MAY 20 1992 Sta. 21 (20)

ENGINEERING DATA TRANSMITTAL

Page 1 of 1

1. EDT 123464

2. To: (Receiving Organization) Distribution

3. From: (Originating Organization) Hydrology Section

4. Related EDT No: NA

5. Proj/Prog/Dept/Div: ED/81230

6. Cog/Proj Engr: A. G. Law

7. Purchase Order No: NA

8. Originator Remarks: Release to file

9. Equip/Component No: NA

10. System/Bldg/Facility: NA

11. Receiver Remarks:

12. Major Assm Dwg No: NA

13. Permit/Permit Application No. NA

14. Required Response Date: 5/15/92

15. DATA TRANSMITTED

(A) Item No.	(B) Document/Drawing No.	(C) Sheet No.	(D) Rev No.	(E) Title or Description of Data Transmitted	(F) Impact Level	(G) Reason for Transmittal	(H) Originator Disposition	(I) Receiver Disposition
1	WHC-SD-EN-ES-021		0	Travel Time and Groundwater mounding Estimates for Alternative Soil Column Disposal Sites, Hanford Site, Washington	4	2		

16. KEY

Impact Level (F)	Reason for Transmittal (G)	Disposition (H) & (I)
1, 2, 3, or 4 see MRP 5.43 and EP-1.7	1. Approval 2. Release 3. Information 4. Review 5. Post-Review 6. Dist (Receipt Acknow. Required)	1. Approved 2. Approved w/comment 3. Disapproved w/comment 4. Reviewed no/comment 5. Reviewed w/comment 6. Receipt acknowledged

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2	1	Cog./Proj. Eng A.G. LAW	A Law	5/14/92	H4-56						
2	1	Cog./Proj. Eng. Mgr. A.J. KNEPP	A J Knepp	5-14-92	H4-56						
		QA									
		Safety									
3		EDMC (2)			H4-22						
3		IRA CLEARANCE			H4-17						

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Signature of EDT Originator — Date

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21. DOE APPROVAL (if required)
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BD-7400-172 (2/89)

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Title Travel Time and Groundwater Mounding estimates for Alternative Soil Column Disposal Sites Hanford Site, Washington

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WHC Program/Project	[]	[X]			
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Publication Services	[X]	[]	L Hermann for DE Smith		5/15/92
Other Program/Project	[]	[X]			

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References Available to Intended Audience	[X]	[]
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BD-7600-062 (08/91) WEF074

Part 1

SUPPORTING DOCUMENT

1. Total Pages 61

2. Title	3. Number	4. Rev No.
Travel Time and Groundwater Mounding Estimates for Alternative Soil Column Disposal Sites Hanford Site, Washington	WHC-SD-EN-ES-021	0

5. Key Words

tritium, crib, travel time, estimated parameters, groundwater

APPROVED FOR PUBLIC RELEASE
5/15/92 M. Solis

6. Author

Name: A. G. Law

Signature

Organization/Charge Code 81230/PHIAA

7. Abstract

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9. Impact Level 4

10. RELEASE STAMP

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APPENDICES

APPENDIX A Numerical Groundwater Modeling

1.0 INTRODUCTION

Computer simulations of groundwater flow at the Hanford Site in southeastern Washington were conducted to estimate the groundwater travel times to the Columbia River from three alternative sites for an effluent disposal facility. The groundwater travel time is the estimated time required for a particle of groundwater to travel between the site and the Columbia River at the average groundwater seepage velocity. The facilities would be used for disposal of tritium-bearing waste streams. Because tritium is not retarded and is physically nearly identical to ordinary water, the average travel time for tritium would be essentially the same as that for groundwater. The simulations were performed using a two-dimensional finite element model of the unconfined aquifer in the Pasco Basin west of the Columbia River.

Locations of the three alternative sites were provided by Westinghouse Hanford Company and are shown on Figure 1. Both Washington State Land Coordinates and Hanford Land Coordinates for these sites are listed in Table 1. Washington State Land Coordinates are provided because these are used by the model. Hanford Land Coordinates are given to allow comparison with site coordinates provided by Westinghouse. Model coordinates for Site 2 differ from those provided by Westinghouse because effluent from the facility flows northeast along the unsaturated bedrock surface before entering the saturated region of the model. This is more fully explained later in the text. The model coordinates for Site 3 differ from those provided by Westinghouse because of the need to maintain a consistent nodal spacing. Minor changes in location should not affect the results appreciably. The liquid effluent disposal facility would have dimensions of approximately 220 feet by 100 feet.

Table 1. Coordinates of Alternative Disposal Site Locations.

Site	Washington State Coordinates	Hanford Coordinates used in model	Hanford Coordinates from Westinghouse
1	N 452,987 E 2,218,029	N 48,000 W 77,000	N 48,000 W 77,000
2	N 453,400 E 2,252,962	N 48,400 W 42,100	N 48,500 W 43,000
3	N 449,712 E 2,223,487	N 44,700 W 71,600	N 45,500 W 71,500

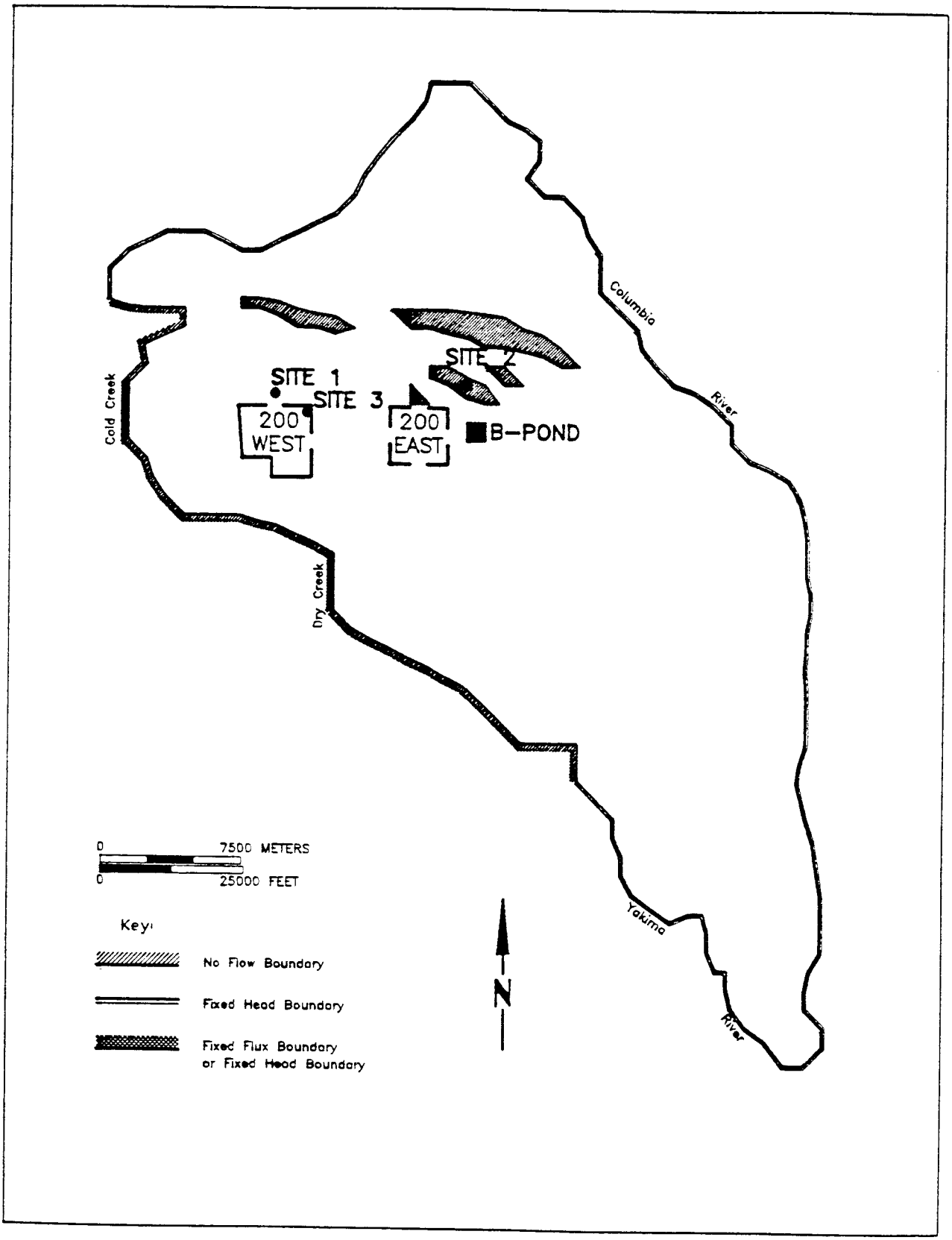

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Figure 1. Simulated Region.

An earlier version of this model has been previously used to predict travel times from other sites (Engineering-Science, 1989; Golder Associates Inc., 1990). The only difference between the present version of the model and the previous version is that the present version includes a finer grid spacing in areas surrounding the alternative sites evaluated in this study. This finer grid spacing was used to provide a more realistic simulation of groundwater mounding and flow directions in areas near the alternative facilities. Travel times were determined with and without mass influx from the disposal sites.

2.0 HANFORD SITE GROUNDWATER MODEL

2.1 DEVELOPMENT OF THE MODEL

The groundwater flow model was developed using Golder Associate's Golder Groundwater Package, a collection of finite element computer programs for simulation of groundwater flow and contaminant transport. The program AFPM (Aquifer Flow in Porous Media) was used to simulate the two-dimensional flowfield, and the program FLOCON (Flow Contouring) was used to prepare the graphical presentations. The simulations were performed on a IBM RS-6000 work station and required between 10 to 35 seconds for steady state solutions. A complete description of the model, which was initially presented in an earlier report (Engineering Science, 1989), is included in Appendix A, and is summarized below.

As shown in Figure 2, an earlier version of the model consisted of 976 nodes and 920 elements. Except for the boundaries of the model, where geometric constraints necessitated irregular element shapes, a uniform grid spacing of 3275 feet was used over most of the modeled region. Hydraulic head results using the previous version of the grid are shown in Figure 3. These results are for the same conditions modeled in Case 1 of Golder's 1990 report (Golder Associates Inc., 1990). The only artificial influx included in this example was 16.5 million gallons per day from B-Pond.

In previous studies the design disposal facility inflow rate was low enough (58 gallons per minute) that the flowfield and travel time estimates were not significantly affected by mass influx. For this study, however, an influx rate of 150 gallons per minute was stipulated by Westinghouse and information concerning groundwater mounding was desired. As a result, the simulations in this study explicitly included mass influx from the alternative facilities. In order to provide a realistic estimate of groundwater mounding and flow changes associated with the mass influx it was necessary to increase the grid density in the area near the alternative sites. The grid density was also increased near B-Pond. The finite element mesh used in this study, shown in Figure 4, is composed of 1086 nodes and 1083 elements. The same problem shown in Figure 3 was re-run using the refined grid to determine if significant differences resulted from the changes to the grid. Hydraulic head results using the refined grid are shown in Figure 5. The results using the new grid are very similar to the results using the former grid, with the exception of minor differences in the area near B-Pond and just northeast of Site 2. These differences arise from the grid refinement in these areas.

Boundary conditions and calibration of the model are discussed in Appendix A. In summary, fixed head conditions were applied along the Columbia River, no flow boundaries were used where basalt bedrock rises above the water table, and non-zero fixed flux conditions were applied along Dry Creek and Cold Creek Valleys. The fixed fluxes across

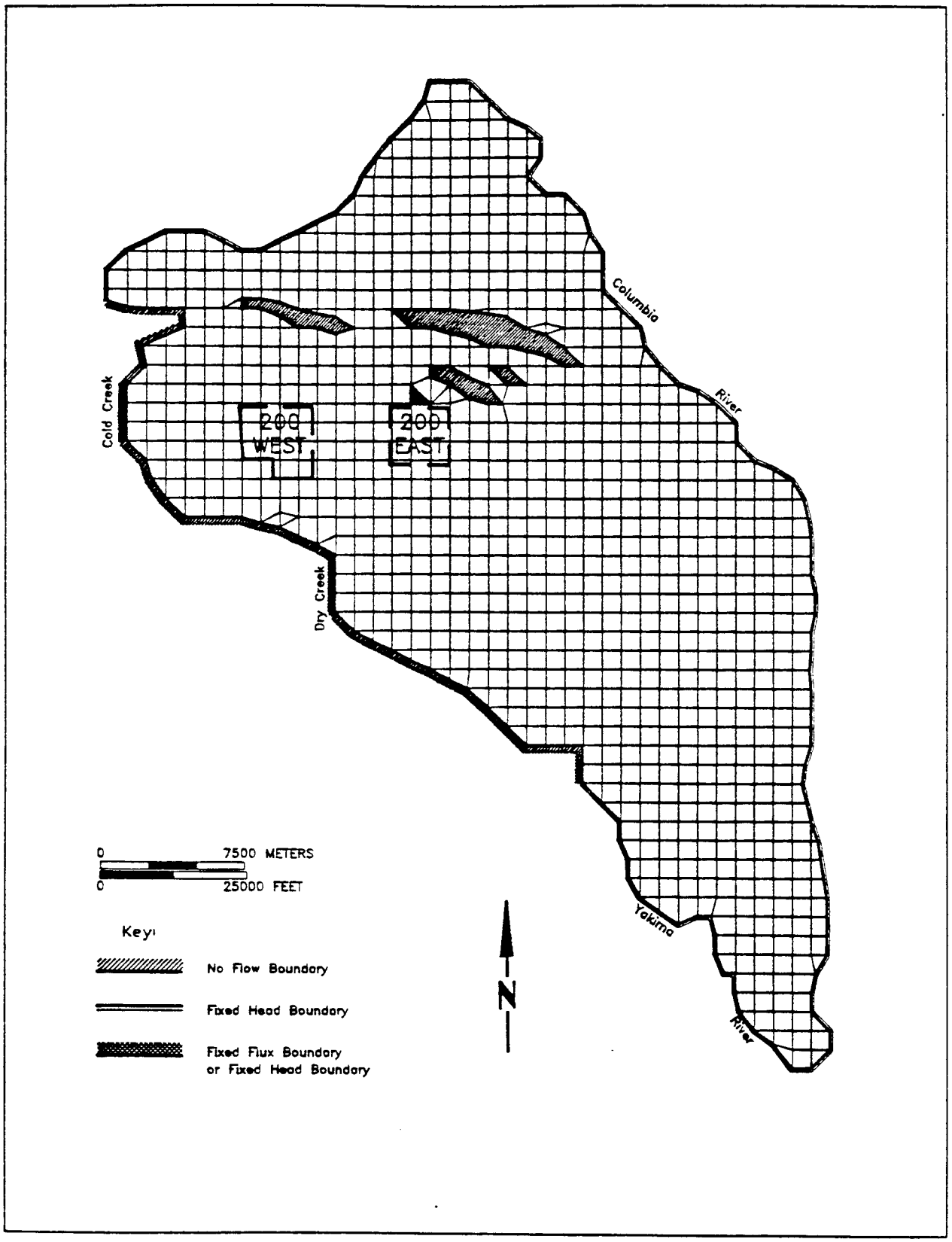

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Figure 2. Previous Finite Element Grid.

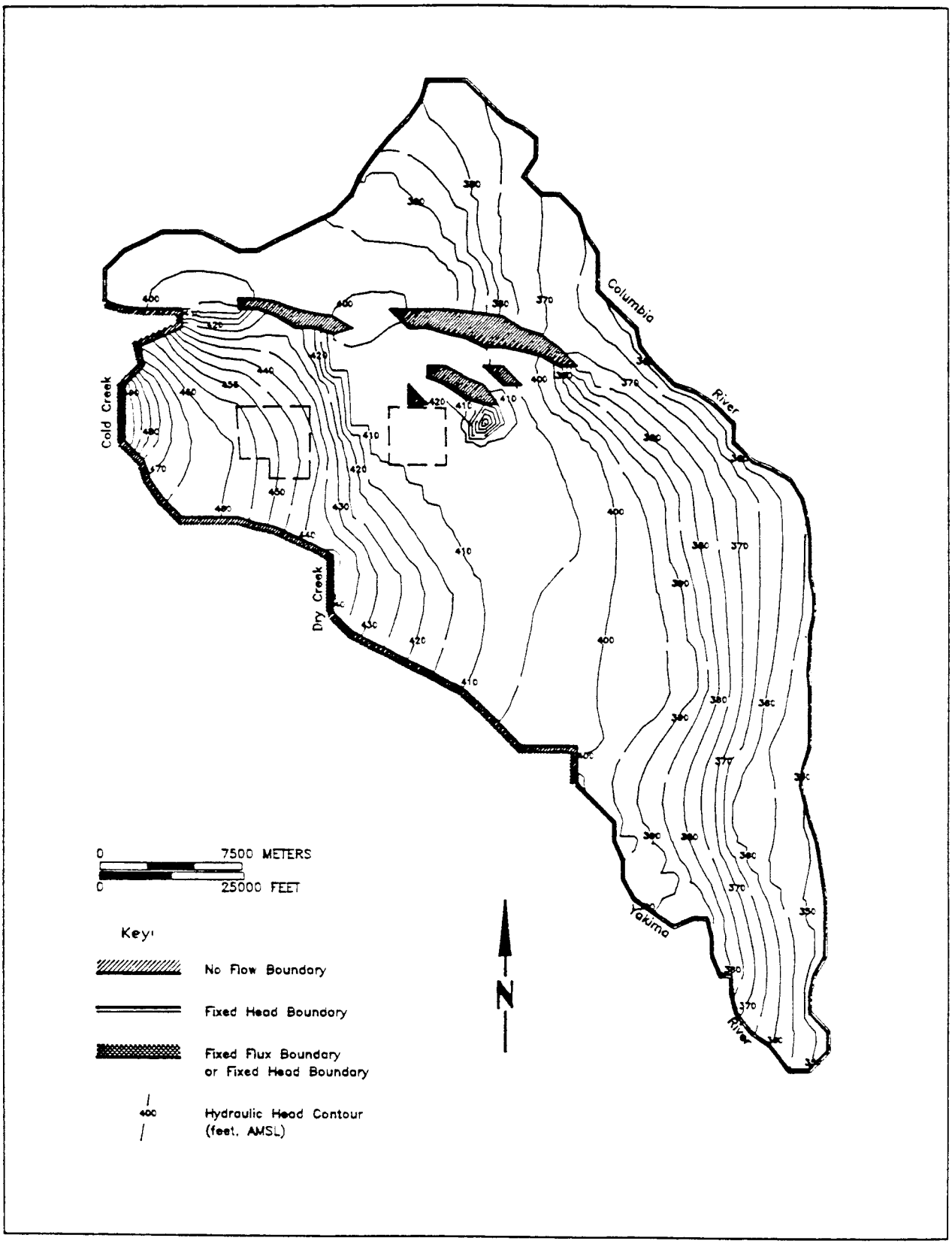

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Figure 3. Hydraulic Head Contours Using Previous Finite Element Grid (B-Pond Influx Only).

