migration pathway. A period of time therefore elapses until there is breakthrough of the ^{90}Sr along the new flowpath.

The ratios of the total discharge of ^{90}Sr with a barrier wall to the total discharge without a wall over a period of about 300 years are summarized in Table 2-1. These results show that, for the best estimate value of hydraulic conductivity of 261 ft/d, the 2,000-ft barrier wall reduces the total ^{90}Sr loading to 26% of what it would have been without the wall. Similarly, wall lengths of 3,000 and 3,800 ft result in reductions in the total loadings to 8% and 2% of the no-wall value, respectively.

Table 2-1. Loading to Columbia River (Curies/year).

Time (Years)	Time Interval over which the Loading is Applied (Years)	Nowall Avg ldg (Ci/y)	2000 ft Avg ldg (Ci/y)	3000 ft Avg ldg (Ci/y)	3800 ft Avg ldg (Ci/y)
0.14	0.27	3.63e-01	8.70e-02	7.21e-01	0.00
2.88	5.21	3.41e-01	7.90e-02	8.74e-03	0.00
10.96	10.96	2.94e-01	7.13e-02	1.24e-02	1.13e-03
21.92	10.96	2.43e-01	6.16e-02	1.39e-02	2.47e-03
41.10	27.40	1.69e-01	4.75e-02	1.27e-02	2.88e-03
68.49	27.40	1.06e-01	3.02e-02	1.09e-02	2.83e-03
95.89	27.40	7.40e-02	1.73e-02	8.20e-03	2.40e-03
136.99	54.79	3.51e-02	7.92e-03	4.36e-03	1.74e-03
191.78	54.79	9.07e-03	2.26e-03	1.27e-03	8.24e-04
315.07	191.78	1.87e-03	5.14e-04	2.77e-04	1.85e-04
Total loading Ci		20.1	5.15	1.55	0.44
Ratio to Nowall		100%	25.6%	7.80%	2.18%

2.2.3 Effect of Gap in Barrier Wall

There is the potential that boulders or other obstructions might be encountered during driving of the barrier wall. To evaluate the impact on ^{90}Sr loading to the river if such obstructions prevented complete closure of the barrier wall, the 3,800-ft wall with a 10-ft gap midway along the wall was simulated. The gap was placed at the center of the wall where the highest concentrations of ^{90}Sr have been detected. The 10-ft gap was modeled by assigning constant head boundary conditions to the appropriate nodes over a 10-ft interval.

The equipotentials and steady-state pathlines are shown in Figures 2-13 and 2-14 for the 3,800-ft wall with a 10-ft gap midway along the wall. The variation of the ^{90}Sr discharge with time is shown in Figures 2-15 to 2-17. For a hydraulic conductivity of 261 ft/d, the total loading to the river over a period of about 300 years compared with the no-wall and 3,800-ft wall models is tabulated as follows.

	No-Wall	3,800-ft Wall	3,800-ft Wall with 10-ft gap
Total ^{90}Sr Loading to River	20 Ci	0.4 Ci	10 Ci

The probability that a gap of 10 ft in the barrier would be undetected and not mitigated is very low. However, the major impact of a gap that represents less than .25% of the barrier length emphasizes the need to ensure the complete integrity of the barrier wall system. Additionally, since this gap was placed in the center of plume, it represents the worst-case scenario. If additional gaps develop, the barrier would not be able to maintain the same water level behind it, and the gaps would be off the center of the plume. Release from additional gaps would not be the same as this one.

2.2.4 Barrier Wall with Pump-and-Treat Systems

The *Action Memorandum: N-Springs Expedited Response Action Cleanup Plan* (Ecology 1994) requires that a pump-and-treat system be installed. The intent of the pump-and-treat system is to provide a full-scale field test of the technology to treat ^{90}Sr-contaminated ground water, to remove ^{90}Sr from the ground-water system, and to provide additional ^{90}Sr plume interception.

The seven alternative ground-water pump-and-treat systems evaluated are shown in Table 2-2.

Table 2-2. Modeled Ground-water Pump-and-Treat Systems.

Model Case	Barrier Length (ft)	Number of Injection Wells	Number of Pumping Wells	Total Flowrate (gal/min)
2000W5	2,000	1	1	50
NSPRW50	3,800	1	1	50
NSPRW100	3,800	2	2	100
NSPRW180	3,800	2	3	180
2000W5	2,000	1	1	50
2000W18	2,000	2	3	180
3000W5	3,000	1	1	50
3000W18	3,000	2	3	180

Three ground-water pump-and-treat systems were evaluated using a barrier length of 3,800 ft (the baseline scenario): NSPRW50, NSPRW100, and NSPRW180. For NSPRW50, there is one pumping well, pumping at a rate of 50 gal/min, located in the area of high concentrations of ^{90}Sr. The injection well flow rate is the same as the pumping well, so that there is no net flow being removed from the aquifer. The injection well was located upgradient of the pumping well.

For NSPRW100, there are two pumping wells, pumping at a rate of 50 gal/min each, with a total extraction of 100 gal/min. These wells are located with two injection wells operating at the same flow rates. A third pumping well is included for the 180 gal/min scenario (NSPRW180). The extraction rates for the NSPRW180 run are 60 gal/min per well, with two injection wells each operating at a flow rate of 90 gal/min.

The effects of the ground-water pump-and-treat system were also evaluated for the 2,000-ft and 3,000-ft barrier scenarios (FLOWPATH files for 2000W5, 2000W18, 3000W5, 3000W18). The arrangement of extraction and injection wells is similar to that used for the same pumping rates for the 3,800-ft barrier. However, some minor adjustments to well locations were required to prevent lines from the injection wells passing between pumping wells. This would result in higher ^{90}Sr discharges because the pathline would pass through an area of high ^{90}Sr concentrations.

For the 3,800-ft barrier wall, pump-and-treat systems with capacities of 50, 100, and 180 gal/min have been evaluated. The equipotentials and steady-state ground-water pathlines are shown in Figures 2-18 to 2-23. The area affected by the pumping and injection wells can be seen by comparing these figures to the equivalent figure without the pumping and injection wells. For a hydraulic conductivity of 261 ft/d, the variation in ^{90}Sr discharge with time is shown in Figure 2-24. The total ^{90}Sr loadings to the Columbia River over a period of about 300 years are summarized in Figure 2-24 for the three extraction/injection rates and compared with the loading for the 3,800-ft wall without the pump and treat.

For the 3,000-ft wall, a pump-and-treat system with a capacity of 50 and 180 gal/min has been simulated. The equipotentials and steady-state pathlines are shown in Figures 2-25 through 2-28. The variation with time of the ^{90}Sr loading to the river and total loading over a period of about 300 years is shown in Figure 2-29.

For the 2,000-ft wall, a pump-and-treat system with capacities of 50 and 180 gal/min has been simulated. The equipotentials and steady-state pathlines are shown in Figures 2-30 through 2-33. The variation with time of the ^{90}Sr loading to the river and total loading over a period of about 300 years is shown in Figure 3-34.

The analyses of the barrier wall with pump-and-treat systems indicate that locating the extraction system in the area of highest ^{90}Sr concentration results in only a minor decrease in the total loading of ^{90}Sr to the river relative to the ^{90}Sr loading without pump and treat. This is because the barrier walls alone provide long migration paths from these regions and hence time for significant retardation and decay of the ^{90}Sr. The addition of the pump-and-treat systems into these areas therefore provides only a minor reduction to the overall release of ^{90}Sr to the river. Positioning the pumping wells closer to the ends of the barrier wall system might provide a greater reduction in the calculated loading of ^{90}Sr to the river. However, if the extraction wells were located closer to the ends of the barrier walls, the ^{90}Sr concentrations in the pumped ground water would be much lower than when the wells are located in the high ^{90}Sr concentration area. Testing of the ^{90}Sr treatment technology would be more difficult since the concentrations would be lower, and the mass of ^{90}Sr removed would be reduced.

2.2.5 2-D Plan View Modeling Summary

The results of the two-dimensional modeling are summarized in Table 2-3 for the best-estimate hydraulic conductivity of 261 ft/d. The modeling shows that a barrier wall is effective in reducing the ^{90}Sr flux to the river over its period of activity, about 300 years. The extraction wells for the pump-and-treat systems are located in the area of highest ^{90}Sr ground-water concentration. Their operation helps to further reduce the ^{90}Sr release to the river.

Table 2-3. Summary of Estimated ^{90}Sr Releases (Ci).

RUN	10 years	50 years	100 years	300 years
No wall	3	11.5	16.5	20.1
Wall length 2,000 ft	0.66	2.9	4.3	5.15
2000 ft w/ wells (50 gal/min)	0.7	2.85	4.2	5
2000 ft w/ wells (180 gal/min)	0.6	2.5	3.68	4.4
Wall length 3,000 ft	0.1	0.62	1.12	1.57
3000 ft w/ wells (50 gal/min)	0.1	0.54	0.93	1.26
3000 ft w/ wells (180 gal/min)	0.08	0.44	0.72	0.94
Wall length 3,800 ft	0.005	0.16	0.24	0.44
3800 ft w/ wells (50 gal/min)	0	0.037	0.103	0.189
3800 ft w/ wells (100 gal/min)	0	0.034	0.091	0.149
3800 ft w/ wells (180 gal/min)	0	0.028	0.068	0.107
Wall length 3,800 ft w 10-ft gap	0.7	5.2	8.4	10.1

The barrier walls are effective because they extend the contaminant migration path lengths and reduce the ground-water velocities in the area of high ^{90}Sr concentration. The analyses of the flux resulting from a gap within the wall indicated the importance of ensuring the integrity of the wall during construction.

2.3 Model Results Two-Dimensional Cross-Section

For each of these cases, the two-dimensional steady-state flow field was solved. These steady-state flow velocities were used to solve the contaminant transport equation for 200 years. A brief description of each case follows. With the descriptions is a figure showing the model results for that case. Each figure shows the steady-state flow field as a flooded contour of equipotentials (upper left hand corner), and flooded contours of ^{90}Sr concentration at three different times. Overlain on all figures is the location of the vertical barrier, the flux plane over which the mass ^{90}Sr was summed, streamlines showing the path over which a particle would move, and travel time markers for water (circles) on the streamline. Each travel time marker represents the distance a particle would travel over a period of time. The delta time for the markers is given in each figure. The travel time markers for ^{90}Sr (squares) have been adjusted for a retardation factor of 100 on the contaminant transport plots.

2.3.1 Case 1: No-Action

In this case, the river boundary has been set to 383 ft. The existing ground-water gradient was calculated (0.003 ft/ft) from the March 1994 water table map. The gradient was then applied over the length of the model to determine the upstream boundary. The no-flow boundary under the river causes the equipotential lines to curve (Figure 2-35a) forcing flow in the Ringold mud unit to move toward the river. Figures 2-35b-d present the ^{90}Sr plume for 30, 90, and 180 years. From these figures, the movement of ^{90}Sr is essentially one dimensional with very little movement of the contaminant in the vertical direction. The ground water travel time can be estimated by counting the travel time markers on the stream lines. From the right boundary to the left for water is ~25 days, while the contaminant travel time would be ~2,500 days. The peak concentration is arriving now and will decay exponentially to half that at the end of 30 years.

The release in curies to the river can be predicted by multiplying the relative flux passing the location of the barrier calculated in the model by an assumed average concentration of ^{90}Sr of 2,500 ρCi/L over a distance of 2,000 ft. The assumption of 2,500 ρCi/L across that distance comes from the ^{90}Sr concentrations in wells 199-N-3, 199-N-46, 199-N-14 of 857, 6000, and 1060 ρCi/L, respectively. The total mass released in Curies to the river over 50, 100, 200, and 300 years would be 14.22, 16.75, 17.29, and 17.30 Ci, respectively. The total mass released in the cross section model does compare well to the plan view model.

2.3.2 Case 2: Anchor Barrier 4 ft into Ringold Mud Unit

Cases two through four had the right boundary set to an elevation of 387 ft (Appendix B) and the left boundary set to the mean annual river elevation. Case 2 has the barrier anchored 4 ft into the underlying Ringold mud unit. The barrier drastically alters the flow shown in Case 1. The flow is water diverted under the barrier (Figure 2-36a). The net effect is to reduce the flow velocities behind the wall and lengthen the streamlines to the river. The travel time for a water particle in the middle of the plume (second streamline right of the barrier) to the river is 4 years, while travel time for a contaminant particle at the same location would be 400 years. It is also evident from Figures 2-36b through 2-36d that the leading edge of the plume takes approximately 80 years to travel underneath the barrier with the highest relative concentration (0.001) arriving at the river sometime between 90 and 180 years. If this two-dimensional slice was located at the highest concentration of ^{90}Sr (6000 ρCi/L), the concentration arriving at the river would be 6 ρCi/L.

2.3.3 Case 3: K_h for Ringold Mud Unit Increased by a Factor of 10

The horizontal hydraulic conductivity for the Ringold mud unit for case 3 was increased by a factor of 10. The flow lines for case 3 are now asymmetric under the barrier because of the anisotropy in the Ringold mud unit (Figure 2-37a). The travel time for water to the river on the same streamline used in Case 3 is approximately 3.5 years, while for the contaminant particle starting from the same location it would be 350 years. The highest relative concentration (~0.0025) arriving at the river occurs between 90 and 150 years (Figures 2-37b-d).

2.3.4 Case 4 Anchor Barrier at the Top of Ringold Mud Unit

The vertical barrier for this case was not anchored into the Ringold mud unit but sits at the interface between the gravels and the mud. The effect of this is to shorten the streamlines through the lower conductivity Ringold mud unit (Figure 2-38a). In turn, the shortened streamlines reduce the travel time for the same water and contaminant particles used in the previous cases to approximately 1.75 years (water) and 175 years (contaminant). The leading edge travels under the barrier between 10 and 30 years (Figure 2-38b). The highest relative concentration arrives at the river between 30 and 90 years (Figure 2-38c-d).

2.3.5 Case 5 Anchor Barrier 2 ft above the Top of Ringold Mud Unit

For this case, the vertical barrier sits 2 ft above the top of the Ringold mud unit. The assumption that the unconfined aquifer would mound behind the wall is not valid for this case because of the high hydraulic conductivity of the Ringold. Therefore, the right boundary condition is the same as in Case 1. Leaving a 2-ft gap between the barrier and the Ringold mud unit creates a more direct path to the river in a highly transmissive unit (Figure 2-39a). The travel time has been reduced to 191 days for water and 52 years for the same particle used in the previous cases. The leading edge travels under the barrier by the end of three years (Figure 2-39b). The highest relative concentration arrives at the river sometime between 5 and 30 years (Figures 2-39c through 2-39d).

2.3.6 Summary of the Cross-Section Model Results

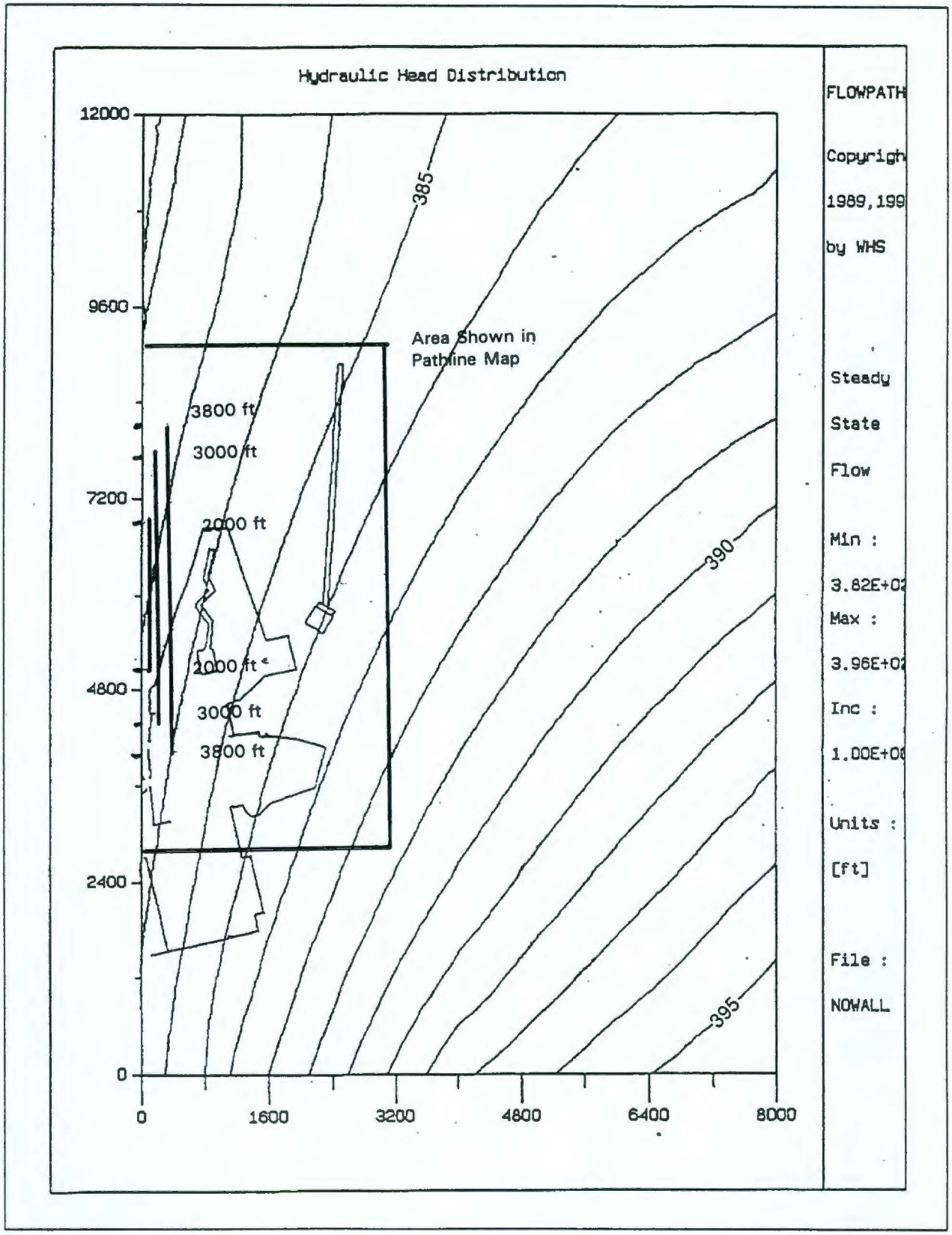
The effectiveness of the vertical barrier as compared with the no-action case was calculated by the following method. The mass of ^{90}90 passing through a plane (normal to the model and located at the barrier) was summed over the time of the simulation. The total mass of ^{90}Sr passing through that plane for cases 2 through 5 was divided by the mass passing through that same plane for the no-action case (1) to estimate the relative efficacy of the wall. The results are summarized in Table 2-4 and Figure 2-40.

Table 2-4. Release of ^{90}Sr from Underneath the Vertical Barrier.

Case	Maximum Percentage Mass Released for Any One Year	Year of Maximum Release from Present	Percentage of Total Mass Released
Case 2 4 ft into mud	0.00096	120	0.12
Case 3 Anisotropy mud	0.0017	113	0.17
Case 4 At mud	0.015	62	1.2
Case 5 2 ft above mud	0.2	21	11.1

The results in the table are in terms of percentages, while the results in the figure are normalized to one. Divide the table results by 100 to compare to the figure. Figure 2-40a compares the normalized yearly releases for all four cases. Figure 2-40b is the normalized total release for all four cases. Figures 2-40c through 2-40f are the results for each individual case. Note both the Y-scale and second Y-scale change for Figures 2-40c through 2-40f.

Figure 2-1. No Wall: Equipotentials.



943 1106/53382/9-28-94

Figure 2-2. No Wall: Pathlines.

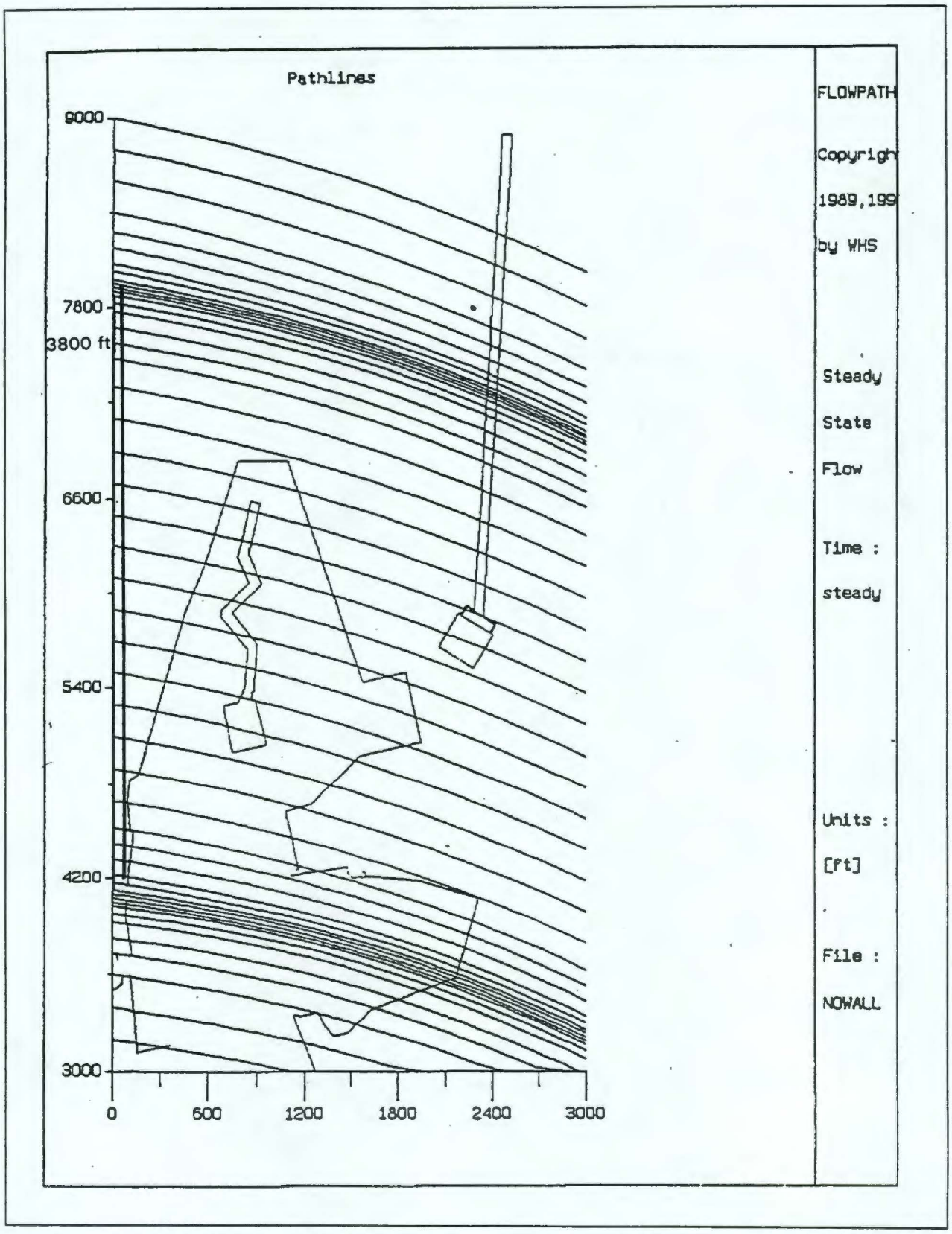


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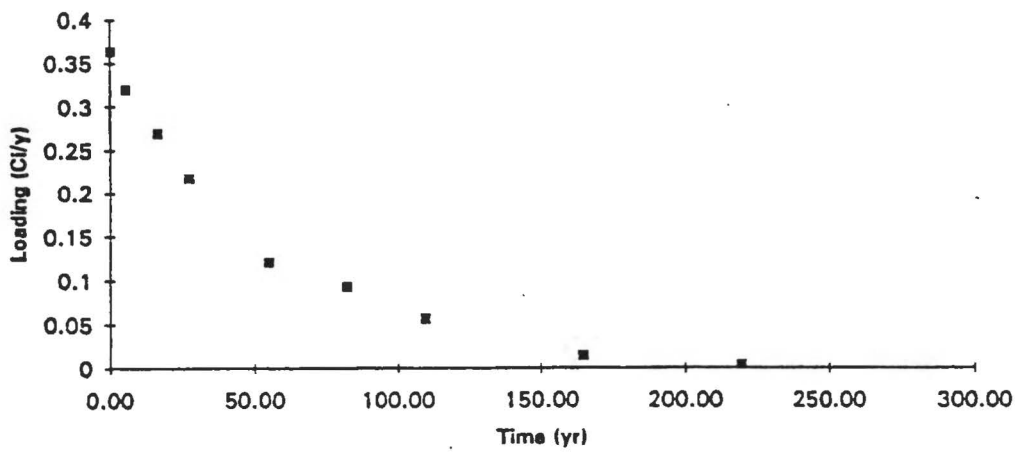
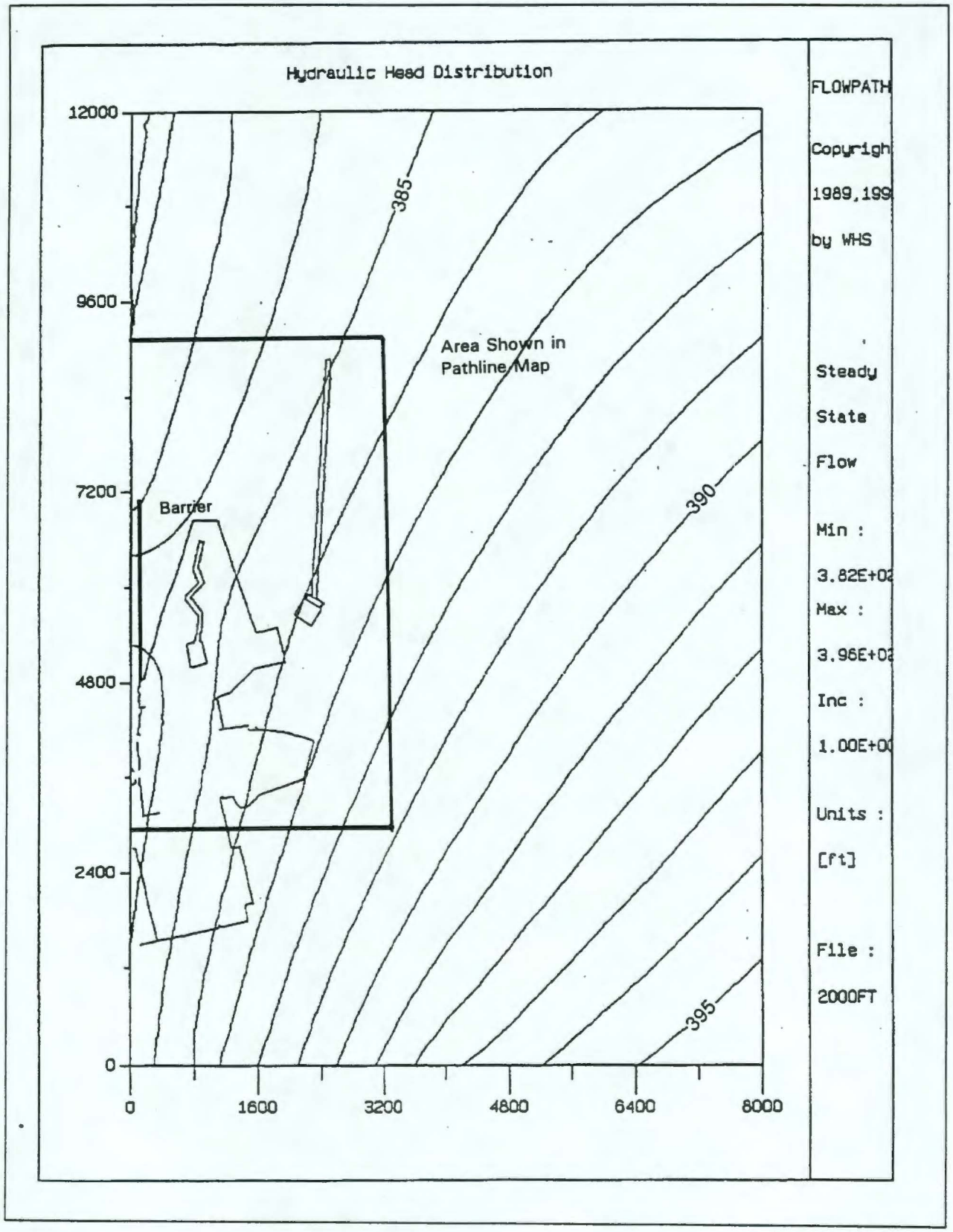
Figure 2-3. No Wall: Strontium-90 Release to River.



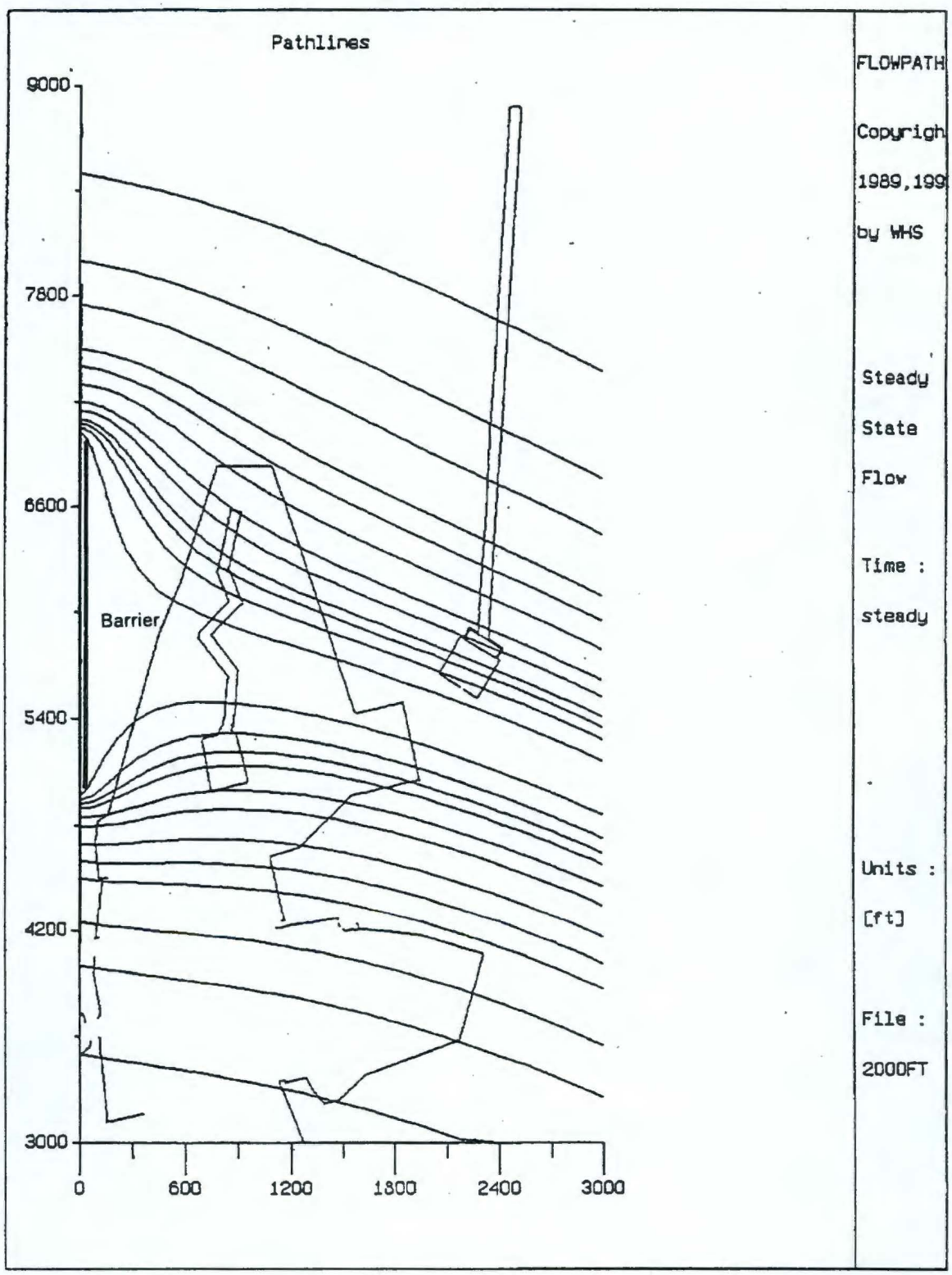
943 1106/53384/9-28-94

Figure 2-4. 2,000-Ft Wall: Equipotentials.



