A 3D model, which would answer all remaining questions, would cost approximately $100,000 to $200,000. All of the complex geology and contamination data would be used for this model. The run time for each scenario would take days, resulting in the high cost. The time needed for each scenario would also tend to limit the number of scenarios run.

A simple 2D-slice model would make more sense, and would include the portion of the plume, barrier wall, and flow through the barrier gate. It is not clear at this time if the current model could be adapted, or if another model would be created. Cost of developing and running this model is estimated at $60,000 to $80,000.

If you have any questions concerning this information please contact me at extension 4385.

ALP/aw

Attachment:
As Stated

cc:
A. C. Crawford
T. Greengard
RMRS Records

SUMMARY OF PHASE I ANALYSES OF THE REMEDIAL ALTERNATIVES FOR THE SOLAR PONDS PLUME

SPP Conceptual Model

- The SPP ground water flow system is conceptualized as a shallow hillslope aquifer consisting of an upper alluvium layer and an underlying weathered bedrock zone (Figure 1). The weathered bedrock zone grades into relatively impermeable competent bedrock that forms the base of the flow system. Ground water enters the SPP area as underflow from the plant area and leakage from the Solar Ponds as well as entering the hillslope as precipitation recharge. Ground water naturally discharges to North Walnut Creek, and is also extracted by the ITS located in the alluvium on the hillslope between the SEPs and the creek. A more complete summary of the SPP ground water flow system is presented in Section 7 of the Conceptual Model Report.

Remedial Alternatives

- Four remedial alternatives for the SPP were analyzed in Phase I
  - Baseline conditions
  - Existing ITS ground water capture (with SEP cap in 2005)
  - Enhanced ITS ground water capture (with SEP cap in 2005)
  - Phytoremediation

Analysis Protocol

- Analyses were conducted following the protocol described in Section 8.3 of the SPP Conceptual Model report
- Limitations that constrained these analyses are described in Section 6.0 of the SPP Conceptual Model Report
- The specific criteria that results were compared against are described in Section 8.2 of the SPP Conceptual Model Report
- Three of the alternatives (Baseline, Existing ITS, and Enhanced ITS) were analyzed using computer modeling techniques; the Phytoremediation alternative was evaluated by

comparing known or anticipated features of its performance against certain design requirements for the SPP remediation system

Analysis Tools

- Several modeling tools were developed for use in the Phase I analyses
  - Plume flushing model – developed to provide a preliminary estimate of plume cleanup time
  - 2-D analytical horizontal plane plume model – developed to provide estimates of plume migration rates, assist in evaluating parameter values, and to provide preliminary sensitivity analyses for key transport parameters
  - 2-D numerical vertical plane flow and transport model – developed to perform analyses to evaluate the three non-phytoremediation remedial alternatives
- The numerical flow and transport model was used to perform calculations of:
  - water levels, hydraulic gradients, and ground water flow rates
  - dissolved chemical transport (plume migration) rates
  - ground water fluxes in the alluvium and weathered bedrock aquifer zones
  - changes in the water budget for each aquifer zone caused by SEP capping
  - chemical concentrations in the alluvium and weathered bedrock aquifer zones
  - fluxes of both ground water and dissolved mass to North Walnut Creek

Ground Water Flow Model Selection and Setup

- MODFLOW-SURFACT and MODPATH were used to analyze ground water flow within a vertical cross-section that extended from the SEPs to North Walnut Creek (Figure 1)
- The vertical profile model is oriented from the SEPs along the axis of the SPP to North Walnut Creek (Figure 2)
- MODFLOW-SURFACT (HydroGeoLogic 1996) is a three-dimensional numerical finite-difference model based on the widely used MODFLOW model of the U.S. Geological Survey; in this application it was used to construct a two-dimensional vertical profile model
- MODPATH (USGS, 1994) utilizes output from MODFLOW-SURFACT to calculate the flow path of particles within the ground water flow field
- Two hydrostratigraphic units are represented in the model:
  - an upper alluvium layer varying in thickness from approximately 5 to 20 feet
  - a lower weathered bedrock layer varying in thickness from approximately 20 to 60 feet

- The underlying competent bedrock forms the impermeable base of the flow system
- The model consists of 10 layers and 353 columns; layers 1 and 2 represent the alluvium and layers 3 through 10 represent the weathered bedrock (Figure 3)
- Parameter values used in setting up the cross-section model were based on the results of previous investigations (Table 1)

Matching Ground Water Flow Model to Observed Site Conditions

- The flow model was checked using the following observed conditions for the SPP aquifer and ITS:
  - ground water levels measured in February 1998 (representing winter months during which little recharge occurs) and in May/June 1995 (representing conditions immediately following the wetter spring months)
  - measurement of volume of ground water captured by the ITS
  - estimated water level conditions prior to installation of the ITS including the consideration of reports of seeps on the hillslope
- Model parameter values were adjusted to the values shown in the rightmost column of Table 1 to produce a good match between model and observed water levels (Figure 4 - alluvium, Figure 5 - weathered bedrock)
- Based on evidence that showed fracture frequency decreasing with depth within the weathered bedrock, the hydraulic conductivity, porosity and specific storage within the weathered bedrock were decreased smoothly with depth within the range of values given in Table 1
- The numerical model, which distributes ground water recharge uniformly over the year, generally produced water levels that fall between the measured dry and wet condition water levels indicating a good match and reasonable model performance
- The model also produces a reasonable ITS ground water extraction rate as follows:
  - ITS extraction rate measured during a dry six-month period in 1993 would equate to an annual rate of approximately 1.8 million gallons per year
  - The volume of water captured by the ITS in the cross-sectional model was approximately 1,230 gallons per linear foot of the ITS annually. If this capture volume is assumed to be constant across the approximate 1,600 foot width of the ITS, this corresponds to a volume of approximately 2 million gallons per year
- While no ground water level measurements are available for the period prior to ITS installation, several studies reported the existence of seeps along the hillslope between the SEPs and North Walnut Creek. When the model was run without the ITS in operation, water levels exceeded land surface in a zone adjacent to North Walnut Creek indicating that ground water seeps would occur in this area (Figure 6). While the model was not adjusted to mirror the actual location of the historic seeps, the results

demonstrated that the model was performing well by producing surface manifestations of ground water that were known to occur. A refinement of the model parameters such as topography, infiltration, and hydrogeologic characteristics to match the exact location of these historic seeps was considered beyond the scope of these analyses.