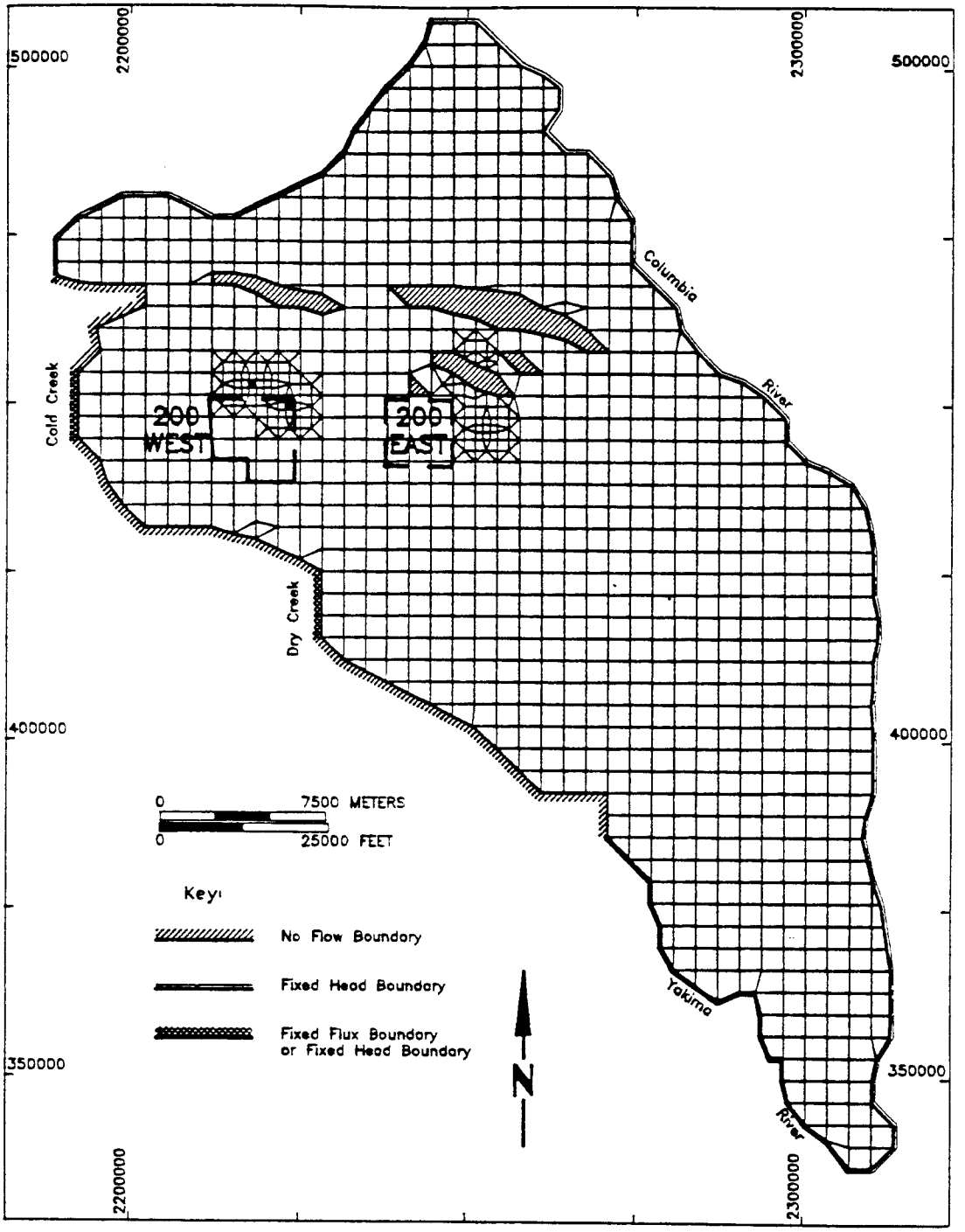

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Figure 4. Refined Finite Element Grid.

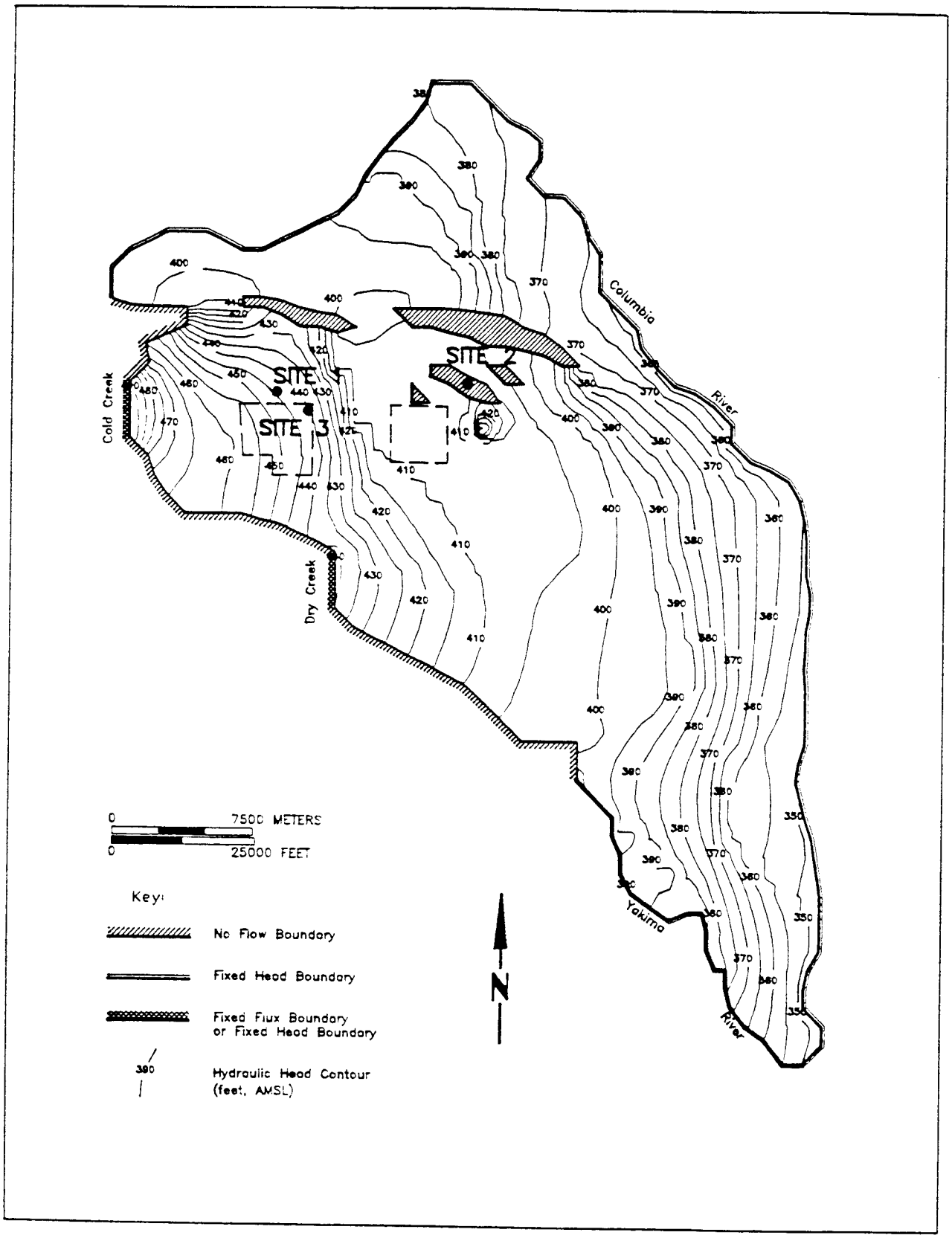

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Figure 5. Hydraulic Head Contours with B-Pond Influx and No Influx from Disposal Facilities.

Dry Creek and Cold Creek Valleys were the same as those determined in the 1979 calibration exercise.

2.2 ASSUMPTIONS

For all the simulations presented in this report the influx from B-Pond was assumed to be 16.5 million gallons per day. This is the average total effluent discharge to B-Pond estimated by Westinghouse for future operations at the Hanford Site. As shown in Figure 1, the B-Pond influx was applied evenly over a square with side lengths of 3,275 feet.

It was assumed that the time period during which the disposal practices studied in this report will be implemented will be far enough in the future that the remnant mounding in the 200 West Area will have dissipated. Since the alternative disposal sites investigated in this study are at least 5,000 feet from the apex of the existing 200 West Area mound, travel time estimates should not be significantly altered if the mound has not completely dissipated. Even under today's conditions (with prominent mounding in the 200 West Area) the hydraulic gradient near Sites 1 and 3 is less than ten percent greater than when the mound is completely dissipated (compare Figure 5 and Figure H-2 in Appendix A). Since velocity is directly related to hydraulic gradient, the travel times should also be affected by less than ten percent. Site 2 is too distant to be significantly affected by remnant mounding in the 200 West Area.

For simulations that include influx to a disposal facility, the discharge rate was assumed to equal 150 gallons per minute, and the discharge was applied at a node. Due to numerical averaging between nodes, a nodal discharge is equivalent to an area infiltration rate over the elements neighboring the node. This infiltration rate is highest near the discharge node and decreases linearly to zero at the opposite edges of the neighboring elements. As a result, the estimated amount of mounding is inversely related to the grid spacing surrounding the discharge node; that is, groundwater mounding increases as nodal spacing decreases. The effect of grid spacing on mounding is a localized phenomenon which is negligible beyond the nodes immediately surrounding the discharge node. The total area of the elements surrounding the discharge node was approximately 1.2 million square feet for Sites 1 and 3, and 3.0 million square feet for Site 2. Although the potential subsurface spreading of the effluent within the unsaturated zone was not investigated for this report, a cursory review of existing mounds and plumes indicates that these areas are of the correct order of magnitude. Also note that the model assumes the influx is injected over the full thickness of the aquifer, not just at the surface. This is a necessary limitation in a two-dimensional model, and may result in predictions of groundwater mounding that are low. A more refined evaluation of mounding will be presented in a subsequent study.

3.0 RESULTS AND COMPARISONS FOR ALTERNATIVE FACILITY LOCATIONS

The results of four simulations are presented in this section: one simulation includes influx from B-Pond and no influx from any of the facility locations, and the other three include influx from both B-Pond and one of the alternative facility locations. Travel times were determined both with and without facility influx to provide information concerning the sensitivity of the results to discharge rate.

3.1 B-POND INFLUX ONLY

This simulation included influx of 16.5 million gallons per day from B-pond, and no influx from the alternative disposal facilities. This simulation was already introduced in Section 2.1, and is the same as Case 1 described in Golder's 1990 report (Golder Associates Inc., 1990). The hydraulic head contours for the entire modeled region are shown in Figure 5. Figure 6 shows vectors which are linearly scaled to represent the magnitude of the Darcy velocity within each element. From this figure it is apparent that the groundwater velocities are much higher in the conductive sediments that trend northwest/southeast beneath the 200 East Area. Because the arrows would be too small, velocities are not shown for elements with velocities less than 0.1 feet per day. Darcy velocities in the region near the 200 West Area are as low as 0.01 feet per day in places. Figure 7 shows the flow direction in each element, where the length of the arrow is fixed regardless of magnitude.

Details of the contours near the facility locations are shown in Figure 8 for Sites 1 and 3, and Figure 9 for Site 2. The sharp turns in the contours northeast of the 200 West Area are due to the abrupt change in transmissivity across element boundaries in this area. Although these sharp angles in the contours are not realistic, the general hydraulic gradient through this area is consistent with observed conditions. Refinement of the grid in this area would reduce the angular nature of the contours.

Figures 10 and 11 show flow paths and travel times from the alternative facility locations to the Columbia River. The travel times are rounded to the nearest 10 years to reflect the level of uncertainty in the estimates. The travel times range from 90 years for Site 3, to 180 years for Site 2.

3.2 INFLUX FROM SITE 1

This simulation included influx of 16.5 million gallons per day from B-pond, 150 gallons per day from Site 1, and no influx from the other facility locations. Contours of hydraulic head for the entire modeled area are shown in Figure 12. Velocity vectors are not shown because they are similar to those shown on Figure 6.

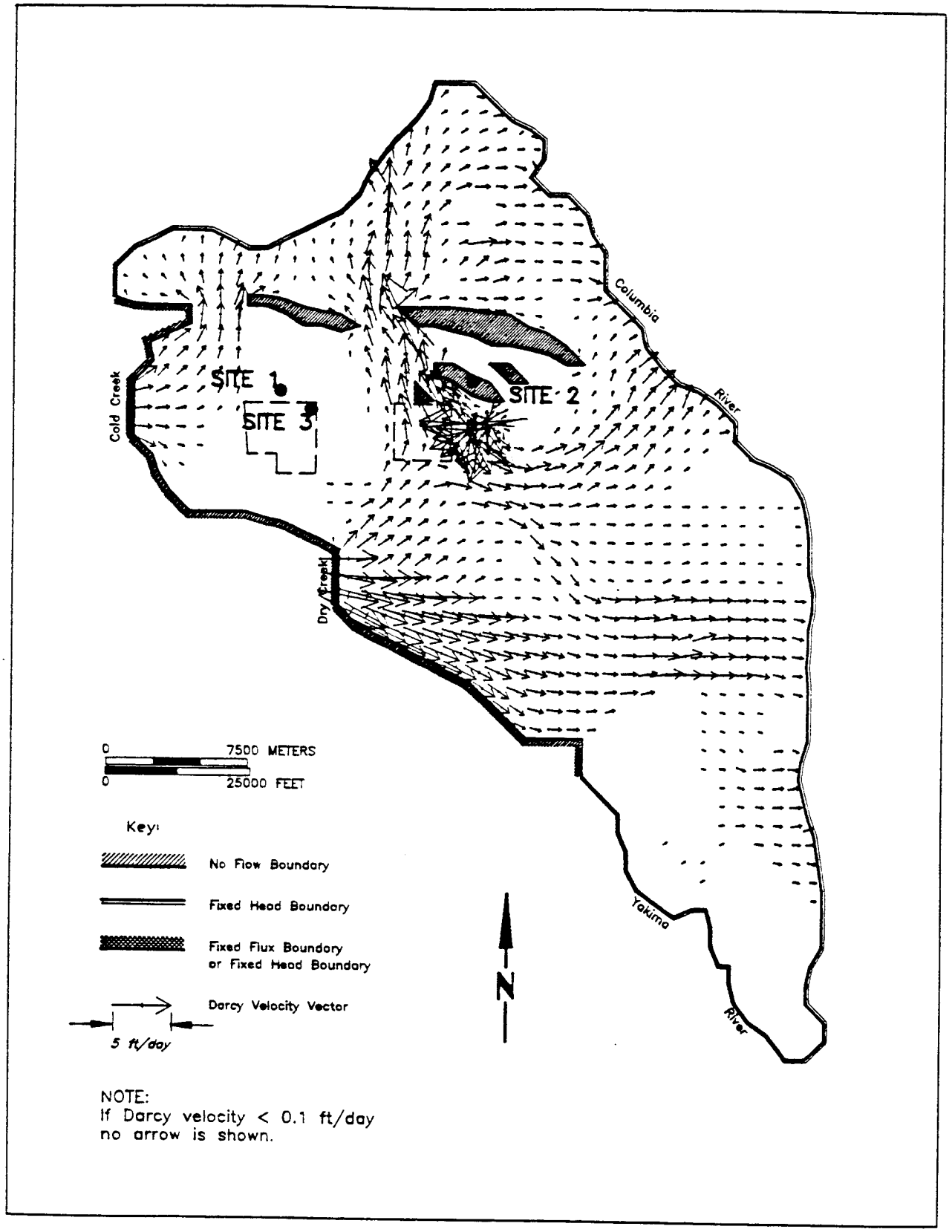

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Figure 6. Darcy Velocity Vectors (B-Pond Influx Only).

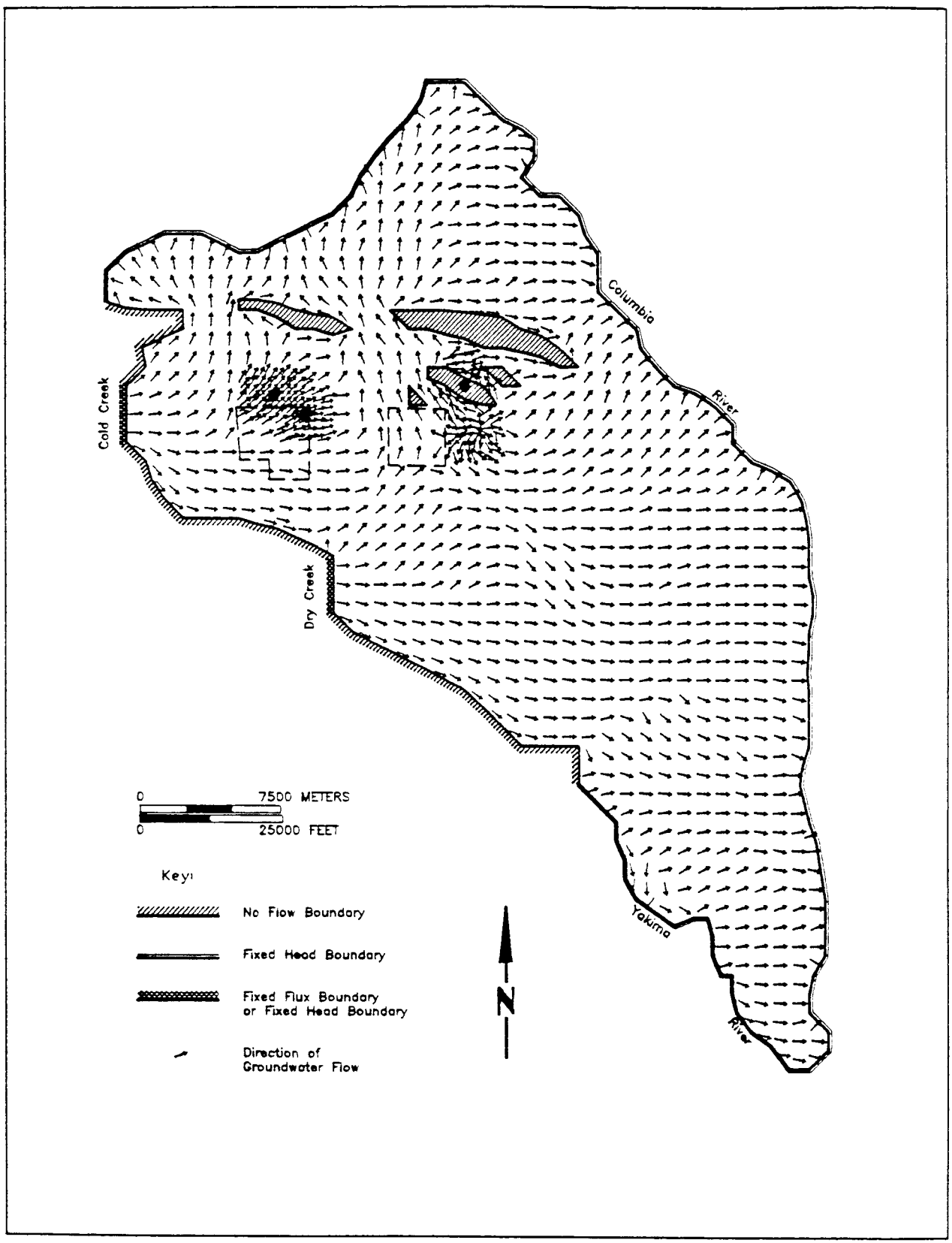

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Figure 7. Groundwater Flow Direction (B-Pond Influx Only).