943 1106/53385/9-28-94

Figure 2-5. 2,000-Ft Wall: Pathlines.



943 1106/53386/9-28-94

Figure 2-6. 3,000-Ft Wall: Equipotentials.

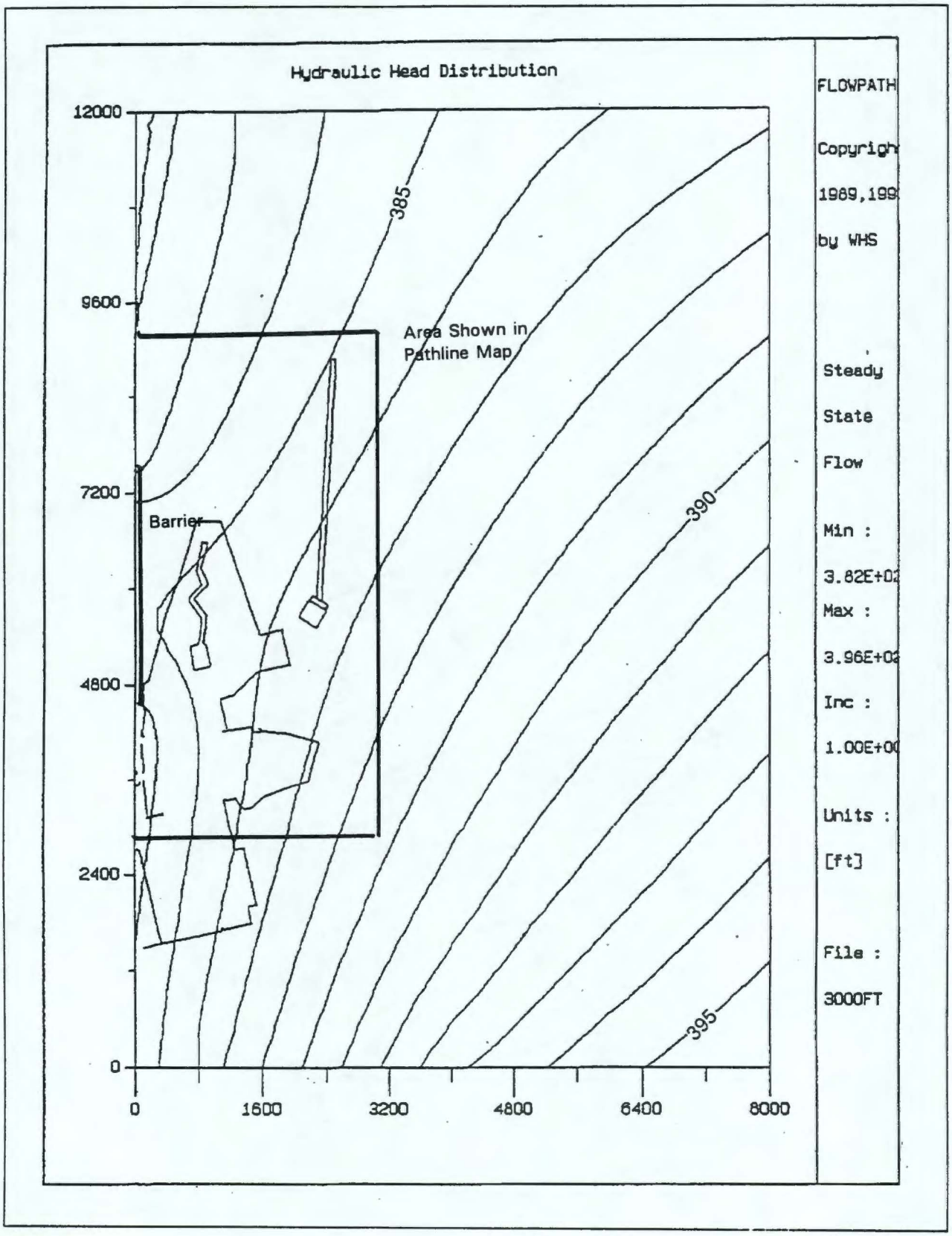


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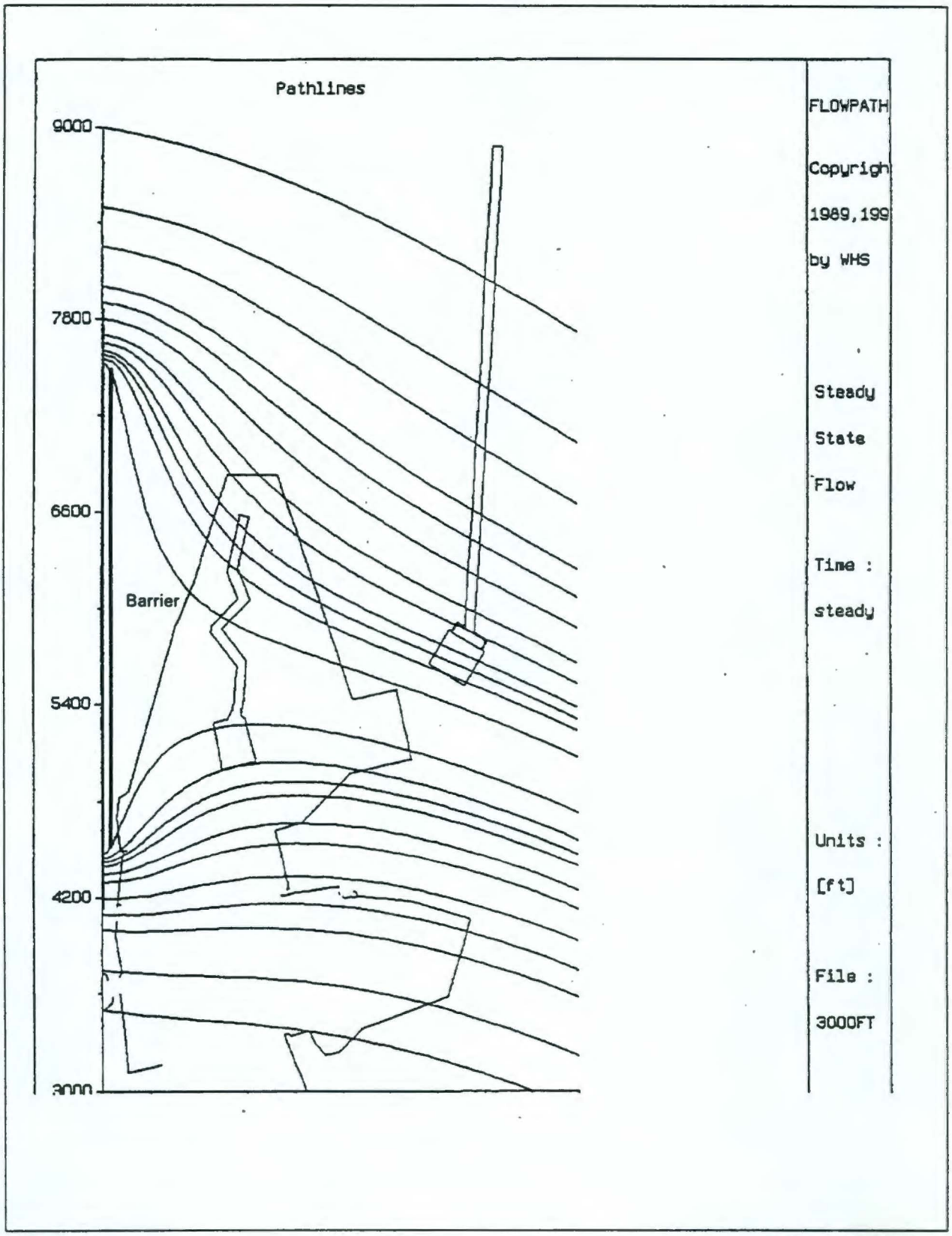
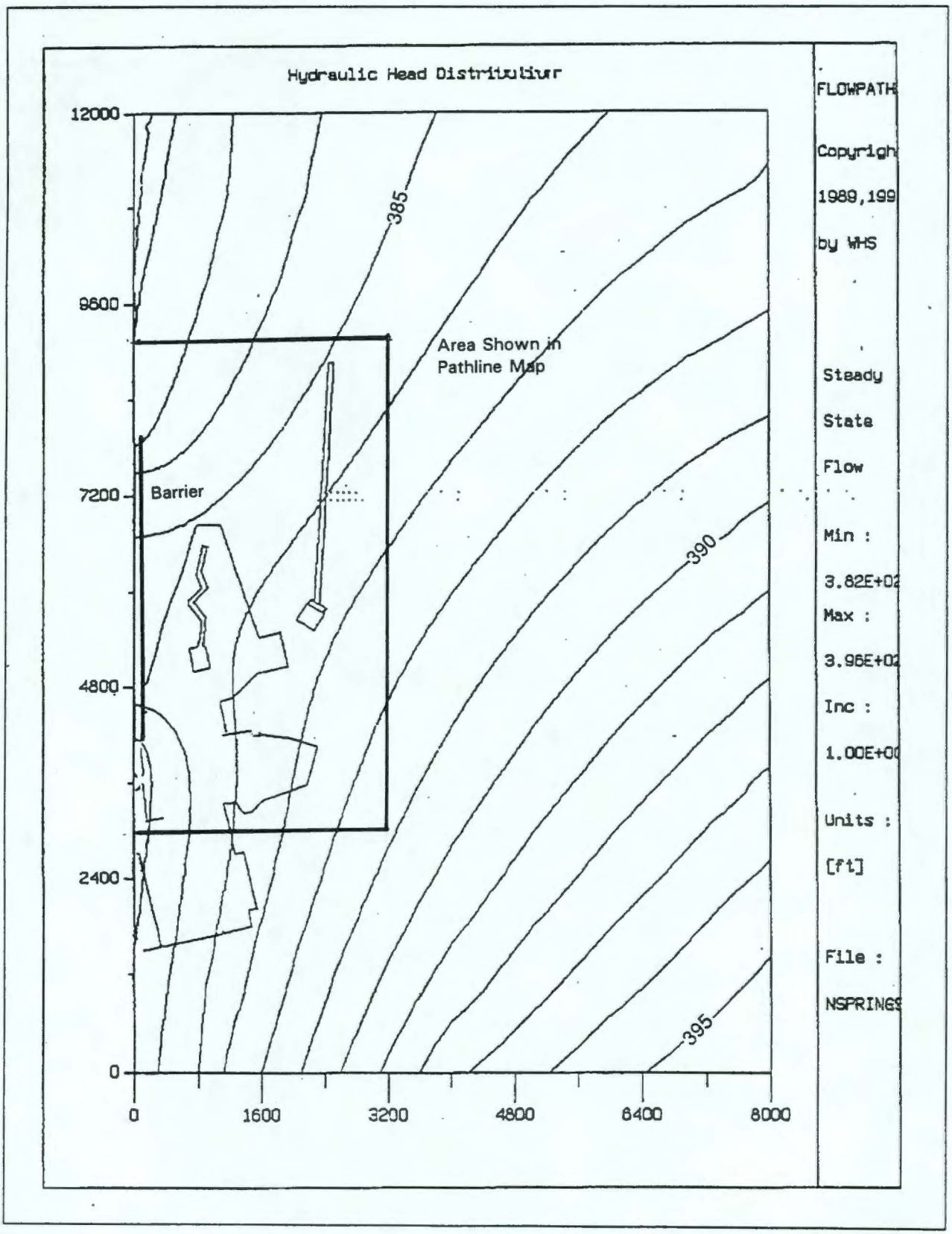
Figure 2-7. 3,000-Ft Wall: Pathlines.



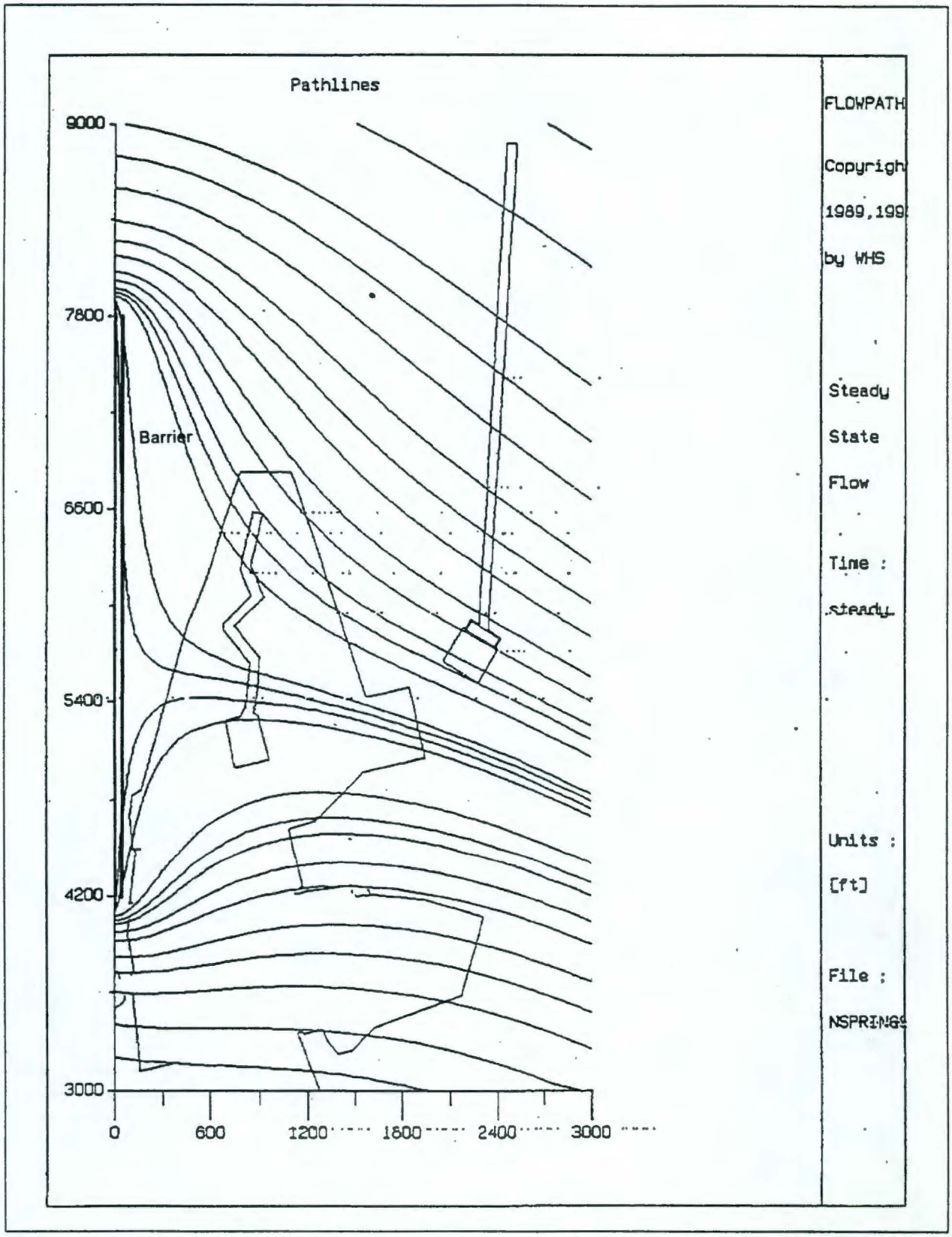
943 1106/53388/9-28-94

Figure 2-8. 3,800-Ft Wall: Equipotentials.



943 1106/53389/9-28-94

Figure 2-9. 3,800-Ft Wall: Pathlines.



943 1106/50189/9-28-94

Figure 2-10. Strontium-90 Releases to River for 2,000-Ft, 3,000-Ft, and 3,800-FT Wall Lengths K = 100 Ft/d.

	Wall length (ft)		
	2000	3000	3800
K used in FLOWPATH (ft/d)	261	261	261
K for these calcs (ft/d)	100	100	100
Retardation coefficient	100	100	100
Radionuclide	Sr-90	Sr-90	Sr-90
Half-life (yr)	28	28	28
Total release (Ci)	1.597428	0.304762	0.043502

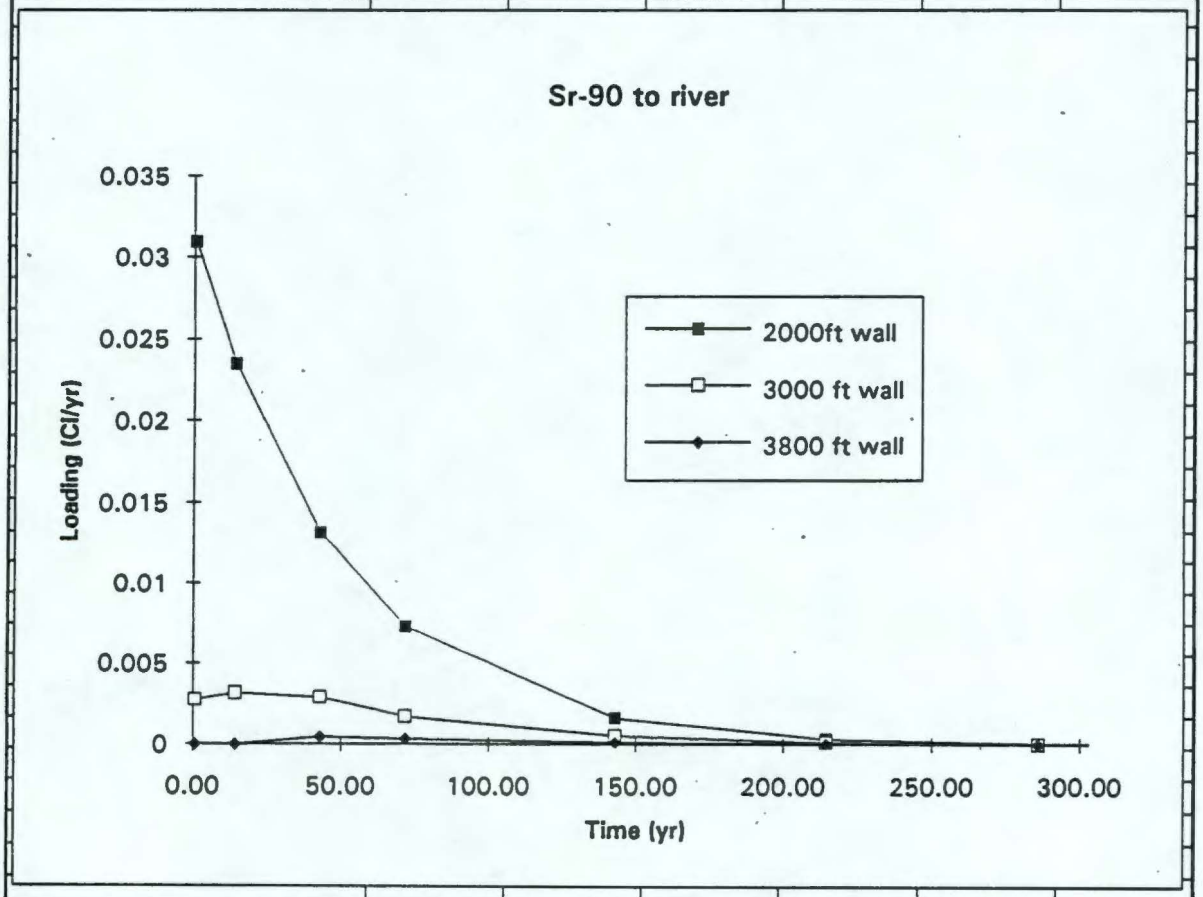


Figure 2-11. Strontium-90 Releases to River for 2,000-Ft, 3,000-Ft, and 3,800-Ft Wall Lengths K = 261 Ft/d.

	Wall length (ft)		
	2000	3000	3800
K used in FLOWPATH (ft/d)	261	261	261
K for these calcs (ft/d)	261	261	261
Retardation coefficient	100	100	100
Radionuclide	Sr-90	Sr-90	Sr-90
Half-life (yr)	28	28	28
Total release (Ci)	5.128554	1.565794	0.43777

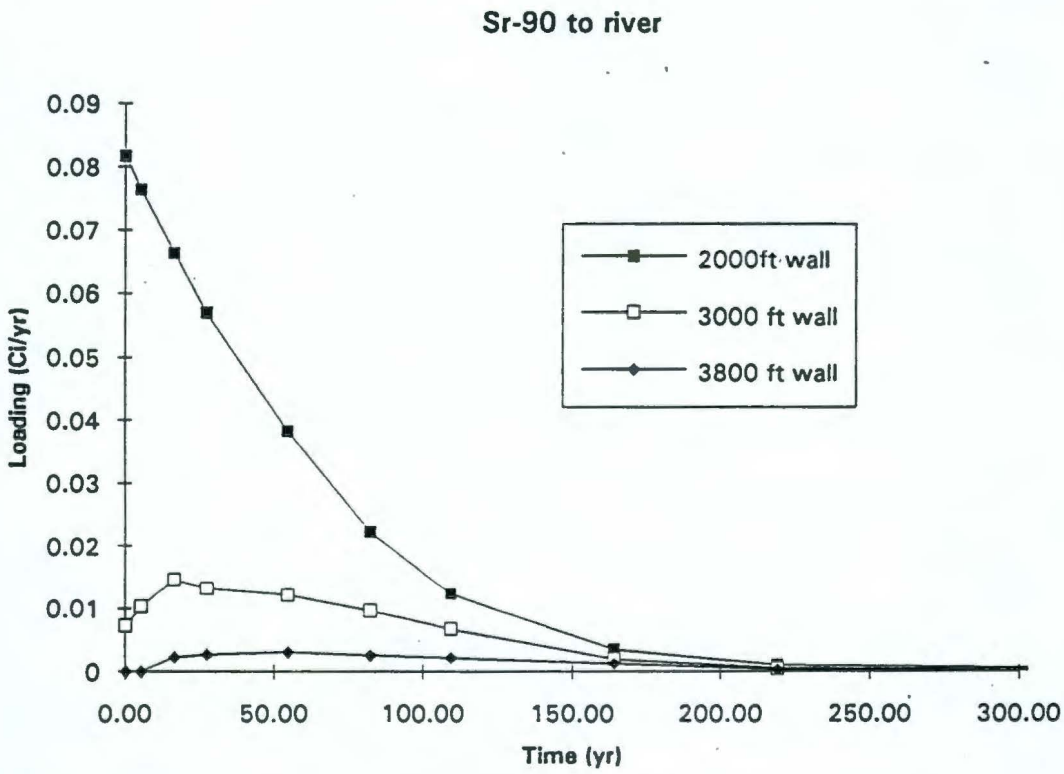


Figure 2-12. Strontium-90 Releases to River for 2,000-Ft, 3,000-Ft, and 3,800-Ft Wall Lengths K = 500 Ft/d.

	Wall length (ft)		
	2000	3000	3800
K used in FLOWPATH (ft/d)	261	261	261
K for these calcs (ft/d)	500	500	500
Retardation coefficient	100	100	100
Radionuclide	Sr-90	Sr-90	Sr-90
Half-life (yr)	28	28	28
Total release (Ci)	11.88428	4.754389	1.926651

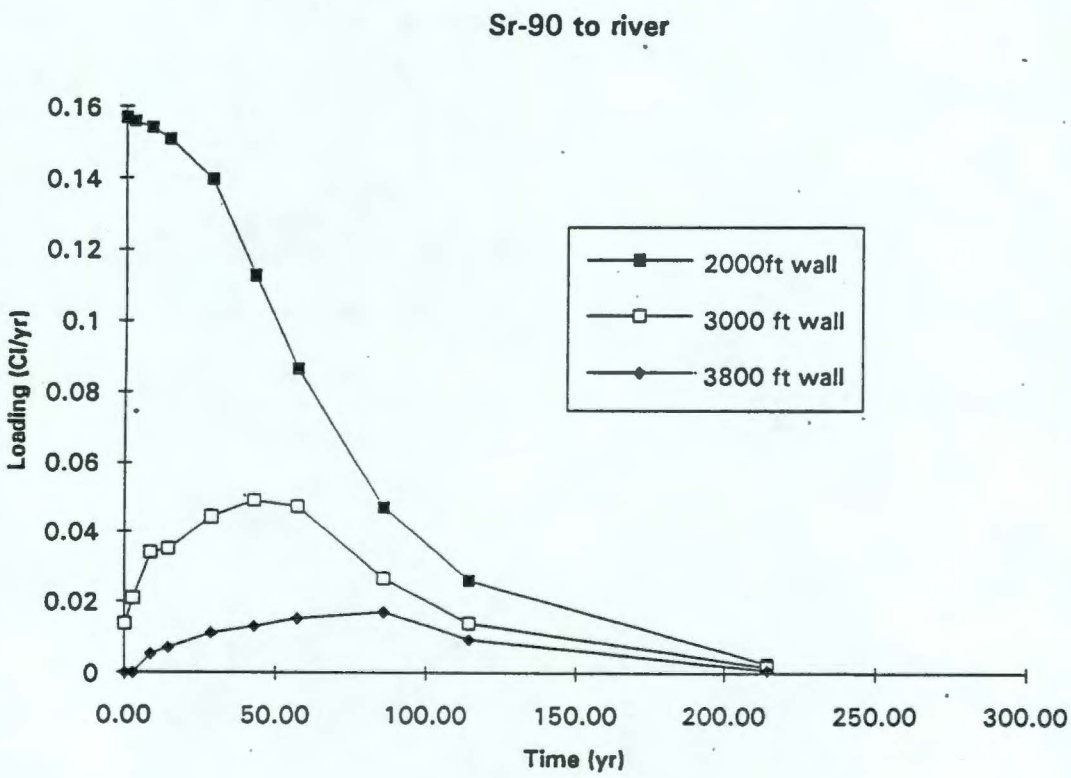
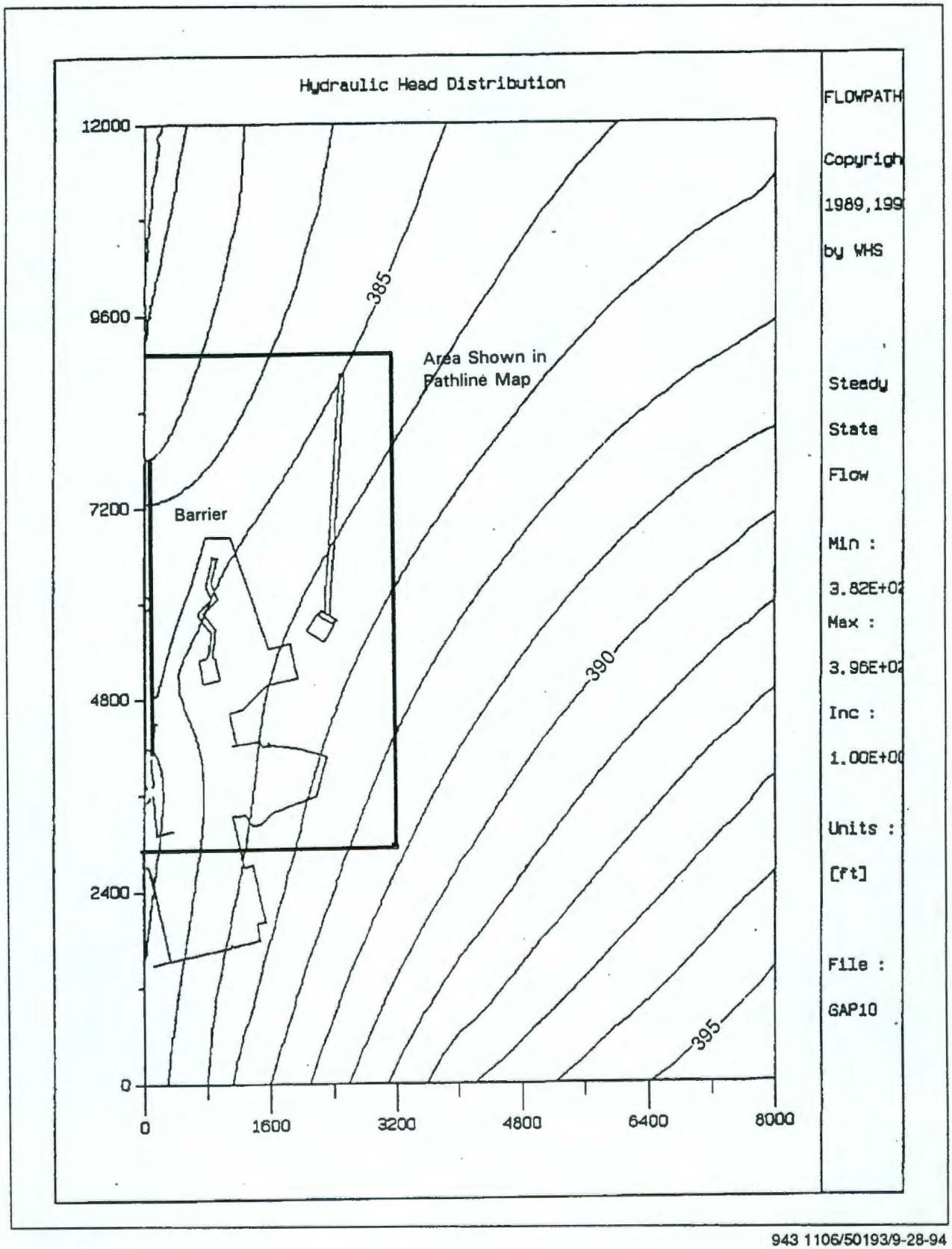


Figure 2-13. 3,800-Ft Wall with 10-Ft Gap: Equipotentials.