Contaminant Transport Model Selection and Setup

- MODFLOW-SURFACT was also used as the contaminant transport model in the Phase I analysis
- The distribution of dissolved nitrate and uranium contamination in ground water along the cross-section being modeled was determined from the ground water sampling carried out in February and March 1998 supplemented the interpretation, by RMRS, of recent uranium isotope data identifying the distribution of anthropogenic versus background uranium
- Samples were collected from 50 wells distributed as follows:
  - 21 wells screened entirely in the weathered bedrock
  - 22 wells screened entirely in the alluvium
  - 7 wells screened in both the alluvium and weathered bedrock
- Initial plume conditions for transport simulations were estimated from the measured data using an inverse distance weighted interpolation and extrapolation technique
- Initial plumes within the alluvium and weathered bedrock zones were estimated for nitrate (Figure 7a and 7b) and anthropogenic uranium (Figure 8a and 8b). Figures 7a and 8a depict the initial plumes as contoured data while Figures 7b and 8b depict a more detailed gray-scaled illustration of the plumes. The number of field sample data values used in the calculation of the initial nitrate concentration within each model cell is shown in Figure 7c.
- Contaminant transport parameters (dispersion, adsorption/retardation, and degradation) were estimated from literature values (Table 2)
- In the absence of site-specific data quantifying denitrification, a conservative approach of not representing denitrification in the model was chosen. RMRS has indicated that nitrogen isotope data reveals the presence of denitrification processes, however, site-specific data quantifying denitrification rates and capacity in the SPP area is not available. In the future, as denitrification data are gathered, degradation of nitrate could be incorporated into the model for a more accurate representation of the in situ processes.

Contaminant Transport Model Testing

- The contaminant transport model was tested by attempting to simulate the formation of the nitrate plume. The greater number of field measurements permitted a more robust delineation of the nitrate plume, and nitrate was selected as the primary constituent for which Phase I simulations were to be performed. This historical simulation followed the site chronology shown in Table 3
- The simulated 1998 nitrate plume (Figures 9a and 9b) matches well with the plume interpolated from the February 1998 ground water sampling data (Figures 7a and 7b)

Evaluation of Phytoremediation Alternative

- Model simulations were not conducted for the phytoremediation alternative. Instead, information was obtained from the CH2M Hill phytoremediation team to evaluate the likely performance of phytoremediation for the SPP.
- Discussions with the CH2M Hill phytoremediation team lead to the following findings:
    - phytoremediation would likely be effective in remediating nitrate, but would likely be significantly less effective in remediating the uranium plume
    - plant evapotranspiration would likely lower the ground water levels in certain portions of the SPP, thereby reducing or eliminating ground water discharge to portions of North Water Creek; however, contaminated ground water would be likely to migrate as underflow and eventually enter North Walnut Creek farther downstream
    - evaporation processes would likely be overwhelmed during wetter periods of the year resulting in discharge of contaminated ground water to North Walnut Creek
    - the plant species currently being considered for the phytoremediation alternative would have a root zone depth of approximately 6 feet; in addition, the effectiveness of removal would decrease with depth so that removal would only effectively occur in the upper few feet beneath land surface
- Consideration of these findings in light of the requirement for remediation of the uranium plume and the depth to which both the nitrate and uranium plumes extend, led to elimination during Phase I of phytoremediation as a remedial alternative for the SPP

Phase I Screening of Non-Phytoremediation Remedial Alternatives

- Beginning with the 1998 plume conditions estimated from the February 1998 sampling data, model simulations were conducted to evaluate three remedial alternatives:
    - removal of ITS (ITS drain cells removed from the model)
    - continued operation of the existing ITS (simulation of existing system with ITS extending to contact between alluvium and weathered bedrock)

- enhancement and continued operation of the ITS (five southern drain cells extended 5 feet below alluvium/weathered bedrock contact, and northernmost drain cell extended to approximately one-half the depth of the weathered bedrock zone)

- Outputs of the simulations that were used as a basis for comparison and decision making included:
  - concentration versus time plots
  - water budget calculations
  - estimate of fluxes to North Walnut Creek

- Simulations were performed for approximately 100 years for nitrate and 200 years for uranium, both beginning in 1998

- Plots of nitrate concentration versus time in the weathered bedrock ground water adjacent to North Walnut Creek along the axis of the SPP indicated exceedances of the specified criteria for greater than 100 years (Figure 10). For these simulations, it was assumed that an impermeable cap was placed over the SEPs in 2005, and any surface run-off from the capped area was collected and diverted.

- Plots of nitrate concentration in the weathered bedrock zone versus time for the existing ITS for scenarios in which (1) the SEPs were capped in 2005, and (2) the SEPs were not capped indicated exceedances of the specified criteria for greater than 100 years (Figure 11); ground water concentrations adjacent to North Walnut Creek declined more rapidly for the "no capping" scenario, but nitrate mass fluxes to the creek were higher under this scenario. Nitrate concentrations continued to increase after placement of a cap due to the presence of high concentrations of nitrate beneath the ITS in the weathered bedrock that eventually reached North Walnut Creek (Figures 7a and 7b).