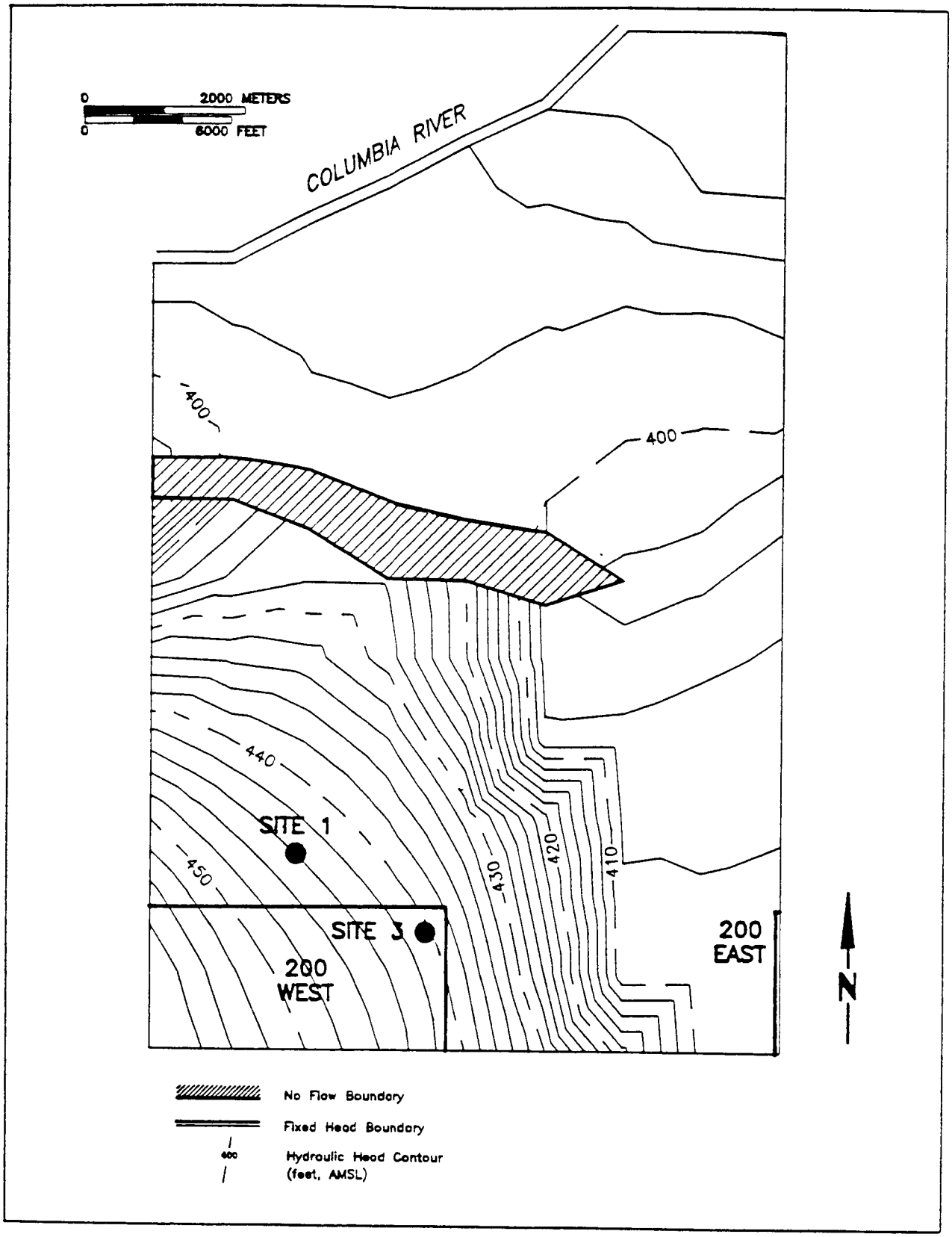

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Figure 8. Hydraulic Head Contours near Sites 1 and 3 with B-Pond Influx and No Influx from Disposal Facilities.

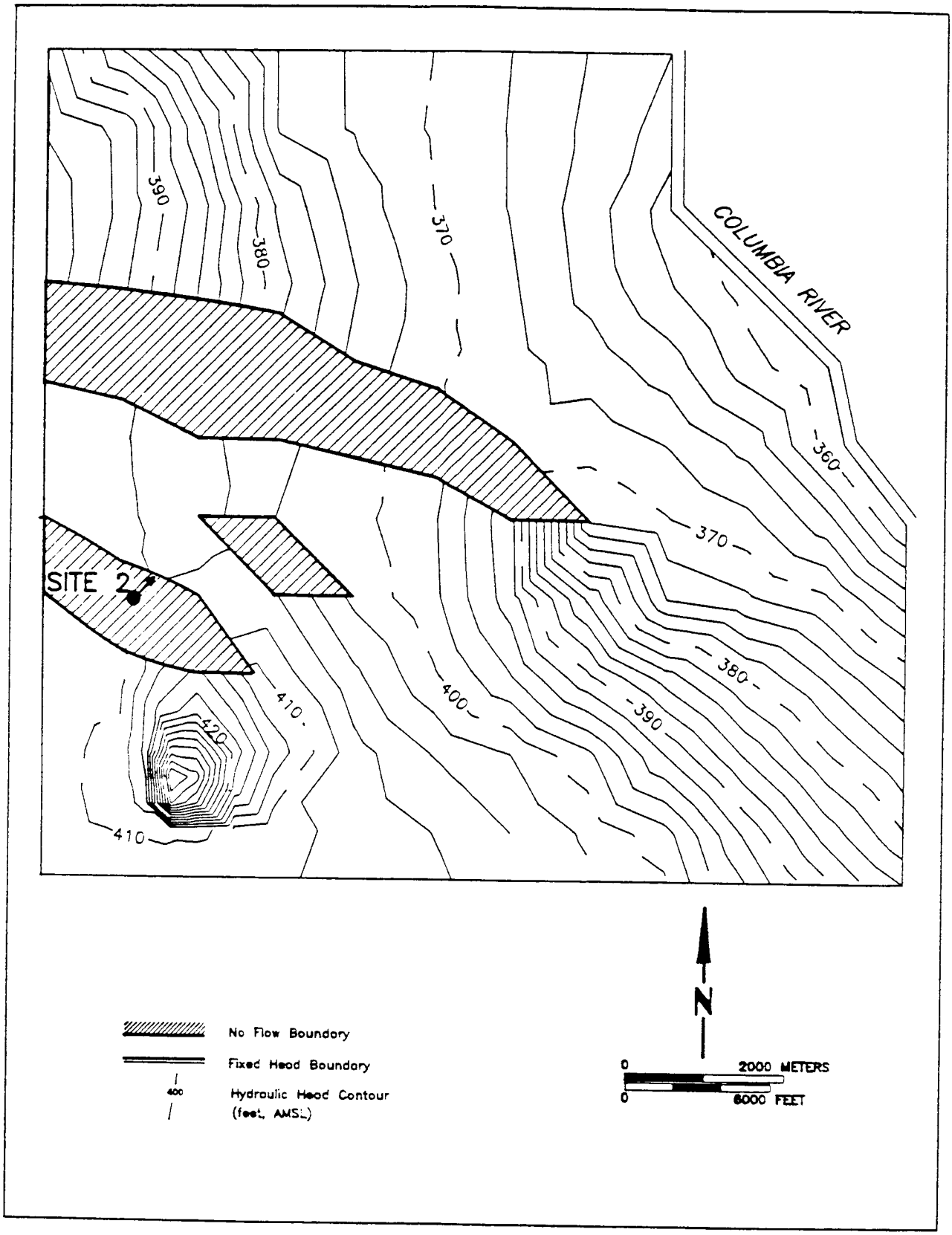

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Figure 9. Hydraulic Head Contours near Site 2 with B-Pond Influx and No Influx from Disposal Facilities.

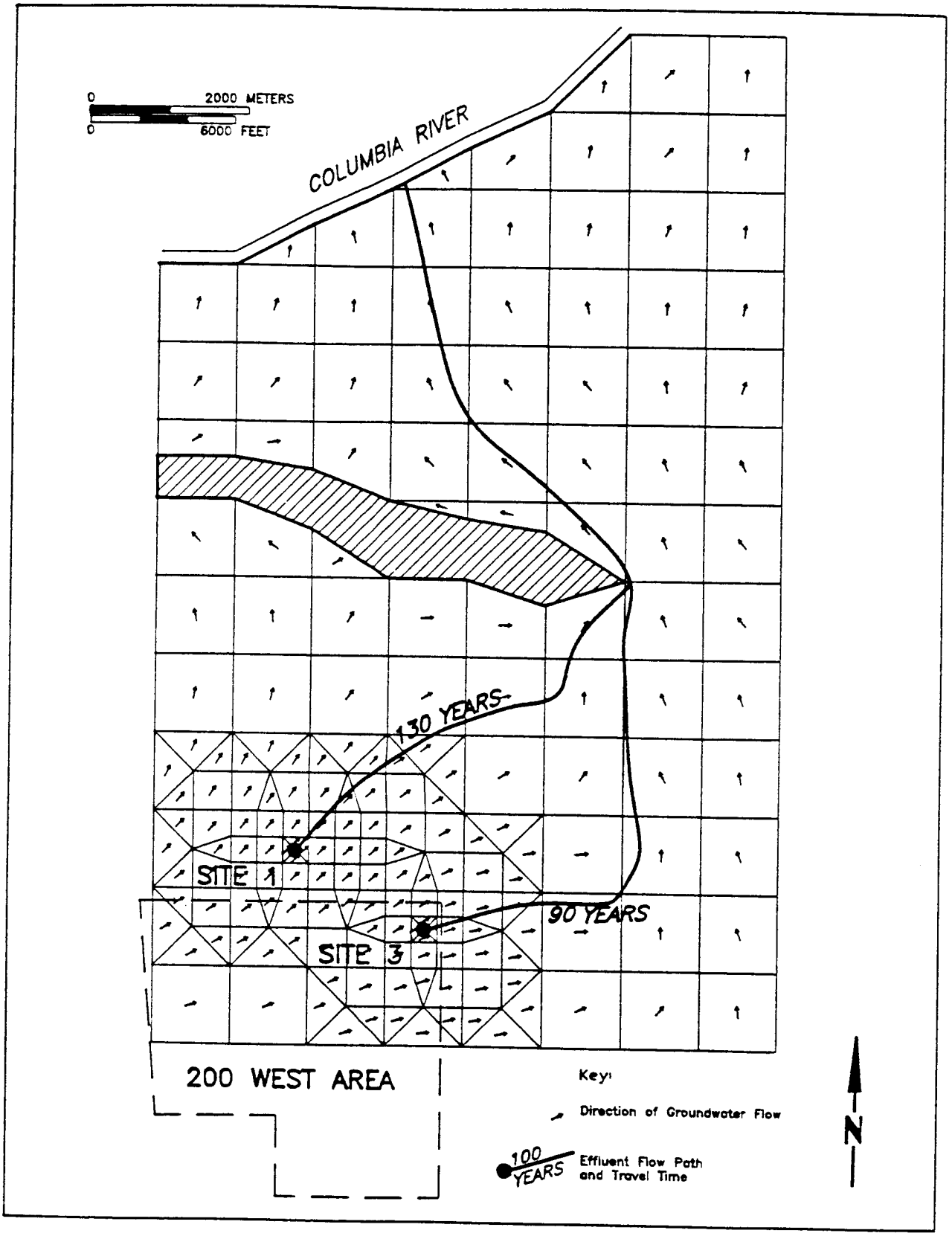

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Figure 10. Travel Times from Sites 1 and 3 with No Disposal Facility Influx.

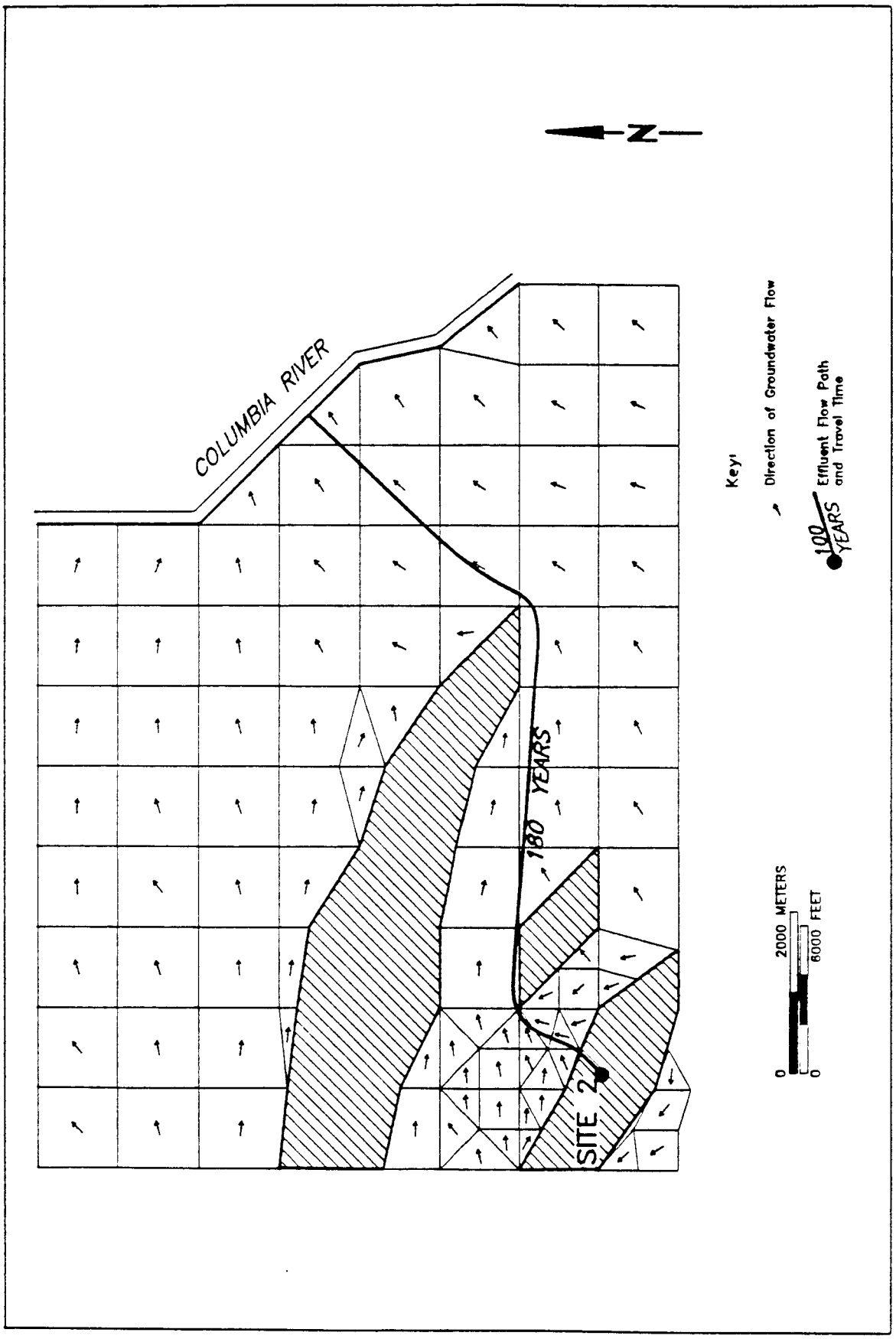

Figure 11. Travel Time from Site 2 with No Disposal Facility Influx.

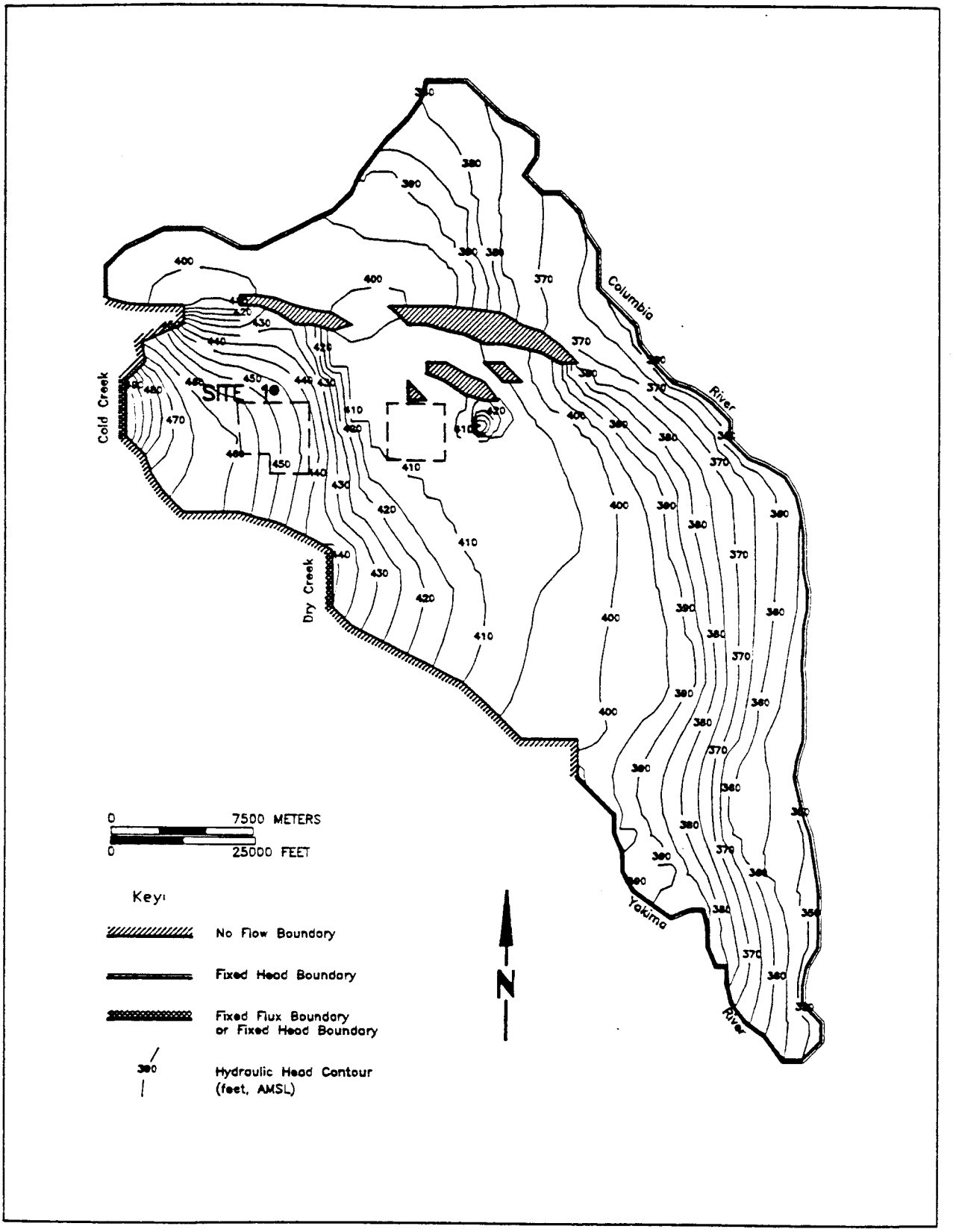

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Figure 12. Hydraulic Head Contours with Influx from Site 1.

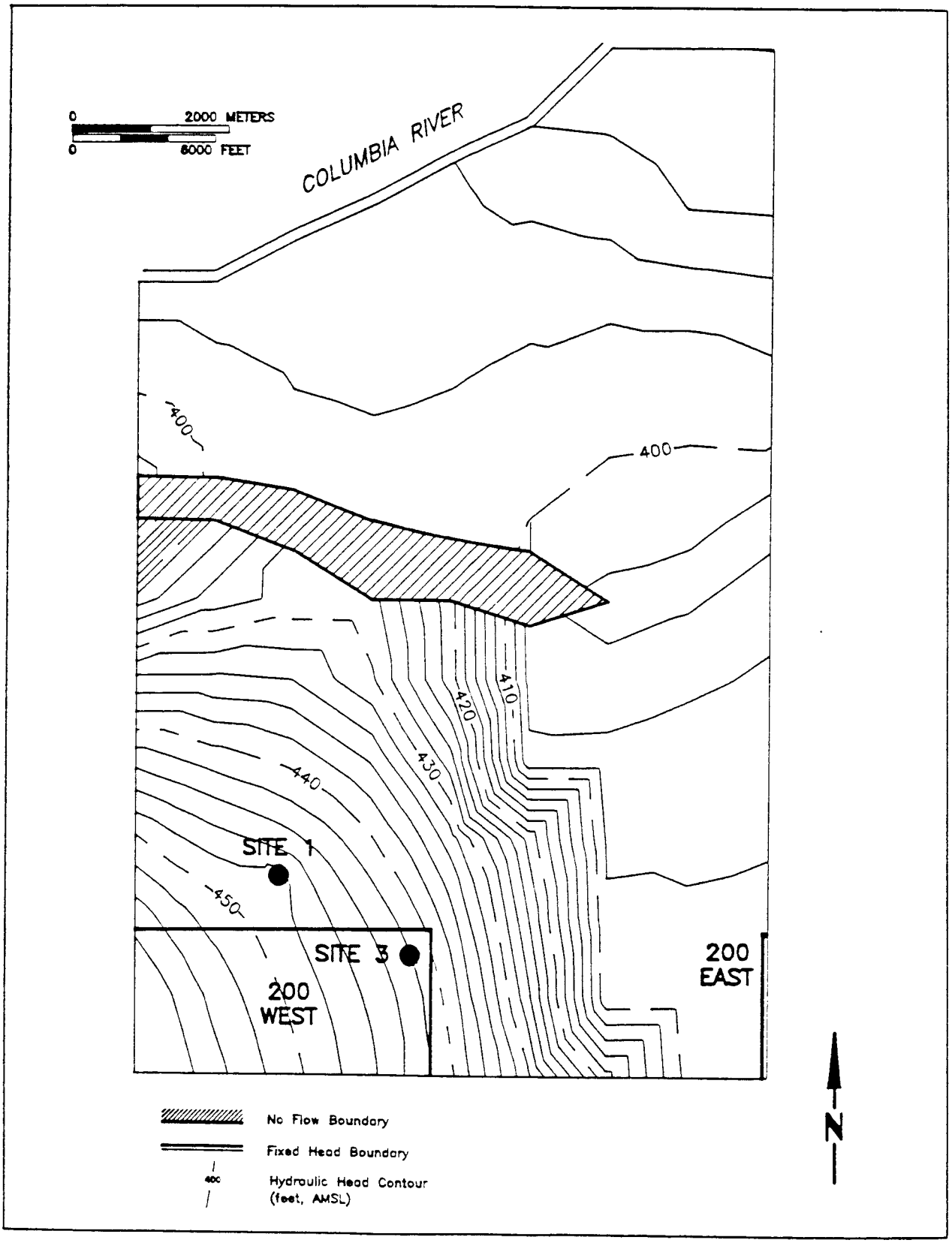

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Figure 13. Details of Hydraulic Head Contours with Influx from Site 1.