943 1106/50193/9-28-94

Figure 2-14. 3,800-Ft Wall with 10-Ft Gap: Pathlines.

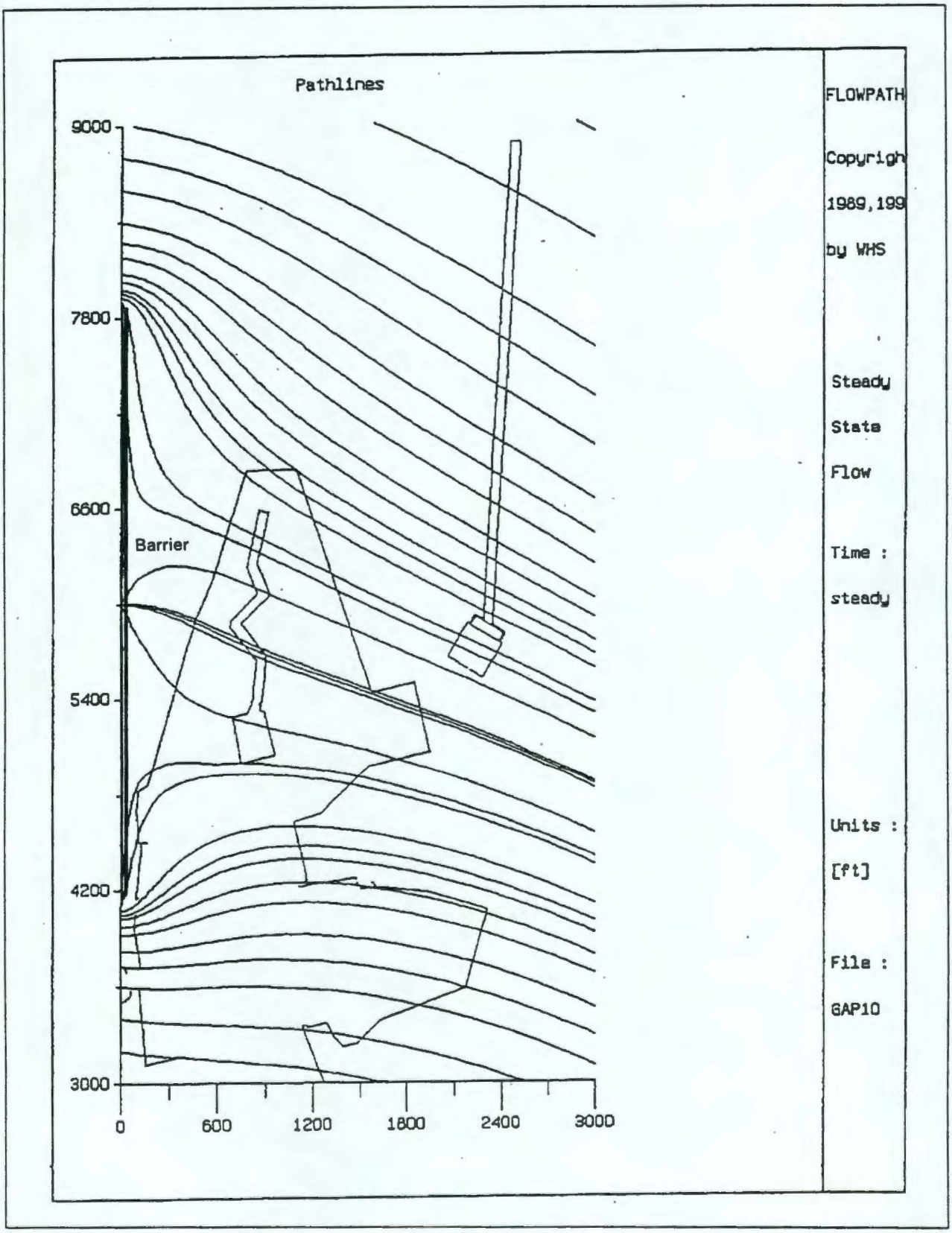


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Figure 2-15. Strontium-90 Releases to River for 3,800-Ft Wall with 10-Ft Gap: K = 100 Ft/d.

	Intact	10ft gap
K used in FLOWPATH (ft/d)	261	261
K for these calcs (ft/d)	100	100
Retardation coefficient	100	100
Radionuclide	Sr-90	Sr-90
Half-life (yr)	28	28
Total release (Ci)	0.043502	2.420175

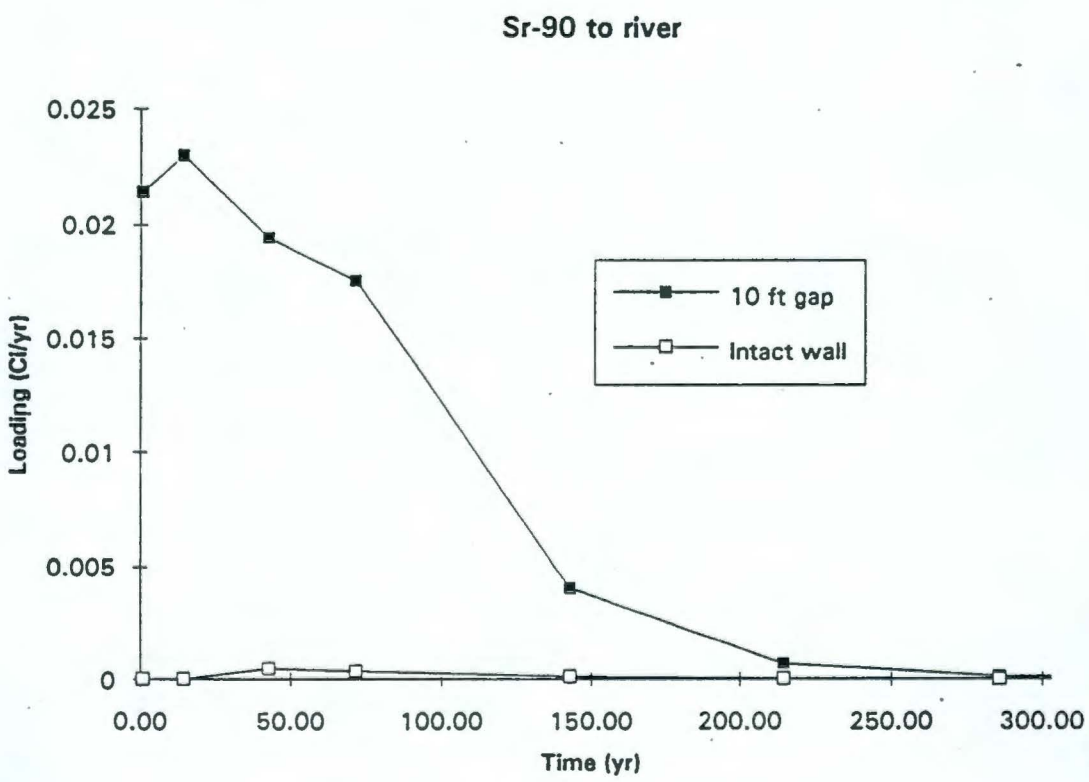


Figure 2-16. Strontium-90 Releases to River for 3,800-Ft. Wall with 10-Ft Gap: K = 201 Ft/d.

	Intact	10ft gap
K used in FLOWPATH (ft/d)	261	261
K for these calcs (ft/d)	261	261
Retardation coefficient	100	100
Radionuclide	Sr-90	Sr-90
Half-life (yr)	28	28
Total release (Ci)	0.43777	10.25241

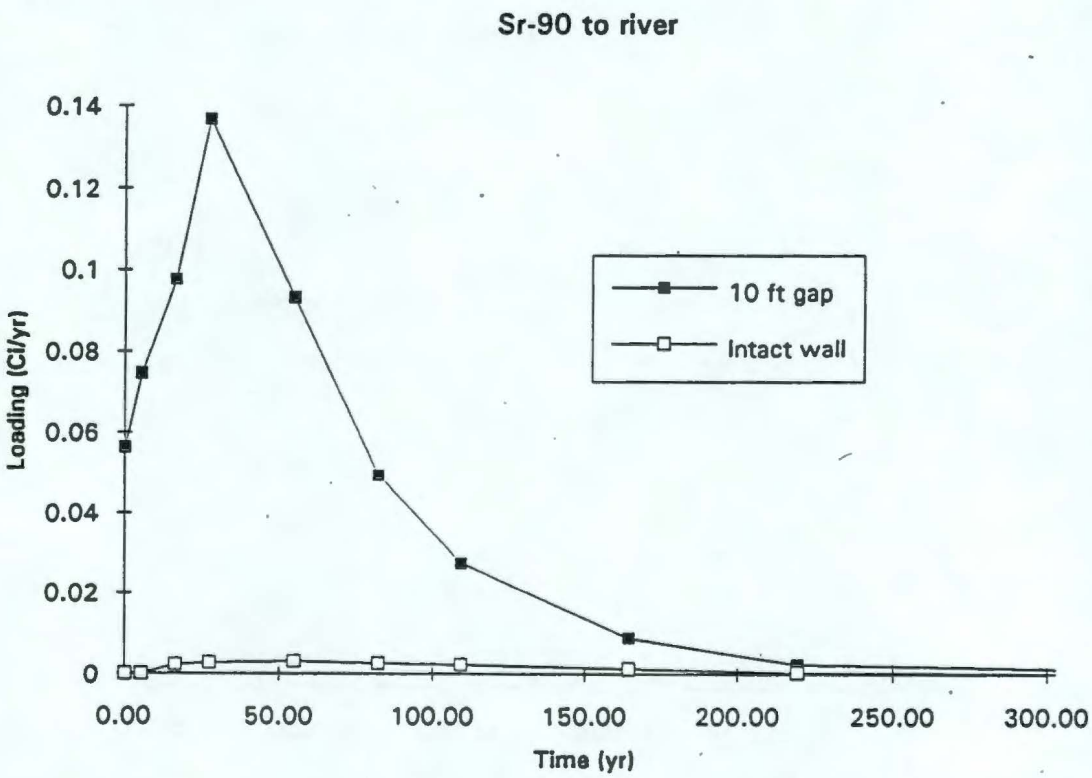


Figure 2-17. Strontium-90 Releases to River for 3,800-Ft Wall with 10-Ft Gap: K = 500 Ft/d.

	Intact	10ft gap
K used in FLOWPATH (ft/d)	261	261
K for these calcs (ft/d)	500	500
Retardation coefficient	100	100
Radionuclide	Sr-90	Sr-90
Half-life (yr)	28	28
Total release (Ci)	1.926651	25.82945

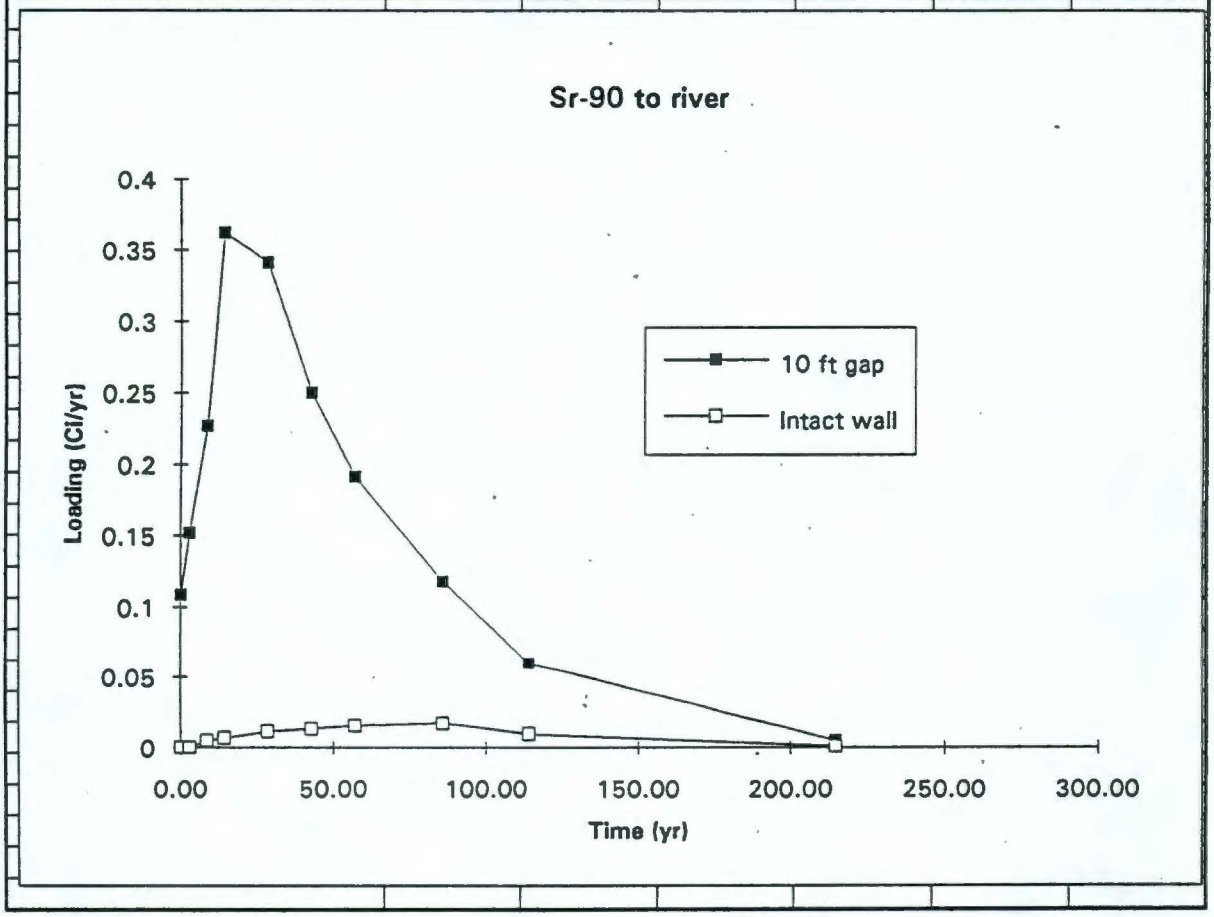
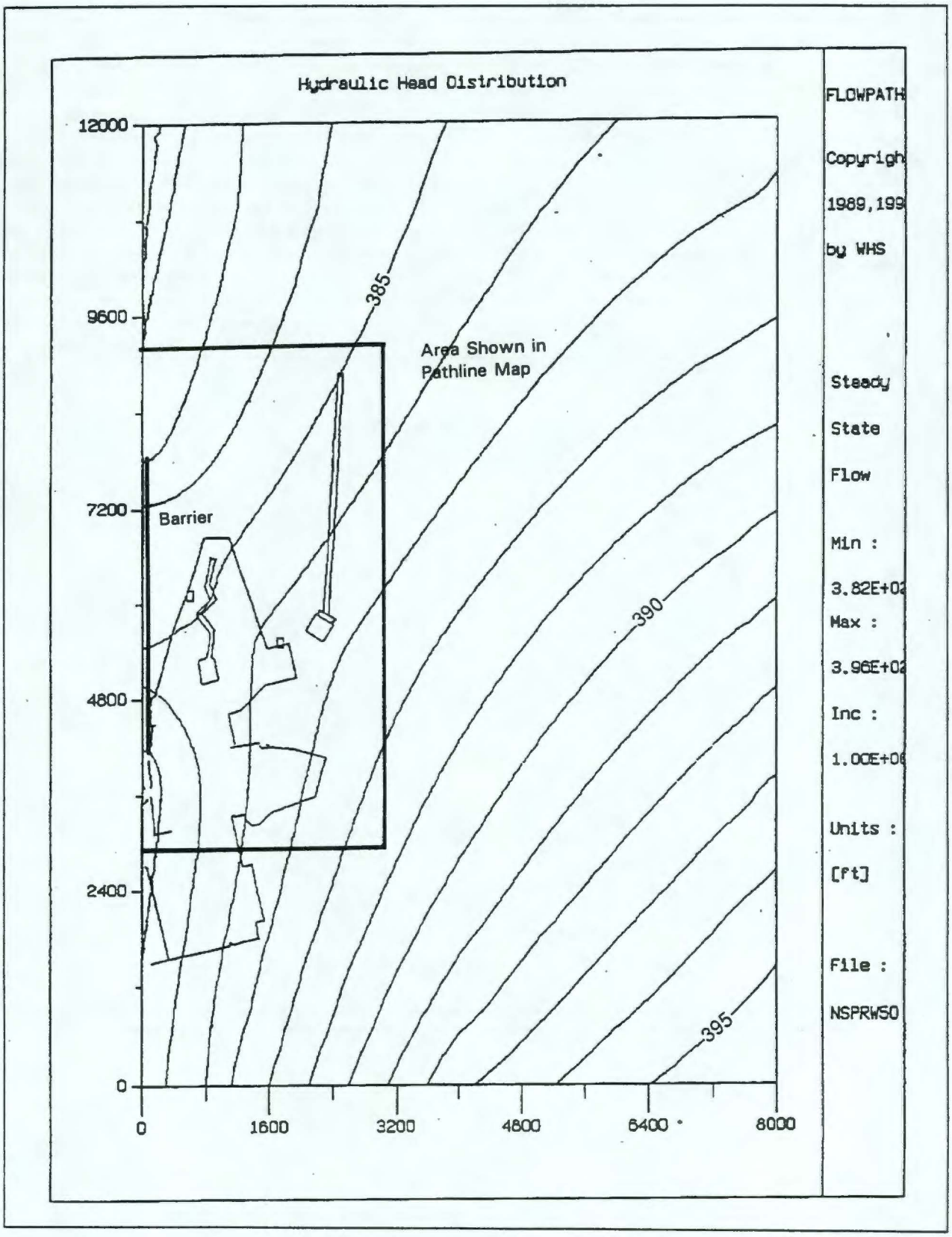
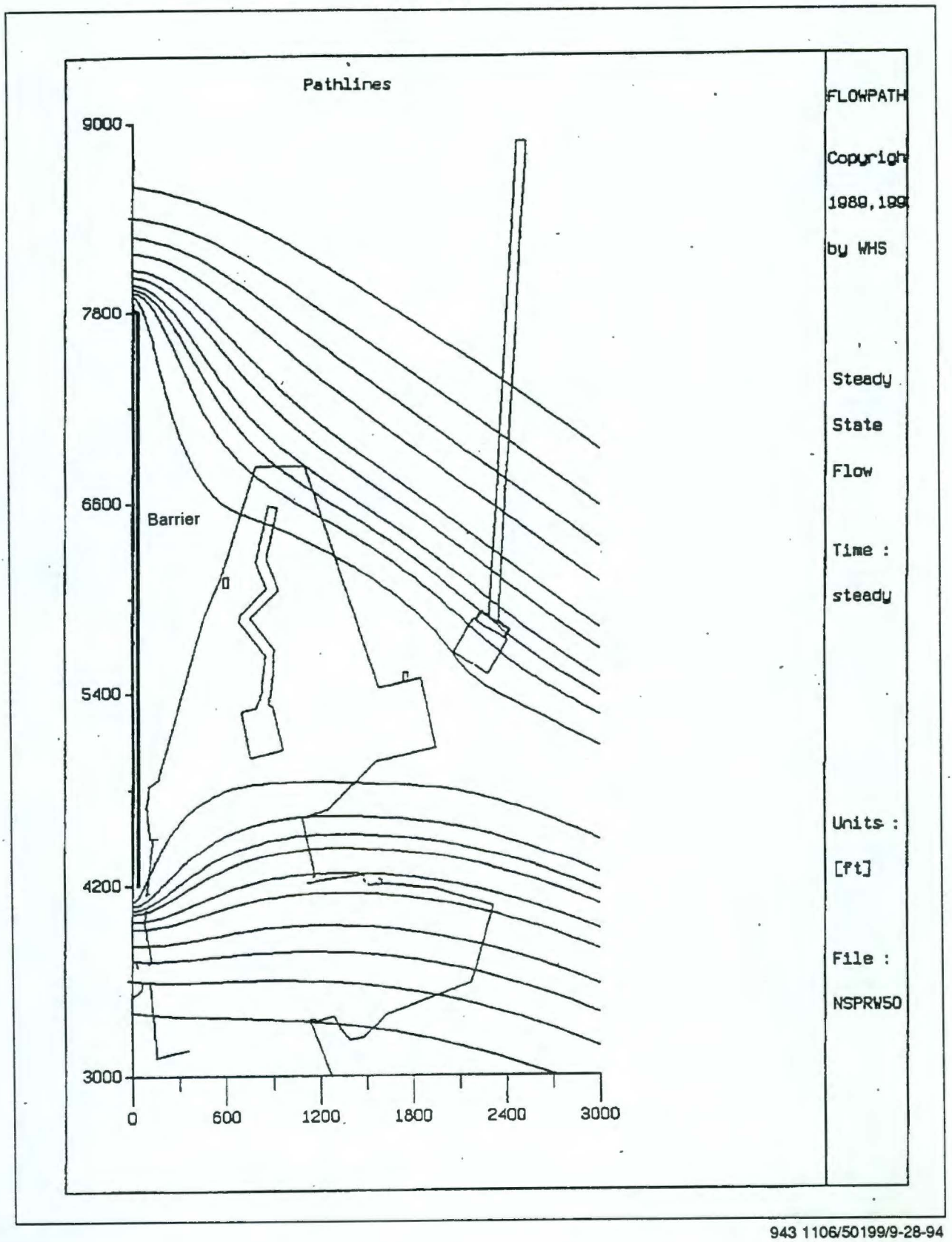


Figure 2-18. 3,800-Ft Wall 50 gal/min Pump and Treat: Equipotentials.



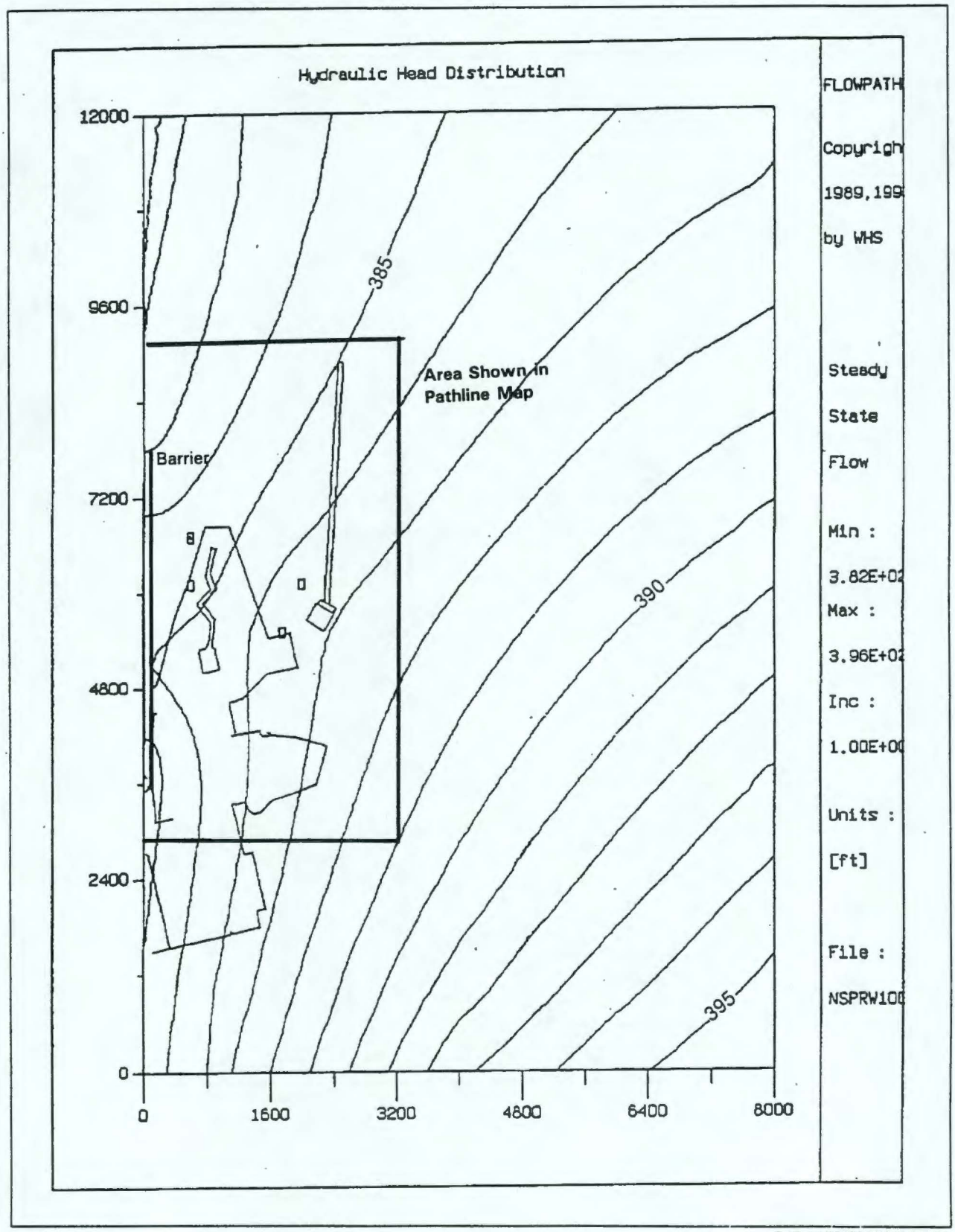
943 1106/50198/9-28-94

Figure 2-19. 3,800-Ft Wall 50 gal/min Pump and Treat: Pathlines.



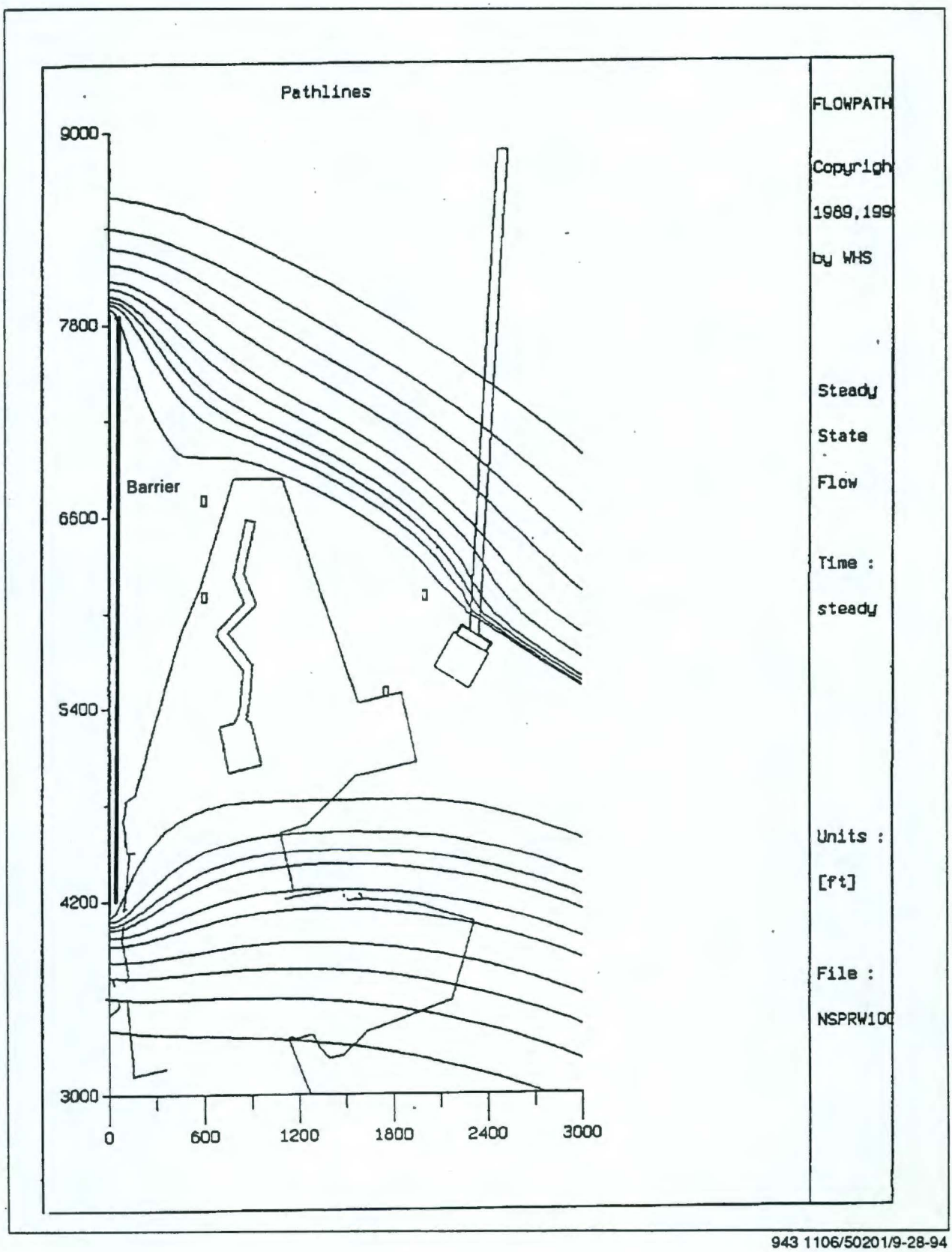
943 1106/50199/9-28-94

Figure 2-20. 3,800-Ft Wall 100 gal/min Pump and Treat: Equipotentials.