- Plots of anthropogenic uranium concentration versus time in the weathered bedrock zone ground water adjacent to North Walnut Creek along the axis of the SPP indicated that there would be no exceedances of the specified criteria for approximately 140 years (Figure 12). This is a result of the retardation of uranium in the geologic material. Anthropogenic uranium at concentrations above the specified criteria of 10 pCi/L would begin to reach North Walnut Creek after approximately 140 years under the no ITS scenario and after approximately 200 years under the existing ITS scenario. Under the enhanced ITS scenario, anthropogenic uranium entering the creek would not exceed the specified criteria for the length of time (200 years) that the model was run.

- An analysis was performed for a scenario in which the SEPs were not capped, but instead an additional 5 feet of hydraulic head was maintained on the ponds to attempt to flush ground water contamination more rapidly from the hillslope aquifer. Plots of nitrate concentration versus time in both alluvium and weathered bedrock zone ground water adjacent to North Walnut Creek along the axis of the SPP indicated exceedances of the specified criteria for greater than 100 years (Figure 13). Concentrations declined more rapidly than for the base case scenario, but nitrate mass flux to North Walnut Creek was increased.

- An analysis of the water budget for the hillslope aquifer prior to and subsequent to capping of the SEPs (Figures 14 and 15) indicated that:
  - capping effectively removed the water budget component associated with pond infiltration
  - ground water discharge to the ITS (which occurs almost exclusively from the alluvium zone) was reduced by a concomitant amount
  - ground water discharge to North Walnut Creek remained largely unaffected by the capping of the SEPs
- Model simulations of nitrate mass flux to North Walnut Creek for the scenarios of (1) placing a cap on the SEPs in 2005 with the existing ITS (Figure 16) and placing a cap on the SEPs in 2005 without the ITS (Figure 17) support the following conclusions:
  - the existing ITS significantly reduces the rate of nitrate mass flux to North Walnut Creek by reducing flow through the alluvium; the initial increase in mass flux is a result of the high nitrate concentrations in the weathered bedrock underlying the ITS that will eventually bypass the ITS and reach the creek
  - nitrate mass flux is higher in the alluvium than in the weathered bedrock
  - approximately 90 percent of nitrate mass flux in the weathered bedrock occurs in the upper half of the unit
  - the combined nitrate mass flux from alluvium and weathered bedrock zones per unit width of aquifer along the axis of the SPP is approximately 6 grams per foot per day; this flux declines slowly over time to approximately one-half of this initial rate after 100 years

Conclusion

- Based on the Phase I modeling analyses for ITS-related remedial alternatives, and the evaluation of the phytoremediation alternative, results indicate all of the four originally proposed alternatives do not meet the specified criteria.

REFERENCES:

HydroGeoLogic, Inc. 1996. *MODFLOW-SURFACT Flow and Transport Simulator User's Manual.*

McDonald, M.G., and Harbaugh, A.W., 1988, *A modular three-dimensional finite-difference ground-water flow model*: U.S. Geological Survey Techniques of Water-Resources Investigations, book 6, chap. A1, 586 p.

Pollock, D.W., 1994, *User's Guide for MODPATH/MODPATH-PLOT, Version 3: A particle tracking post-processing package for MODFLOW, the U.S. Geological Survey finite-difference ground-water flow model*: U.S. Geological Survey Open-File Report 94-464, 6 ch.

RMRS. 1996. *Management Plan for the Interceptor Trench System Water.* May.