Details of hydraulic head contours near Site 1 are shown in Figure 13. Although it is not immediately obvious from the contours, model results indicate that facility influx at Site 1 results in a maximum groundwater rise of about 6 feet, and that it occurs at the discharge node.

Figure 14 shows three flow paths and travel times from Site 1 to the Columbia River. Because of the radial flow created by the facility influx, many flow paths with differing travel times are possible. The three flow paths shown on Figure 14 include a relatively direct flow path with a travel time of approximately 120 years, and two non-direct flow paths with travel times of approximately 140 and 170 years. The flow paths shown on the figure do not necessarily represent the shortest and longest travel times, but they do indicate the general range that could be expected. The direct flow path has a travel time that is 10 years less than the travel time with no discharge at the facility.

3.3 INFLUX FROM SITE 2

This simulation included influx of 16.5 million gallons per day from B-pond, 150 gallons per day from Site 2, and no influx from the other facility locations. Site 2 is located directly over an area where the basalt bedrock rises above the water table, resulting in a no-flow region. Based upon the shape of similar bedrock anticlines in the area the basalt surface is expected by Westinghouse to slope to the northeast in this area. For this reason, the influx from Site 2 was applied to a node on the northeast side of the no-flow region. Under actual conditions the facility influx will eventually saturate the underlying sediments and the length of the flow path to the river will be slightly longer than assumed in this report. Contours of hydraulic head for the entire modeled area are shown in Figure 15. Velocity vectors are not shown because they are so similar to those shown in Figure 6.

Details of hydraulic head contours near Site 2 are shown in Figure 16. The model results indicate that the facility influx at Site 2 results in a maximum groundwater rise of about 4 feet at the discharge node. The groundwater rise for Site 2 is less than for Site 1 both because the transmissivity near the site is higher, and because the increased nodal spacing spreads the influx over a larger area. Given the uncertainties in these estimates, it may be concluded that the mound heights at Sites 1 and 2 would be similar. A more refined evaluation of the vertical and lateral extent of mounding at Site 2 will be presented in a subsequent study.

Figure 17 shows three flow paths and travel times from Site 2 to the Columbia River. The most direct flow path has a travel time of about 90 years, which is half of the travel time with no facility influx. The drastic reduction in travel time occurs because with no facility influx the site is located in an area where hydraulic gradients are extremely low. The facility influx displaces the low gradient regions to either side, thereby reducing the travel time via relatively direct flow paths. The travel times for the two non-direct flow

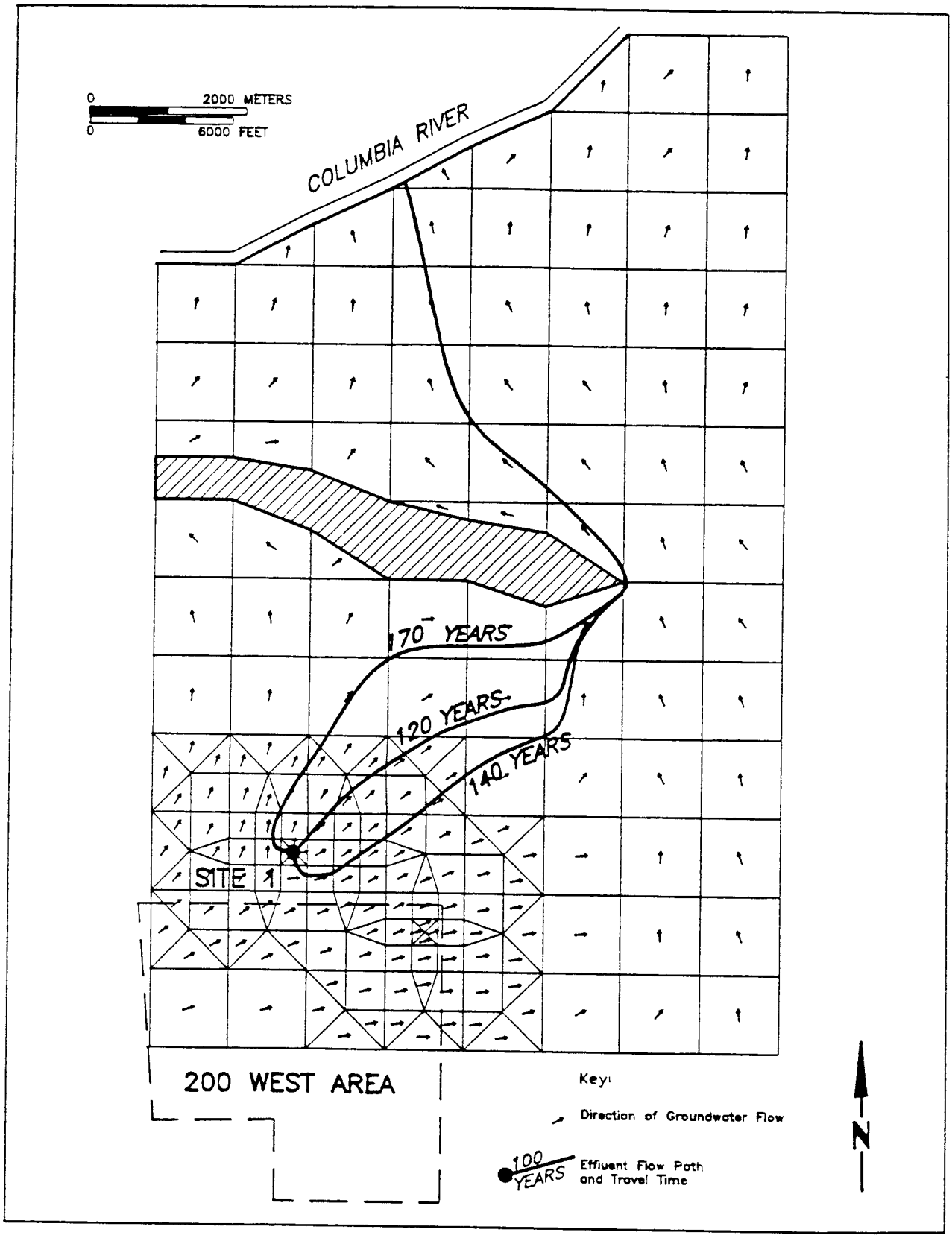

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Figure 14. Travel Times from Site 1 with Disposal Facility Influx.

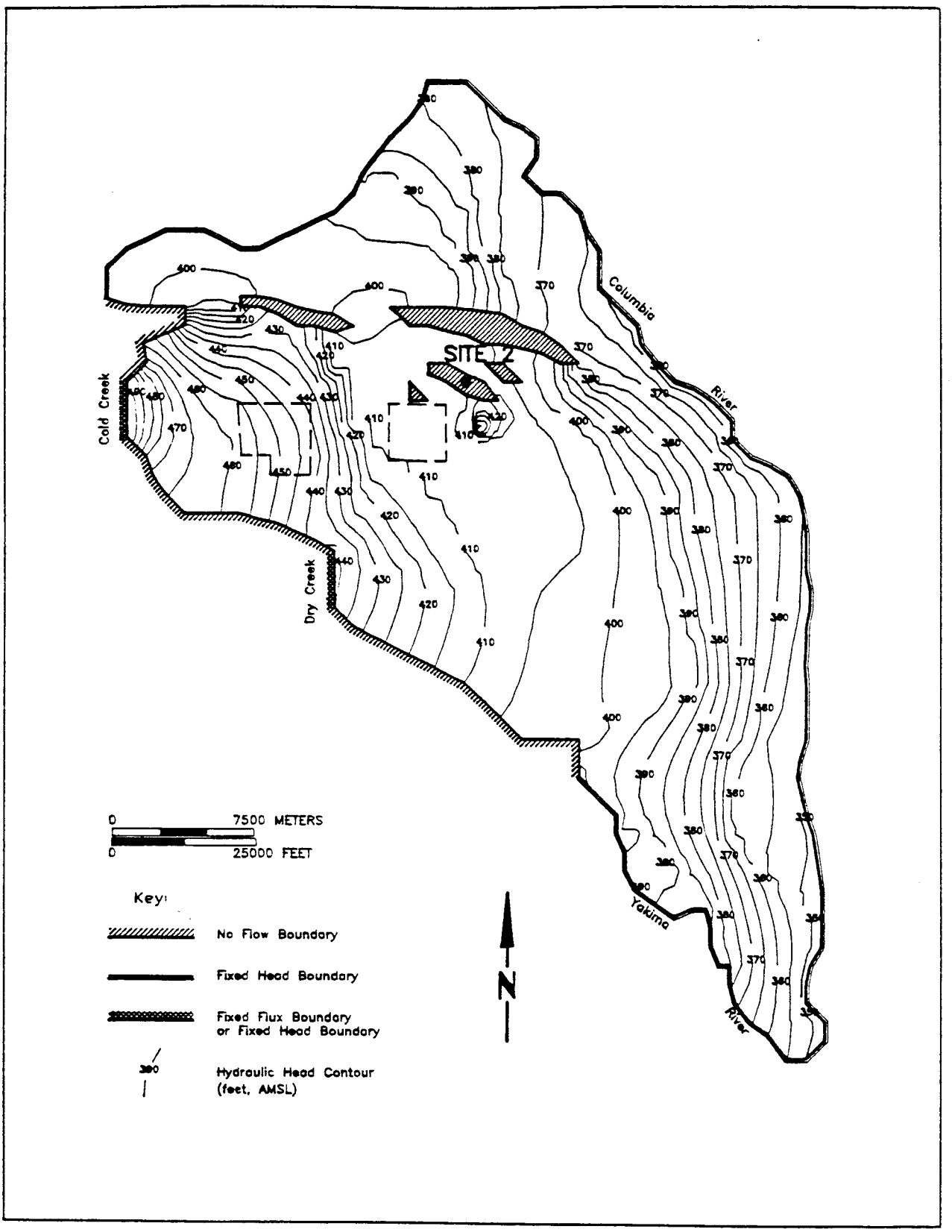

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Figure 15. Hydraulic Head Contours with Influx from Site 2.

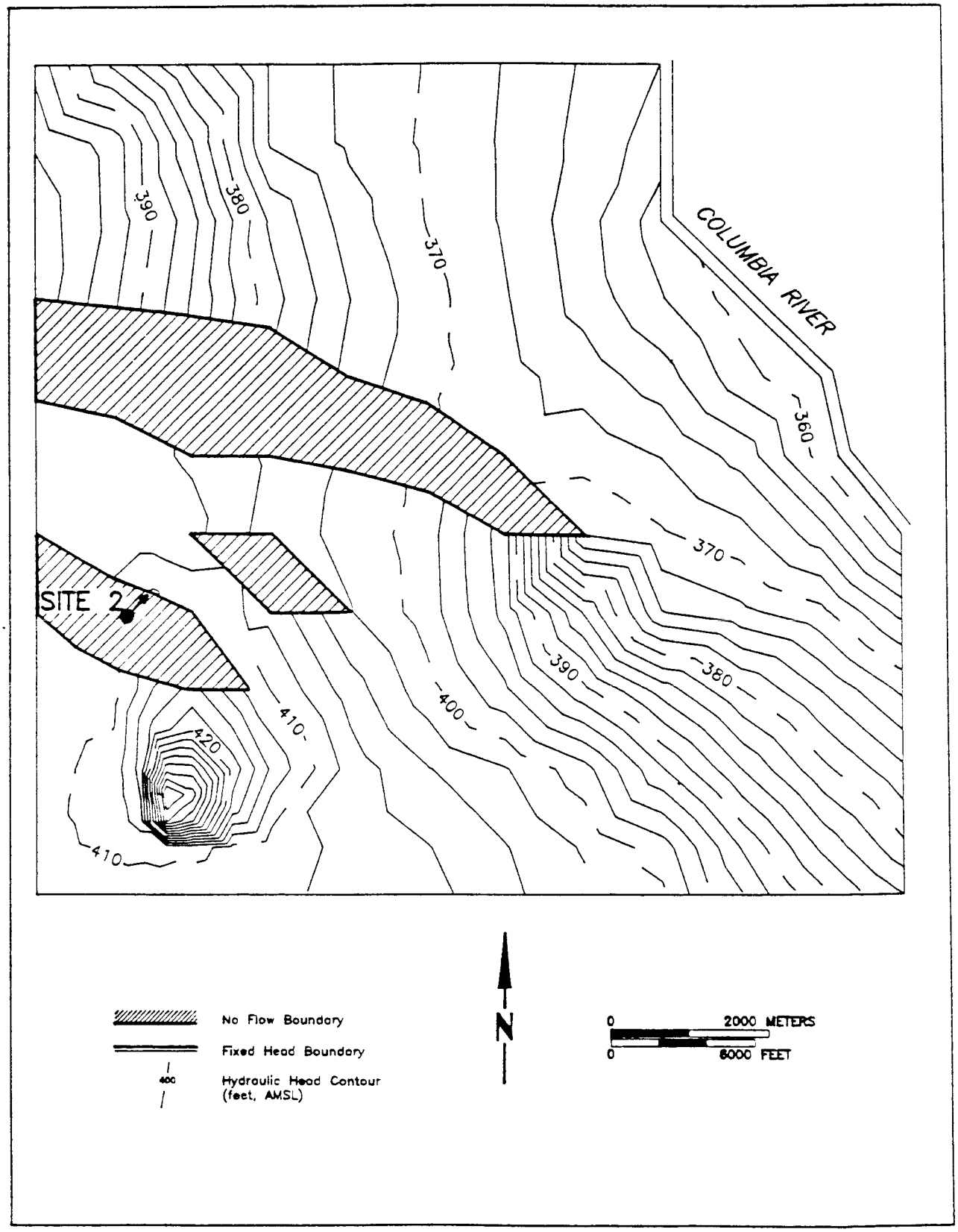

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Figure 16. Details of Hydraulic Head Contours with Influx from Site 2.

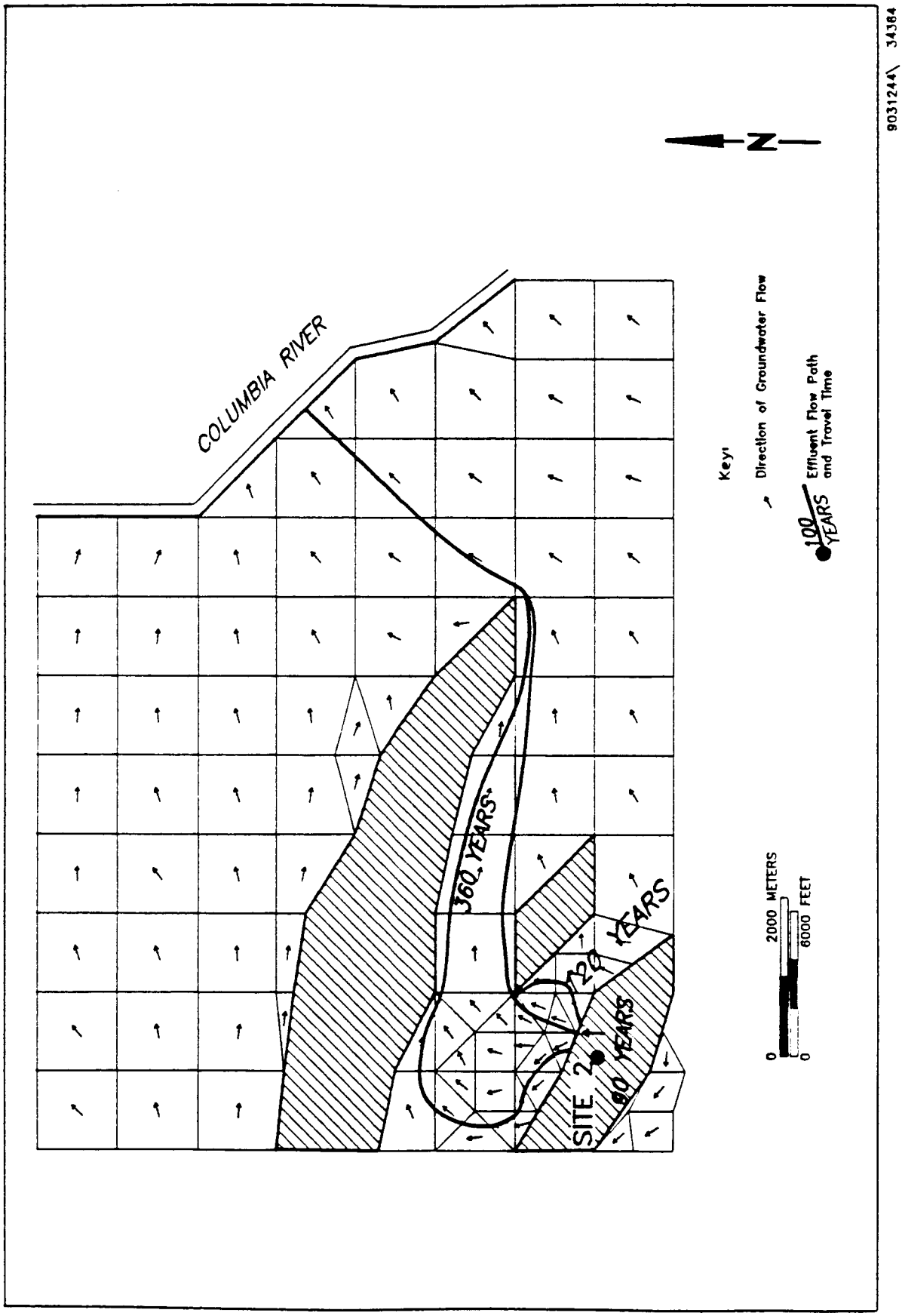

Figure 17. Travel Time from Site 2 with Disposal Facility Influx.

paths are about 120 and 360 years. The 360 year travel time occurs because of a new low-gradient region which forms to the northwest of the discharge node. Note that if effluent were to flow southwest down the bedrock surface it would enter a region of high groundwater velocities and the travel time would be much less.

3.4 INFLUX FROM SITE 3

This simulation included influx of 16.5 million gallons per day from B-pond, 150 gallons per day from Site 3, and no influx from the other facility locations. Contours of hydraulic head for the entire modeled area are shown in Figure 18. Velocity vectors are not shown because they are so similar to those shown in Figure 6.

Details of hydraulic head contours near Site 3 are shown in Figure 19. The model results indicate that the facility influx at Site 3 results in a maximum groundwater rise of about 11 feet at the discharge node. This is the largest groundwater rise of any of the facility locations and results from the low transmissivity at this location. Facility influx at Site 3 also has the most extensive impact on groundwater flow patterns of any of the three sites.