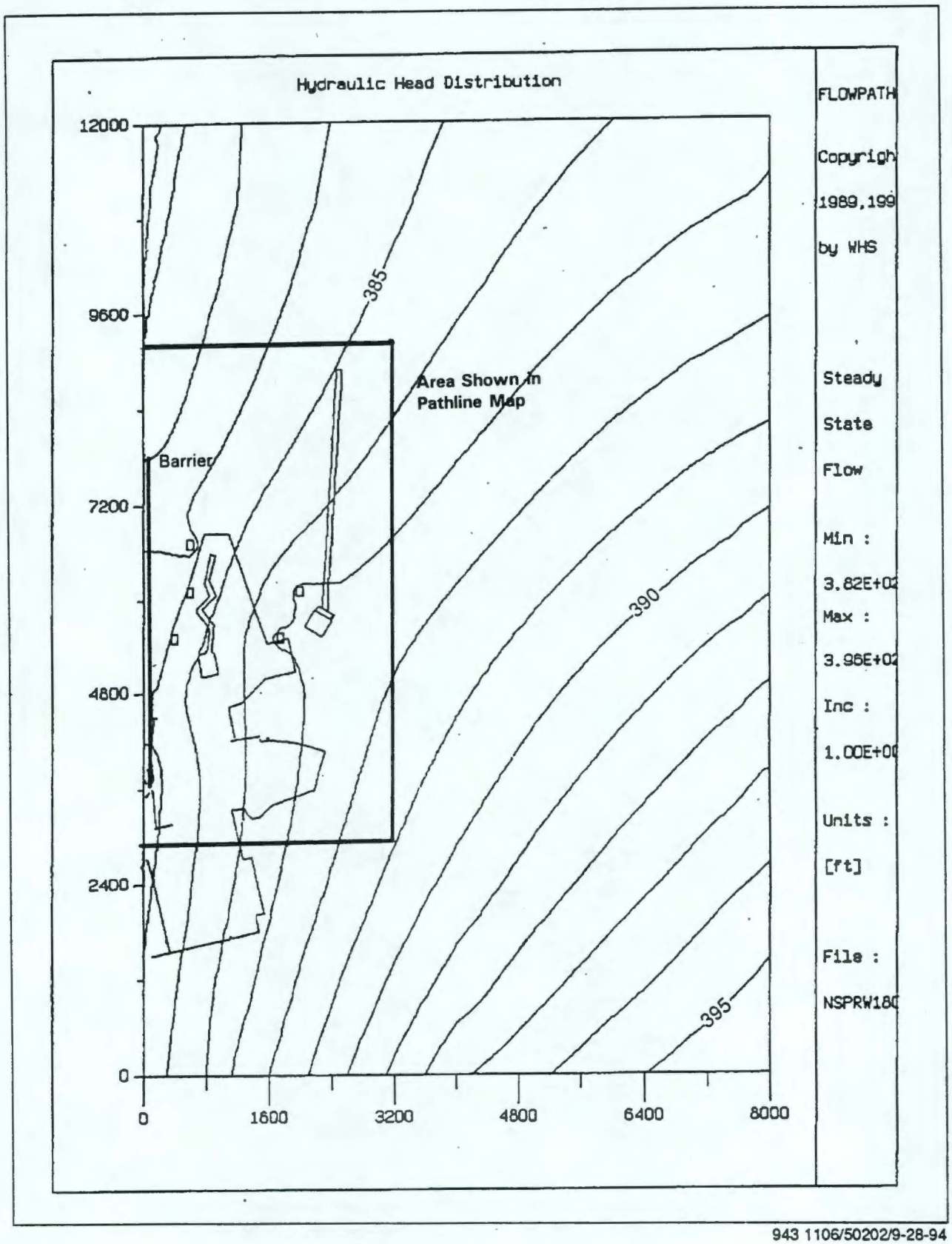
943 1106/50200/9-28-94

Figure 2-21. 3,800-Ft Wall 100 gal/min Pump and Treat: Pathlines.



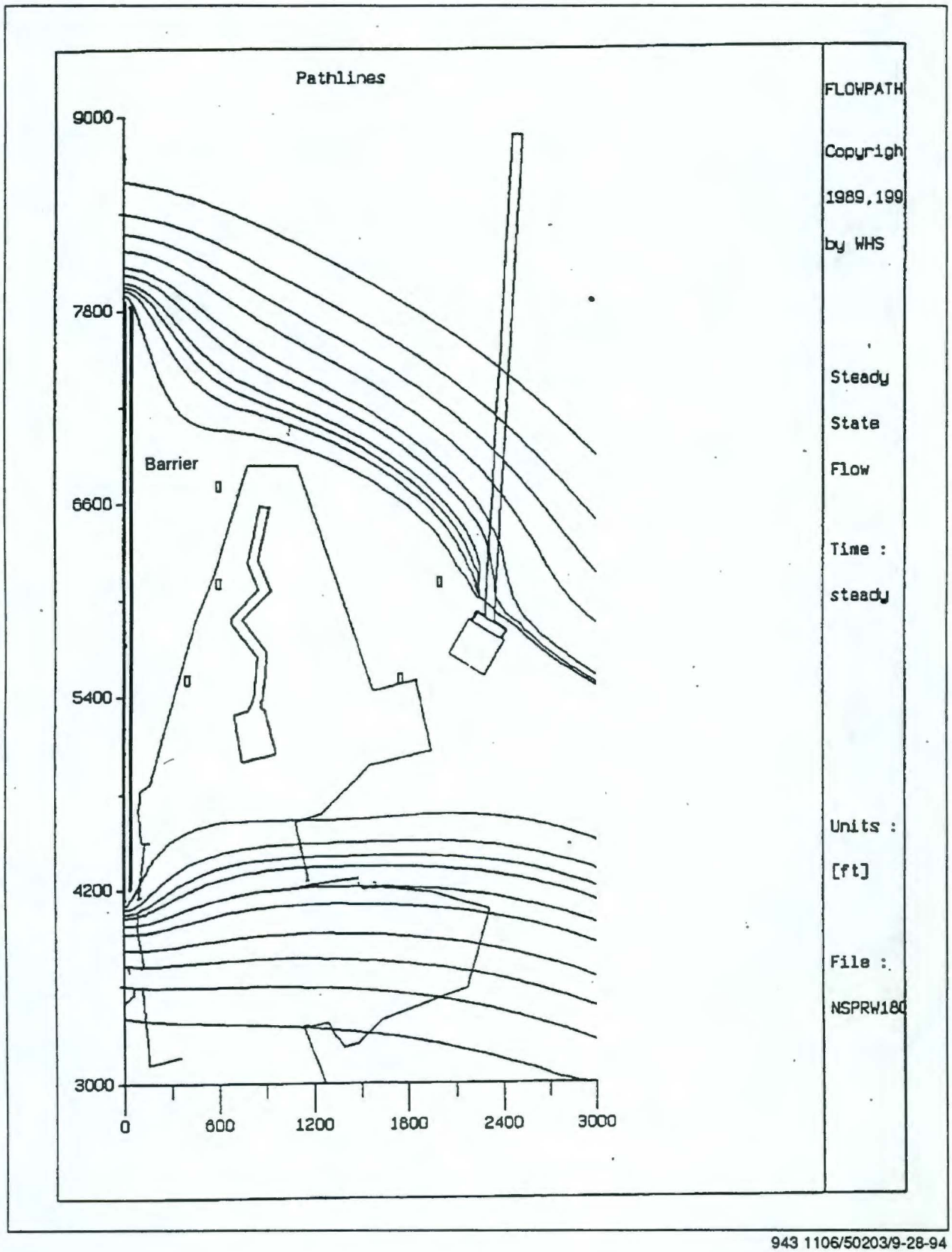
943 1106/50201/9-28-94

Figure 2-22. 3,800-Ft Wall 180 gal/min Pump and Treat: Equipotentials.



943 1106/50202/9-28-94

Figure 2-23. 3,800-Ft Wall 180 gal/min Pump and Treat: Pathlines.



943 1106/50203/9-28-94

Figure 2-24. Strontium-90 Releases to River for 3,800-Ft Wall with Pump and Treat: K = 261 Ft/d.

	3800 ft			
	No pumping	50 gpm	100 gpm	180 gpm
K used in FLOWPATH (ft/d)	261	261	261	261
K for these calcs (ft/d)	261	261	261	261
Retardation coefficient	100	100	100	100
Radionuclide	Sr-90	Sr-90	Sr-90	Sr-90
Half-life (yr)	28	28	28	28
Total release (Ci)	0.43777031	0.199789	0.157166	0.113293

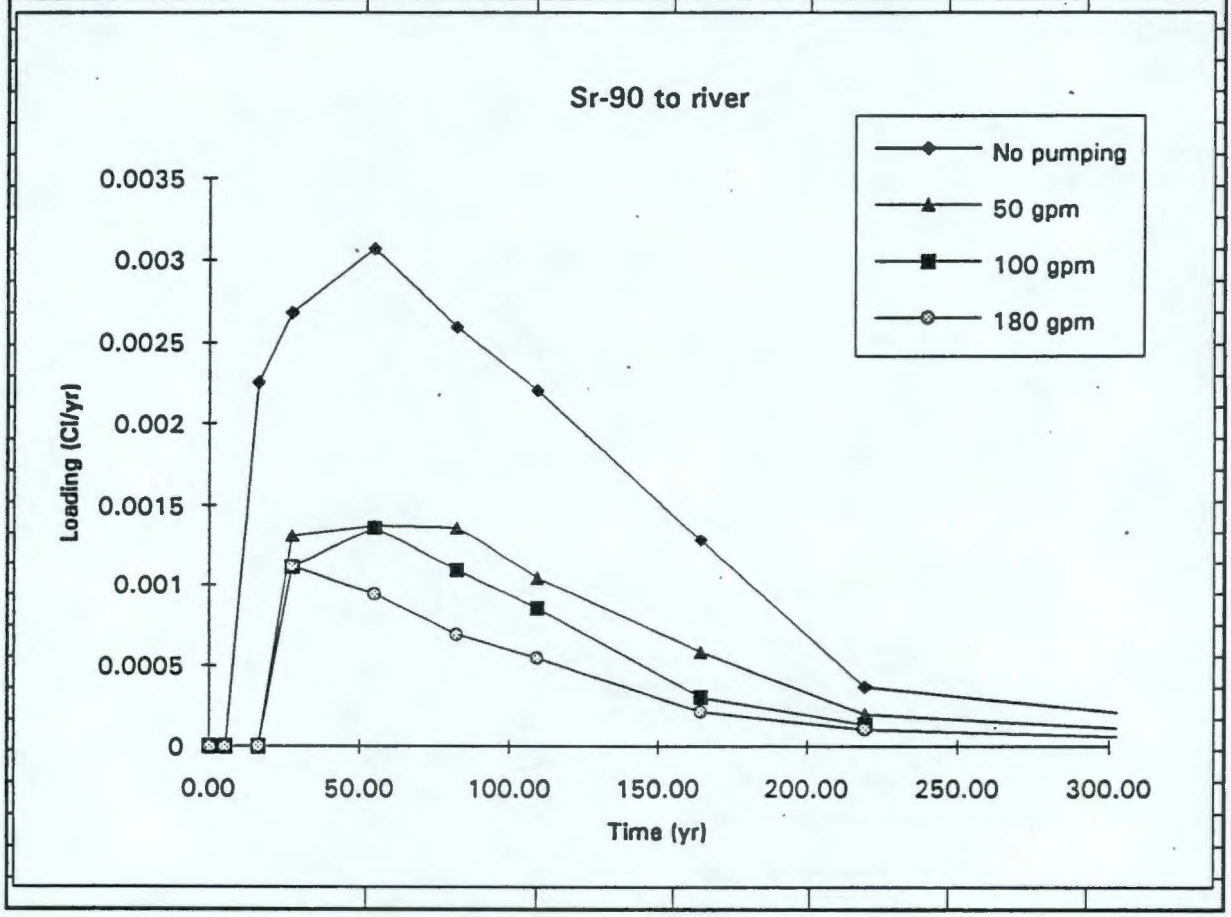
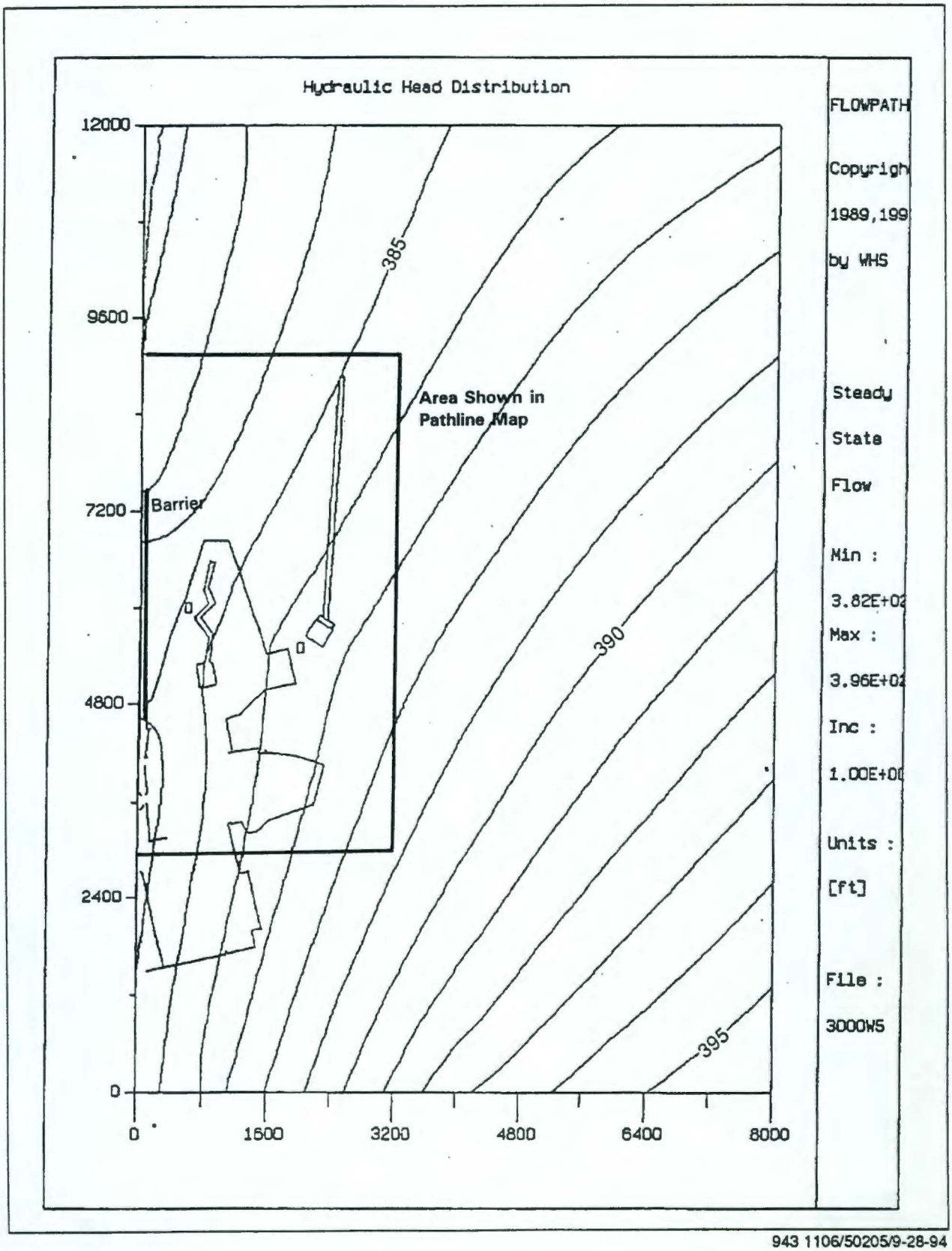
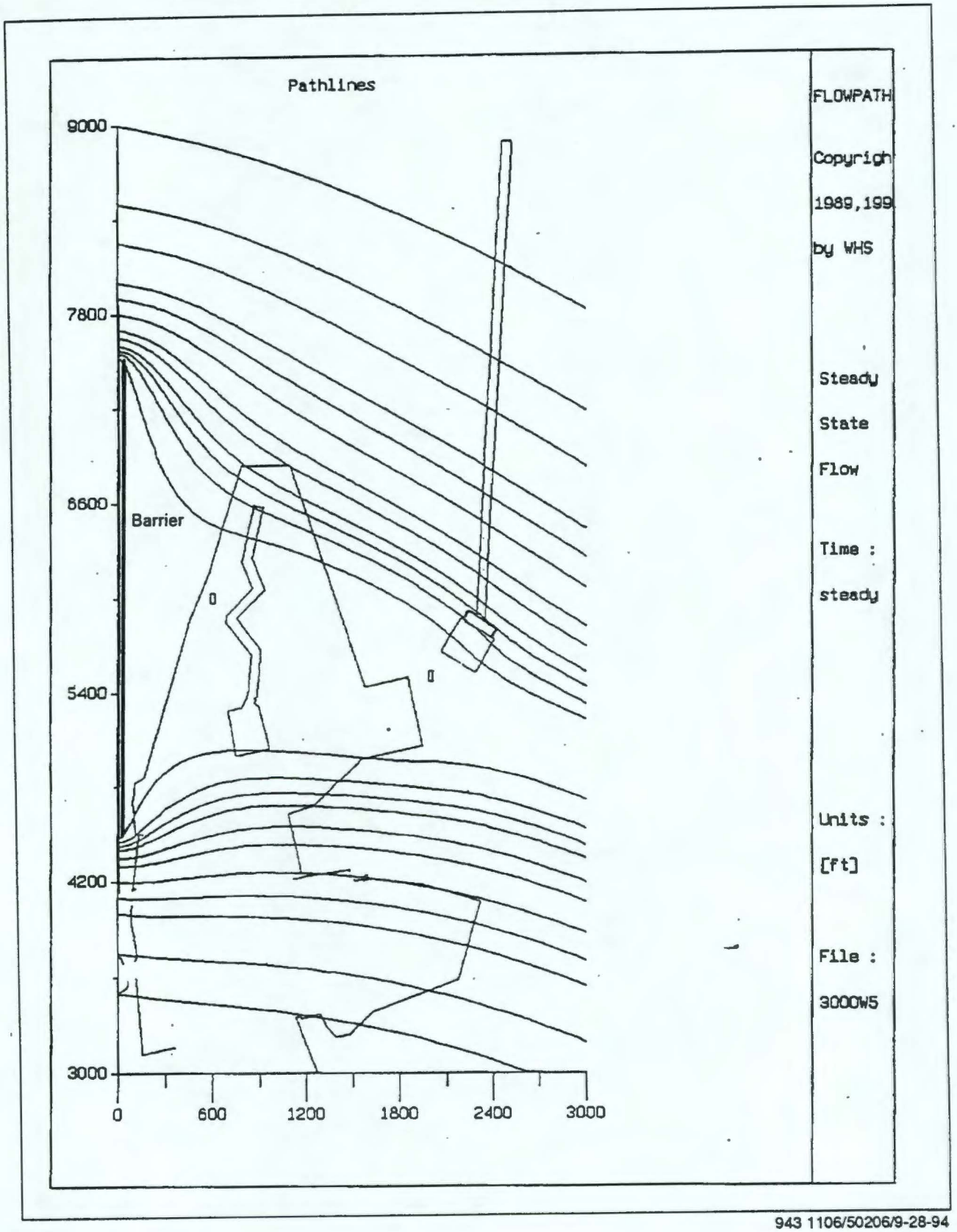


Figure 2-25. 3,000-Ft Wall 50 gal/min Pump and Treat: Equipotentials.



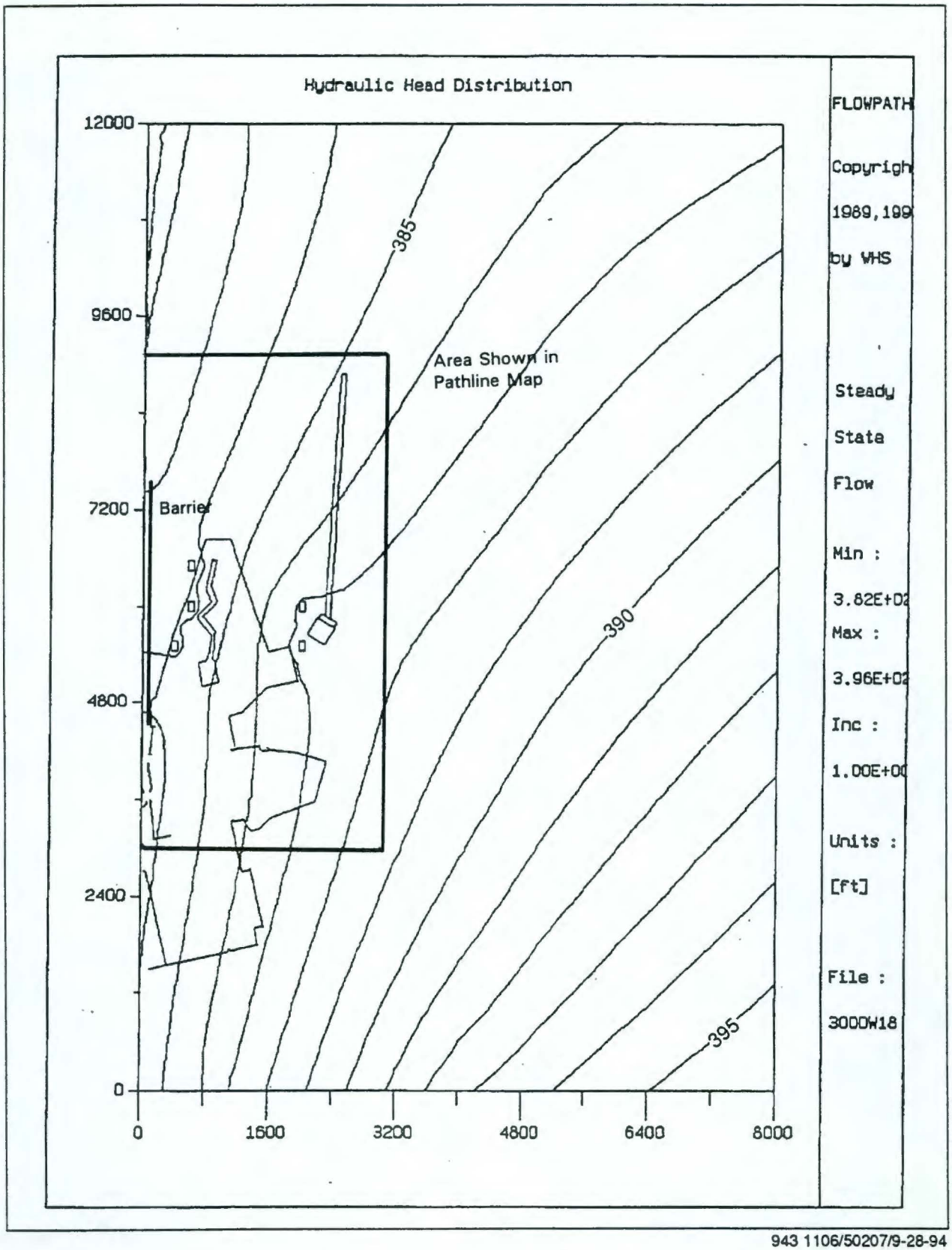
943 1106/50205/9-28-94

Figure 2-26. 3,000-Ft Wall 40 gal/min Pump and Treat: Pathlines.



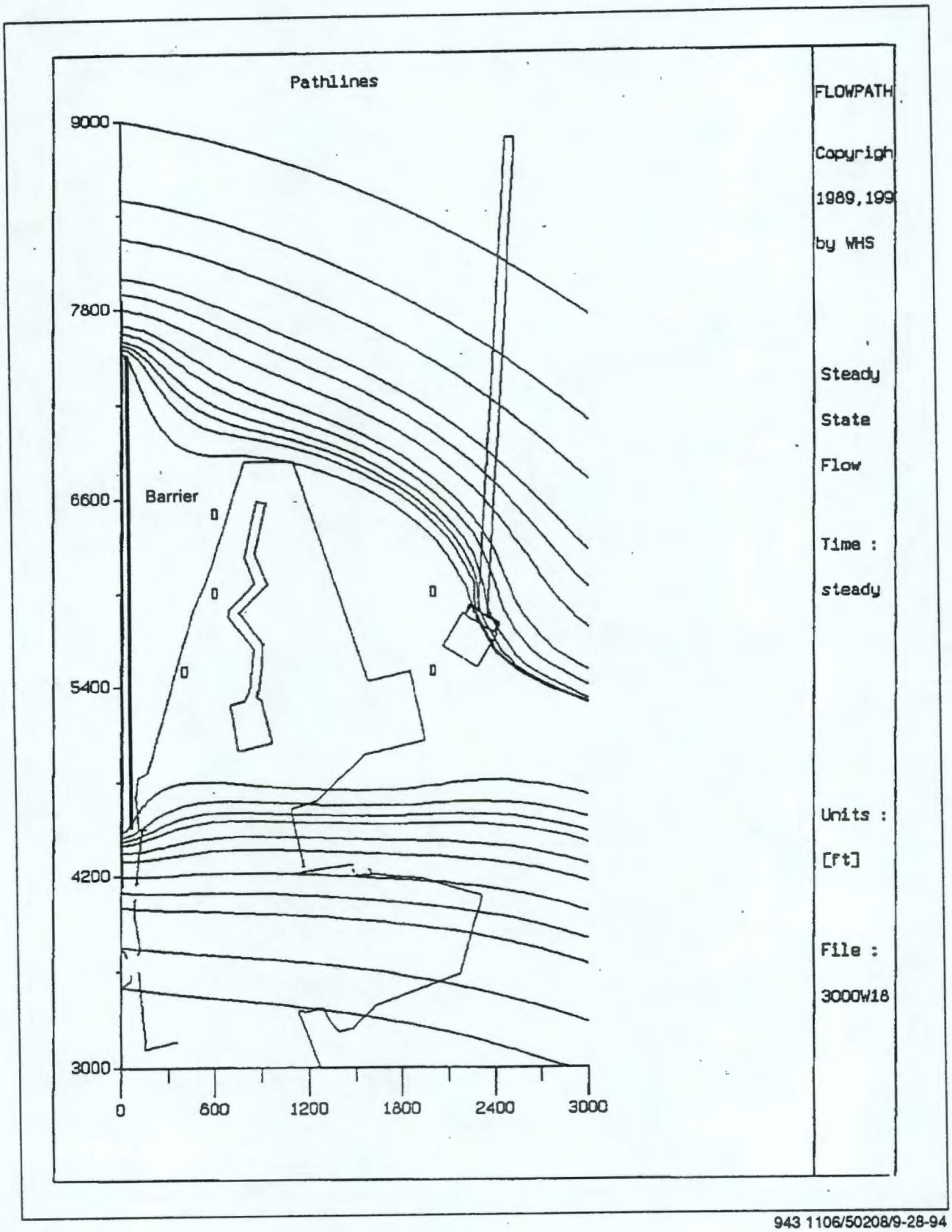
943 1106/50206/9-28-94

Figure 2-27. 3,000-Ft Wall 180 gal/min Pump and Treat: Equipotentials.



943 1106/50207/9-28-94

Figure 2-28. 3,000-Ft Wall 180 gal/min Pump and Treat: Pathlines.



943 1106/50208/9-28-94

Figure 2-29. Strontium-90 Releases to River for 3,000-Ft Wall with Pump and Treat: K = 261 Ft/d.

	3000 ft				
	No pumping	50 gpm	180 gpm		
K used in FLOWPATH (ft/d)	261	261	261		
K for these calcs (ft/d)	261	261	261		
Retardation coefficient	100	100	100		
Radionuclide	Sr-90	Sr-90	Sr-90		
Half-life (yr)	28	28	28		
Total release (Ci)	1.56579354	1.286903	0.961024		