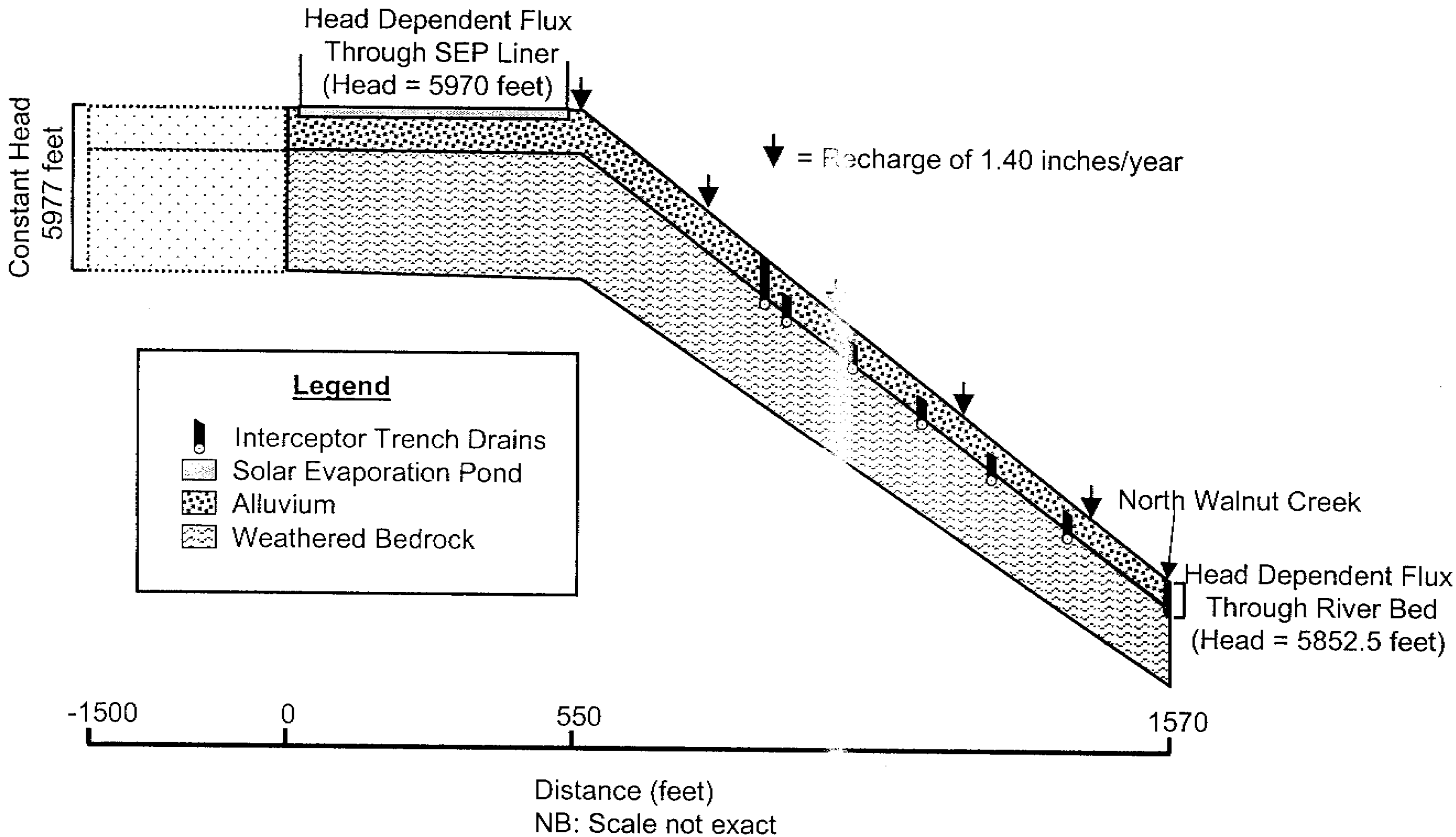

Figure 1: Conceptual diagram of SPP groundwater flow system and model boundary conditions.