Figure 20 shows three flow paths and travel times from Site 3 to the Columbia River. The most direct flow path has a travel time of about 80 years, which is 10 years shorter than the travel time with no facility influx. The travel times for the two non-direct flow paths are about 120 and 220 years.

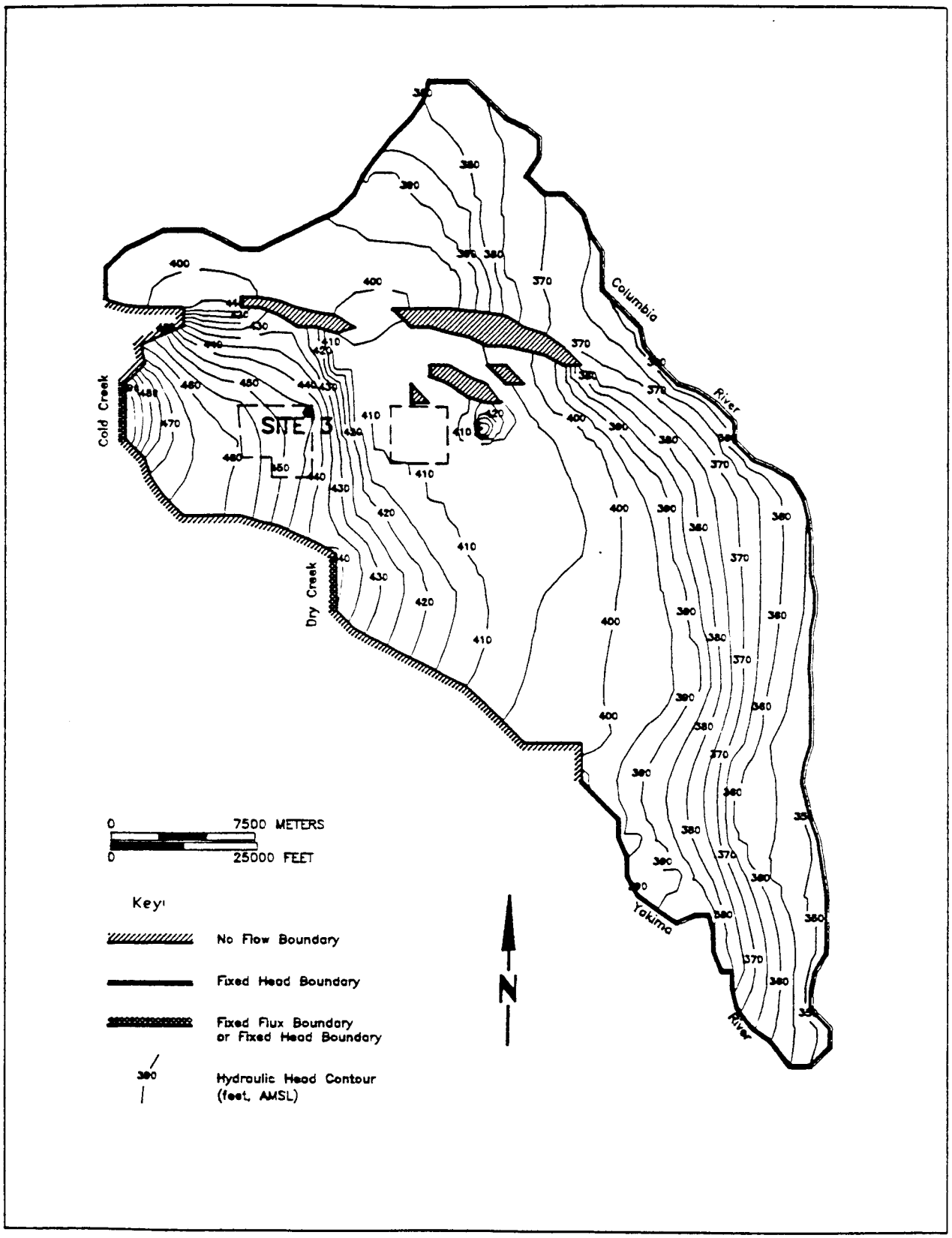

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Figure 18. Hydraulic Head Contours with Influx from Site 3.

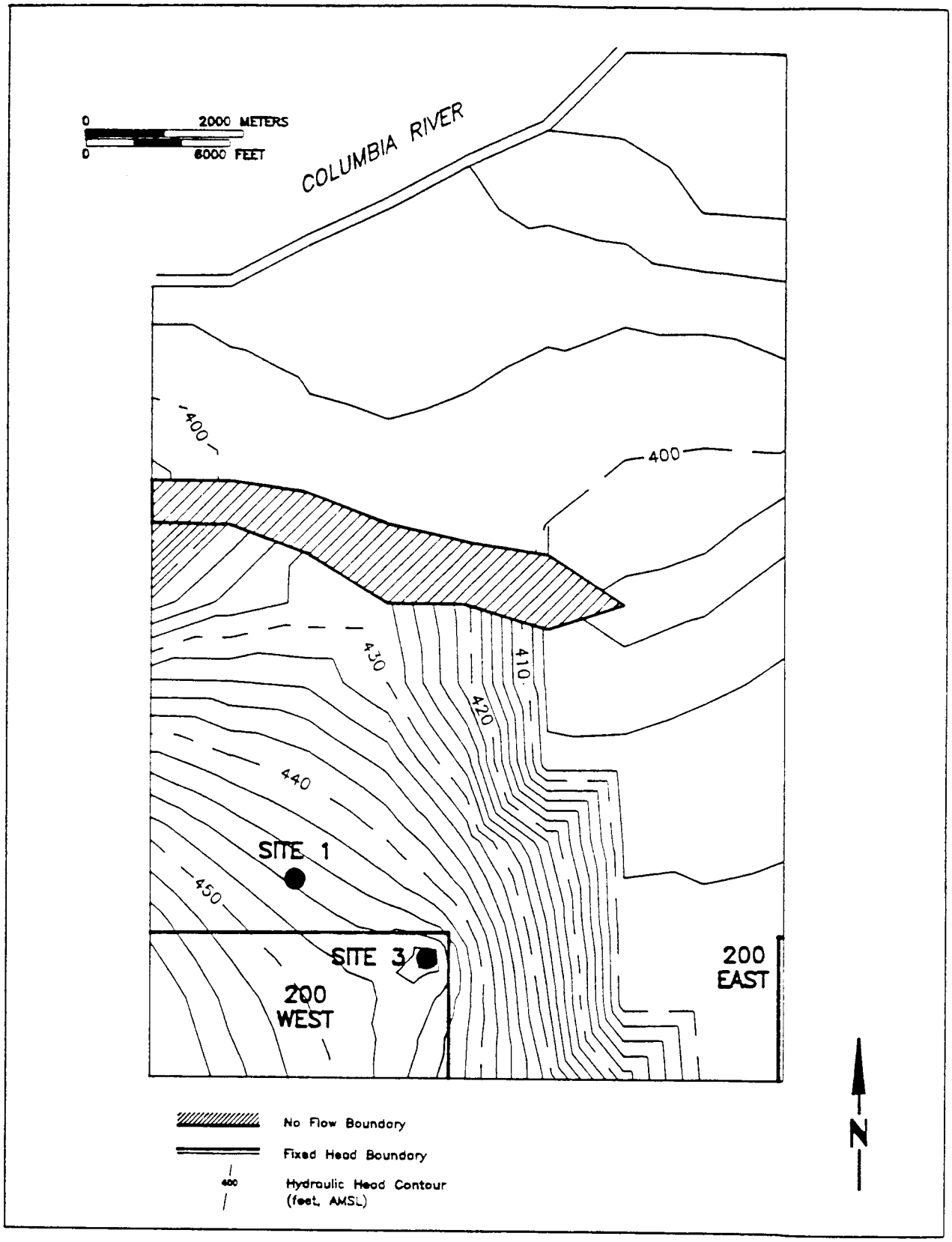

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Figure 19. Details of Hydraulic Head Contours with Influx from Site 3.

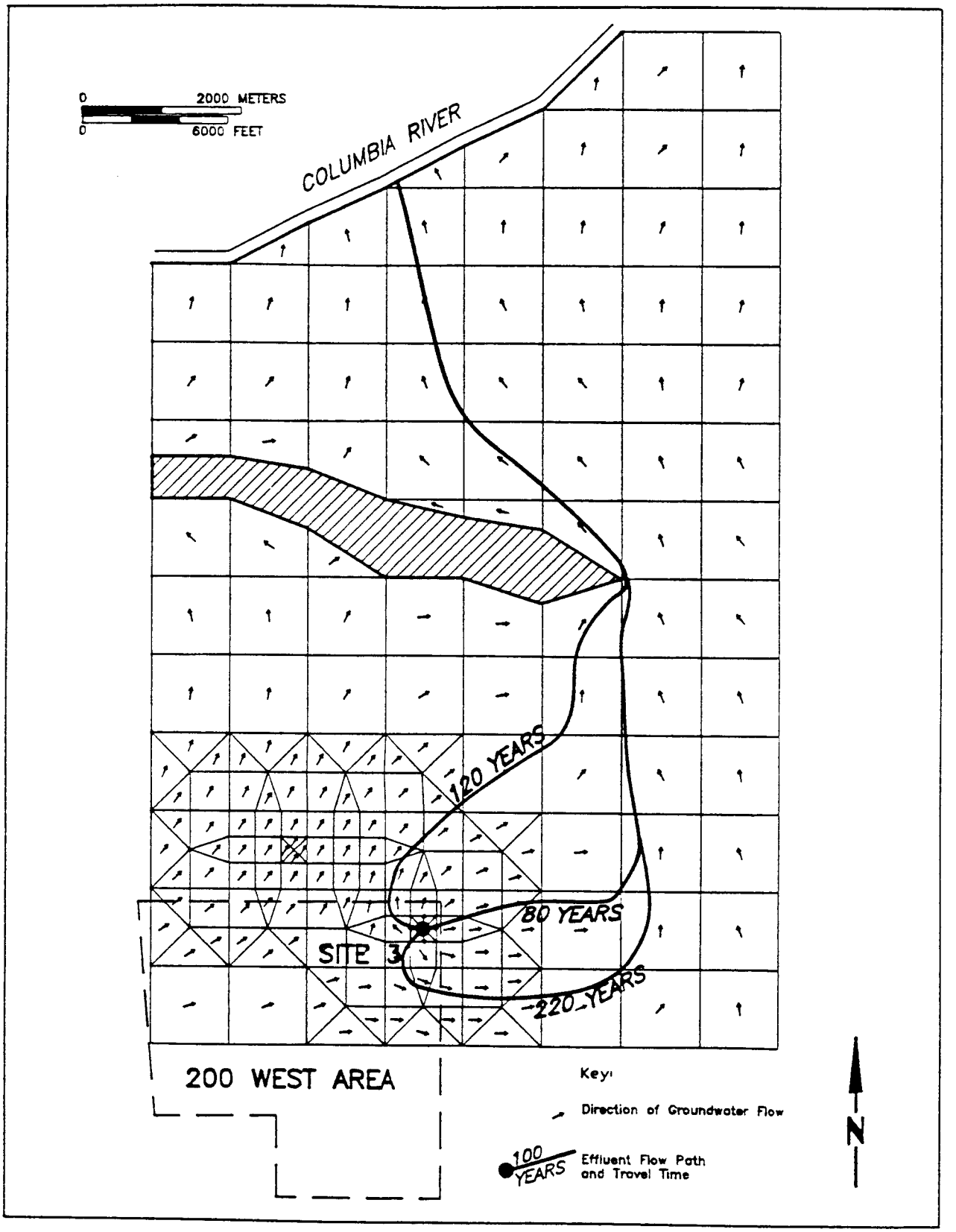

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Figure 20. Travel Times from Site 3 with Disposal Facility Influx.

4.0 CONCLUSIONS AND RECOMMENDATIONS

Maximum groundwater mounding associated with discharge at the alternative disposal facility locations ranged from approximately 4 feet at Site 2, to approximately 11 feet at Site 3. These differences in groundwater mounding are due to differences in hydraulic conductivity, aquifer thickness, and the area over which the influx is distributed. Table 2 summarizes groundwater mounding and aquifer parameters for the three sites. As mentioned in Section 2.2 the two-dimensional assumption implicit in the model may result in an underestimation of groundwater mounding.

Table 2. Groundwater Mounding and Aquifer Parameters for the Alternative Disposal Site Locations.

Site	Maximum Groundwater Mounding (ft)	Hydraulic Conductivity (ft/day)	Thickness (ft)	Transmissivity (ft^2/day)
1	6	20	180	3,600
2	4	120	60	7,200
3	11	20	80	1,600

Groundwater mounding will cause changes in flow patterns near the facilities, and the impact of these changes on nearby groundwater monitoring networks and the potential mobilization of existing soil and groundwater contaminants should be assessed. Because Site 3 is located inside the 200 West Area it appears to have the most potential for changing flow directions in areas that are heavily monitored.

Travel times both with and without the facility influx are summarized in Table 3 for the alternative facility locations. Travel times without facility influx range from approximately 90 years for Site 3 to approximately 180 years for Site 2, suggesting that Site 2 would provide the longest residence time for low volume streams. The direct travel times for simulations with facility influx of 150 gallons per minute ranged from 80 years for Site 3 to 120 years for Site 1, suggesting that Site 1 would provide the longest residence time for streams with flow rates in this range.

Table 3. Travel Times to the Columbia River for the Alternative Disposal Site Locations.

Site	Travel time with no facility influx (years)	Travel Times with facility influx (years)		
		Direct	Left	Right
1	130	120	170	140
2	180	90	360	120
3	90	80	120	220

The range in travel times will cause the tritium concentration at the river to increase gradually, even when the additional effects of dispersion and radioactive decay are not considered. The effects of the groundwater mounding on the buildup of tritium concentrations at the river are difficult to predict from the results of the present investigation. A facility location with a shorter direct travel time may experience a slower increase in concentration when the alternative flowpaths resulting from the mounding are considered, and thus would provide a longer average residence time. A subsequent transport modeling study will address these effects.

The travel times presented in this study should be considered approximate. The modeling results are influenced by uncertainties in the geologic and geohydrologic data base, and by the limitations imposed by two-dimensional modeling. The model and its data base are considered adequate and appropriate for the purposes of the travel time analyses, but, as discussed in the text, may underestimate the heights of the groundwater mounds beneath the alternative facility locations. The comparison of simulated plume travel times with observed plumes in Appendix A suggests that the uncertainty in travel times is on the order of 10 to 30 percent for Sites 1 and 3. Given the relative lack of hydrogeologic information near Site 2, the uncertainty may be higher. These uncertainties could be reduced by performing sensitivity studies and reevaluating the mound heights and extents with three-dimensional modeling.

In addition, other factors, beyond the scope of this investigation, should be evaluated before selecting a final disposal site. Facility performance will be sensitive to geologic and geohydrologic conditions at the facility location, and field studies should be conducted to investigate such factors as the presence of potential perching horizons, the vertical and horizontal hydraulic conductivities, and the effective porosity in both saturated and unsaturated zones.

Uncertainties in performance are higher at Site 2 than at the other sites because of the geological complexity of the area and its location above a basalt subcrop. Site 2 is in an area that has experienced substantial folding which could result in pathways for contaminants to reach underlying confined aquifers. Also, the direction the effluent would flow upon reaching the subcrop could significantly affect travel times and should be known before siting a facility at this location.

5.0 REFERENCES

Engineering-Science, Inc., 1989. 200 Area Treated Effluent Disposal Study. Prepared for Westinghouse Hanford Company, Richland, Washington, by Engineering-Science, Inc., Denver, Colorado, under contract to Golder Associates Inc., Redmond, Washington, April.

Golder Associates Inc., 1990. Travel Time Estimates for Alternative Tritium Facility Locations, Hanford Site, Washington. Prepared for Westinghouse Hanford Company, Richland, Washington, by Golder Associates Inc., Redmond, Washington, March.

APPENDIX A

NUMERICAL GROUNDWATER MODELING

APPENDIX A

NUMERICAL GROUNDWATER MODELING

PURPOSE

Groundwater modeling was performed to support consideration of the soil column disposal option. Specific objectives of the modeling effort included:

1) Demonstrate how groundwater flow patterns would be impacted by various disposal schemes.

2) Provide estimates of travel time under various disposal schemes.

3) Investigate whether it is possible to dispose of the necessary volumes of effluent to the subsurface without causing groundwater mounding which would impact existing soil contamination.

4) Estimate the dilution due to dispersion during subsurface flow to the Columbia River from various disposal sites.

THE COMPUTER CODE

The computer codes used for this modeling effort are primarily parts of the Golder Groundwater Package. The Package includes state-of-the-art finite element computer programs for simulation of groundwater flow and contaminant transport, as well as graphics programs for presentation of the results. Golder Associates Inc. (GAI) has developed the package to simulate a variety of two- and three-dimensional systems. For the purposes of this modeling effort the program AFPM (Aquifer Flow in Porous Media) was utilized. AFPM is designed to simulate groundwater flow through a system of interconnected aquifers, although only one layer was used in this work. The program accommodates variable aquifer properties, a changing phreatic surface, transient boundary conditions, and other characteristics useful for groundwater modeling at the Hanford Site.

DEVELOPMENT OF THE CONCEPTUAL MODEL

The initial stage of conceptual model development was to define a domain and discretize that domain into a finite element grid. For purposes of modeling large-scale groundwater flow at the Hanford Site, a two-dimensional grid was defined between the basalt ridges on the west side, and the Columbia and Yakima Rivers on the north, east, and south sides of the modeled region. Locations of the basalt ridge boundaries were determined using maps from Gephart et al. (1979) and Serkowski et al. (1988); the river boundaries were located using the United States Geological Survey (USGS) 7.5′ topographic quadrangles. Arbitrary boundaries were defined across Cold Creek and Dry Creek Valleys. The modeled domain along with the nodes and elements comprising the grid are shown in Figure H.1. 976 nodes and 920 elements were used to discretize the domain. Most of the elements were square with side lengths of 3275 feet.

After discretizing the domain, the boundary conditions were defined. Fixed-head conditions were established along the river boundaries using values of head from the June 1987 water table map in Serkowski et al. (1988). For calibration purposes, fixed head conditions were also used across the Cold Creek and Dry Creek Valleys. The head values across these boundaries were fixed according to the observed heads reported on the respective calibration standards discussed in the following paragraphs. Along boundaries defined by basalt extending above the water table the model assumed zero flux conditions across the boundary. Zero flux conditions were also assumed along the base of the aquifer. The validity of these boundary conditions will be discussed in the next section.

Initial hydraulic conductivity values were estimated from Plate III-5 in Gephart et al. (1979). The domain was divided up into 27 regions, each of which was assigned a value for hydraulic conductivity, storativity and specific yield. Storativity and specific yield were only important for transient simulations. Although some transient flow modeling was conducted the results were not found to be relevant to the objectives of the study and are not presented.