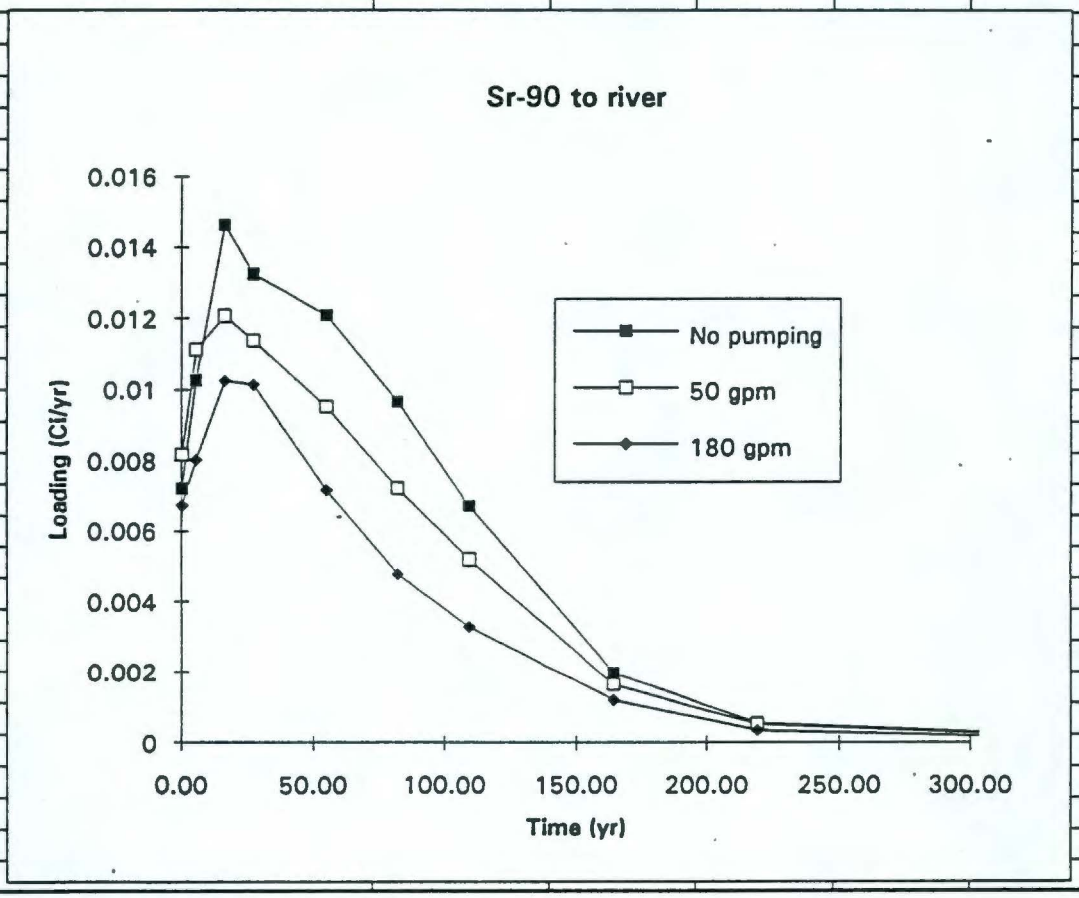
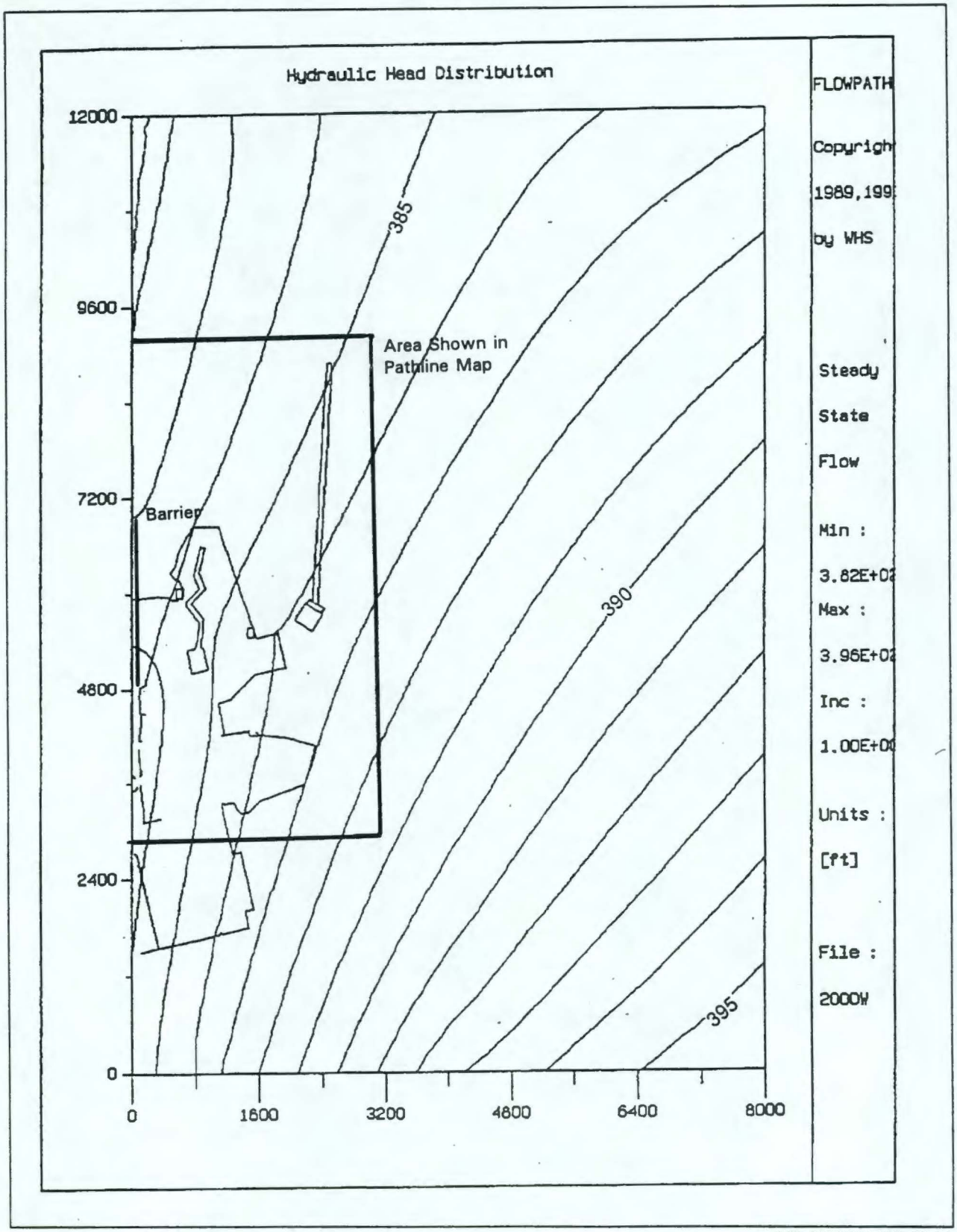
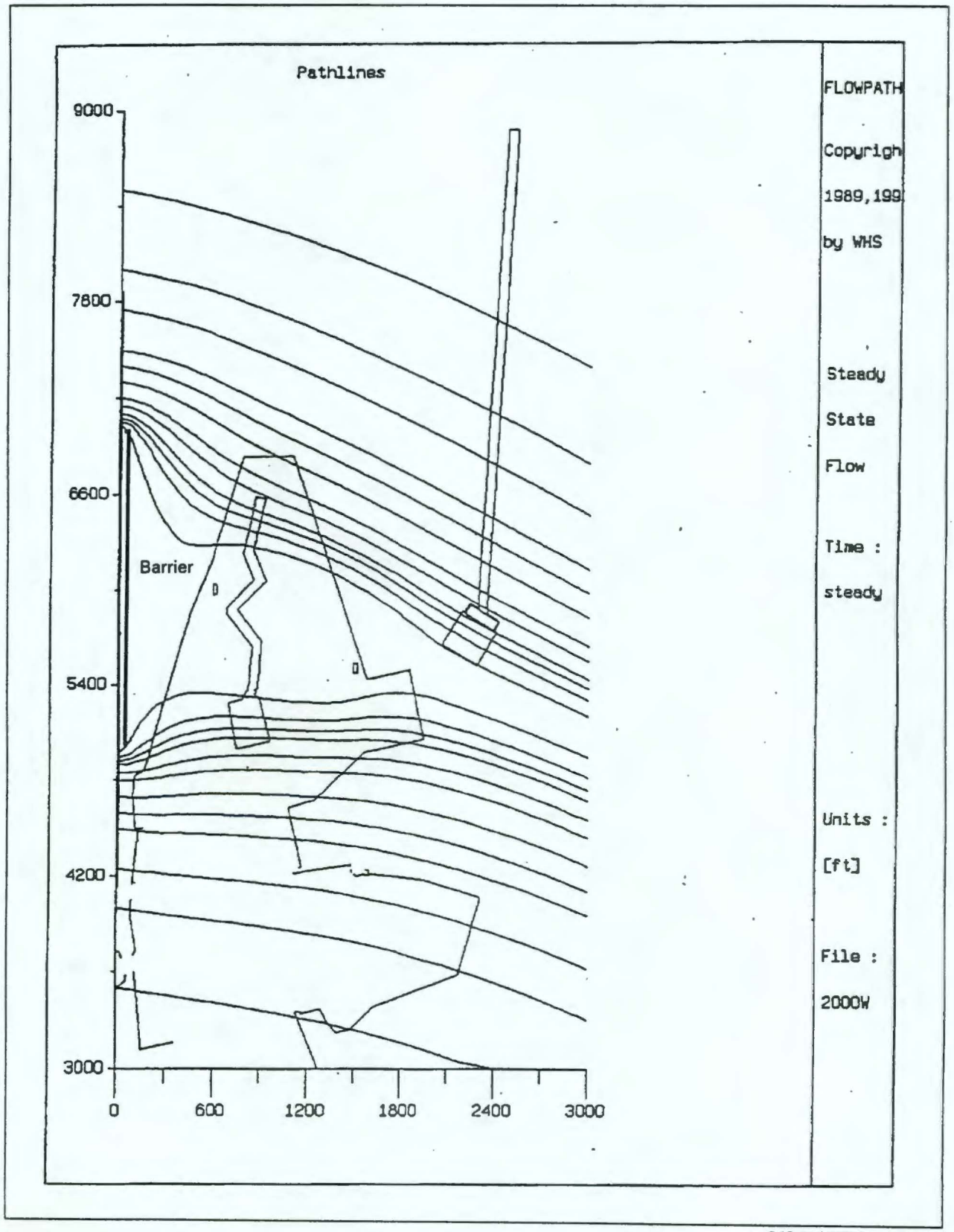


Figure 2-30. 2,000-Ft Wall 50 gal/min Pump and Treat: Equipotentials.



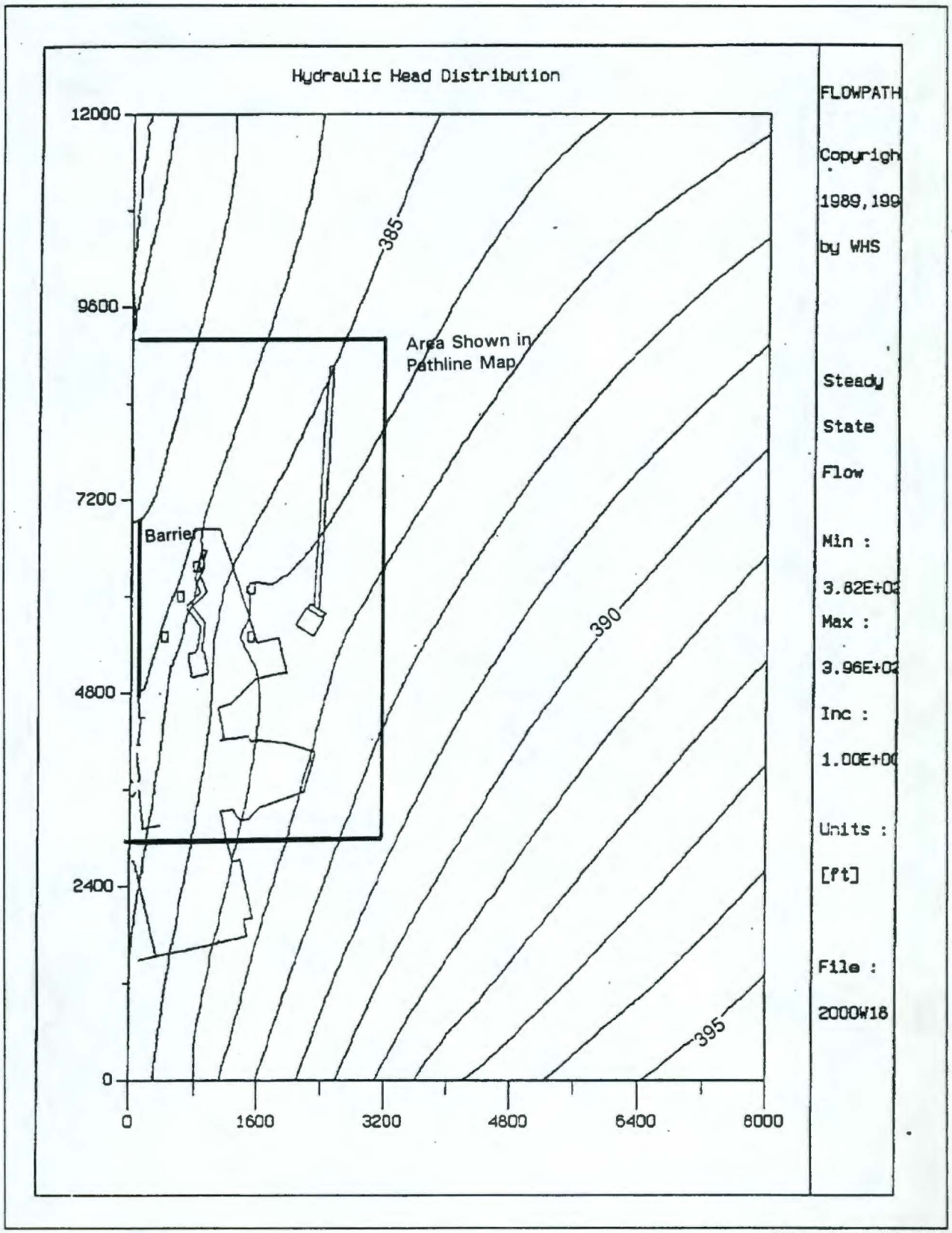
943 1106/50210/9-28-94

Figure 2-31. 2,000-Ft Wall 50 gal/min Pump and Treat: Pathlines.



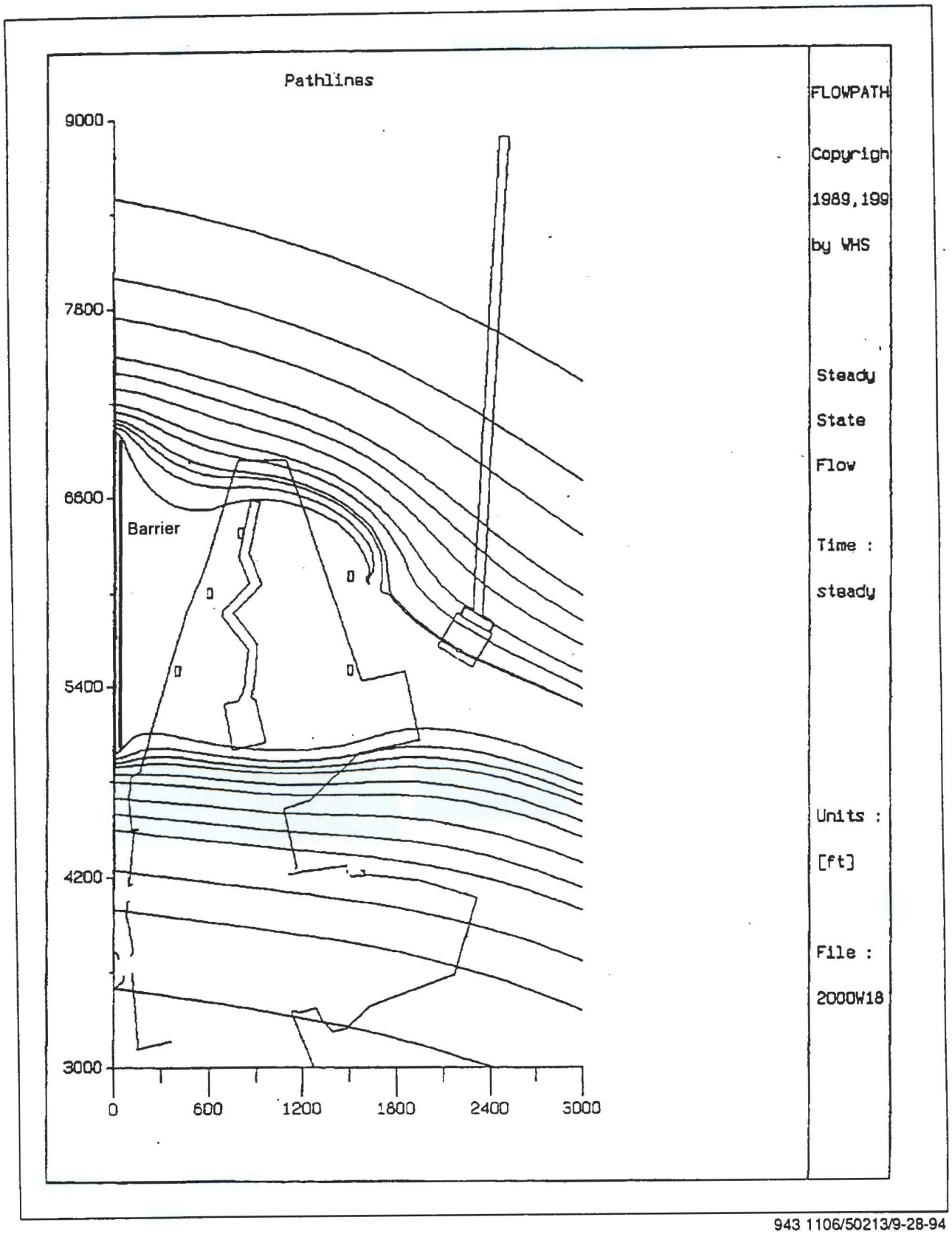
943 1106/50211/9-28-94

Figure 2-32. 2,000-Ft Wall 180 gal/min Pump and Treat: Equipotentials.



943 1106/50212/9-28-94

Figure 2-33. 2,000-Ft Wall 180 gal/min Pump and Teat: Equipotentials.



943 1106/50213/9-28-94

Figure 2-34. Strontium-90 Releases to River for 2,000-Ft Well with Pump and Treat: K = 261 Ft/d.

	----------2000 ft ----------		
	No pumping	50 gpm	180 gpm
K used in FLOWPATH (ft/d)	261	261	261
K for these calcs (ft/d)	261	261	261
Retardation coefficient	100	100	100
Radionuclide	Sr-90	Sr-90	Sr-90
Half-life (yr)	28	28	28
Total release (Ci)	5.1285539	5.087951	4.414588

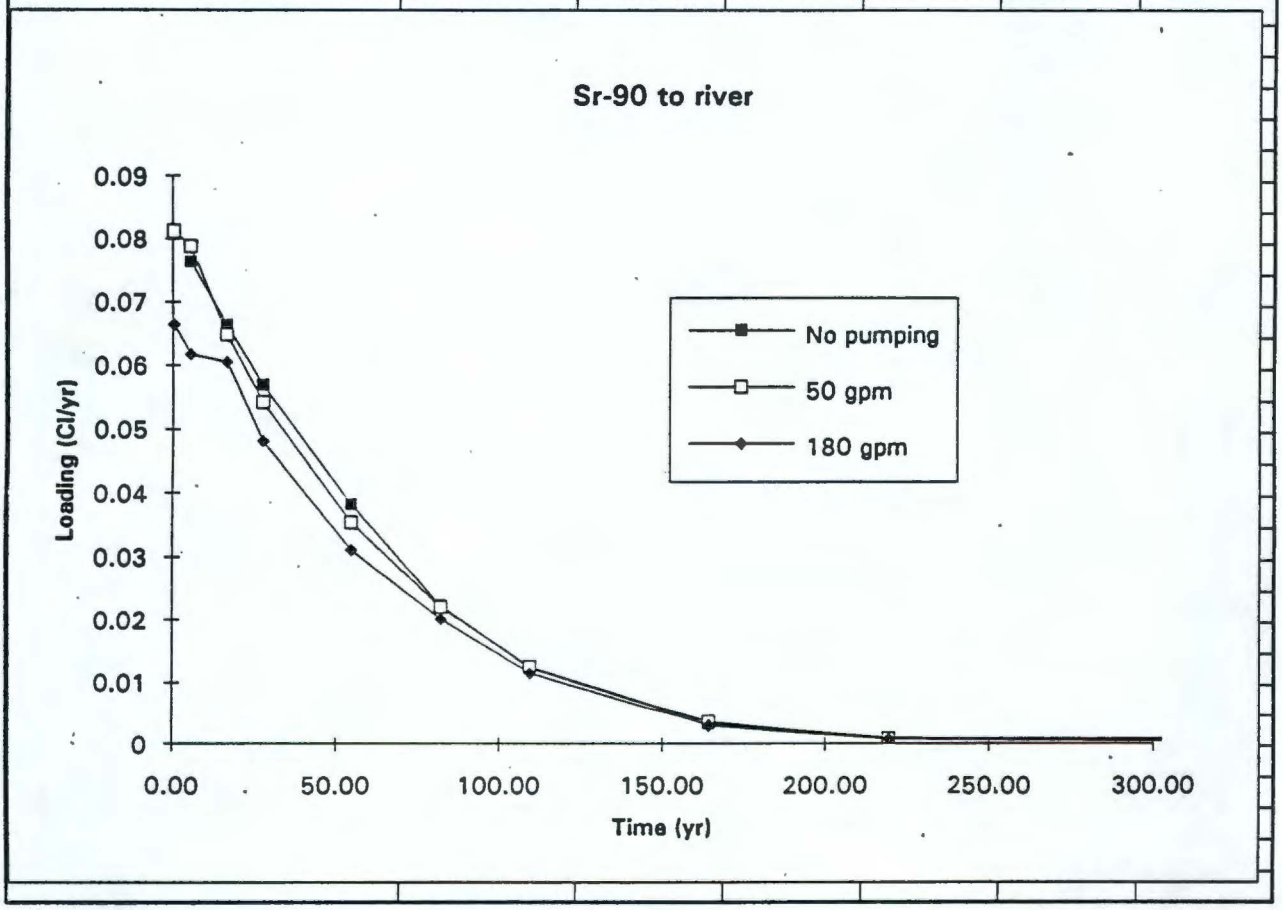


Figure 2-35. Case 1: No Wall Two-Dimensional Cross-Section: Equipotentials and Water Travel Time (a) Contaminant Distribution and Contaminant Travel Time at 30 (b), 90 (c),d and 180 (d) years.

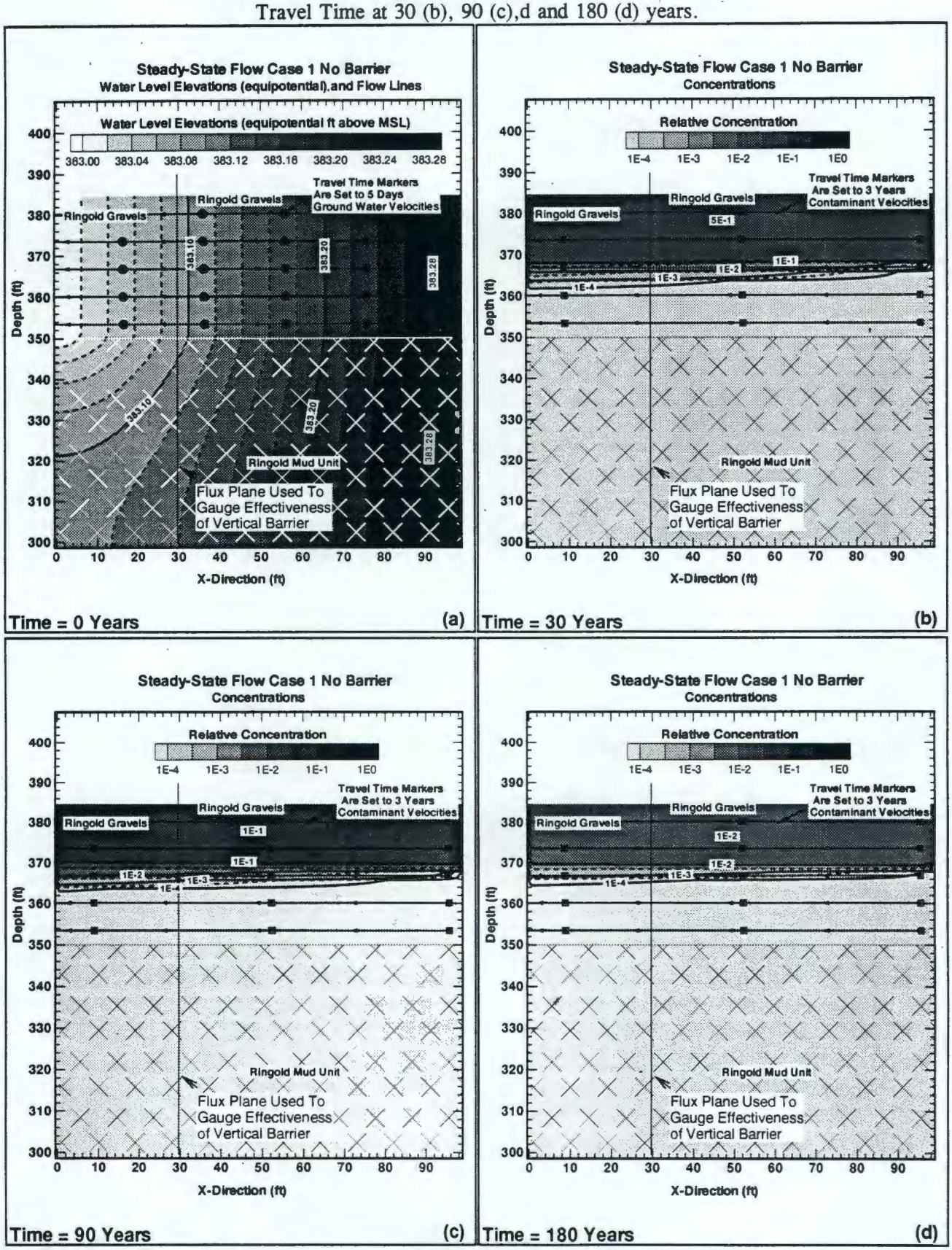


Figure 2-36. Case 2: Barrier Set 4 ft into Ringold Mud: Equipotentials and Water Travel Time (a) Contaminant Distribution and Contaminant Travel Time at 30 (b) 90, (c) and 150 (d) years.

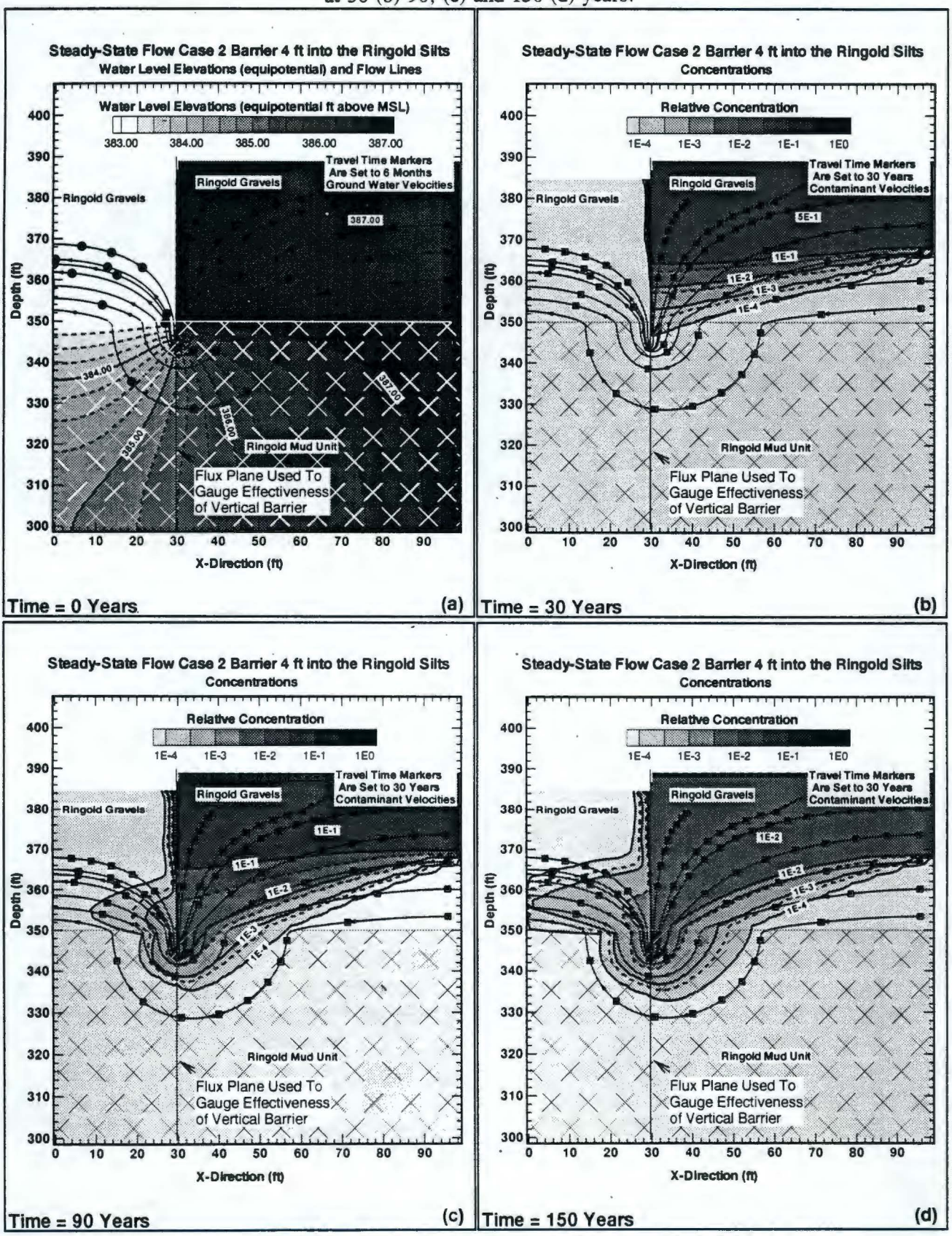


Figure 2-37. Case 3: Barrier Set 4 Ft into Ringold Mud and K_h for Ringold Mud a Factor of 10 over Previous Case 2: Equipotentials and Water Travel Time (a) Contaminant Distribution and Contaminant Travel time at 30 (b), 90 (c), and 150 (d) Years.

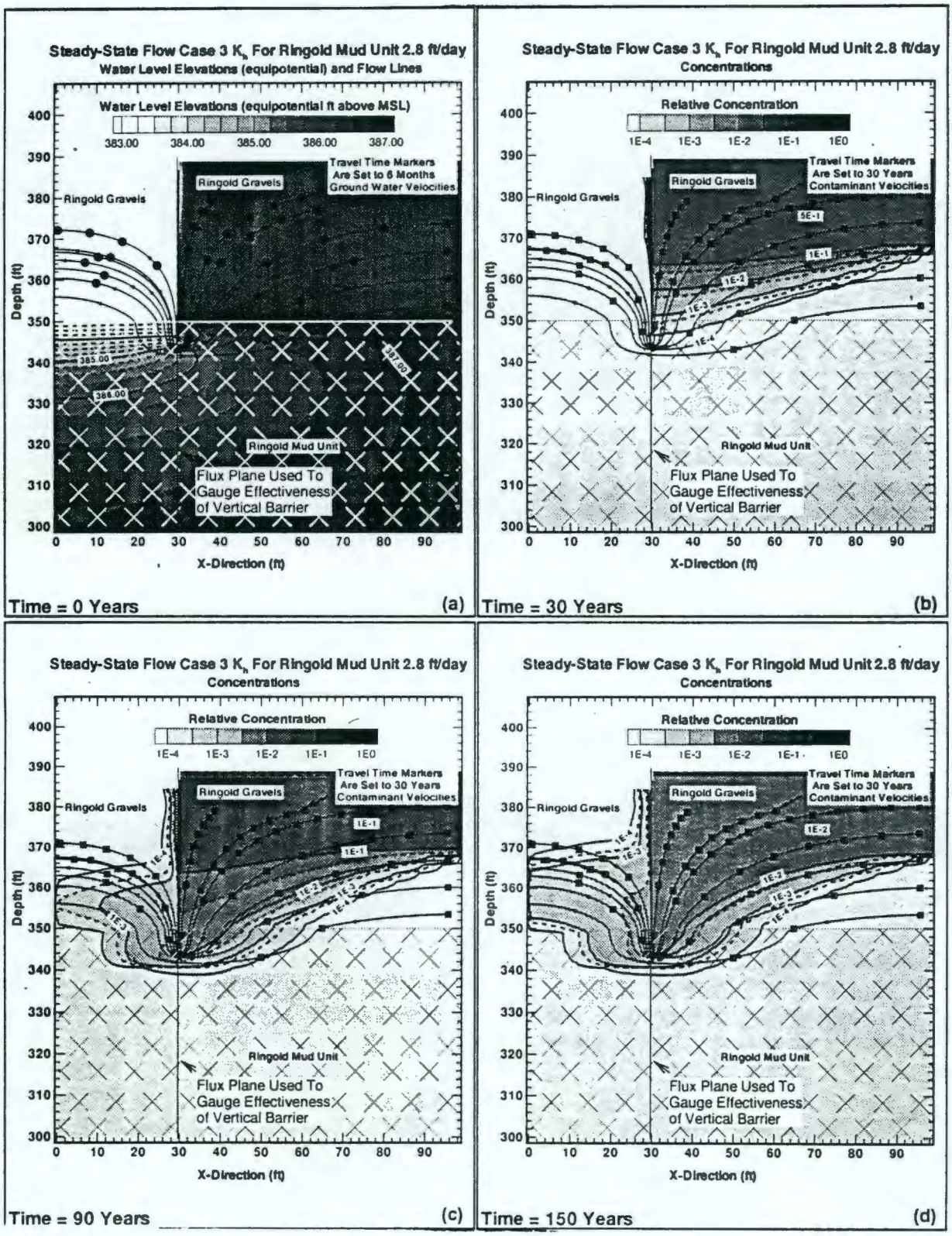


Figure 2-38. Case 4: Barrier Set at Ringold Mud: Equipotentials and Water Travel Time (a), Contaminant Distribution and Contaminant Travel Time at 10 (b), 30 (c), and 90 (d) Years.