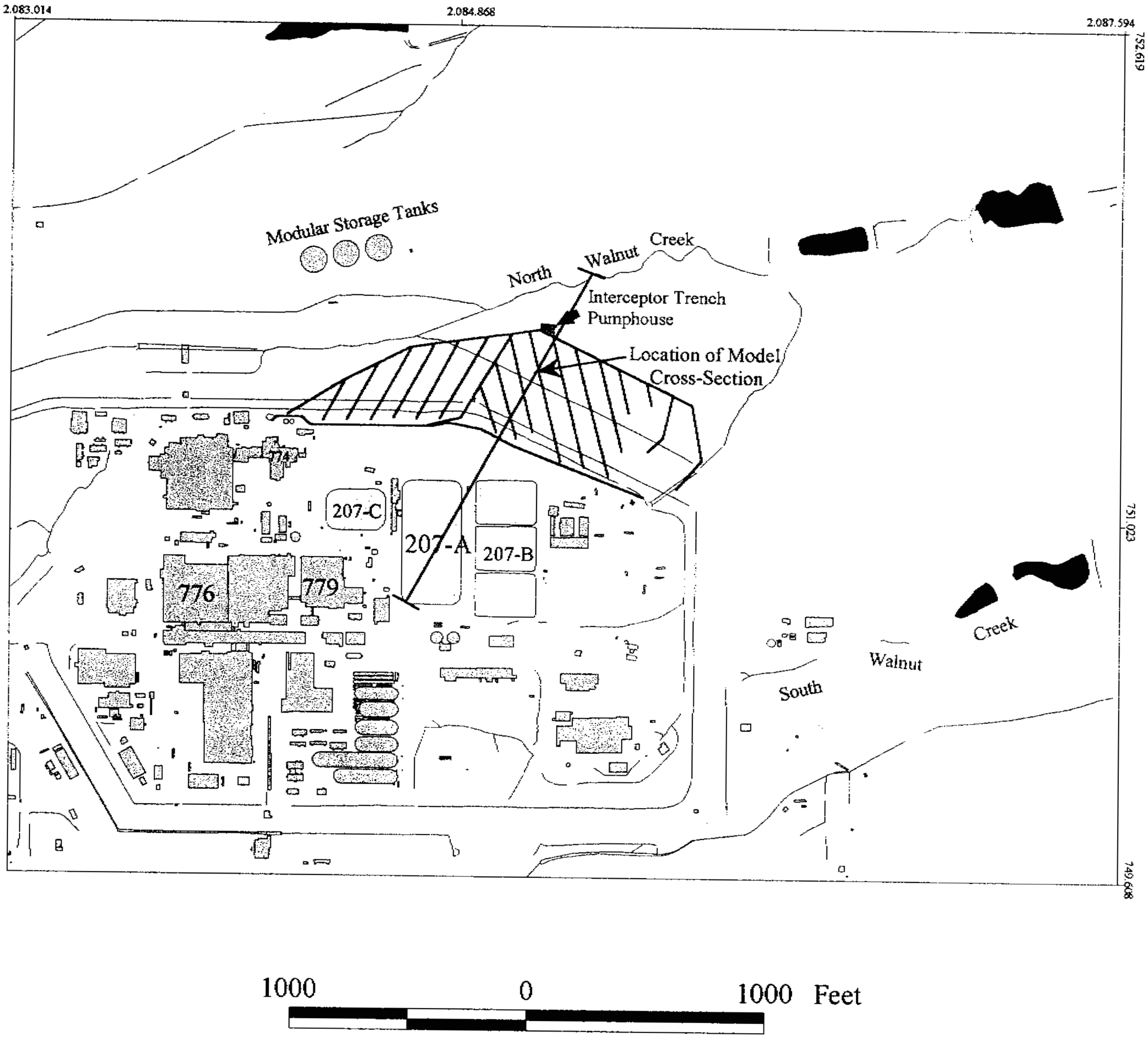

Figure 2

Location of Model Cross-Section

Rocky Flats Environmental Technology Site

Explanation

- Streams
- Interceptor Trench System (ITS)
- Solar Ponds
- Buildings
- Lakes

N

McLane Environmental, L. L. C.
Princeton, NJ

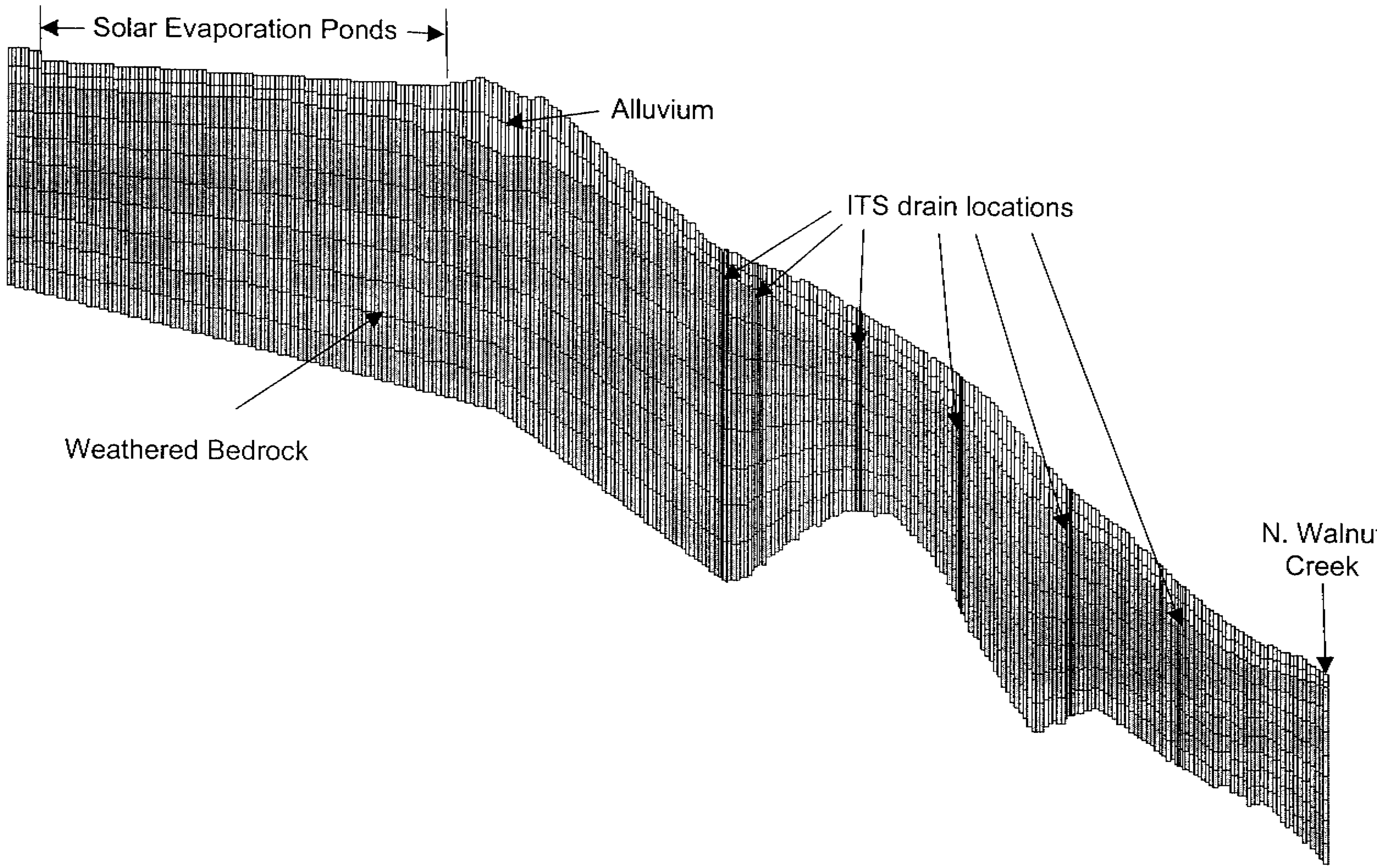

Figure 3: Vertical profile model grid used for MODFLOW-SURFACT analyses.