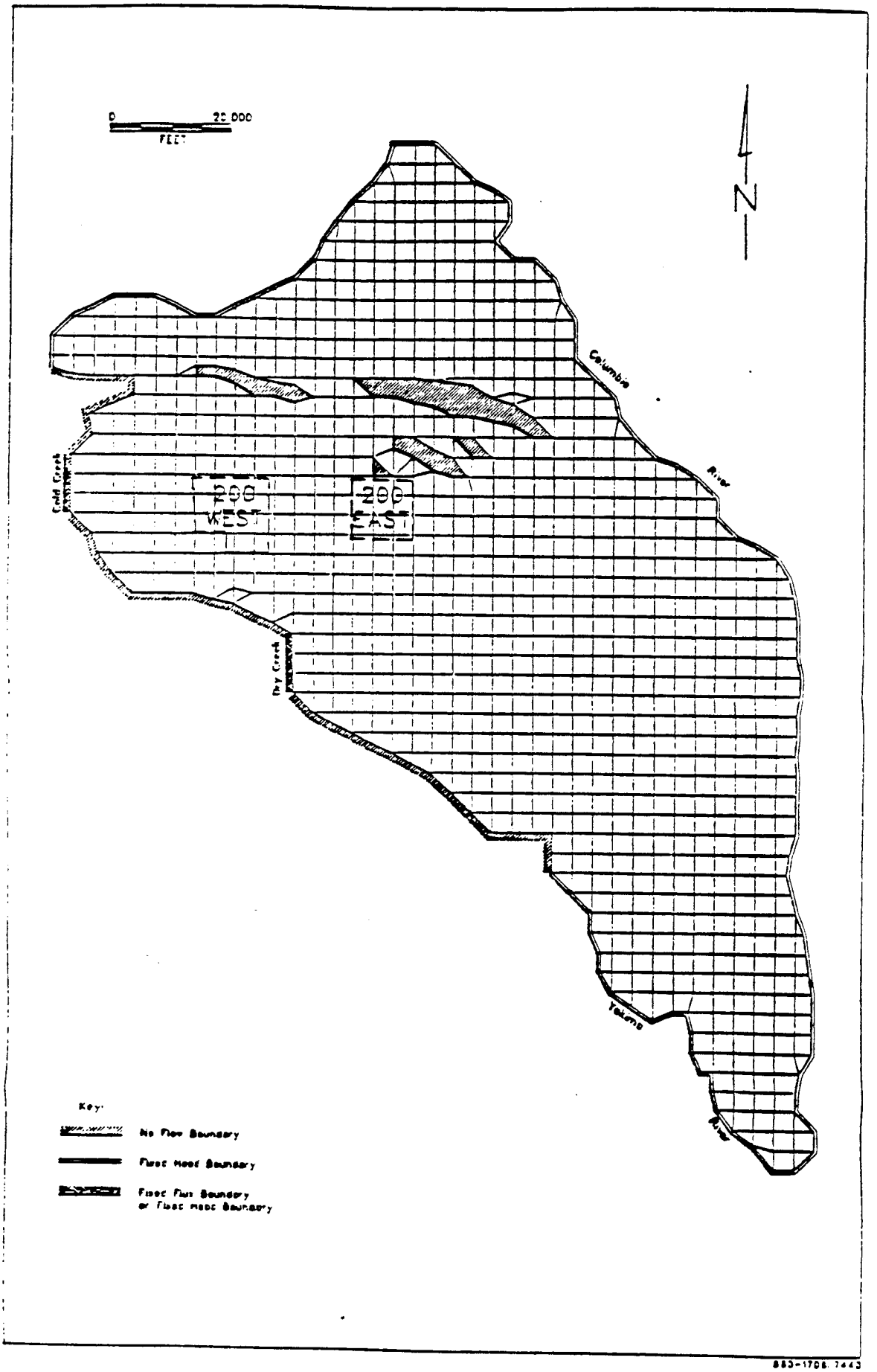

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Figure II-1. Finite Element Grid

For the first calibration analysis a contour map of 1979 water levels was used as a standard (Plate III-4 in Gephart et al. (1979)). By 1979 the major disposal facilities, B-Pond, Gable Mountain Pond and U-Pond, had been operating for several decades, and groundwater elevations were probably close to steady state levels. The assumed distribution and rates of artificial recharge used for this calibration were estimated from data summarized in Zimmerman et al. (1986); the location and rates of artificial recharge are shown on Figure H.2. Hydraulic conductivities were adjusted until the steady state solution visually approximated the observed 1979 head contours to within about five vertical feet.

To help confirm the estimated hydraulic conductivities a second calibration analysis was performed using a contour map of 1944 water table elevations from Gephart et al. (1979) as a standard. Since effluent discharge was not significant until the mid to late 1940's no artificial recharge was applied to the simulation region. Hydraulic conductivities were adjusted until reasonably close results were obtained for both the 1944 and 1979 calibration standards. When calibration was complete the hydraulic conductivities ranged from 20 to 15000 feet/day. These values are similar to the range of 9 to 10000 feet/day reported by Graham et al. (1981) for the middle Ringold and Hanford units. The hydraulic head contours and Darcy velocity fields for the calibration runs are shown in Figures H.2 through H.5.

During calibration runs fixed head conditions were used across Cold Creek and Dry Creek Valleys. In order to model the various effluent disposal schemes it was necessary to allow the head elevations to change along these sections of boundary. Consequently, these boundaries were changed from fixed head to fixed flux boundaries. The amount of flux across the Cold Creek and Dry Creek boundaries for simulation of future disposal schemes was fixed at the rate which occurred in the 1979 calibration run. These fluxes are as much as ten times larger than those calculated by others (Graham et al. (1981)). Implications of these discrepancies are discussed in the following section.

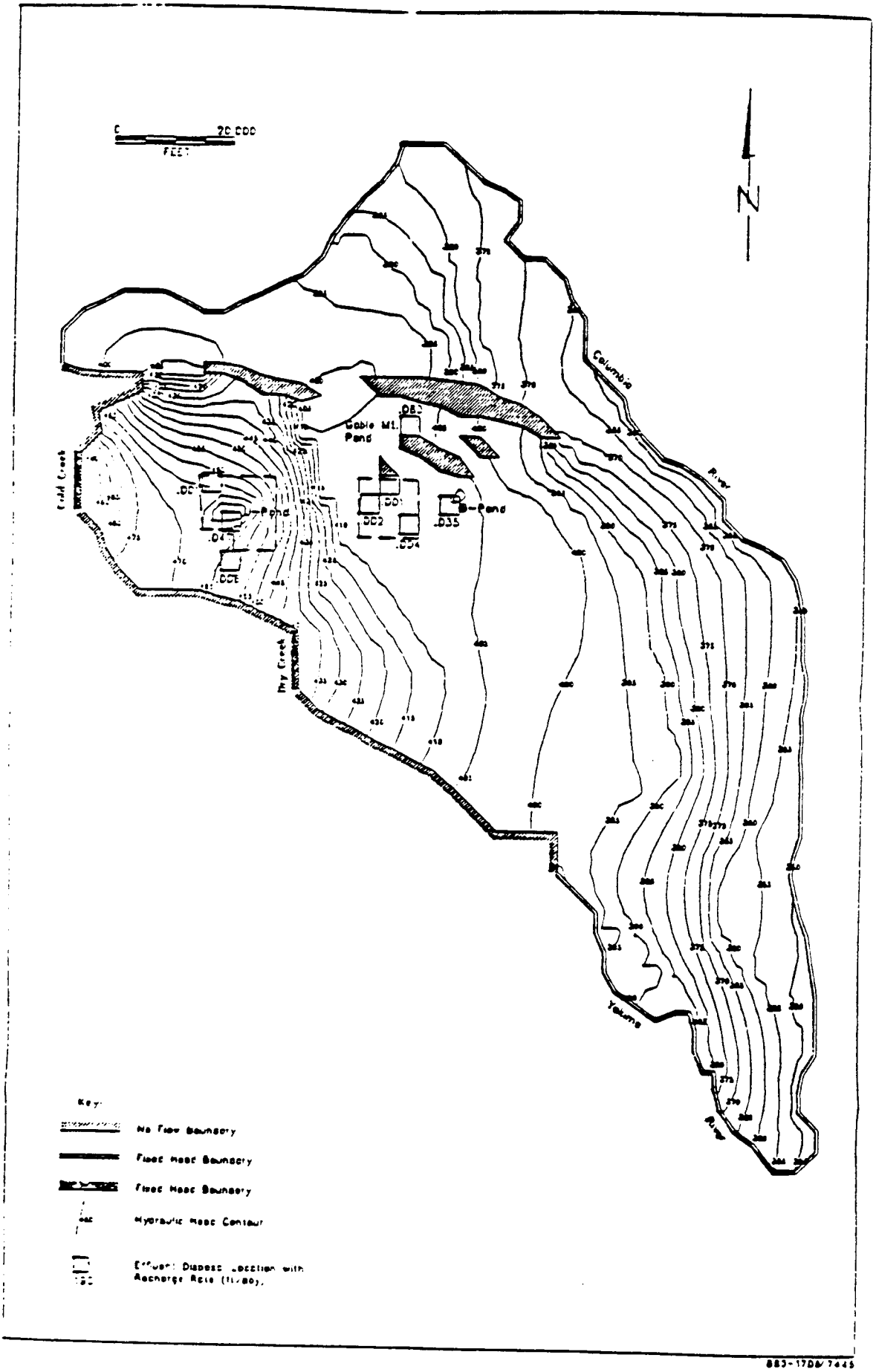

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Figure II-2. 1979 Calibration Results
Hydraulic Head Contours

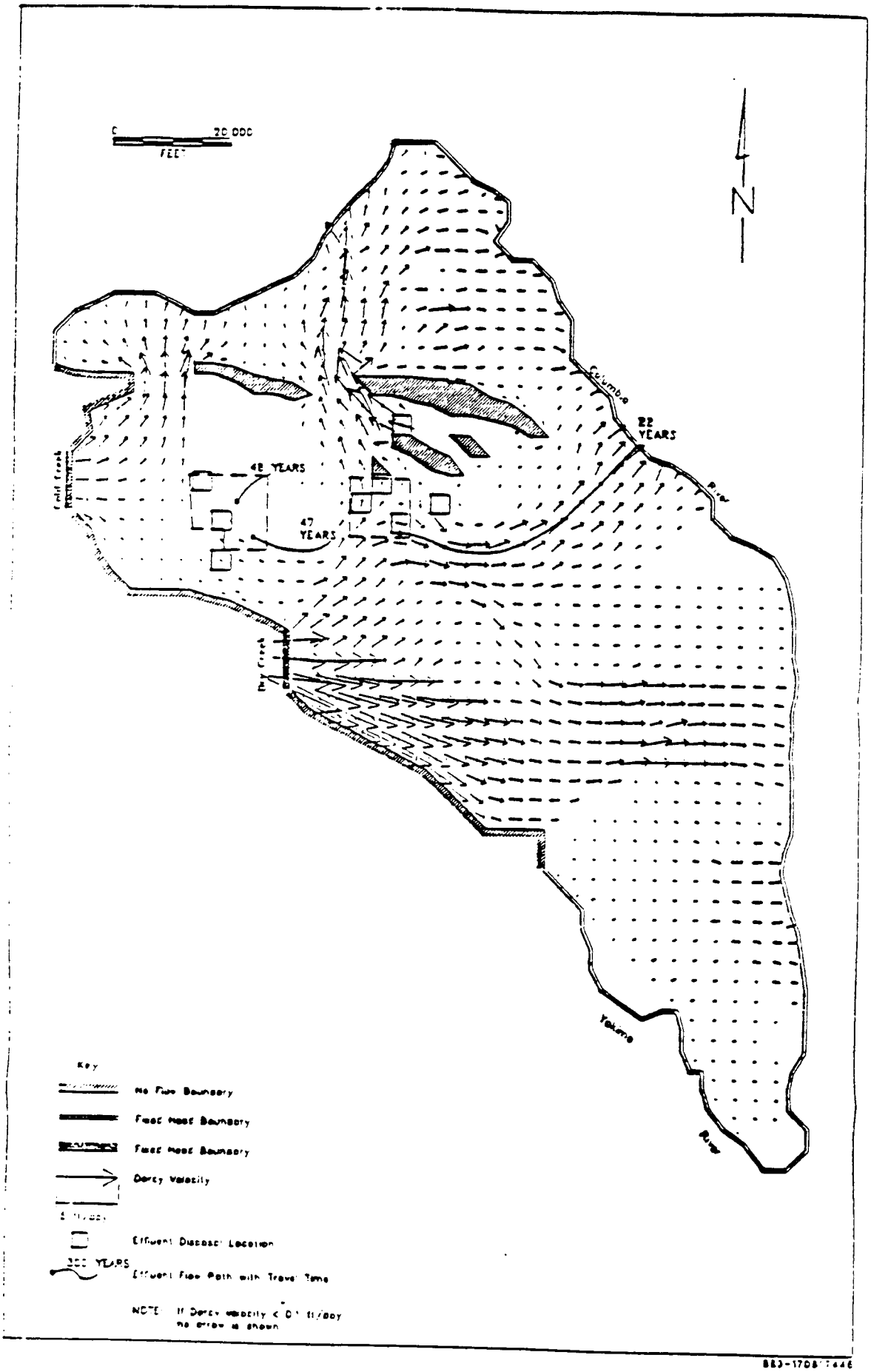

Figure II-3. 1979 Calibration Results
Darcy Velocity Vectors

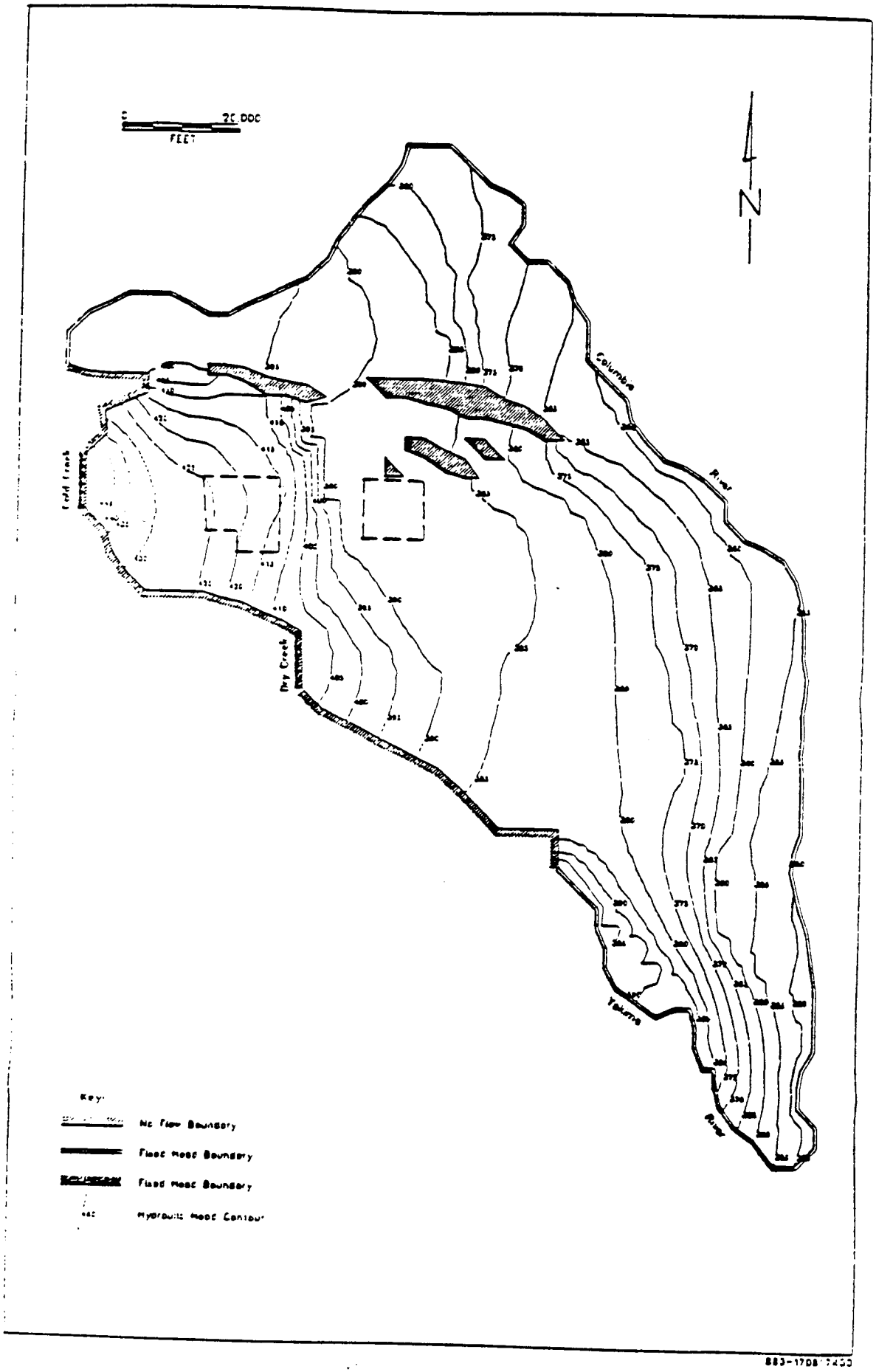

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Figure H-4. 1944 Calibration Results
Hydraulic Head Contours

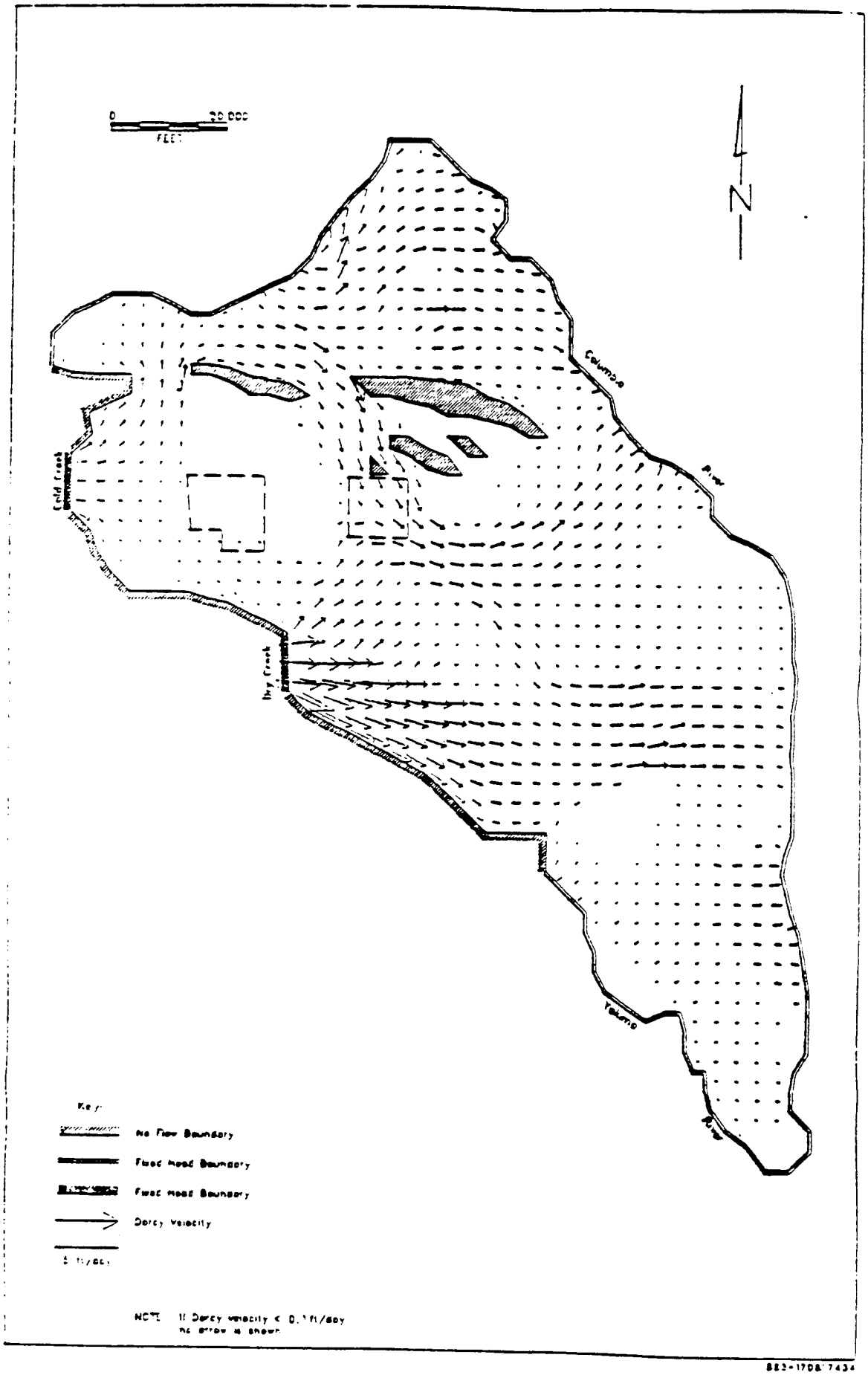

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Figure II-5. 1944 Calibration Results
Velocity Vectors

ASSUMPTIONS AND LIMITATIONS

Any modeling of groundwater processes requires some assumptions. An explanation of the rational for the assumptions is helpful for assessing the uncertainty of the results. The assumptions used in this modeling effort are discussed below.