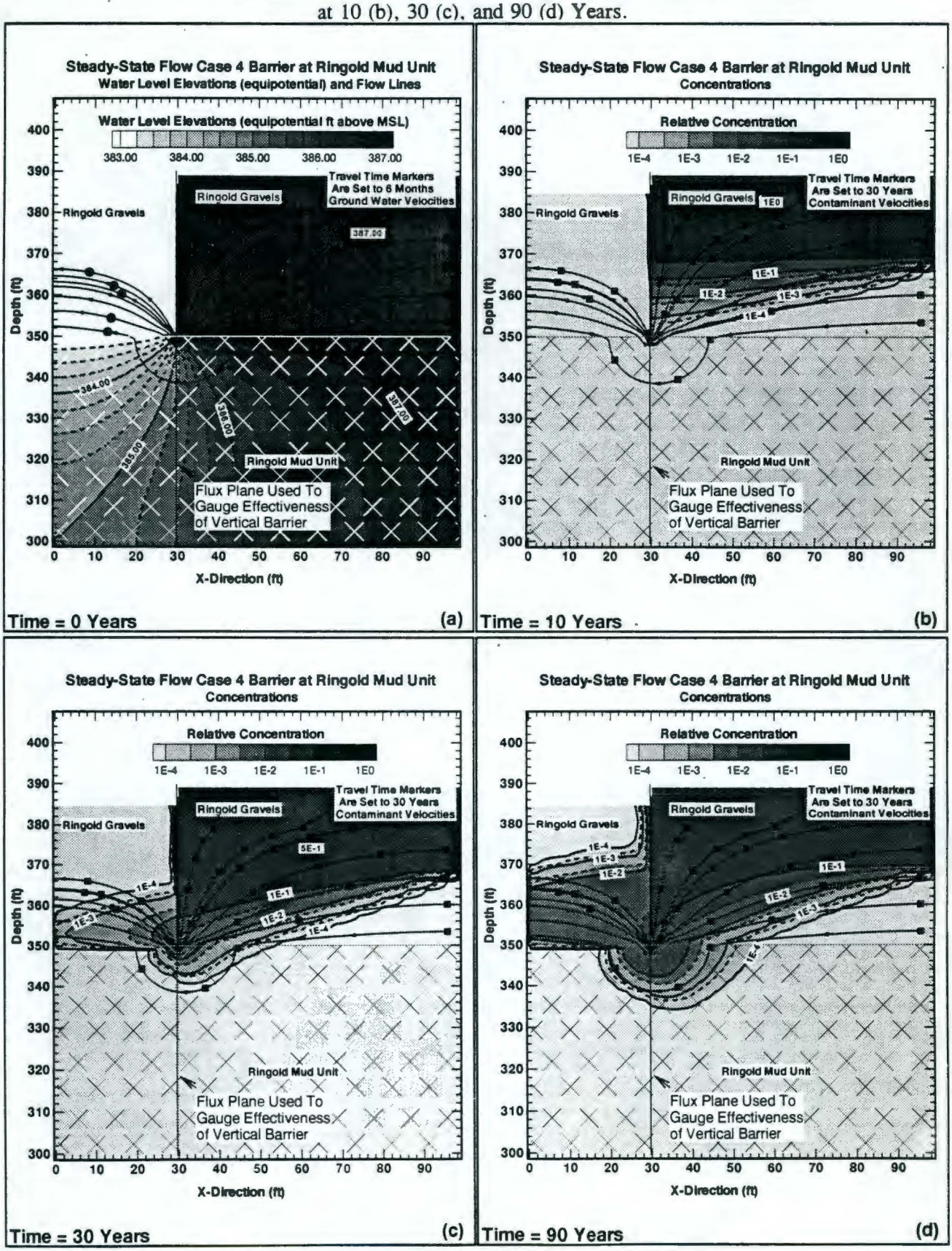


Figure 2-39. Case 5: Barrier Set 2 Ft above Ringold Mud: Equipotentials and Water Travel Time (a) Contaminant Distribution and Contaminant Travel Time at 10 (b), 30 (c), and 90 (d) Years.

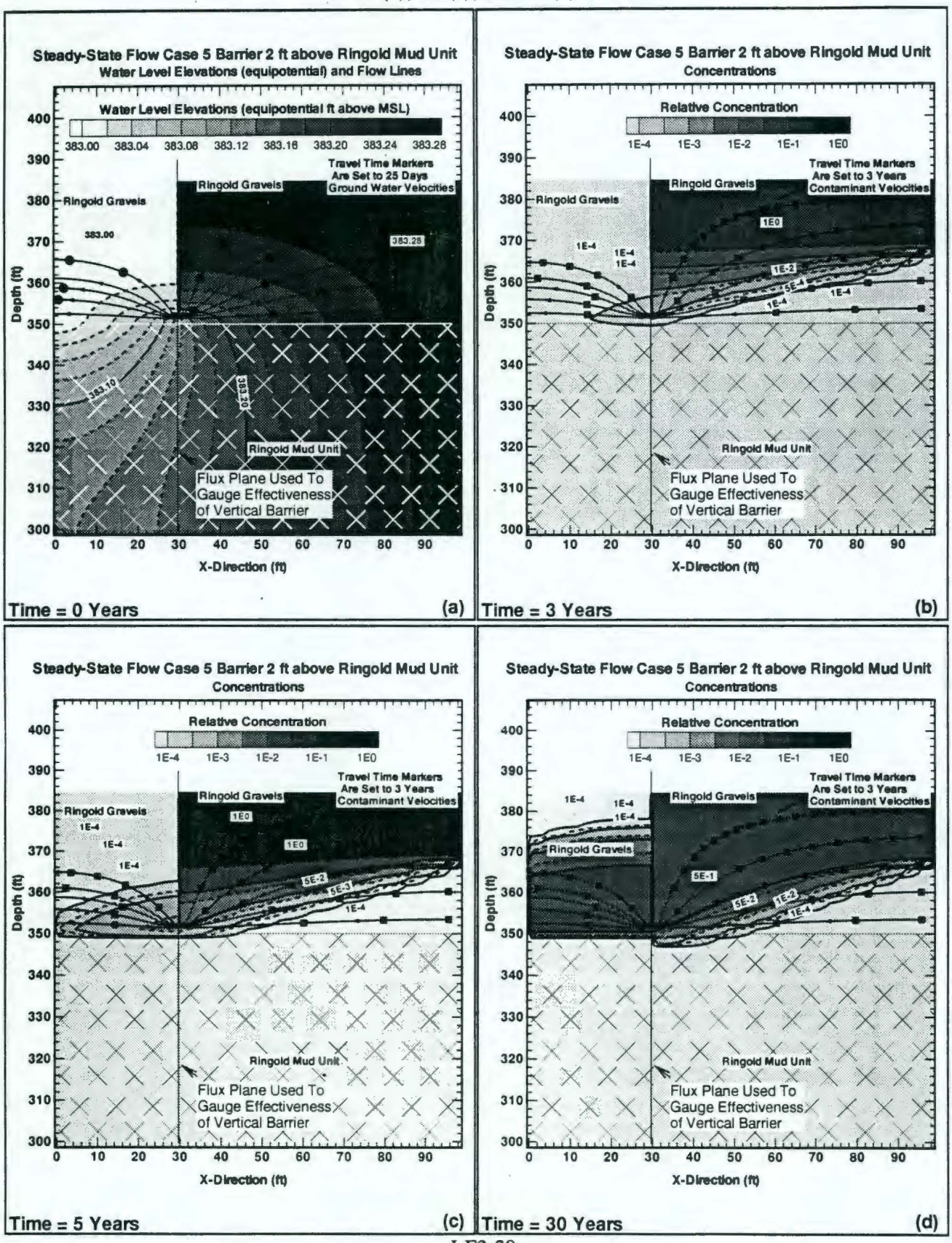
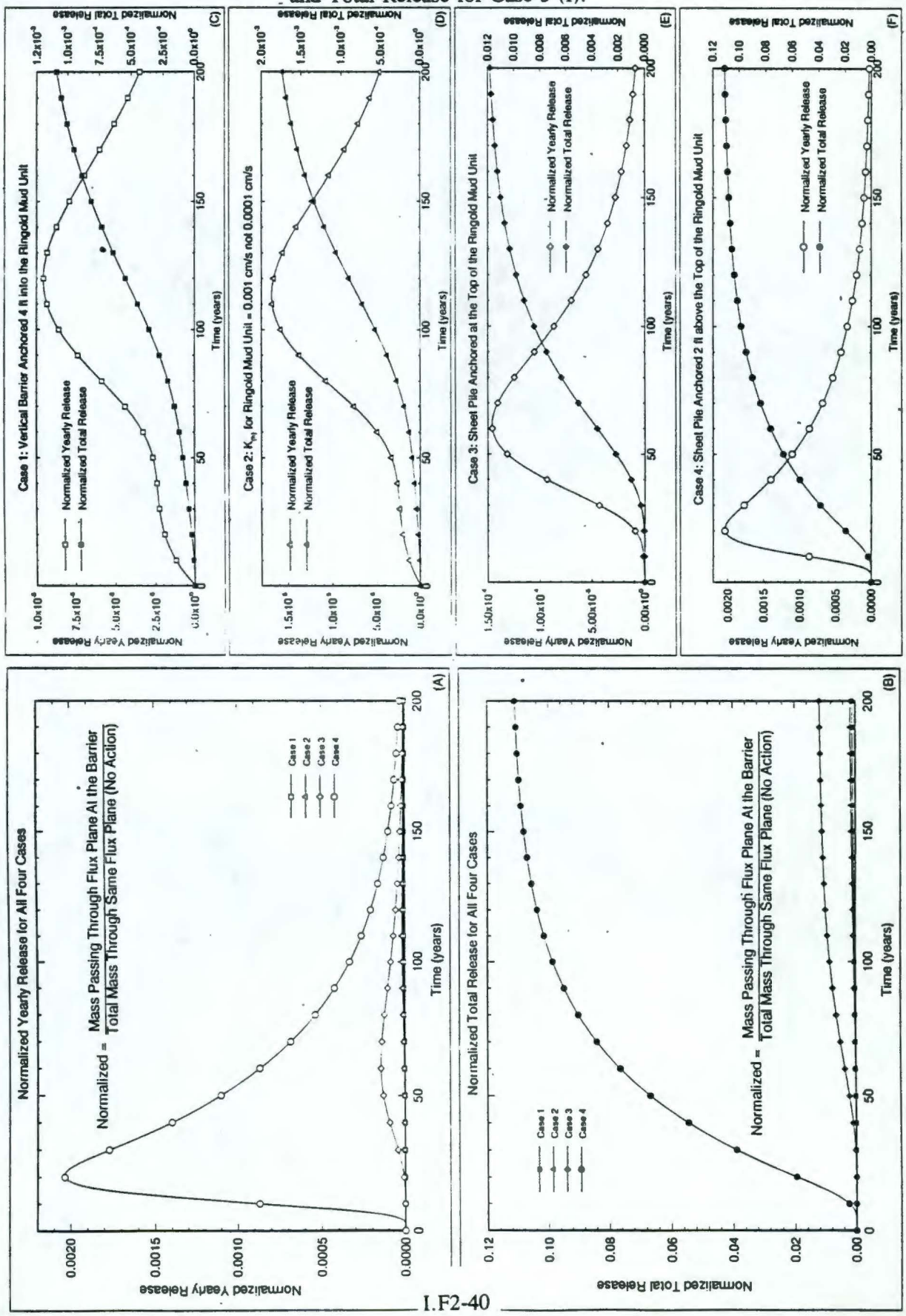


Figure 2-40. Release Comparison for Cases 2 - 5 Against Case 1. Yearly Release for Cases 2 - 5 (a); Total Release for Cases 2 - 5 (b); Yearly and Total Release for Case 2 (c); Yearly and Total Release for Case 3 (d); Yearly and Total Release for Case 4 (e); Yearly and Total Release for Case 5 (f).



3.0 Conclusions and Recommendations

The results presented in this document demonstrate that the vertical barrier will reduce the flux of ^{90}Sr to the Columbia River by extending the travel path for ^{90}Sr to the river and lowering the hydraulic gradient in the area of highest concentration of ^{90}Sr. A pump-and-treat system located behind the wall will not significantly improve the performance of the wall. These wells are located in the highest concentrations of ^{90}Sr in order to remove ^{90}Sr from the aquifer and to test treatment technologies.

Although several attempts were made to analyze the release of ^{90}Sr from between the river and the barrier, it was not successful. The mass of ^{90}Sr located here is estimated to be between 2.5 and 6 Ci. However, 99% of ^{90}Sr is adsorbed onto the sediments with only 1% dissolved in the ground water. The release of this mass is dependent upon how the constant flushing of the Columbia River causes strontium to be desorbed from these sediments. This is unknown at this time. To minimize the release of ^{90}Sr located between the river and barrier, the barrier should be located as close to the river as possible.

The exact location of the barrier with respect to the ^{90}Sr plume could be further refined, but to do so requires the collection of additional hydrologic data. In all plan-view models the ^{90}Sr was released from the upstream side of the barrier before the downstream side. This suggests that the barrier location should be moved upstream (to the southwest). However, Gilmore (1992) postulated that there was a zone of low hydraulic conductivity to the southwest (wells 199-N-3, 199-N-20, 199-N-23, and 199-N-25). However, until additional data are collected and modeling can be refined, the recommendation is that the wall-end locations be placed where assumed in the model.

The data that should be collected in a number of wells are hourly water level measurements, specific conductance, and water temperature. From these hourly measurements, flooded contour maps of the hourly measurements are prepared and then displayed sequentially, creating an animation of the interaction between the unconfined aquifer and the Columbia River. This data would provide the following information:

- Validate the model results
- Test for the presence of preferential pathways
- Provide information on relative hydraulic conductivities across the 100-N Area
- Provide a baseline to estimate the effectiveness of the barrier and pump and treat
- Further refine the location of the barrier and pump and injection wells
- Provide estimates on the amount of river/aquifer mixing.

The automated data loggers that can collect this data already exist onsite. The expense would be from removing the loggers from existing wells and installing them in wells within the 100-N Area. Once installed, their measurements are sent to a computer in the 2440 Stevens Building and are available immediately.

Additional modeling should be done once this data becomes available to refine the placement of barrier and pumping-and-injection wells.

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PART II:

WELL USABILITY TESTING RESULTS FOR WELLS 199-N-3, 199-N-14, AND 199-N-75 IN THE 100-N AREA

CONTENTS

Part II. Well Usability Testing Results for Wells 199-N-3, 199-N-14, and 199-N-75 in the 100-N Area.

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3. Well Construction and Completion Summary, Well 199-N-14 . . . . . FII.3

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PART II. WELL USABILITY TESTING RESULTS FOR WELLS 199-N-3, 199-N-14, AND 199-N-75 IN THE 100 N AREA

1.0 Introduction

Part II of this document presents results of hydraulic testing at three wells in the 100-N Springs area. These test wells, 199-N-3 (N-3), 199-N-75 (N-75), and 199-N-14 (N-14), are located north of the 100 N reactor building between the 1301-N facility and the Columbia River (Figure 1). The objective of testing was to evaluate ^{90}Sr concentrations in response to pumping (Tri-Party Agreement Milestone M-16-12C) and to estimate groundwater production from candidate extraction wells for a pilot-scale pump-and-treat test. Wells N-3, N-75, and N-14 were selected because they are located within the 1000 ρci/L or higher ^{90}Sr isopleth and contained sufficient depth of water to install a pump. The wells were tested on June 13, June 15, and July 26, 1994, respectively.

2.0 Procedure and Results

Hydraulic testing consisted of placing a 1.5 hp electric submersible pump in the well to estimate production capacity. Testing was complete when the water level in the well stabilized at the highest pump rate possible at a constant head or when water disposal facilities had been filled. Because the three test wells were not designed to be extraction wells, caution must be exercised to interpolate production for a long-term pump-and-treat project.

The objective of testing was to estimate production in gallons per minute (gal/min) for each well. Analysis was simply discharge rate (gal/min) at stable drawdown divided by the total drawdown (ft) to calculate specific capacity (gal/min/ft). Estimated production (gal/min) was determined by specific capacity multiplied by 50% of the saturated screen length (ft) multiplied by a conservative factor of 80%. Table 1 shows the formula used and calculated values for each well.

Transducers were installed in the well during pumping for drawdown measurements. Table 1 summarizes the drawdown and discharge rates and gives an estimated ground-water production rate.

Chemical sampling was conducted in all three wells to evaluate changes in ^{90}Sr concentration in response to pumping (Table 1). Additional sampling in wells N-3 and N-75 for major cations and major anions over time was conducted (Table 2) as well as an end-of-test sample for appendix 9 constituents. Sampling was conducted according to the following schedule:

Sample 1. As soon as the purge water clears the discharge pipe
Sample 2. 30 minutes into the test
Sample 3. 60 minutes into the test
Sample 4. 120 minutes into the test
Sample 5. 240 minutes into the test or at the end of the test
Sample 6. At the end of the test if a 240 minute sample was taken.

Because of the higher production rates of wells N-14 and N-75, the purge truck was filled to capacity before the 240-minute test could be completed. Well N-3, however, had a low production rate, allowing the 240-minute sample test to be taken.

2.1 Hydraulic Test Results

Estimated production in well N-3 is low at 5 gal/min and dropped with time of pumping. Low production may be attributed to well construction, plugged perforations, or formation characteristics. Type of testing did not yield conclusive evidence for low estimated production. Figure 2 is a well construction schematic. The saturated interval was the longest of all wells tested but had the lowest estimated production of 5 gal/min.

Estimated production in well N-14 is 26.4 gal/min, almost five times the well production at well N-3. Well construction shown on Figure 3 is similar to that of well N-3. Specific capacity was the highest of the three wells tested at 5.62 gal/min/ft. The saturated perforated interval is very short at 4.7 ft, indicating that the well would probably produce at a higher rate if more water was standing in the well.

Well N-75 had the highest estimated production at 26.9 gal/min. This well was built to *Resource Conservation and Recovery* (RCRA) standards with wire wrap stainless steel screen (Figure 4). Specific capacity in well N-75 is 3.54 gal/min/ft, which is considerably less than in well N-14.

2.2 Chemical Results

Strontium and tritium did not vary with pumping time. Wells N-75 and N-14 had similarly higher levels of both constituents compared with well N-3. The only volatile organic constituents of significance were methylene chloride at 1 ppb in both wells and chloroform at 3 ppb and 5 ppb in wells N-3 and N-75, respectively. Well N-14 was sampled only for unfiltered tritium and filtered and unfiltered strontium because most major anions and cations in the well N-3 and N-75 analyses were less than primary and secondary drinking water standards. Only iron exceeded drinking water standards, and this can be attributed to well construction materials. Table 1 gives time of sampling during pumping as well as results of tritium and ^{90}Sr analyses with time in the three wells tested. Table 2 summarizes the results of major cation and major anion analyses for wells N-3 and N-75.

3.0 Conclusion of Tests

The objectives of testing in wells N-3, N-14 and N-75 were met. Results of testing indicate that ^{90}Sr does not vary with time of pumping for the short-term duration of the testing. Reported values of groundwater production should be viewed as estimates and not necessarily as indicators of sustained long-term pumping. Wells N-14 and N-75 had the highest production (26.4 and 26.9 gal/min) on the day of the testing. Well N-3 had the lowest rate of production (5.0 gal/min). Reasons for the low rate of production were not conclusive based on the type of testing performed.

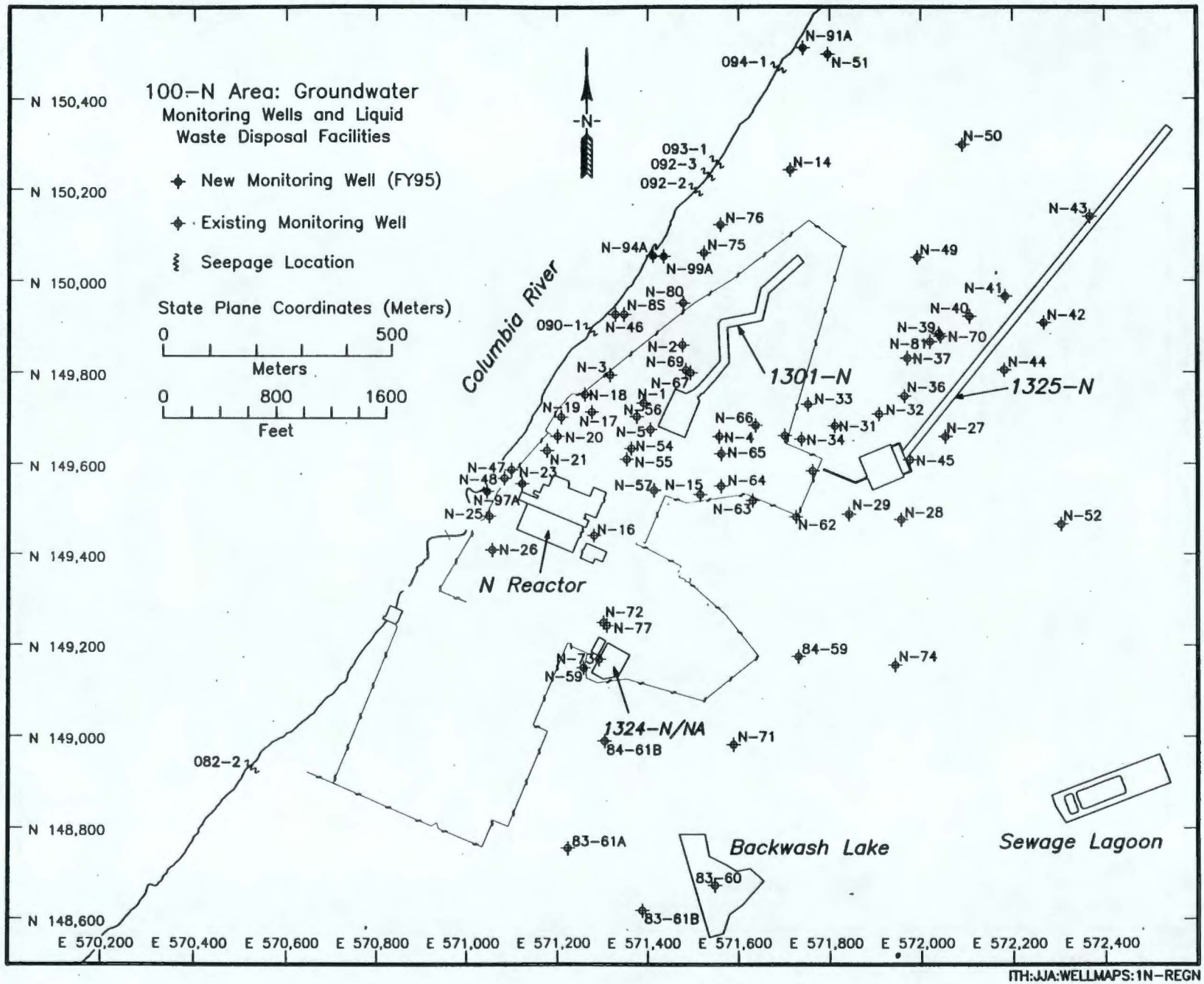


Figure 1. Monitoring Well Locations.

9513334.0624

Figure 2. Well Construction and Completion Summary, Well 199-N-3.

WELL CONSTRUCTION AND COMPLETION SUMMARY

Drilling Method: Cable tool
Drilling Fluid Used: Water
Driller's Name: Shafer
Drilling Company: Bach Dilling Co.
Date Started: 02Jun64

Sample Method: Hard tool (nom)
Additives Used: Not documented
WA State Lic Nr: Not documented
Company Location: Not documented
Date Complete: 12Jun64

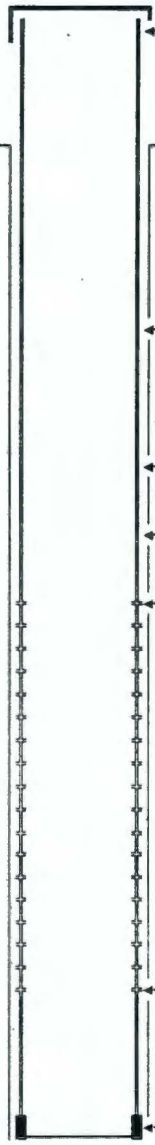
WELL NUMBER: 199-N-3
TEMPORARY WELL NO:
Hanford Coordinates: N/S N 86,365 E/W W 60,828
State Coordinates: N 491,511 E 2,234,277
Start Card #: Not documented T R S
Elevation Ground surface (ft): 457.8 Estimated

Depth to water: 63.0-ft Jun64
(Ground surface) 74.4-ft 18Mar93

GENERALIZED STRATIGRAPHY Driller's Log

0-11: BOULDERS and DUST
11-15: BOULDERS and SAND
15-17: BOULDER, SAND and DUST
17-20: COBBLES and SAND
20-21: BOULDERS and SAND
21-22: BOULDERS and GRAVEL
22-63: SAND and GRAVEL
63-68: SAND
68-74: SAND and GRAVEL
74-76: SAND
76-98: SAND and GRAVEL
98-104: SAND
104-106: SAND and GRAVEL
106-125: Not documented

REMEDIATION:
Removal of piezometers and probable setting of plug not documented.



Elevation of reference point: [459.45-ft] (top of casing)
Height of reference point above ground surface [1.7-ft]
Depth of surface seal [ND]
Type of surface seal: None documented
I.D. of surface casing (If present) [ND]
I.D. of riser pipe: [8-in]
Type of riser pipe: Carbon steel
Diameter of borehole: [9-in nom]
Type of filler: None documented
Elevation/depth top of seal
Type of seal: None documented
Depth top of perforations: [34-ft]
Description of perforations: Not documented
Depth bottom of perforations: [95-ft]
Depth bottom of casing: [125-ft]
Depth bottom of borehole: [125-ft]

Drawing By: RKL/1-N-03.ASB Date: 07Apr93
Reference: HANFORD WELLS

Figure 3. Well Construction and Completion Summary, Well 199-N-14.

WELL CONSTRUCTION AND COMPLETION SUMMARY

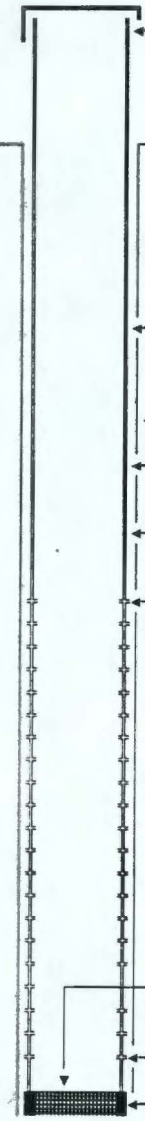
Drilling Method: Cable tool	Sample Method: Hard tool (nom)
Drilling Fluid Used: Water	Additives Used: Not documented
Driller's Name: Rodda	WA State Lic Nr: Not documented
Drilling Company: Bach Dilling Co.	Company Location: Not documented
Date Started: 27Apr69	Date Complete: 13May69

WELL NUMBER: 199-N-14	TEMPORARY WELL NO:
Hanford Coordinates: N/S N 87,834	E/W W 59,535
State Coordinates: N 492,983	E 2,235,565
Start Card #: Not documented	T R S
Elevation Ground surface (ft): 443.2 EStimated	

Depth to water: 51.0-ft May69
(Ground surface) 68.1-ft 18Mar93

GENERALIZED STRATIGRAPHY — Driller's Log

0↔20: SAND, GRAVEL and COBBLES
20↔48: SAND and GRAVEL
48↔50: SAND
50↔80: SAND and GRAVEL



- Elevation of reference point: [445.70-ft] (top of casing)
- Height of reference point above ground surface [2.5-ft]
- Depth of surface seal [ND]
  Type of surface seal: None documented
- I.D. of surface casing (If present) [ND]
- I.D. of riser pipe: [6-in]
  Type of riser pipe: Carbon steel
- Diameter of borehole: [7-in nom]
- Type of filler: None documented
- Elevation/depth top of seal
  Type of seal: None documented
- Depth top of perforations: [45-ft]
  Description of perforations:
  45↔59-ft, 1 cut/rd/ft
  60↔78-ft, 2 cuts/rd/ft
- Depth to bottom, 79.6-ft, 10Aug92
- Cement plug documented @ ~78-ft
- Depth bottom of perforations: [78-ft]
- Depth bottom of casing: [80-ft]
- Depth bottom of borehole: [80-ft]

Drawing By: RKL/1-N-14.ASB Date: 07Apr93

Reference: HANFORD WELLS

Figure 4. Well Construction and Completion Summary, Well 199-N-75.

WELL CONSTRUCTION AND COMPLETION SUMMARY

Drilling Method: Cable tool
Drilling Fluid Used: None
Driller's Name: L. Watkins
Drilling Company: Kaiser Engineers
Date Started: 13Apr92

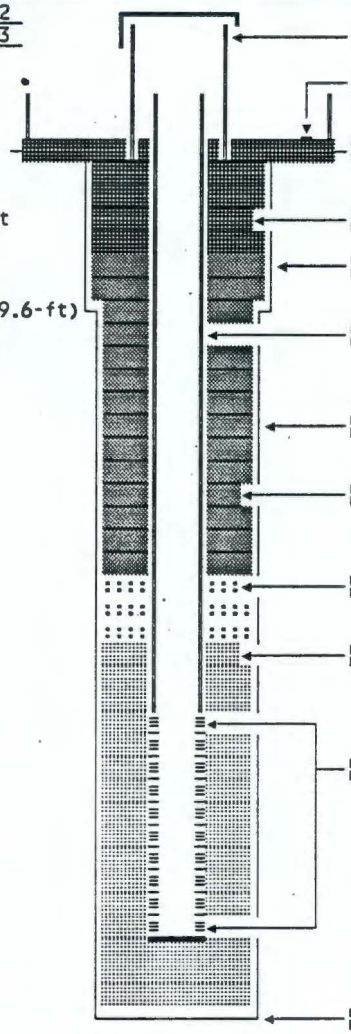
Sample Method: Drive barrel
Additives Used: None
WA State Lic Nr: Not documented
Company Location: Hanford
Date Complete: 06May92

WELL NUMBER: 199-N-75
TEMPORARY WELL NO:
Hanford 100N Coordinates: N/S N 87,235.4 (N 8,266.0) E/W W 60,149.7 (W 6,214.4)
State NAD83 Coordinates: N 150,060.72m E 571,523.58m
N 492,383 E 2,234,952
Start Card #: Not documented T___ R___ S___
Elevation Ground surface (ft): 453.64 (Brass cap)

Depth to water: 68.3-ft 06May92
(Ground surface)68.5-ft 17Jun93

GENERALIZED STRATIGRAPHY Log
Geologist's
Sl=slightly

0↔35: Silty sandy GRAVEL
35↔44: Sandy GRAVEL
(Hanford/Ringold E contact @ 44-ft)
44↔49: Gravelly SAND
49↔70: Sandy GRAVEL
(Rad contamination, 50↔89.6-ft)
70↔73: Gravelly SAND
(SILT/CLAY lens @ 71-ft)
73↔89.6: Sandy GRAVEL



Elevation of reference point: [456.78-ft] (top of casing)
Height of reference point above ground surface [3.14-ft]
Depth of surface seal [+0.5↔9.5-ft]
Type of surface seal: 4x4-ft x 6-in concrete surface pad
Cement grout, 0.0↔9.5-ft
Hole diameter, 13-in nominal, 0.0↔20.0-ft
Riser pipe, 4-in T304 stainless steel, +1.1↔64.4-ft
Hole diameter, 11-in nominal, 20.0↔89.6-ft
8↔20-mesh bentonite crumbles annular seal, 9.5↔54.9-ft
⅜-in bentonite pellet plug, 54.9↔59.1-ft
20↔40-mesh silica sand pack, 59.1↔89.5-ft
4-in continous wrap, T304 stainless steel screen, #10-slot, 64.4↔84.8-ft
Depth to bottom of borehole: [89.6-ft]

Drawing By: RKL/1-N-75.ASB
Date : 13Jul93
Reference : WHC-SD-EN-DP-056

Table 1. Summary of the Well Usability Testing.