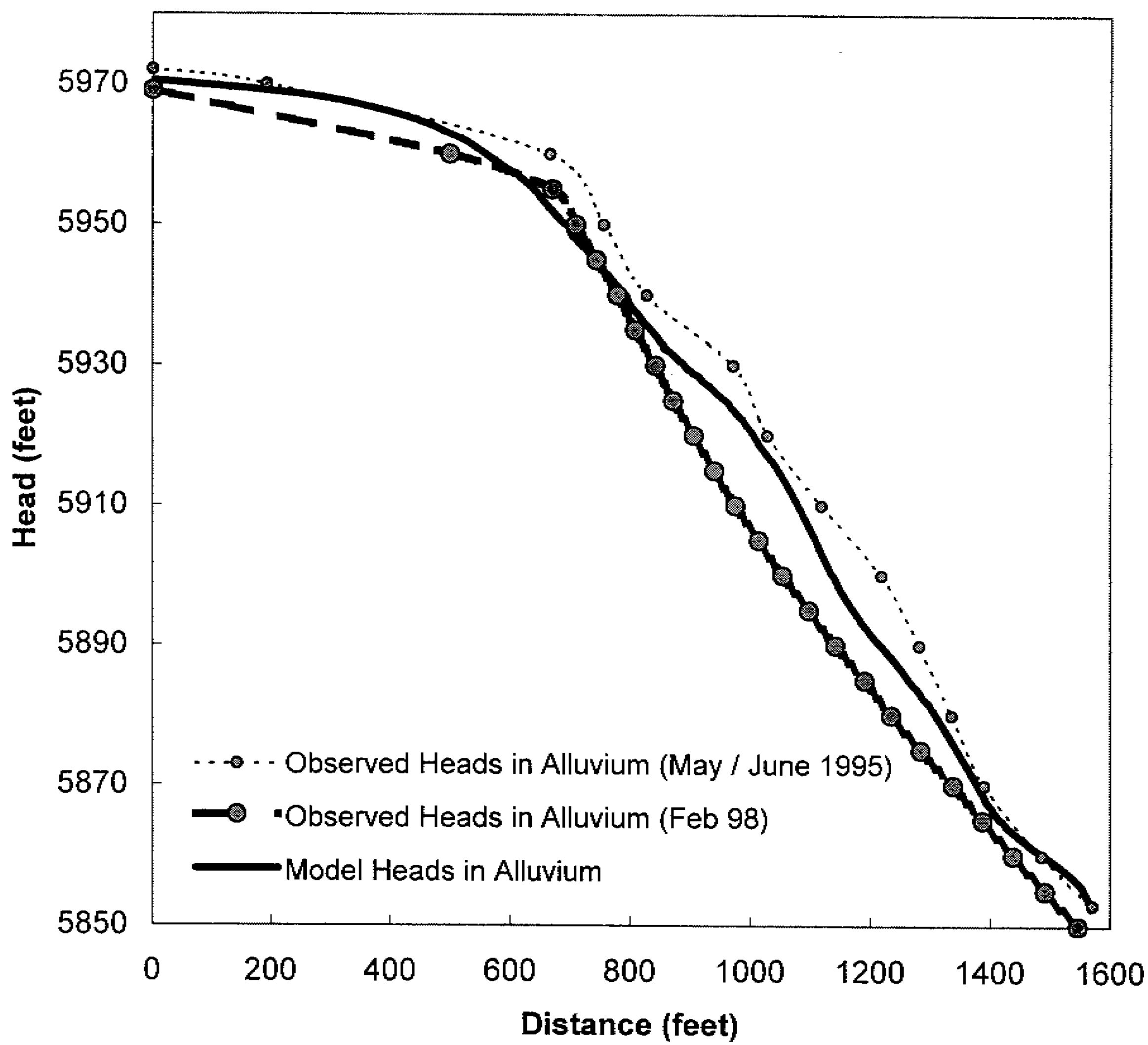

Figure 4: Comparison of observed and simulated hydraulic head in alluvium

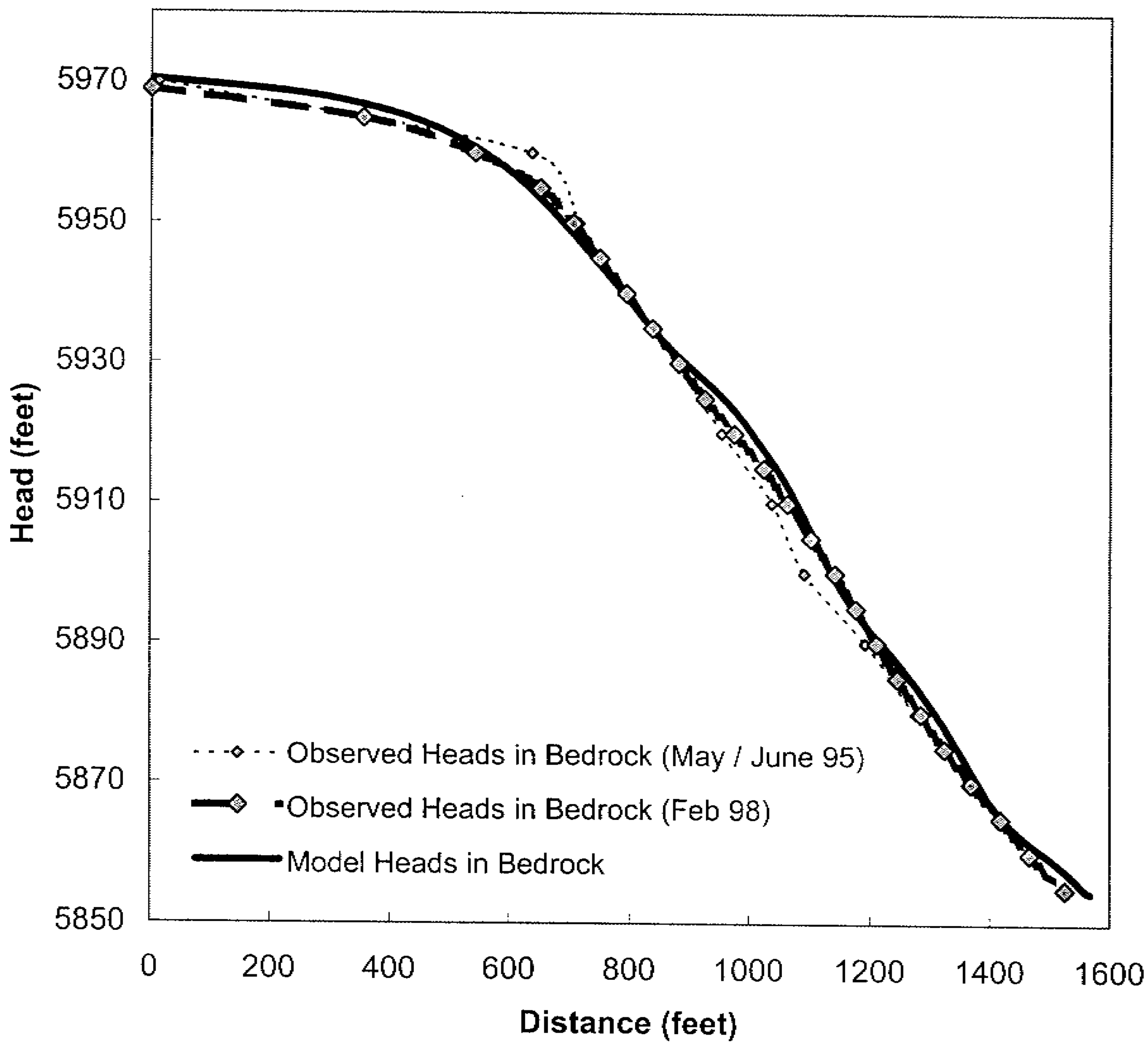

Figure 5: Comparison of observed and simulated hydraulic head in weathered bedrock