1) Fixed head boundary conditions were used along the Columbia and Yakima Rivers. As explained above, the values of head were fixed at elevations reported in a map of 1987 water levels. If a low permeability layer exists along the base of the river a fixed head boundary condition may not be the most appropriate. Since the nature of any low permeability layer is presently unknown, we decided to use fixed head conditions. Furthermore, any fluctuation in the stage of the river may cause transient changes in groundwater flow not accounted for in this conceptual model. These effects should be confined to the region near the river and were not important to the objectives of this modeling effort.

2) Zero flux conditions were assumed along the basalt ridge boundaries and the base of the aquifer. Although flow probably occurs across these boundaries, quantifying this flow is virtually impossible given the current state of knowledge.

3) Natural recharge due to infiltration of precipitation was assumed to equal zero. Lysimeter studies discussed in Gee and Heller (1985) and Gee (1987) have indicated that evapotranspiration removes all precipitation from the soil column if the surface is vegetated. It has also been observed, however, that significant recharge may occur in gravelly surfaces with no vegetation (Gee (1987)). Observations of the Hanford site indicate that vegetation covers most of the surface, suggesting that natural recharge would be insignificant.

   As mentioned in the previous section, our model estimates of fluxes out of Cold Creek and Dry Creek Valleys are considerably higher than those estimated by others. If some

natural recharge across the Hanford Site were allowed, due to precipitation or due to flux across no-flow basalt boundaries, the amount of flow from Cold Creek and Dry Creek Valleys required for proper calibration would be lower. In order to achieve this lower flow in the model the hydraulic conductivities near these valleys would have to be reduced; reduction of hydraulic conductivities near these boundaries might impact hydraulic conductivities, groundwater flow patterns, and calculated travel times over the entire site. Because of the calibration approach used in this study, however, the possible changes in site-wide conductivities would not be expected to be large. The reason for this is that the heights of the groundwater mounds and the fluxes that created these mounds were used in the 1979 calibration run to establish the values of conductivity near the mounds. Because the relative values of conductivity were known over the entire simulation region from calibration to head data, knowing the conductivity at the mounds permitted the remaining conductivity values to be quantitatively determined.

4) The thickness of the aquifer was estimated from Plate III-2 in Gephart et al. (1979). Although the base of the aquifer is defined as the top of the uppermost basalt flow over most of the simulation region, the lower Ringold is defined as the base of the aquifer where it is present. The lower Ringold is a low permeability layer which only occurs in the western part of the modeled region (Tallman et al. (1979)). A high conductivity layer, the basal Ringold, is present beneath the lower Ringold. It is possible that flow through the lower Ringold into the basal Ringold may impact groundwater flow dynamics above the lower Ringold. Although the Golder Groundwater Package is capable of modeling multi-layered aquifers, the general objectives of this modeling effort did not warrant the additional time and expense of modeling a second layer.

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5) The fundamental flow equations used by the AFPM program are derived using standard assumptions for two-dimensional flow modeling, including no vertical flow, vertical averaging of hydraulic conductivity, and deterministic approximation of the flow parameters. These assumptions, plus the assumption of an isotropic medium, were used in the model. Furthermore, the aquifer was modeled as a phreatic aquifer with variable saturated thickness.

RELIABILITY OF THE MODEL

Given the assumptions discussed in the previous section the reliability of the results is difficult to assess. Rigorous quantification of uncertainty would require extensive sensitivity analysis and/or a stochastic approach which were not warranted considering the objectives of this study. A simple method to evaluate the validity of a model is to compare observed travel times with those predicted by the model. A map of the Hanford Site showing tritium concentrations is presented in Figure H.6. At least three tritium plumes originate from sources in the separations area. One of these plumes originates from the 200 East Area and the other two from the 200 West Area.

The plume from the southeast corner of the 200 East Area includes an elevated pulse of tritium which reached the Columbia River in the mid-1980's (Law and Allen (1984); Serkowski et al. (1988)). Tritium is contained in effluent from the PUREX plant which commenced major disposal to cribs in the southeast corner of the 200 East area in the late 1950's (Zimmerman et al. (1986)). Assuming that the main plume of tritium reached the Columbia between 1983 and 1987, the observed travel time to the Columbia River would be approximately 25 years. In a review of travel time estimates, Freshley et al. (1988) concluded that travel times from the 200 East Area could range from 13-23 years. Using the 1979 calibration results, and a porosity of 0.25, the travel time from the southeast corner of the 200 East area is estimated at 22.5 years. The modeled travel path is shown on Figure H.3. Since travel time varies linearly with the value of porosity used in the calculation, and

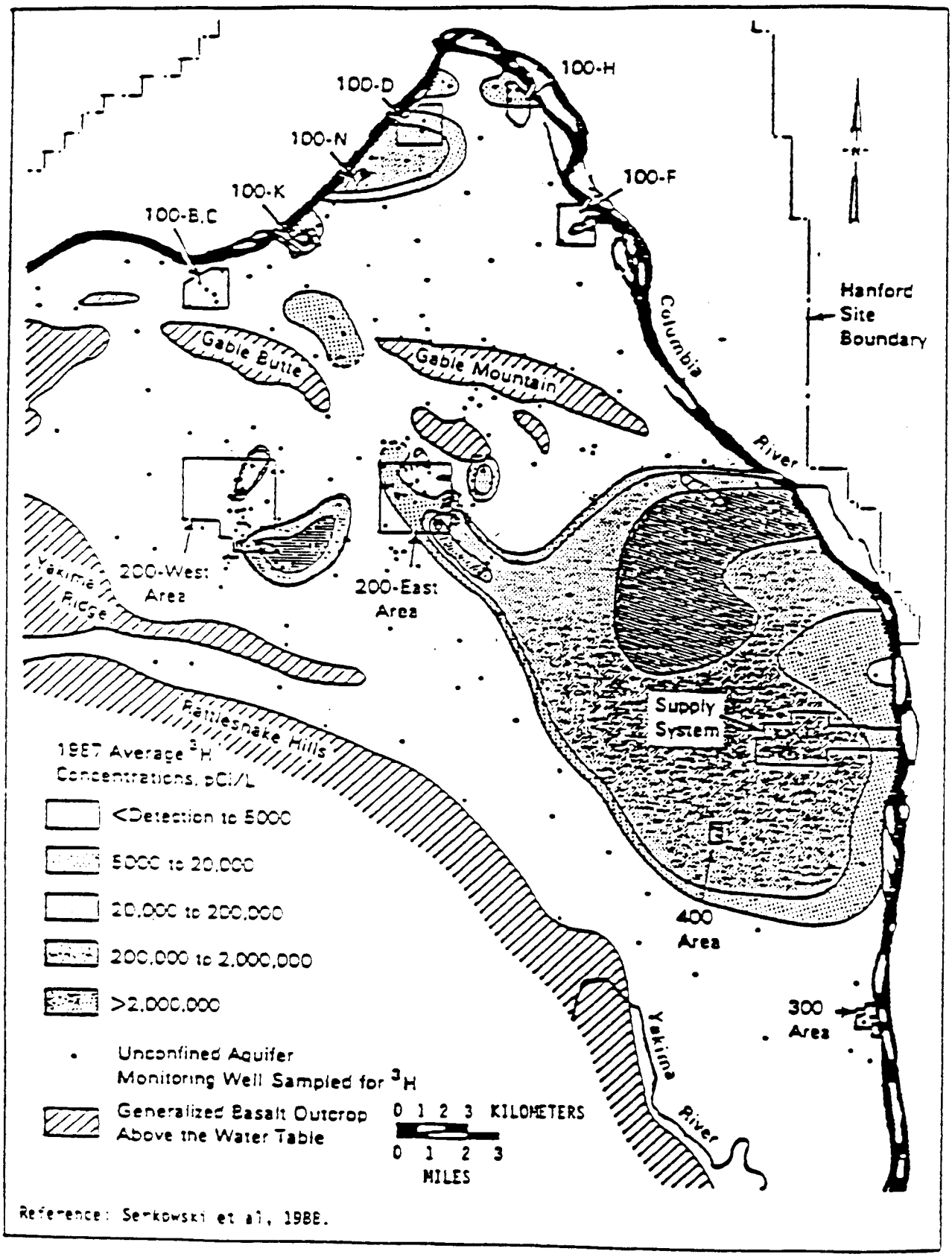

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Figure H-6. Tritium Plume Map for the Hanford Site, 1987

porosity for high permeability materials could range from 0.2 to 0.3, the estimated travel time is probably between 18 and 27 years. This is in agreement with the observed travel time of 25 years.

Two tritium plumes with sources in the 200 West Area are also apparent in Figure H.6. Assuming that both plumes have been produced since effluent disposal began in the late 1940's, they are approximately 40 years old. Travel paths and travel times using the 1979 simulated flowfield are shown on Figure H.3 for transport similar to the observed plumes. Using a porosity of 0.15, the travel times predicted by the model are 47 to 48 years. For the lower permeability materials in the western part of the Hanford Site porosity could vary from 0.1 to 0.2, suggesting a range in travel time from 32 to 63 years. The observed travel time of 40 years is well within this range. The accuracy of the model predictions of travel time lends confidence to the validity of the model.

STEADY STATE RESULTS

Three steady state simulations are presented below. In all three simulations the flux out of Cold Creek and Dry Creek Valleys is fixed at the rate which occurred in the 1979 calibration run.

Simulation 1 is for the case when no effluent is disposed to the groundwater. The resulting water table map and velocity vectors are shown in Figures H.7 and H.8. As expected, the mounding beneath the 200 West Area and beneath B-Pond has dissipated. The results differ from the 1944 calibration run because the flux out of Cold Creek and Dry Creek Valleys has increased significantly, presumably due to increased irrigation in these valleys.

The other two simulations are for effluent disposal to the subsurface at two different sites. These sites are labeled as the "Primary Disposal Site" on Figures H.9 through H.12. Since one criterion for a subsurface disposal site was to avoid impacting existing vadose zone soil contamination, the locations were chosen to lie well outside known solid or liquid waste disposal sites. In addition, the locations were within the high transmissivity zone running through the

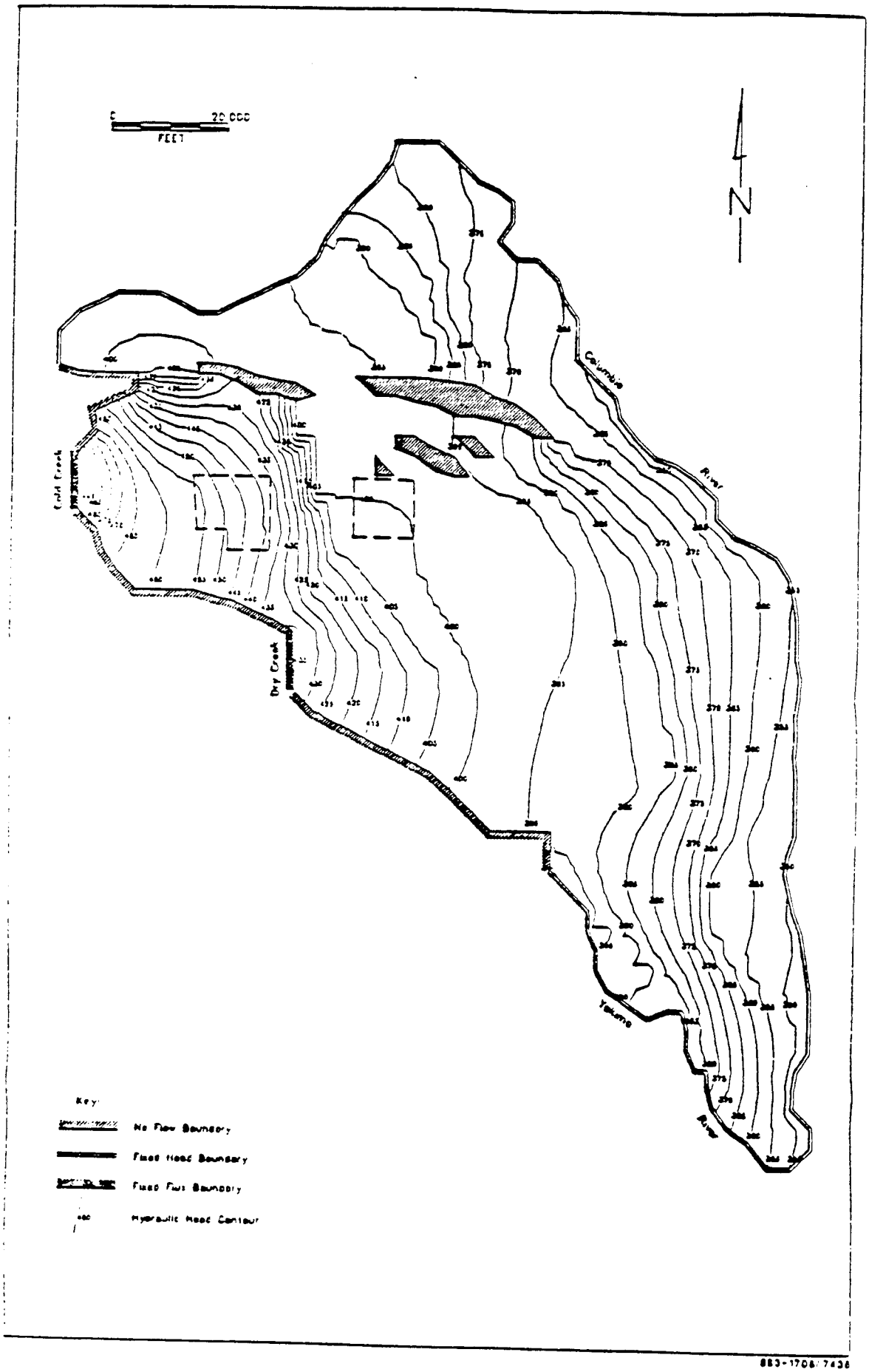

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Figure II-7. Simulation 1 - No Discharge Hydraulic Head Contours

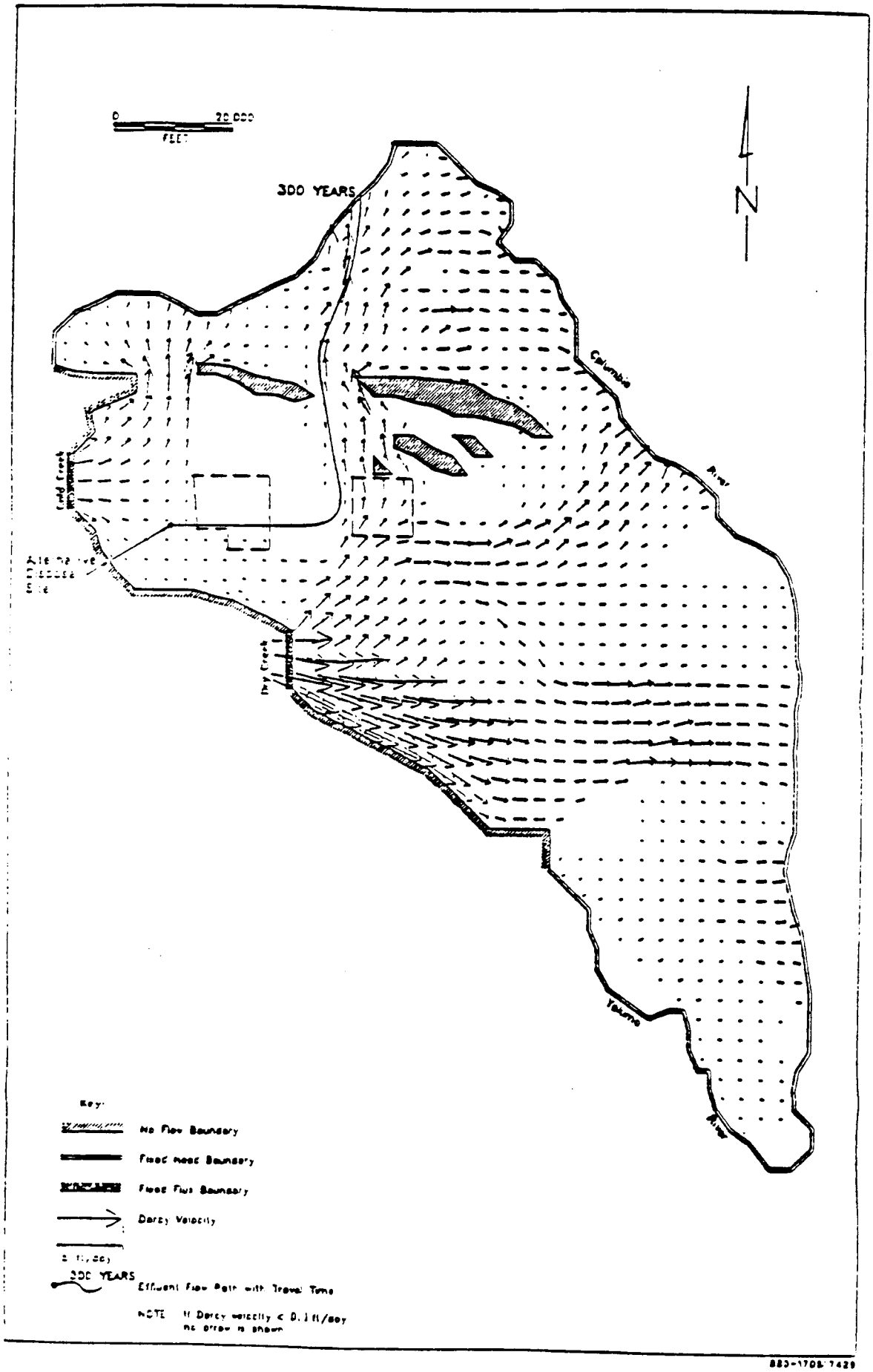

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Figure II-8. Simulation 1 - No Discharge Velocity Vectors

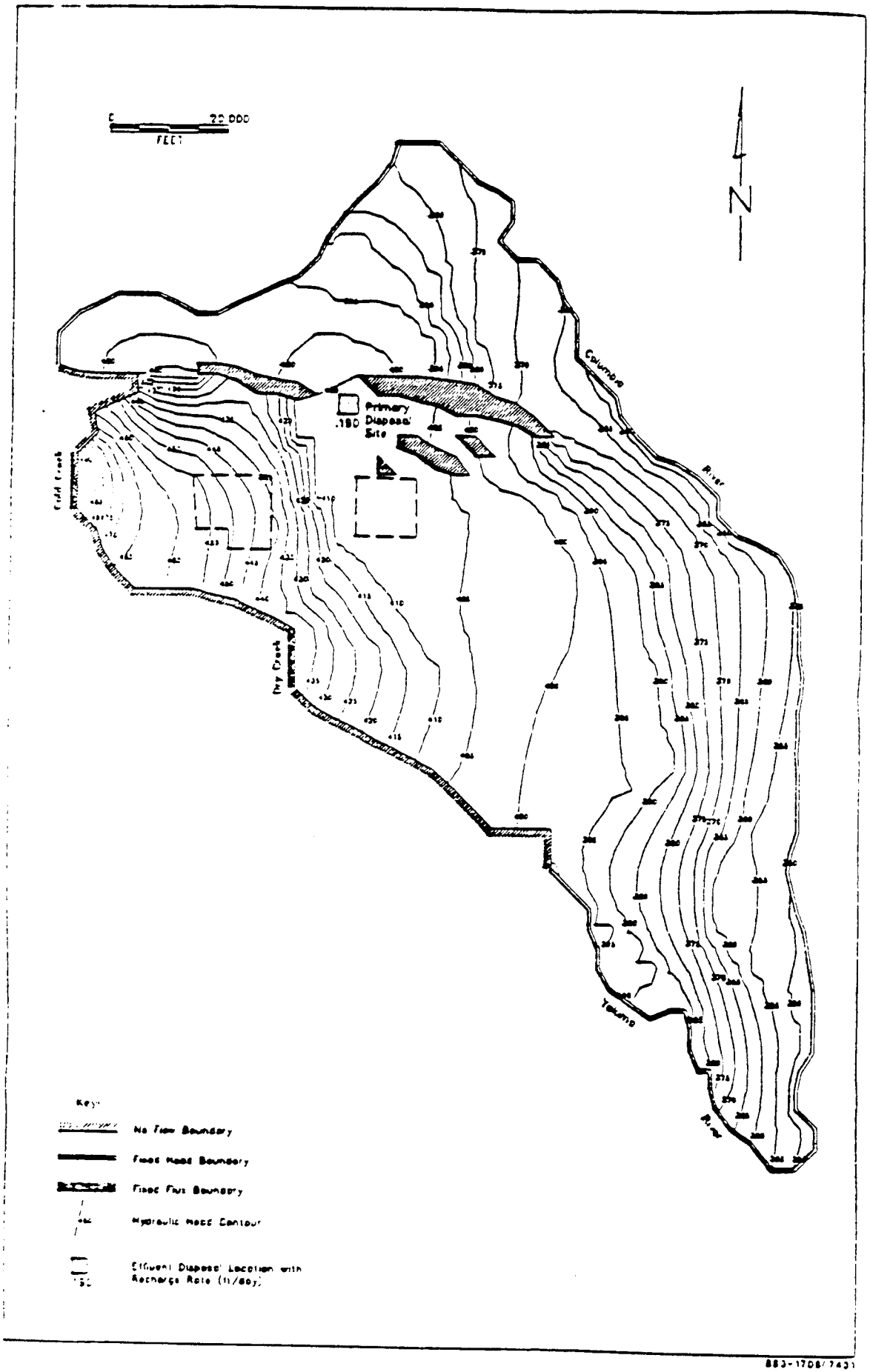

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Figure II-9. Simulation 2
Hydraulic Head Contours