N-75 SWL = 69.57	Date and Time of Sampling 14-Jun-90	Tritium Unfiltered ρCi/L	Strontium Filtered ρCi/L	Strontium Unfiltered ρCi/L	Pumping Discharge gal/min	14-Jun-90 Start 1050 Drawdown (ft)
Sample 1	1055	71300	1080	1060	14	3.3
Sample 2	1125	72700	1130	1170	19.5	5.1
Sample 3	1155	70500	1070	1090	19.5	5.3
Sample 4	1225	72000	1060	1050	19.5	5.5
Sample 5	1255	70500	1050	1060	19.5	5.5
N-3 SWL = 72.40	12-Jun-90	Tritium Unfiltered ρCi/L	Strontium Filtered ρCi/L	Strontium Unfiltered ρCi/L	Pumping Discharge gal/min	12-Jun-90 Start 1031 Drawdown (ft)
Sample 1	1032	16500	406	368	14	12
Restart 1041	1041				14	12
Sample 2	1111	17400	682	675	10	15
Sample 3	1141	17200	674	678	10	15
Sample 4	1241	17100	701	714	9	20
Sample 5	1441	18000	739	719	9	20.3
Sample 6	1541	17700	726	746	9	20.3
N-14 SWL = 68.54	25-Jul-88	Tritium Unfiltered ρCi/L	Strontium Filtered ρCi/L	Strontium Unfiltered ρCi/L	Pumping Discharge gal/min	25-Jul-88 Start 0812 Drawdown (ft)
Sample 1	812	65700	1080	1080	20.8	0.022
Sample 2	842	65100	1120	1120	20.8	3.6
Pump shut down for 1 minute, groundwater fully recovered						
Sample 3	912	68800	1080	1040	20.8	3.7
Sample 4	1016	64800	1110	1110	20.8	3.7
Sample 5	1034	65200	1100	1150	20.8	3.7

Well Parameters	199-N-75	199-N-3	199-N-14
Total Drawdown (feet)	5.51	20.3	3.7
Discharge Rate (gal/min)	19.5	9	20.8
Specific Capacity (gal/min/ft)	3.54	0.44	5.62
50% of Screen (feet)	7.6	11.3	4.7
Estimated Production (gal/min)	26.9	5.0	6.4

Notes: Specific capacity = Discharge rate/Total drawdown

Estimated production = 80% x specific capacity x 50% of screen

Table 2. Major Cations and Anions. (2 sheets)

9/27/94 MAJOR CATIONS AND ANIONS Page 1

ANION

Well	Collect Date	Constituent Name	Units	1032 HRS [1]	1111 HRS [1]	1141 HRS [1]	1241 HRS [1]	1441 HRS [1]	1541 HRS [1]	MDL	DWS [2]
199-N-3	6/13/94	Aluminum	ppb	620	410	260	110	48	28	19.00	50 EPA
199-N-3	6/13/94	Aluminum, filtered	ppb	ND	ND	ND	ND	ND	ND	19.00	50 EPA
199-N-3	6/13/94	Calcium	ppb	110000	120000	120000	120000	120000	120000	47.00	NA
199-N-3	6/13/94	Calcium, filtered	ppb	110000	120000	120000	120000	120000	120000	47.00	NA
199-N-3	6/13/94	Chloride	ppb	14000	14000	14000	15000	16000	16000	71.00	250,000 EPAS
199-N-3	6/13/94	Copper	ppb	8.7	14	8.7	3.1	ND	3.1	2.60	1,000 EPAS
199-N-3	6/13/94	Copper, filtered	ppb	ND	ND	ND	ND	ND	ND	2.60	1,000 EPAS
199-N-3	6/13/94	Fluoride	ppb	600	600	700	700	600	700	51.00	4,000 EPA
199-N-3	6/13/94	Iron	ppb	19000	3000	3800	1900	860	400	18.00	300 EPAS
199-N-3	6/13/94	Iron, filtered	ppb	29	51	51	56	21	38	18.00	300 EPAS
199-N-3	6/13/94	Lead	ppb	40	2.6	2	1.7	1.5	ND	.86	50 EPA
199-N-3	6/13/94	Lead, filtered	ppb	ND	ND	ND	.6	ND	ND	.86	50 EPA
199-N-3	6/13/94	Magnesium	ppb	19000	20000	20000	20000	20000	20000	25.00	NA
199-N-3	6/13/94	Magnesium, filtered	ppb	20000	19000	19000	20000	20000	20000	25.00	NA
199-N-3	6/13/94	Manganese	ppb	730	83	160	56	28	11	1.00	50 EPAS
199-N-3	6/13/94	Manganese, filtered	ppb	29	2.6	2.6	1.3	1.5	1.2	1.00	50 EPAS
199-N-3	6/13/94	Nitrate	ppb	15000	22000	25000	27000	29000	30000	96.00	40,000 EPA
199-N-3	6/13/94	Potassium	ppb	4300	3900	3700	3608	3800	3900	890.00	NA
199-N-3	6/13/94	Potassium, filtered	ppb	4000	3300	3800	3400	3900	4000	890.00	NA
199-N-3	6/13/94	Sodium	ppb	17000	15000	15000	14000	14000	14000	150.00	NA
199-N-3	6/13/94	Sodium, filtered	ppb	17000	14000	14000	15000	14000	14000	150.00	NA
199-N-3	6/13/94	Sulfate	ppb	220000	220000	200000	210000	190000	200000	89.00	250,000 EPAS
199-N-3	6/13/94	Sulfide	ppb	ND	ND	ND	ND	300	300	200.00	NA
199-N-3	6/13/94	Zinc	ppb	2400	48	48	25	16	14	4.40	5,000 WDOE
199-N-3	6/13/94	Zinc, filtered	ppb	130	26	20	17	13	15	4.40	5,000 WDOE

1
ND = not detected

2
DWS = Drinking Water Standard
EPA = National Primary Drinking Water regulations 40 CFR Part 141
EPAS = National Secondary Drinking Water regulations 40 CFR Part 143
WDOE = Public Water Supplies WAC 284-54
NA = none available
MDL = Method Detection Limit

Table 2. Major Cations and Anions. (2 sheets)

9/27/94 MAJOR CATIONS AND ANIONS Page 1

ANION

Well	Collect Date	Constituent Name	Units	1055 HRS [1]	1125 HRS [1]	1155 HRS [1]	1255 HRS [1]	1325 HRS [1]	MDL	DWS [2]
199-N-75	6/15/94	Aluminum	ppb	110	ND	ND	ND	ND	19.00	50 EPA
199-N-75	6/15/94	Aluminum, filtered	ppb	ND	ND	350	24	ND	19.00	50 EPA
199-N-75	6/15/94	Calcium	ppb	27000	26000	27000	27000	26000	47.00	NA
199-N-75	6/15/94	Calcium, filtered	ppb	26000	27000	27000	27000	27000	47.00	NA
199-N-75	6/15/94	Chloride	ppb	1300	1400	1400	1400	1400	71.00	250,000 EPAS
199-N-75	6/15/94	Copper	ppb	ND	3.7	ND	ND	ND	2.60	1,000 EPAS
199-N-75	6/15/94	Copper, filtered	ppb	ND	ND	27	5.6	ND	2.60	1,000 EPAS
199-N-75	6/15/94	Fluoride	ppb	300	400	400	400	400	51.00	4,000 EPA
199-N-75	6/15/94	Iron	ppb	310	64	33	45	28	18.00	300 EPAS
199-N-75	6/15/94	Iron, filtered	ppb	29	22	610	21	25	18.00	300 EPAS
199-N-75	6/15/94	Lead	ppb	.72	1.4	ND	ND	ND	.86	50 EPA
199-N-75	6/15/94	Lead, filtered	ppb	ND	ND	ND	ND	ND	.86	50 EPA
199-N-75	6/15/94	Magnesium	ppb	4200	4200	4200	4200	4200	25.00	NA
199-N-75	6/15/94	Magnesium, filtered	ppb	4000	4300	4300	4300	4300	25.00	NA
199-N-75	6/15/94	Manganese	ppb	7.6	1.1	ND	ND	ND	1.00	50 EPAS
199-N-75	6/15/94	Manganese, filtered	ppb	ND	ND	5.9	ND	ND	1.00	50 EPAS
199-N-75	6/15/94	Nitrate	ppb	6900	7000	7700	7300	7400	96.00	40,000 EPA
199-N-75	6/15/94	Potassium	ppb	1800	1900	1600	1600	1900	890.00	NA
199-N-75	6/15/94	Potassium, filtered	ppb	1800	2000	1900	1600	1900	890.00	NA
199-N-75	6/15/94	Sodium	ppb	2600	2600	2700	2600	2500	150.00	NA
199-N-75	6/15/94	Sodium, filtered	ppb	2600	2700	2700	2700	2700	150.00	NA
199-N-75	6/15/94	Sulfate	ppb	13000	13000	13000	13000	13000	89.00	250,000 EPAS
199-N-75	6/15/94	Sulfide	ppb	200	ND	200	200	300	200.00	NA
199-N-75	6/15/94	Zinc, filtered	ppb	24	11	29	6.3	9.1	4.40	5,000 WDOE

1
ND = not detected

2
DWS = Drinking Water Standard
EPA = National Primary Drinking Water regulations 40 CFR Part 141
EPAS = National Secondary Drinking Water regulations 40 CFR Part 143
WDOE = Public Water Supplies WAC 284-54
NA = none available
MDL = Method Detection Limit

9513334.0628

APPENDIX A

HYDROGEOLOGY

1.0 HYDROGEOLOGY

The stratigraphy of the 100-N Area provides the framework for modeling groundwater flow. The size and position of the geologic units, (e.g. thickness, lateral extent, and variability), combine with the lithology of the units, (e.g. sediment size, mineralogy, and cementation) to determine ground water movement. The interaction of the site geochemistry with the contaminant chemistry determines whether contaminants will move along with ground water or be retarded.

The following sections summarize the geology and hydrology relevant to modeling groundwater flow and contaminant transport. Hartman (1994a) provides a general description of 100 Areas hydrogeology, and Hartman and Lindsey (1993) provide a more detailed description at 100-N Area.

1.0 Hydrogeologic Setting

The uppermost stratigraphic unit of significance in the 100-N Area is the Hanford formation. In the 100-N Area, this unit consists of uncemented, clast-supported pebble, cobble, and boulder gravel with minor sand and silt interbeds. The matrix in the gravel is composed mostly of coarse-grained sand, and an open-framework texture is common. The Hanford formation extends from the surface to just above the water table.

An erosional unconformity separates Hanford from the underlying Ringold Formation. The uppermost Ringold strata at 100-N is unit E, consisting of variably cemented pebble to cobble gravel with a fine- to coarse-grained sand matrix. Sand and silt interbeds also may be present. Unit E forms the unconfined aquifer in the 100-N Area. The base of the aquifer is situated at the contact between unit E and underlying, much less transmissive, silty strata referred to locally as the Ringold upper mud.

Figure A-1 is an index map for ground water monitoring wells. Figure A-2 is a cross section that shows the relationships between the geologic units underlying the 100-N Area, groundwater, and the Columbia River channel. Water table elevation data are from the Hanford Environmental Information System (HEIS). River channel bathymetry data are from an unpublished Corps of Engineers survey conducted in 1986.

Fluctuating river stage influences water level and water quality measurements in monitoring locations along the shoreline. During periods of rising river stage, a pressure pulse moves inland, raising water levels in wells many hundreds of feet inland. Fluctuating water levels in wells may also help to remobilize contamination held in the intermittently saturated sediments immediately above the water table. During high river stage, river water moves into the bank and either mixes or interlayers with ground water. During low river stage, this "bank storage" water drains back into the river and may be observed as springs along the riverbank. The zone of mixing or interlayering is restricted to within several hundred feet of the shoreline.

During the operating periods for the 1301-N and 1325-N facilities, a ground water mound was created as a result of the large volumes of liquid waste discharged. The disposal of the liquid waste moved the water table into more transmissive Hanford sediments, and the steeper gradients resulting from mounding increased ground water flow rate towards the river. During operation of the 1301-N and 1325-N facilities, riverbank seepage was more pronounced than it is today.

1.1 Groundwater Flow Direction and Rate

A regional water table map for March 1994 is shown in Figure A-3. Average ground water velocities are estimated to be between 0.1 to 2 ft/d in the vicinity of 1301-N and 1325-N facilities (Hartman 1993, p 3.2-3). The direction of ground-water flow is northerly turning northwesterly as it approaches the Columbia River. The ground-water gradient varies from 0.0005 to 0.003.

1.2 Strontium-90 Contamination in Groundwater

The highest concentration of ^{90}Sr in groundwater is located on the river side of the 1301-N facility and midway along its length. A second but smaller plume is centered on the 1325-N facility. Figure A-4 (Hartman and Lindsey 1993) shows the concentration of strontium in monitoring wells during February and March 1993. For this figure, the maximum ^{90}Sr concentration is 1580 ρCi/L at well 199-N-75. Strontium-90 is being transported by groundwater flow towards the river, but at a much slower rate than the water flow rate. The movement of strontium is slowed because of adsorption onto the sediments.

In addition to ^{90}Sr measurements in water samples from groundwater monitoring wells, samples are collected periodically along the shoreline to support an NPDES permit. Regular weekly analyses are made for samples from well 199-N-8T/199-N-46, which is the point of compliance for the permit. Samples are collected annually, during the fall seasonal low water, from 13 additional seepage wells, along with 199-N-8T/199-N-46. Data from this sampling program are available from the Westinghouse Hanford Company Environmental Surveillance Program; these data are not stored in HEIS. Annual reports describe the results of the program (Schmidt el al. 1992). The ^{90}Sr map given in Figure A-4 was recently updated, taking into account data from wells 199-N-8T/199-N-46 and 199-N-67. These wells have the highest concentration of ^{90}Sr, approximately 6,000 ρCi/L and 4,000 ρCi/L, respectively. This updated map is given in Figure A-5.

1.3 Aquifer Hydraulic Characteristics

The hydraulic characteristic of an aquifer is determined by properties such as porosity and hydraulic conductivity. Knowledge of these properties, along with hydraulic gradient, is used to determine ground water flow velocities and particle paths through an aquifer. Tests in both Hanford and Ringold sediments have been performed in the 100 Areas; a summary of results is presented in Hartman and Peterson (1992). These tests reveal a wide range of values for hydraulic characteristics, suggesting heterogeneous conditions in the aquifers.

Hydraulic conductivity data from aquifer tests conducted near the 1301-N and 1325-N facilities (Hartman 1991, Table 2-3) indicate values ranging from 100 to 500 ft/d, with an average value of 261 ft/d. These values are for the sandy gravel of Ringold unit E. All of these tests were conducted during operation of the LWDF's with the water table 20 ft higher than it is today. The effective porosity of these sediments is also highly variable, ranging from 0.1 to 0.3. The variability in hydraulic properties displayed by sandy gravel of Ringold unit E is related to lithologic properties as grain size range and cementation.

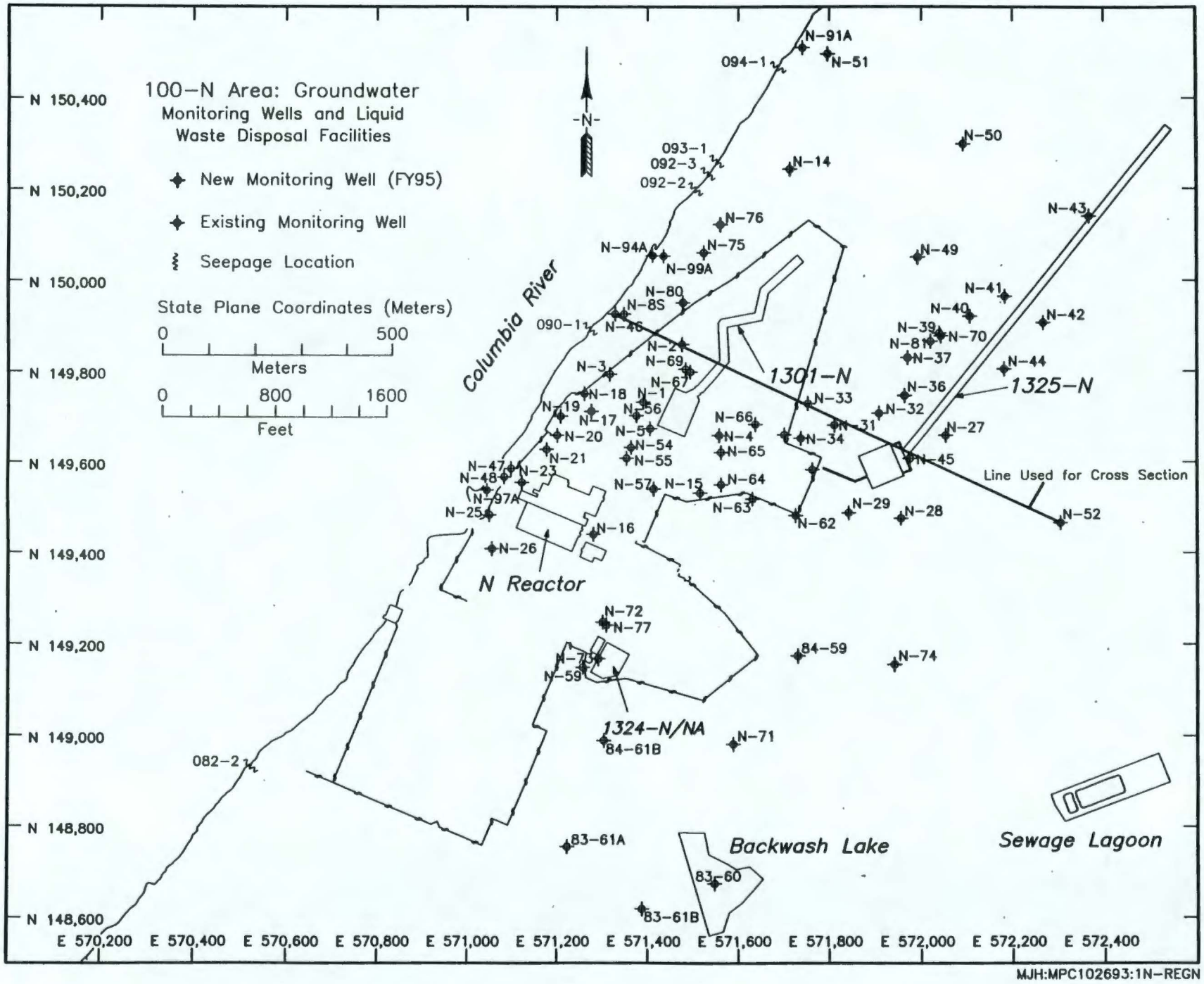


Figure A-1. Monitoring Well Locations.

9513334.0630

Figure A-2. Cross Section Through the 100-N Area. (sheet 1)

EXPLANATION

formation contact

unit or member contact

Representative water table and river stage, June 1993 to June 1994

BF backfill

HUCB Hanford formation, upper cobble/boulder zone

HM Hanford formation, middle pebble/cobble gravels

RE Ringold Formation, unit E

RUM Ringold Formation, upper muds

Lithologic Symbols

backfill

cobble/boulder-rich gravels

pebble/cobble-rich gravels

gravelly sand

sand with minor gravel

sand

sandy silt/clay

silt/clay

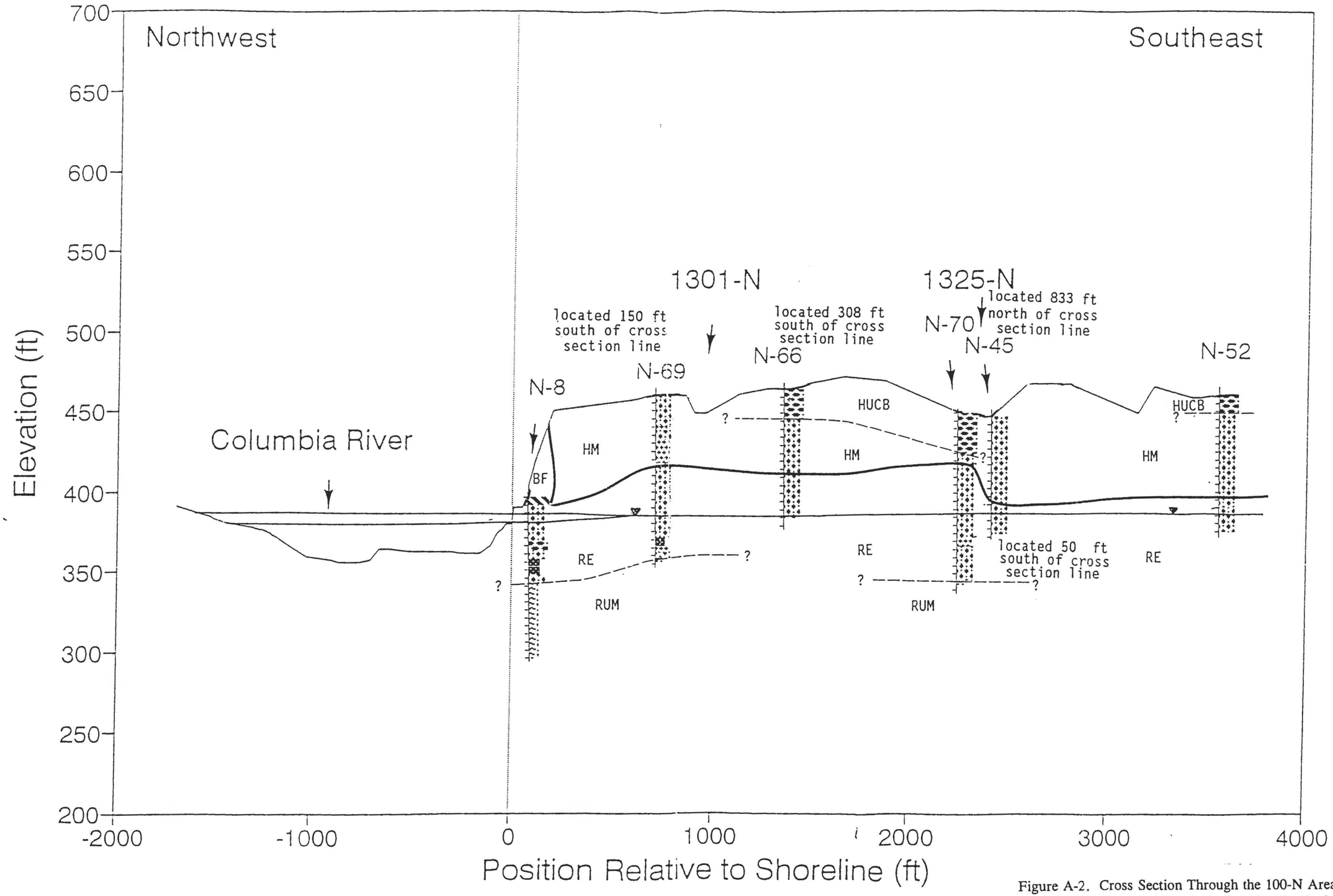


Figure A-2. Cross Section Through the 100-N Area. (sheet 1)
(The 0 line is the approximate location for the barrier.)

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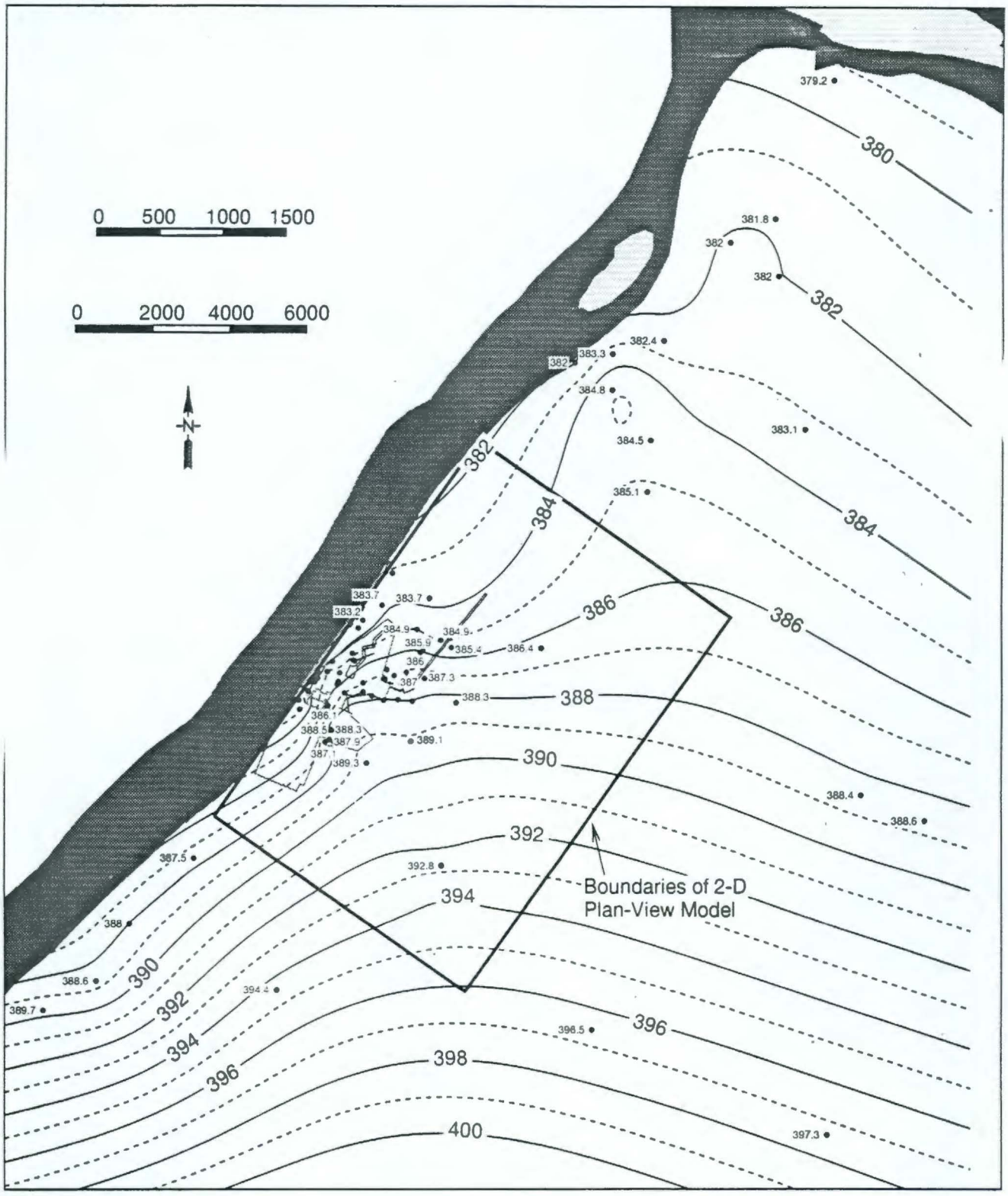
Figure A-3. Regional Water Table Map.