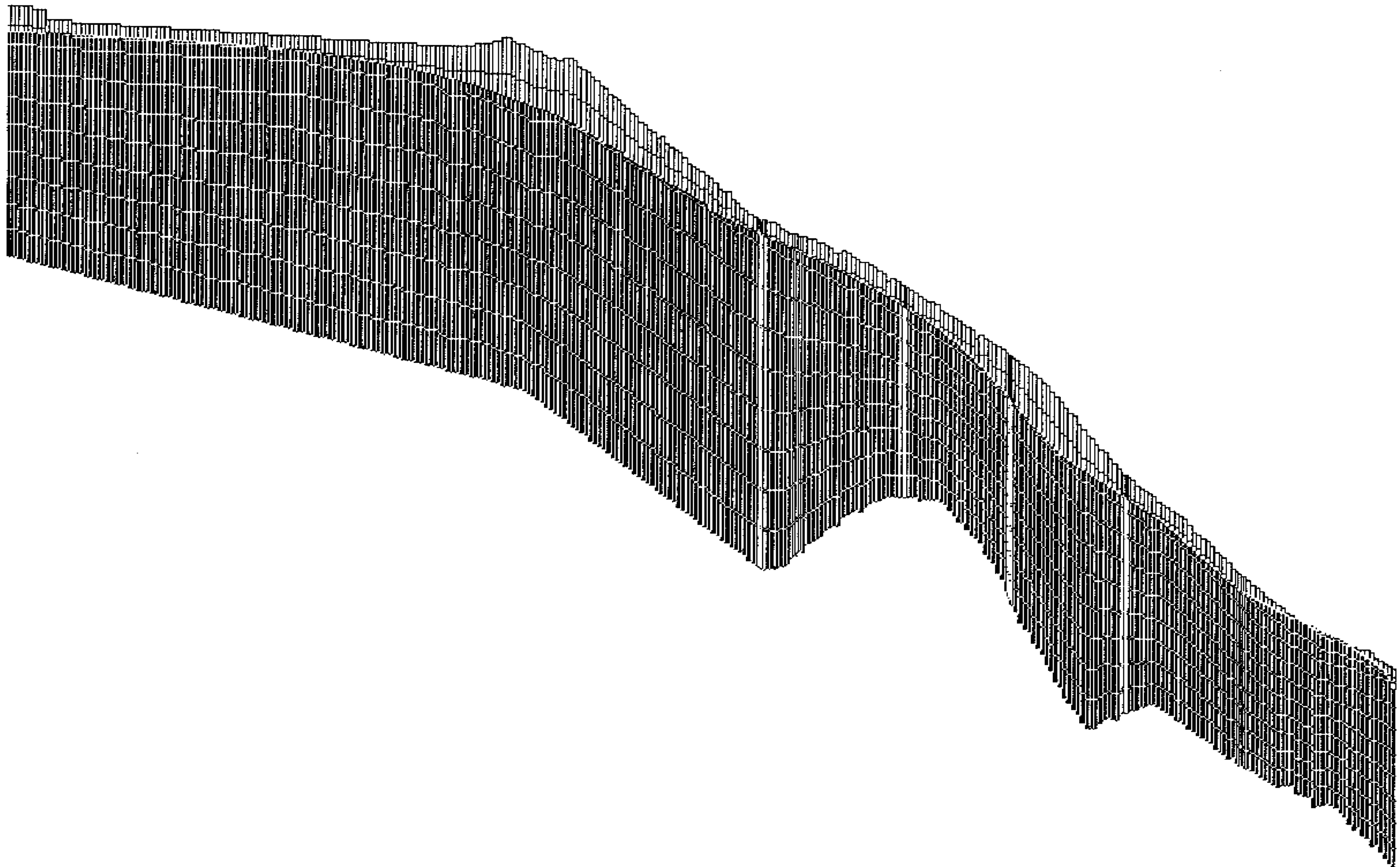

Figure 6: Hydraulic head levels for simulation with no ITS, showing seep at base of hillslope.