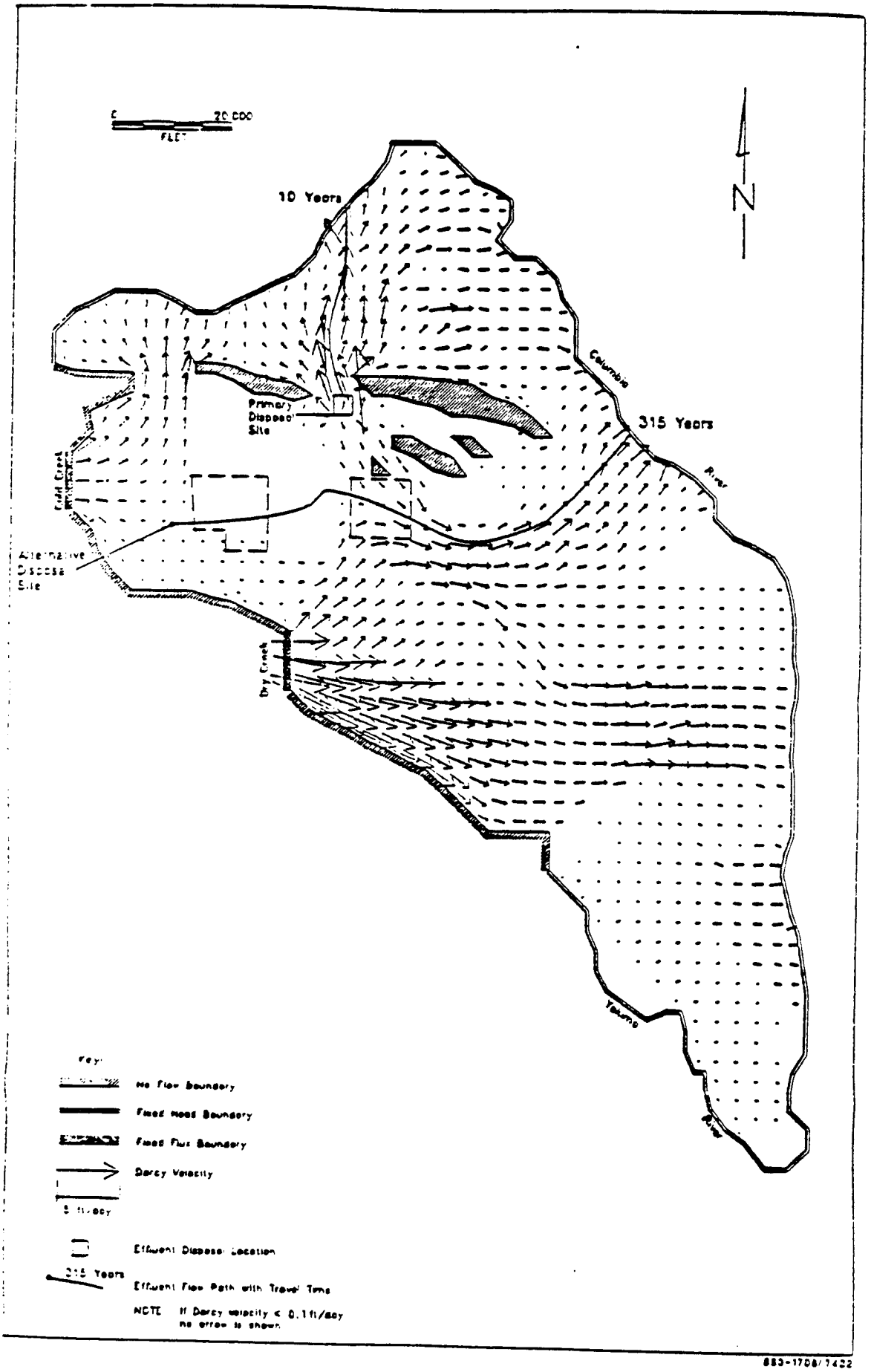

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Figure II-10. Simulation 3
Velocity Vectors

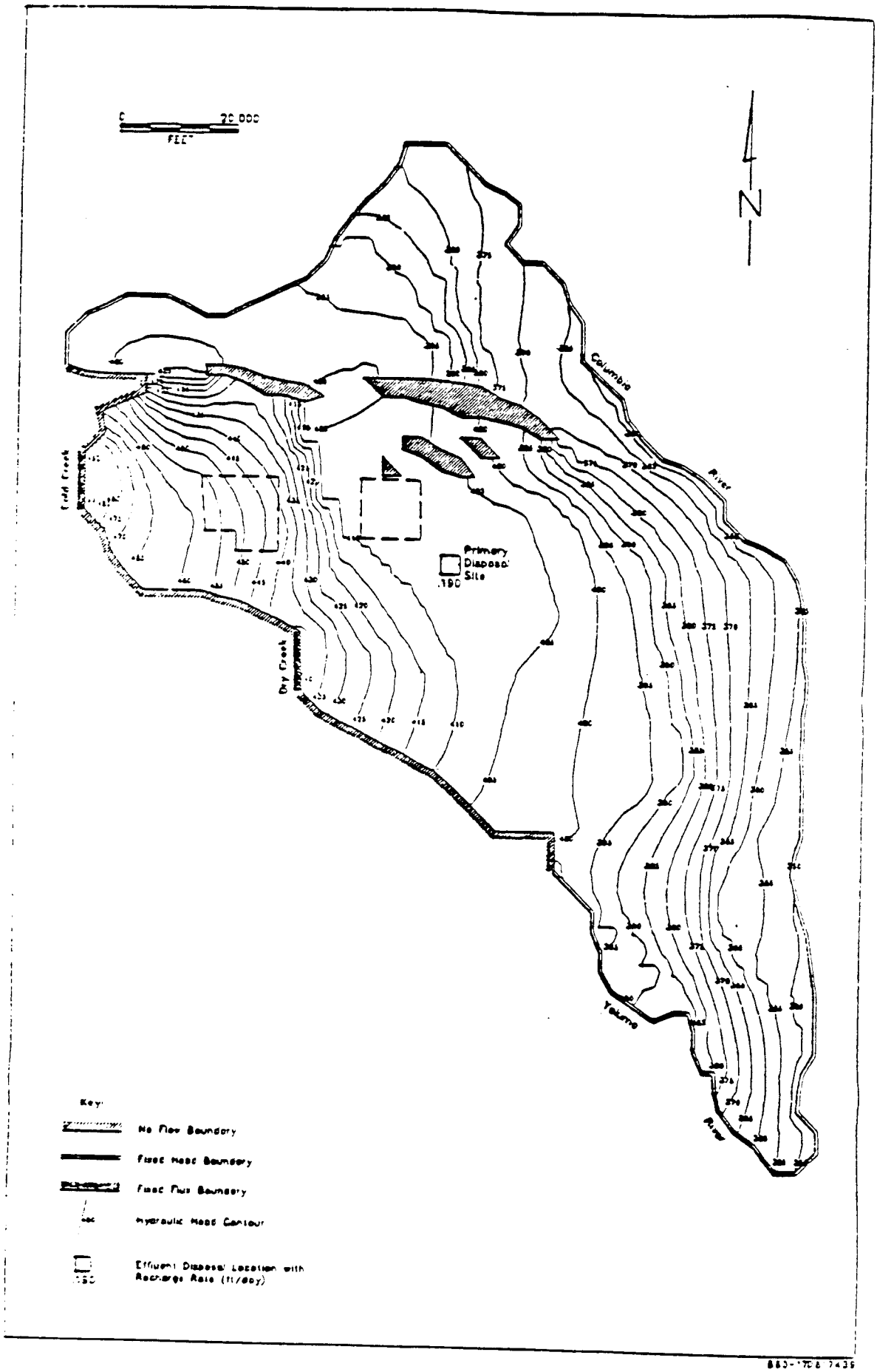

Figure II-1[illegible]. Simulation [illegible]
Hydraulic Head Contours

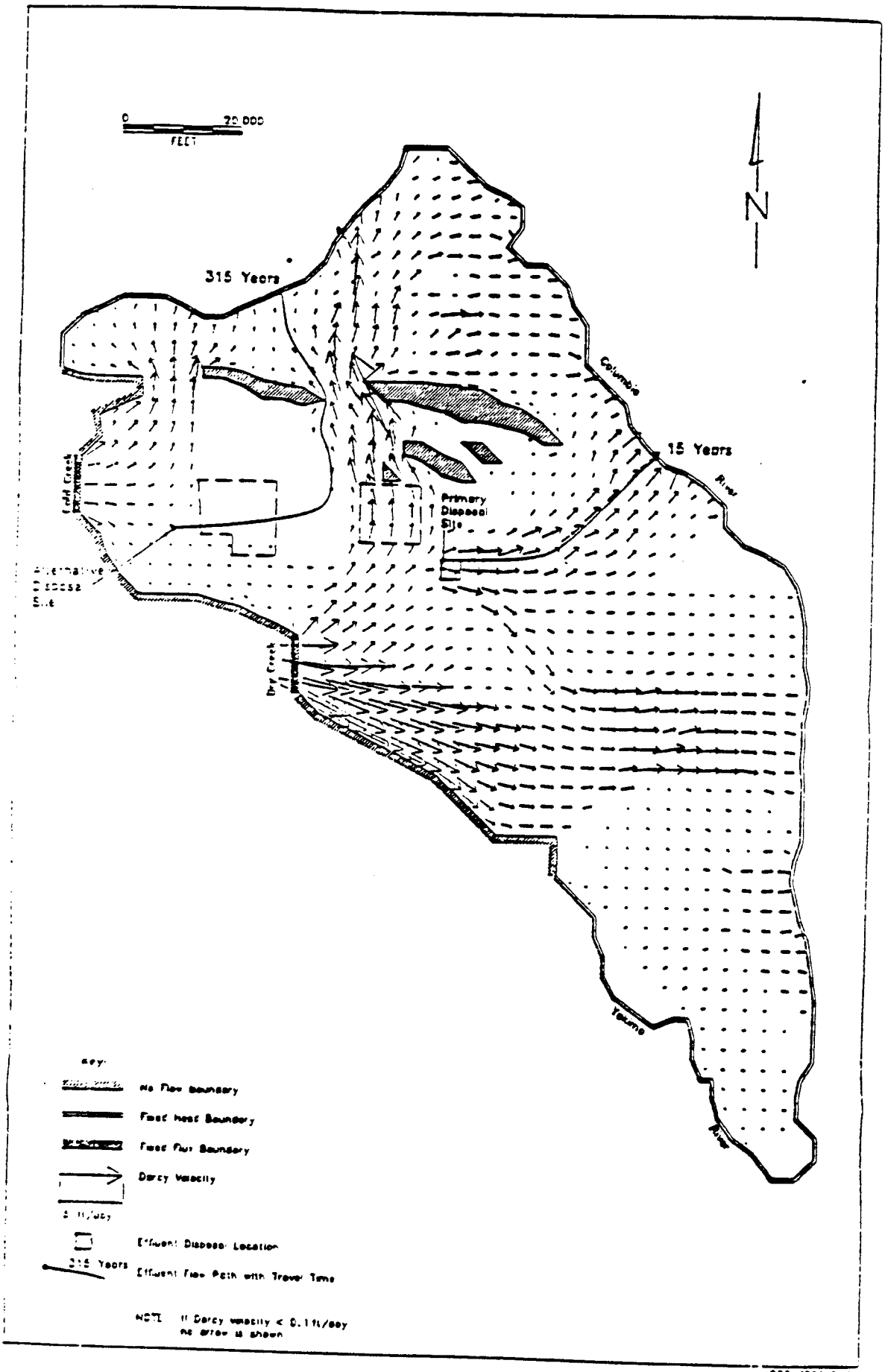

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Figure II-12. Simul ..ion 3
Velocity Vectors

200 East Area to minimize the height of mounding. In both simulations mounding was less than five feet and would not be expected to impact any existing soil contamination. The amount of effluent released in the simulations was 2 million cubic feet per day, approximately equal to the total effluent presently produced at both the 200 East and 200 West areas. As shown in the figures, the recharge has been uniformly distributed over one grid element at a rate of 0.19 feet/day.

Simulation 2 is for a disposal facility located near Gable Mountain Gap, approximately four miles northwest of the proposed retention area at B-Pond. The results are shown in Figures H.9 and H.10. Using a porosity of 0.25, the shortest travel time to the Columbia River from the disposal site is estimated at 10 years. A major disadvantage of this site is that it is located very close to an erosional window through the Rattlesnake Ridge Basalt Flow to the uppermost interbed aquifer (Graham et al. (1984)). Due to the potential for contamination, it would be undesirable to induce flow from the suprabasalt aquifer to a basalt interbed aquifer.

Simulation 3 is for a discharge facility about two miles south of B-Pond. Results are shown in Figures H.11 and H.12. Assuming a porosity of 0.25, the shortest travel time to the Columbia River is estimated at 15 years. This location appears to be better suited than the Gable Mountain location because it is closer to the proposed retention area and it is not close to any erosional windows to the interbed aquifers.

Inspection of the velocity vectors for the three simulations indicates that groundwater flow patterns would be significantly impacted by different effluent disposal schemes. For example, comparison of Figures H.10 and H.12 show that in Simulation 3 the groundwater flow direction across the 200 East Area is completely reversed from that in Simulation 2. Since changes in groundwater flow patterns would affect the movement of any existing contamination plumes, the location of the disposal facility may require re-evaluation of groundwater monitoring networks for regulatory compliance.

ALTERNATIVE DISPOSAL SITE FOR TRITIUM STREAMS

One objective of this study was to investigate the possibility of disposing tritium-contaminated streams in a low conductivity area with a long travel time to the Columbia River. Based upon the flow patterns observed in these simulations an example site was chosen west of the 200 West Area which maximized travel time to the Columbia River. The location is labeled as the "Alternative Disposal Site" on Figures H.8, H.10 and H.12. Since the tritium-contaminated effluent streams are low volume they would not noticeably alter general flow patterns. For transport through the low-conductivity regions near the 200 West Area a porosity of 0.15 was used. A porosity of 0.25 was used for transport through the higher conductivity regions in the central and eastern parts of the Hanford Site. The pathway and travel time from the alternative tritium disposal site for each of the three steady-state simulations presented in the previous section are shown on Figures H.8, H.10, and H.12. For the case when no effluent is disposed to groundwater (Simulation 1) the travel time is about 300 years. The other two simulations, when all the effluent is disposed to groundwater, both have travel times of approximately 315 years. These results suggest that disposal of effluent to groundwater, instead of directly to the river, creates a partial barrier which may slightly retard the movement of upstream plumes.

Given the comparison of observed versus modeled travel times discussed earlier in this appendix, it is conservative to assume that travel times from a low-volume effluent disposal site just west of the 200 West Area are greater than 150 years and less that 400 years. Additional study would be necessary to refine this estimate.

DILUTION FACTORS

Dilution of effluent due to dispersion in groundwater will reduce the concentration of chemical compounds before they reach the Columbia River. The amount of dilution will be affected by a variety of factors, including the amount of wastewater being released, the amount of spreading in the unsaturated zone, the velocity of the groundwater

beneath the source, the dispersivity of the soil medium, and the distance from the source to the river. Two approaches have been used to estimate the dilution factor, which is defined as follows:

$$\text{Dilution Factor} = C/CO$$

where C equals the concentration at the river and CO equals the initial concentration.

The first approach is to use empirical evidence from the behavior of existing contaminant plumes to determine the dilution factor. As shown in Figure H.6, the highest concentrations of tritium entering the river from the 200 East Area are between 0.2 and 2.0 microcuries/liter. The source of this tritium is the PUREX Process Condensate stream, which is reported in Appendix A to have a concentration of 30 microcuries/liter. Allowing for 25 years of decay would reduce concentrations by 75 percent to 7.5 microcuries/liter. Assuming a maximum concentration at the river of about 1.0 microcuries/liter the dilution factor is estimated as 0.13.

The second approach is to use an analytical transport model. The model used has been described by Domenico and Robbins (1985). It assumes a strip source of constant concentration, a uniform flow field, constant longitudinal and transverse dispersivity, and zero vertical dispersivity. The dilution factors reported here are intended to approximate steady state conditions at the distances of interest. The necessary parameters include the width of the source, longitudinal and transverse dispersivity, and distance. From a review by Gelhar et al. (1985) of many field scale dispersivity measurements a longitudinal dispersivity of 50 feet and a transverse dispersivity of 5 feet was used. Based upon the dimensions of the plume near the southeast corner of the 200 East Area shown in Figure H.6, the width of the source was set equal to 1000 feet. For the primary disposal sites used in Simulations 2 and 3 the dilution factor is about 0.5. Due to the greater travel distance, the dilution factor for the alternative disposal site is reduced to about 0.35. This analysis indicates that between the primary disposal site and the alternative disposal site the dilution factor is reduced by about one-third.

The dilution factors obtained from the analytical model simulations are higher than those estimated from the empirical evidence. The modeled results are quite sensitive to the width of the source and transverse dispersivity, neither of which are known with much certainty. Furthermore, if vertical dispersion were accounted for in the analytical model the dilution factors would be decreased. Given the uncertainty of the model it is probably advisable to rely more upon the empirically based results.

SUMMARY

To support investigations of the soil disposal option a numerical groundwater model was developed. The model was used to simulate large-scale flow at the Hanford Site. This modeling, supported by field observations and simple analytical modeling, resulted in the following conclusions:

1) Travel times to the Columbia River from two potential disposal sites located in the vicinity of B-Pond was 10 to 15 years. Travel times from an alternative site near the 200 West Area for tritium-bearing streams could range from 150 to 400 years.

2) The dilution factor from proposed disposal sites near the 200 East Area was estimated to be about 0.1 to 0.5. Analytical model results suggest that from the alternative disposal site (west of the 200 West Area) the dilution factor was approximated one-third less than at the primary disposal site (near the 200 East Area).

3) Disposal of proposed effluent streams to the high-transmissivity region running beneath the 200 East Area would probably not create groundwater mounding up into contaminated soil regions.

4) Different disposal schemes will significantly impact groundwater flow patterns and movement of existing contamination plumes.

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