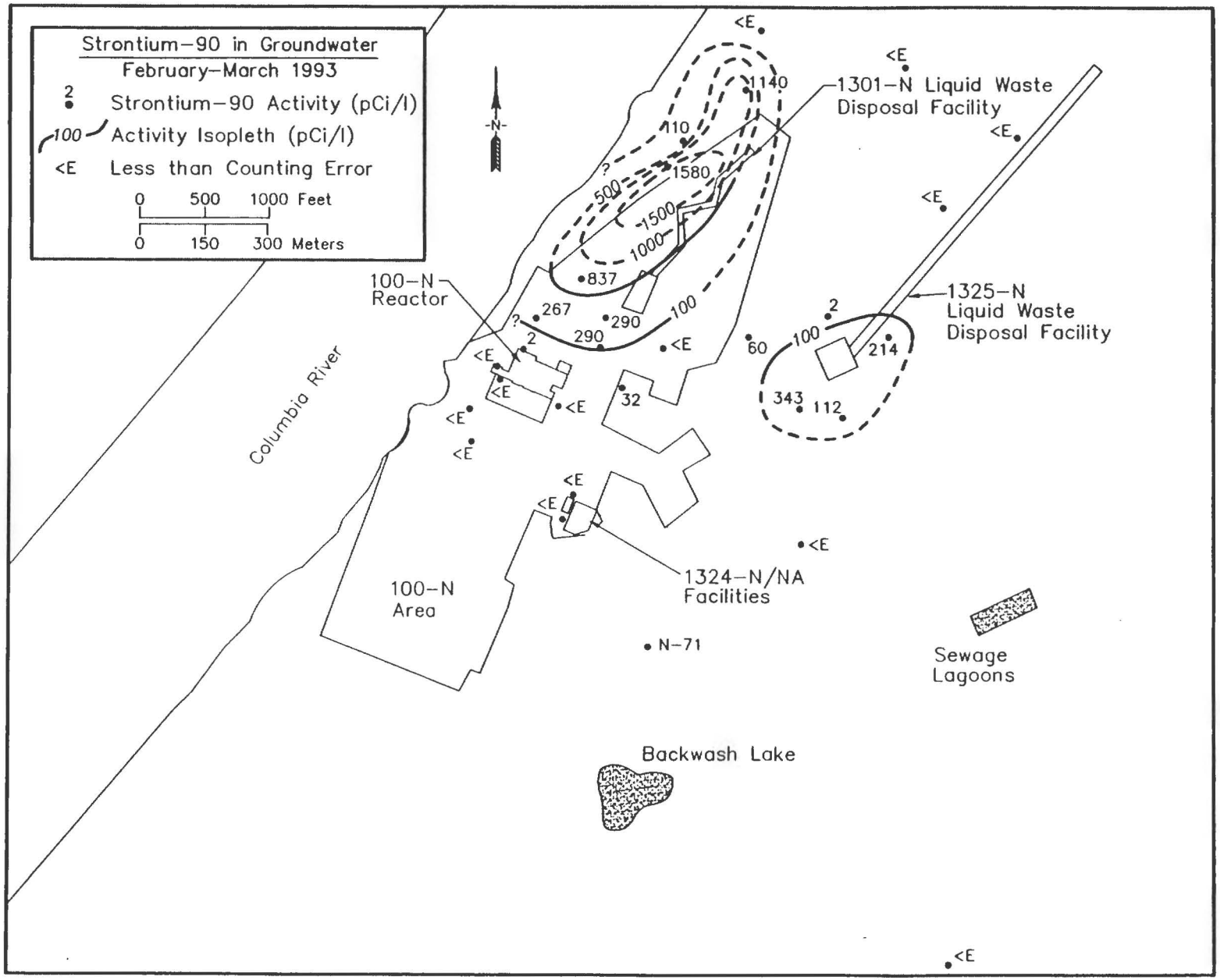


Figure A-4. 1993 Strontium-90 Plume Map. (Hartman and Lindsey 1993)

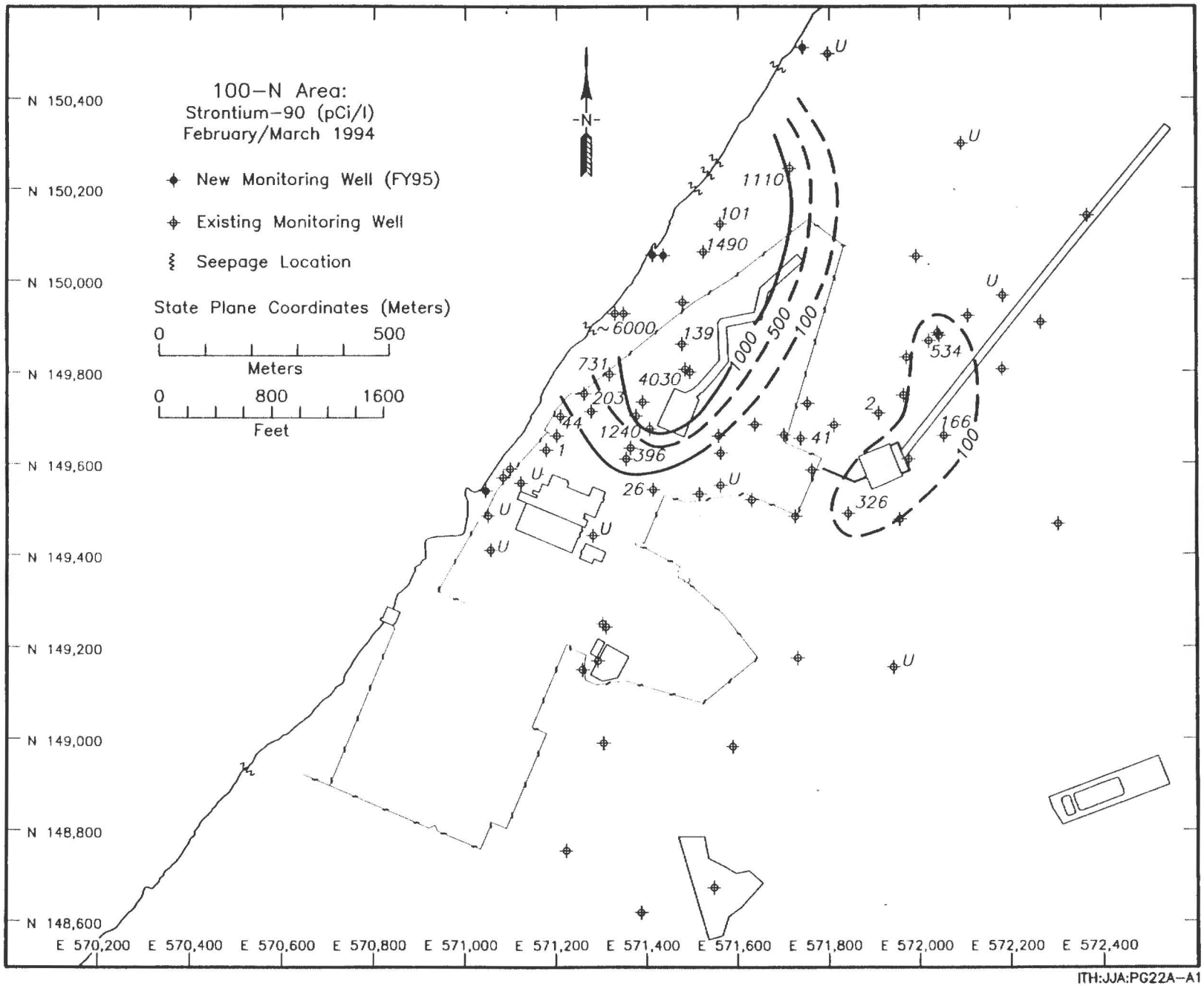


Figure A-5. Updated Strontium-90 Plume Map with Wells 199-N-8T/199-N-46 and 199-N-67 Added.

APPENDIX B

NUMERICAL MODELING

1.0 CONCEPTUAL MODELS

1.1 Two-Dimensional Plan-View Model

The plan-view model used the Two-dimensional finite difference ground-water flow model FLOWPATH version 3.06 developed by Waterloo Hydrogeologic Software (Franz and Guiguer, 1992). The area model extends 12,000 ft along the Columbia River and 8000 ft inland (Figure B-1). These are steady-state analyses. The cases modeled are:

- Existing conditions (no-action)
- 3,800-ft wall with extraction/injection wells at 50, 100, 180 gal/min
- 3,800-ft wall
- 3,000-ft wall with extraction/injection wells at 100 gal/min
- 3,000-ft wall with extraction/injection wells at 50 gal/min
- 3,000-ft wall
- 2,000-ft wall with extraction/injection wells at 100 gal/min
- 2,000-ft wall with extraction/injection wells at 50 gal/min
- 2,000-ft wall
- Effect of 10-ft gap in center of 3,800-ft walls
- 3,800 ft wall with boundaries moved further away from the wall

Figure 1-1 shows the conceptual model with location of the vertical barriers, and pumping-and-injection wells together with ^{90}Sr concentrations in groundwater. An example of a numerical model grid showing the level of discretization is shown in Figure B-2 for the 3,800-ft barriers with 180 gal/min extraction/injection system.

1.2 Two-Dimensional Cross-Sectional Model

The cross-sectional model used the finite difference ground-water flow and contaminant transport code PORFLOW v2.39 by Analytic and Computational Research, Inc (Runchal and Sagar 1993). This analysis is a two-dimensional slice 100 ft by 100 ft, orthogonal to the river and through the center of the plume by the river. This model first calculated the steady-state ground-water flow velocities and then used those velocities to simulate contaminant transport for 200 years. The cases modeled are:

- Existing conditions (no-action)
- Vertical barrier anchored 4 ft into the Ringold silt
- Horizonal hydraulic conductivity for Ringold silt order of magnitude Higher than previous case
- Vertical barrier anchored at the top of the Ringold silt
- Vertical barrier anchored 2 ft above the of the Ringold silt.

Each of these cases examined the movement of ^{90}Sr from the upgradient side of the wall to the river.

Figures 1-2a and 1-2b are diagrammatic depictions of this conceptual model showing the numerical grid, boundary conditions, initial conditions, and the location of the wall for both the flow equation (a) and transport equation (b).

The mass of ^{90}Sr from between the river and vertical barrier is estimated to be between 2.5 and 6 ci dissolved in the ground water and absorbed on the soil. Several attempts were made to examine the release of ^{90}Sr from between the river and the vertical barrier. For these attempts, the model simulated both ground-water flow and contaminant transport in a transient mode. However, the code was not able to maintain mass balance and this case was therefore dropped from the analysis.

1.3 Modeling Assumptions and Methodology

1.3.1 2-D Plan View Model

The principal assumptions used in the modeling are:

- Homogenous and isotropic medium
- Strontium-90 moves at 1/100 the velocity of ground water
- Dispersion and diffusion set to 0
- Instantaneous chemical equilibria between mineral grains & water
- Stream tube analysis assumes no vertical flow
- Deterministic method for assigning material properties
- The modified map (Hartman and Lindsey 1992) ^{90}Sr concentrations are representative of the plume shape and size
- Location of pumping wells in area of highest ^{90}Sr concentration
- Aquifer is contaminated throughout its depth
- The barrier behaves as a no-flux boundary. No leakage through barrier occurs.

1.3.2 2-D Cross-Section View

The principal assumptions used in the modeling are:

- No transverse flow (i.e. flow is forced under the barrier)
- Strontium-90 moves at 1/100 the velocity of ground water
- Advective contaminant transport dominants (dispersion set to 0)
- Deterministic method for assigning material properties
- Only the upper 20 ft of the aquifer is contaminated
- The hydraulic conductivity of the barrier is 2.8E-5 ft/day. This conductivity made the sheet pile behave as a no-flux plane within the model.

1.4 Boundary Conditions and Initial Conditions

The daily changes in river stages of the Columbia River presents a unique challenge for all models in the 100-N Area. The Priest Rapids Dam, directly upstream of the 100-N area, is a peaking power facility. This causes large fluctuations in the river level on a daily basis. These fluctuations can be as much as 8 ft in a single day. At the Hanford Site, these fluctuations are observed in the unconfined aquifer hundreds of feet inland of the river. Although the main purpose of the vertical barrier is to extend the travel path for ^{90}Sr, it also dampens these diurnal fluctuations behind it, thereby allowing the steady-state flow assumption behind the barrier to hold.

To model the pump-and-injection properly without the vertical barrier would require modeling the Columbia River boundary with the diurnal fluctuations. Previous modeling efforts at N-Springs (Connelly 1990) assumed seasonal variation, not daily variations. In August 1993, digital hourly river stage information (Figure B-3) became available when an automated river stage recorder was installed at 100-N Area. Once the hourly data became available, using only seasonal river level variations for the Columbia River boundary was no longer considered appropriate.

1.4.1 Plan View Model

See Figure 1-1 for the boundary conditions. The boundary conditions for the two-dimensional plan view model were calculated by the following method. A water table map (Figure A-3) for the 100-N Area was prepared by contouring the March 1994 water level measurements in the 100-N and adjoining 600 Area wells. The boundaries not adjoining the river were interpolated from this map. Averaging the 100-N hourly river level measurements over the length of time the automated data logger has been operation (10 months) provided an estimate on the mean yearly river level (383 ft). Applying the downstream river gradient (0.000256 ft/ft) to mean yearly river level gave the boundary conditions along the Columbia River. A no-flux condition was set along the vertical barrier. Since this is a steady-state model, initial hydraulic conditions are not necessary.

This model requires information on the thickness and the bottom of the unconfined aquifer. Too few wells penetrate the unconfined aquifer to estimate the unconfined aquifer's base across the model's domain. Wells that penetrate the unconfined aquifer indicate the top of the paleosol is between 349 and 359 ft above MSL. Therefore, the bottom of the model was placed at 350 ft above MSL and given a no-flow boundary because of the silty nature of the underlying Ringold mud unit. Since natural recharge in this area is very small, no areal recharge was included in the model.

The Hartmann and Lindsey (1993) ^{90}Sr plume map was used to estimate contaminant fluxes to the Columbia River for this model. It was updated for this study by adding the ^{90}Sr data from wells 199-N-46/100-N-8T and 199-N-67.

1.4.2 Cross Section Model

Earlier modeling efforts at 100-N (Ebasco Environmental and Hart Crowser 1991) estimated the water table elevation would rise to approximately 387 ft above MSL at 100 ft behind a 3,000 ft vertical barrier. This elevation was used as the upgradient boundary for the cross-section ground-water flow simulation for cases 2 through 4. For Case 1 (no-action), the right (up gradient) (Figure 1-2a) boundary was determined by applying the existing ground-water gradient (0.003 ft/ft) to the distance between the Columbia River and the right boundary. The calculated constant head for the right boundary is 383.3 ft. This was also the boundary condition for case 5 (barrier anchored 2 ft above the Ringold mud Unit), because the water table would not rise for a vertical barrier not anchored into the Ringold mud.

The two-dimensional plan-view model undertaken for this study later predicted the head behind the wall to rise only to 386 ft. However, the 387 ft elevation was used in cross-section model to add an element of conservatism. The left (Columbia River side or down gradient [Figure 1-2a]) boundary for the cross-sectional model presented here was assigned a value of 383 ft, which is the average annual elevation of the Columbia River. The top of model and bottom of the model were assigned to

be no-flow. The model extended 50 ft below the Columbia River. By reason of symmetry, the left vertical boundary below the Columbia River was assigned to be no flow. Again, since this a steady-state problem, initial conditions are not necessary.

Hartman and Lindsey (1992) reported that unlike tritium, ^{90}Sr contamination is limited to the top of the aquifer. Wells screened at the water table (e.g., N-67) have ^{90}Sr contamination orders of magnitude higher than adjacent wells screened 20 to 30 ft deeper (e.g. N-69). Therefore, the upgradient boundary condition for the concentration equation was assigned a relative concentration of 1.0 for the first 20 ft of the aquifer.

Relative concentrations are often used in modeling, because actual concentration levels are not known throughout the model domain. By setting a relative concentration of 1.0, it is possible to scale the results to a range of observed concentrations. This boundary condition will decay with time. All other boundaries were assigned a relative concentration of 0.0 for the contaminant transport simulations. Since these were transient contaminant transport simulations, an initial relative concentration of 1.0 was assigned to the upper 20 ft of the unconfined aquifer directly behind the barrier.

1.5 Numerical Discretization

The numerical simulations were performed using two-dimensional cartesian grids. The axes of the plan view model was aligned SW-NE along the Columbia River. For the 3,800-ft barrier, the grid consisted of 58 nodes along the Y-axis (the Columbia River) and 23 nodes along the X-axis (normal to the Columbia River [Figure B-2]). A variable grid spacing accommodated the large pressure gradients found along the ends of the barrier and near any wells. The cell sizes varied from 25 by 25 to 1000 by 500 ft. A new grid was generated when the length of wall or the location of a pumping or injection well changed.

The cross-section model was discretized into 102 nodes along the X-axis (running inland from the Columbia River) and 50 nodes along the Z-axis (depth). The cell size varied from ~0.25 ft by 2 ft to 1 ft by 2 ft. The tighter grid spacing occurred at the barrier (Figure 1-2).

1.6 Hydrologic and Contaminant Transport Properties

In the deterministic models used in this study, each material property assigned to a numerical cell can have only one value. That value is assumed to represent an average value for that property. However, when building a numerical model, there are usually very few measured values for the hydrologic and transport properties at an individual site. Therefore, simplifying assumptions have to be made when assigning material properties to a numerical model. Spatial material property data throughout the 100-N Area are lacking; consequently, the model assumes homogenous properties. Table B-1 presents the hydrologic and contaminant transport parameters used in the models. A discussion follows.

Table B-1. Hydraulic and Contaminant Transport Properties Used in Modeling.

Model	Conductivity (ft/day)			Retard-ation	Dispersivity (ft)		Diffusion (ft^2/s)
	K_x	K_y	K_z		α_L	α_T	
2-D Plan View							
Case 1	261	261	N/A	100	N/A	N/A	N/A
Case 2	100	100	N/A	100	N/A	N/A	N/A
Case 3	500	500	N/A	100	N/A	N/A	N/A
2-D Cross-Section							
Case 1 No Action Barrier	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Ringold Gavels	261	N/A	26.1	100	0.1	0.01	8.5E-9
Ringold Silt	0.28	N/A	0.28	100	0.1	0.01	8.5E-9
Cases 2,4,5 Vertical Barrier	2.8E-5	N/A	2.8E-5	N/A	N/A	N/A	8.5E-09
Ringold Gavels	261	N/A	26.1	100	0.1	0.01	8.5E-09
Ringold Silts	0.28	N/A	0.28	100	0.1	0.01	8.5E-09
Case 3 Vertical Barrier	2.8E-5	N/A	2.8E-5	N/A	N/A	N/A	8.5E-09
Ringold Gravel	261	N/A	26.1	100	0.1	0.01	8.5E-09
Ringold Silt	2.8	N/A	0.28	100	0.1	0.01	8.5E-09

1.6.1 Hydraulic Properties

In the 100-N Area, six aquifer tests have been completed. All of these tests were conducted when the Liquid Waste Disposal facilities were operating. The water table was 20 ft higher during these tests than it is today. The range in observed hydraulic conductivity was from 100 to 500 ft/day. The geometric mean for these tests was 261 ft/day. All of these tests were within 1,000 ft of each other and in the upper gravels of the Ringold Formation.

In addition to the pump tests, Gilmore et al. (1992) measured the response of the unconfined aquifer in different wells to the daily fluctuations in the Columbia River elevations. From this, he calculated the hydraulic conductivity in each of the wells and postulated that the 100-N Area could be divided into two regions: a southwest region close to N-Reactor and a northeast region by wells 199-N-14 and 199-N-51. He reported the range in hydraulic conductivities in the southwest to be from 36 to 73 ft/day and in the northeast to be from 280 to 325 ft/day.

However, there are not enough hydraulic conductivity data to create a conductivity map covering the area of the model. Therefore, 261 ft/day, the geometric mean of the pump tests, was used as the

basis for the modeling. Sensitivity to hydraulic conductivity at 100 and 500 ft/day was tested for all lengths of the wall, but not for the pumping and injec on wells.

The Ringold gravels on the Hanford Site appear to be anisotropic. Graham (1992) estimated the anisotropy (K_h/K_v) for the unconfined aquifer in the 200 West Area to be 13-16. For this cross-sectional model, an anisotropy of 10 was used. Additionally, hydraulic conductivity for the Ringold paleosol and the barrier was also needed for the cross-sectional model.

To date, no aquifer or permeability tests have been completed for the Ringold paleosol. Since this is a silty sand, a hydraulic conductivity of 0.28 ft/day was taken from the literature (Freeze and Cherry 1979). This unit was assumed to be isotropic in all but Case 3. For this case, the horizontal conductivity was increased by a factor of 10. Cherry (1993) reports that a barrier of this type would have a hydraulic conductivity of 2.8E-05 ft/day and a thickness of approximately 0.032 ft.

1.6.1 Contaminant Transport Properties

The modeling of ^{90}Sr transport required estimates of effective porosity, retardation factor, and dispersion data. Ames and Serne (1991) reported distribution coefficients from 20 to 200 mL/g for ^{90}Sr. Using Freeze and Cherry's approximation for retardation factor:

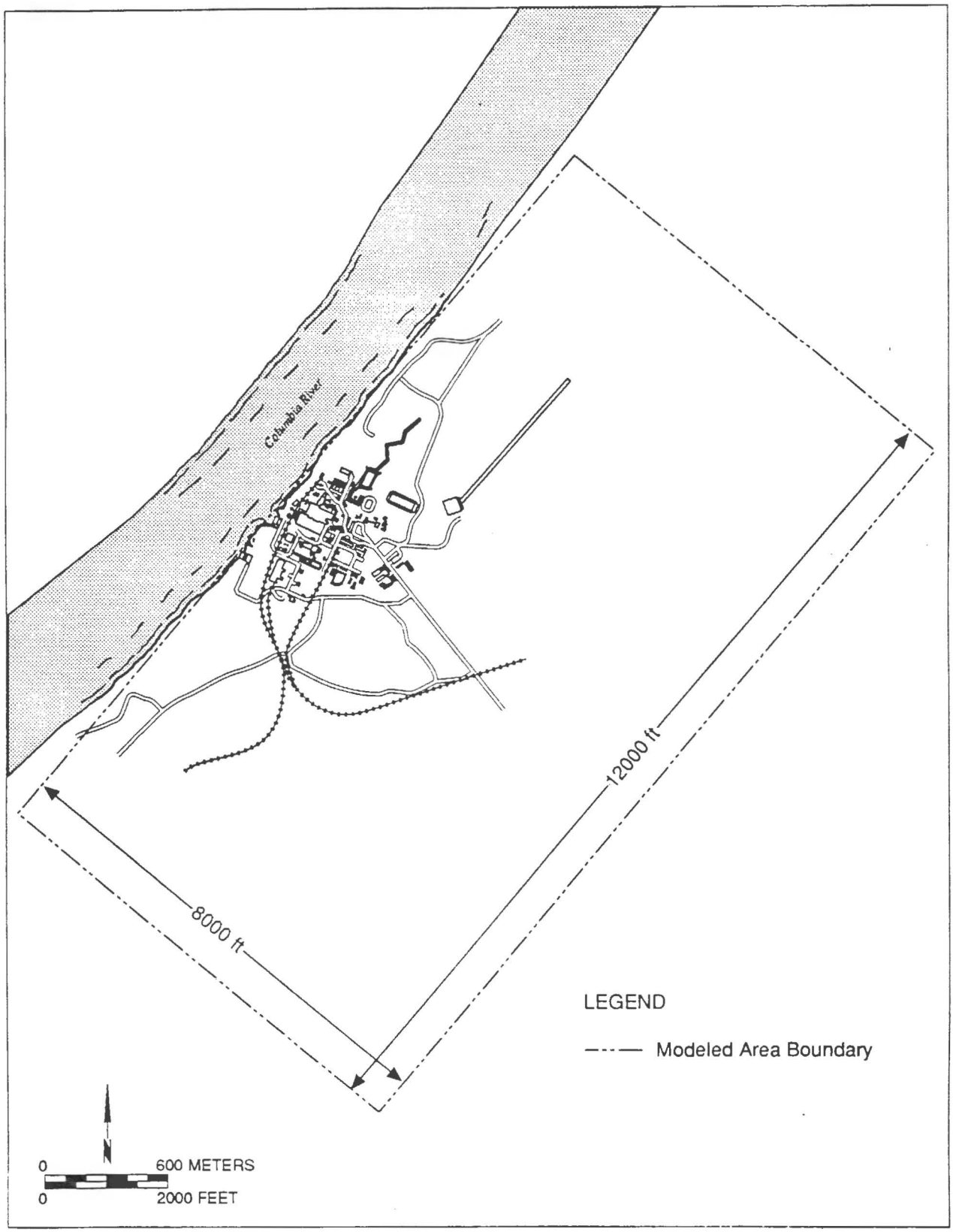
$$r_f = v/v_c = (1 + 4K_d) \text{ to } (1 + 10K_d)$$

where v = groundwater velocity
v_c = contaminant velocity
K_d = distribution coefficient

Using Ames and Serne's (1991) recommended value (25 mL/g), results in a retardation factor for ^{90}Sr of 100. This value was used in both models. Attempts were made to back calculate the in situ retardation factor for ^{90}Sr by comparing arrival times at a well for ^{90}Sr and tritium. However, for this type of analysis to be useful, time history data is needed for both tritium and ^{90}Sr for two wells along the same flow path. Although these data are available for a number of wells in the 100-N Area, no two of these wells are along the same flow path.

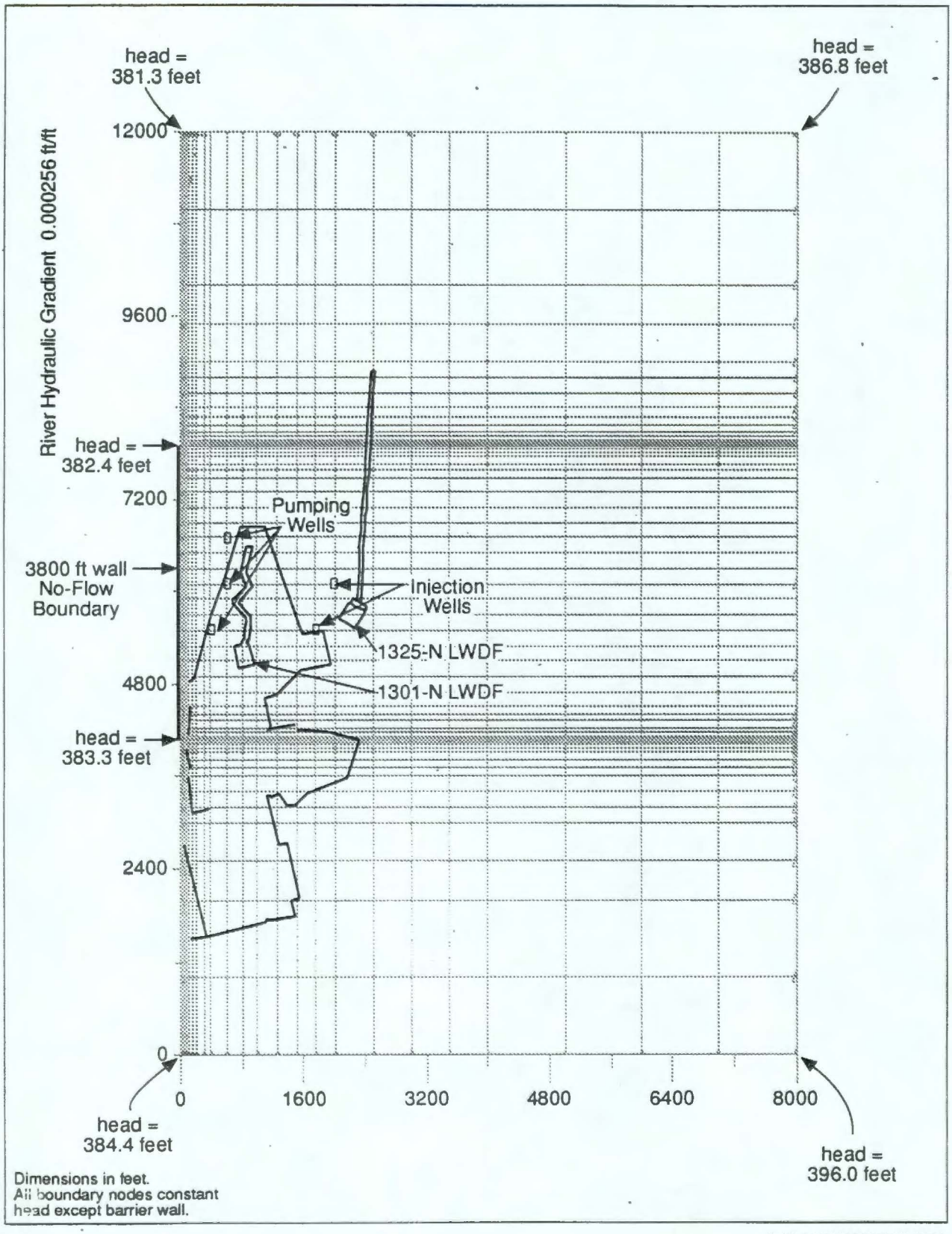
The contaminant transport portion of the cross-section model also needed data on the longitudinal dispersivity, transverse dispersivity, and the diffusion coefficient of ^{90}Sr. There are no measurements for dispersivity in the 100-N Area. Since this was a small scale model in which advective flow would dominate, the dispersivities were set small, approximately 1/10 the grid cell for longitudinal dispersivity (0.1 ft) and 1/100 the grid cell for transverse dispersivity (0.01 ft). The effect this has on the model is to maximize the release, but lessen the spreading on the leading edge of the plume. The diffusion coefficient is 8.5E-9 ft^2/day (Domenico and Schwartz 1990). The sheet piling requires a porosity of close to 0. These codes cannot handle a porosity of 0. Therefore, any contaminant transport through the sheet piling is erroneous and should be discounted, which is why N/A has been applied to all the contaminant transport parameters for the sheet pile in Table B-1.

Figure B-1. Two-Dimensional Plan View Model Area.



943 1106/53337/9-29-94

Figure B-2. Example of Plan-View FLOWPATH Grid.



943 1106/53336/10-3-94

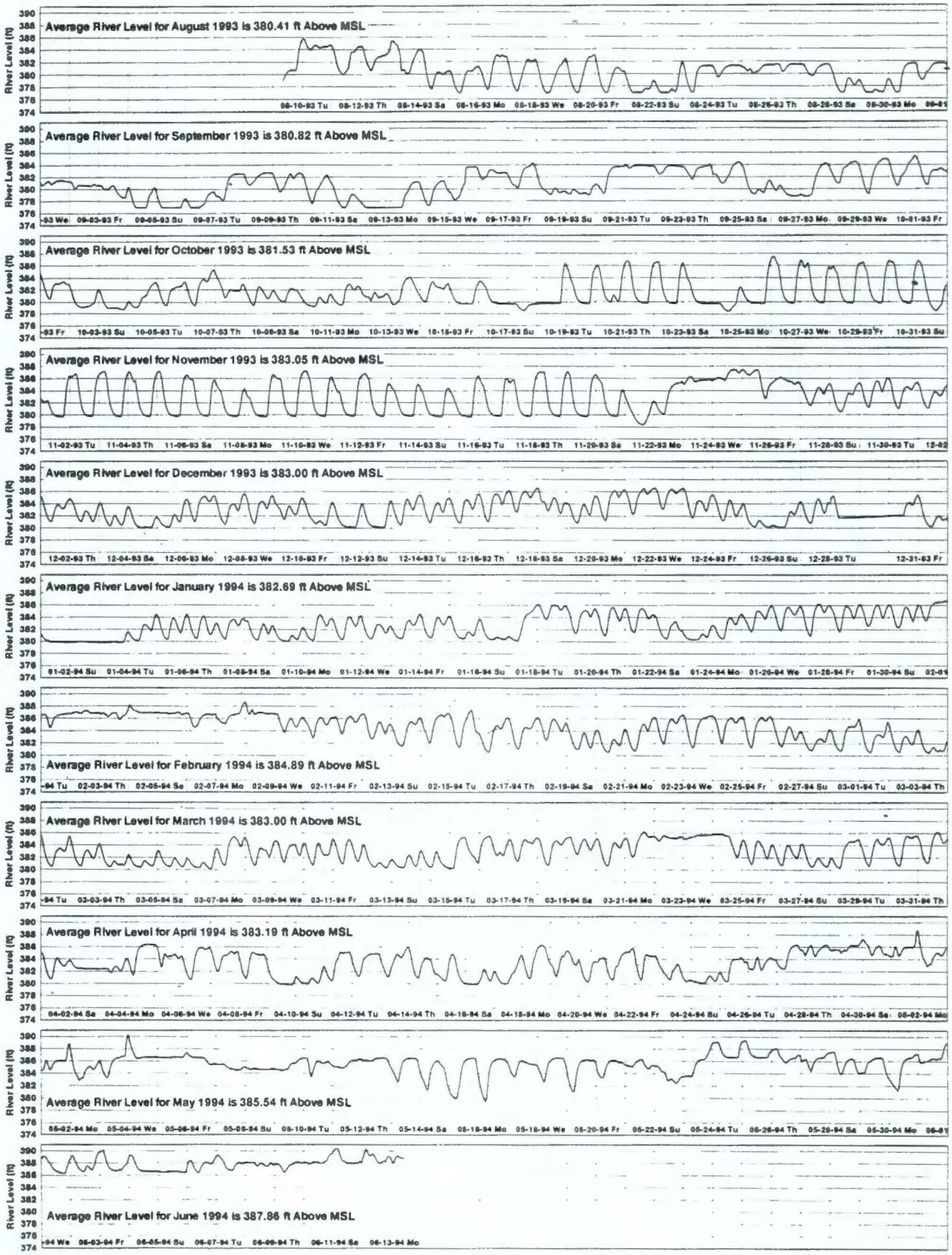



Figure B-3. Daily Columbia River Level Fluctuations from August 1993 to June 1994.