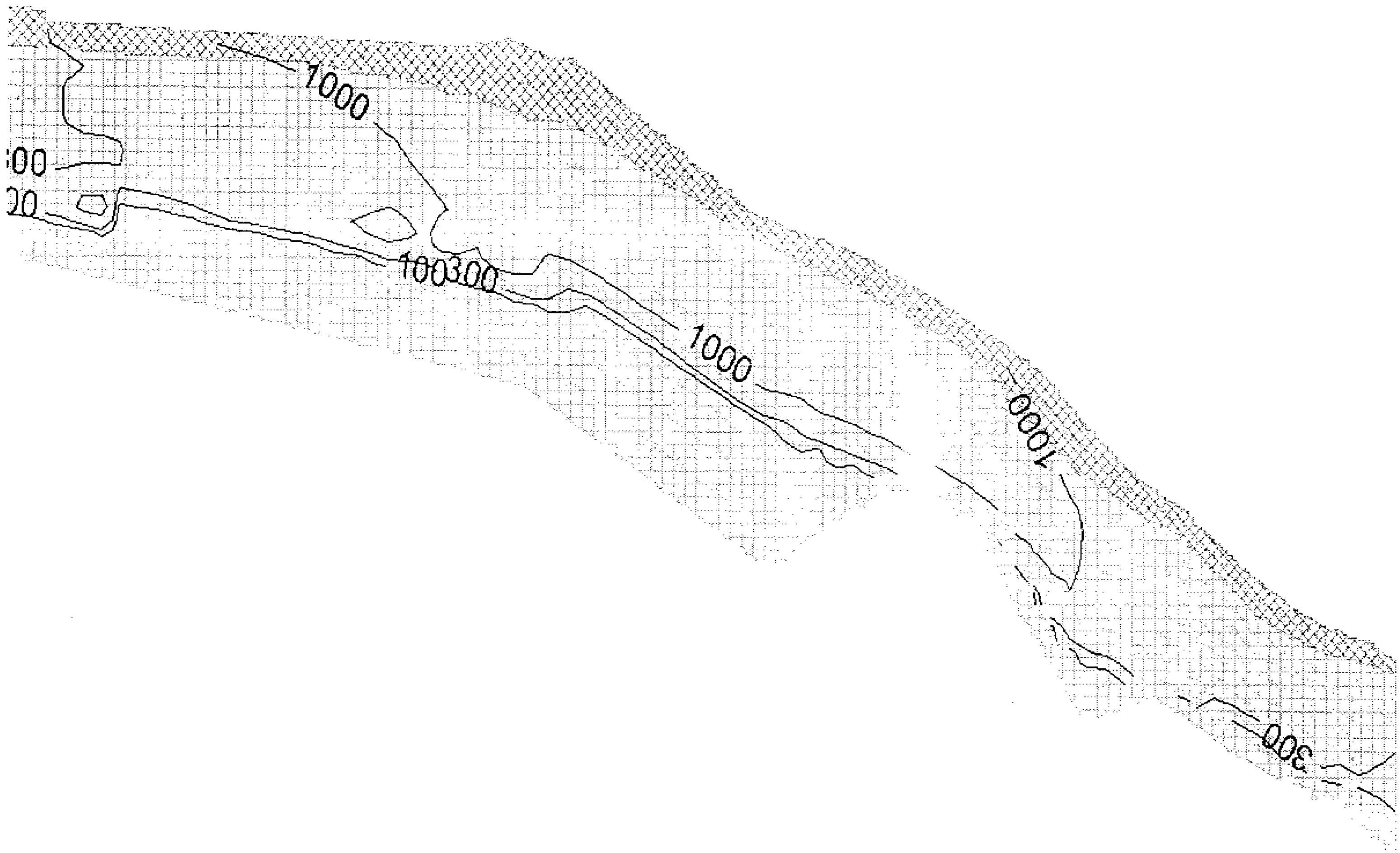

Figure 7a: Contoured nitrate concentrations (Nitrate as N in mg/L) based on February 1998 sampling data, ignoring samples collected greater than a 12-foot depth away.

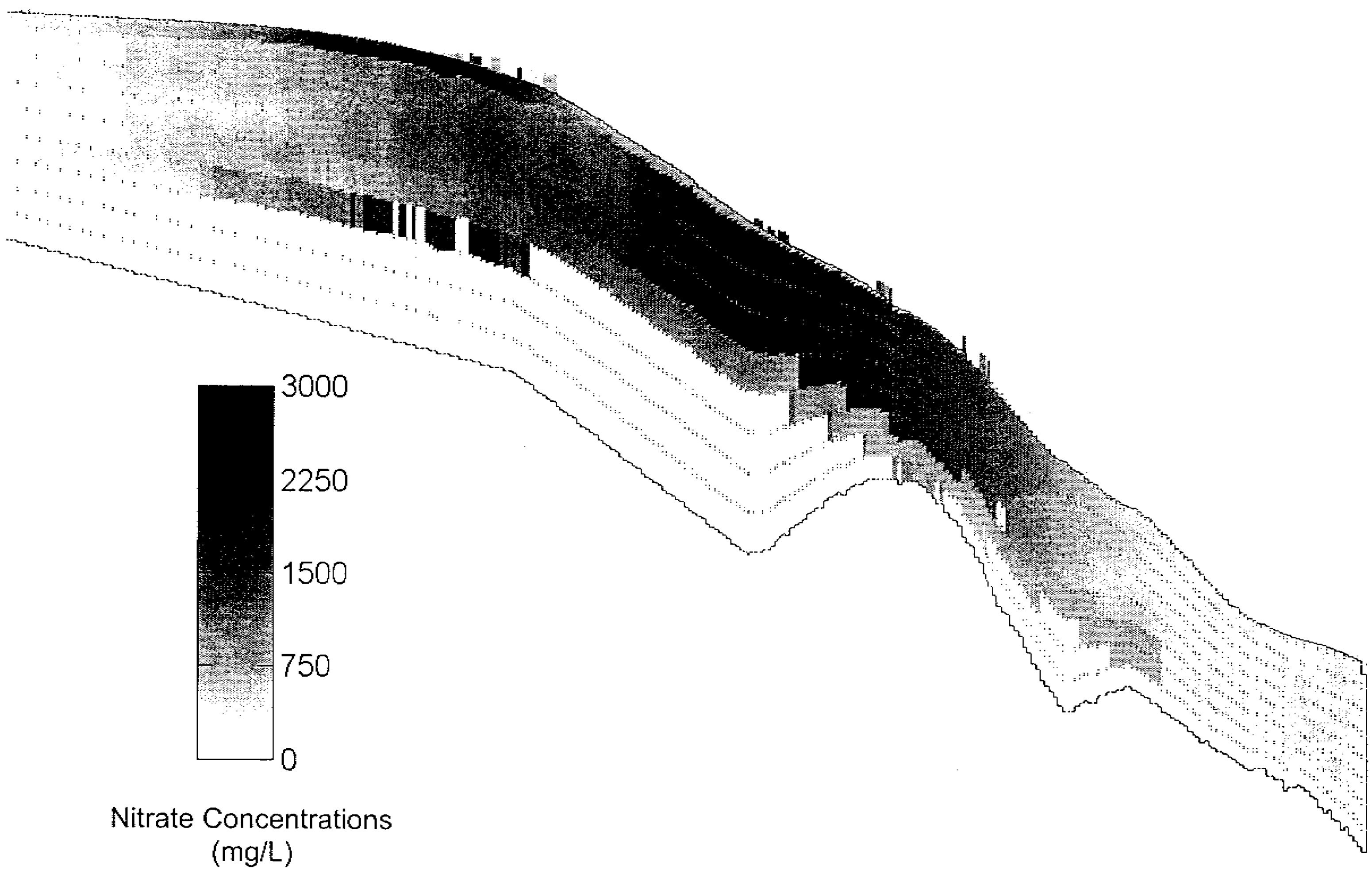

Figure 7b: Nitrate concentrations (Nitrate as N in mg/L) based on February 1998 sampling data, ignoring samples collected greater than a 12-foot depth away.

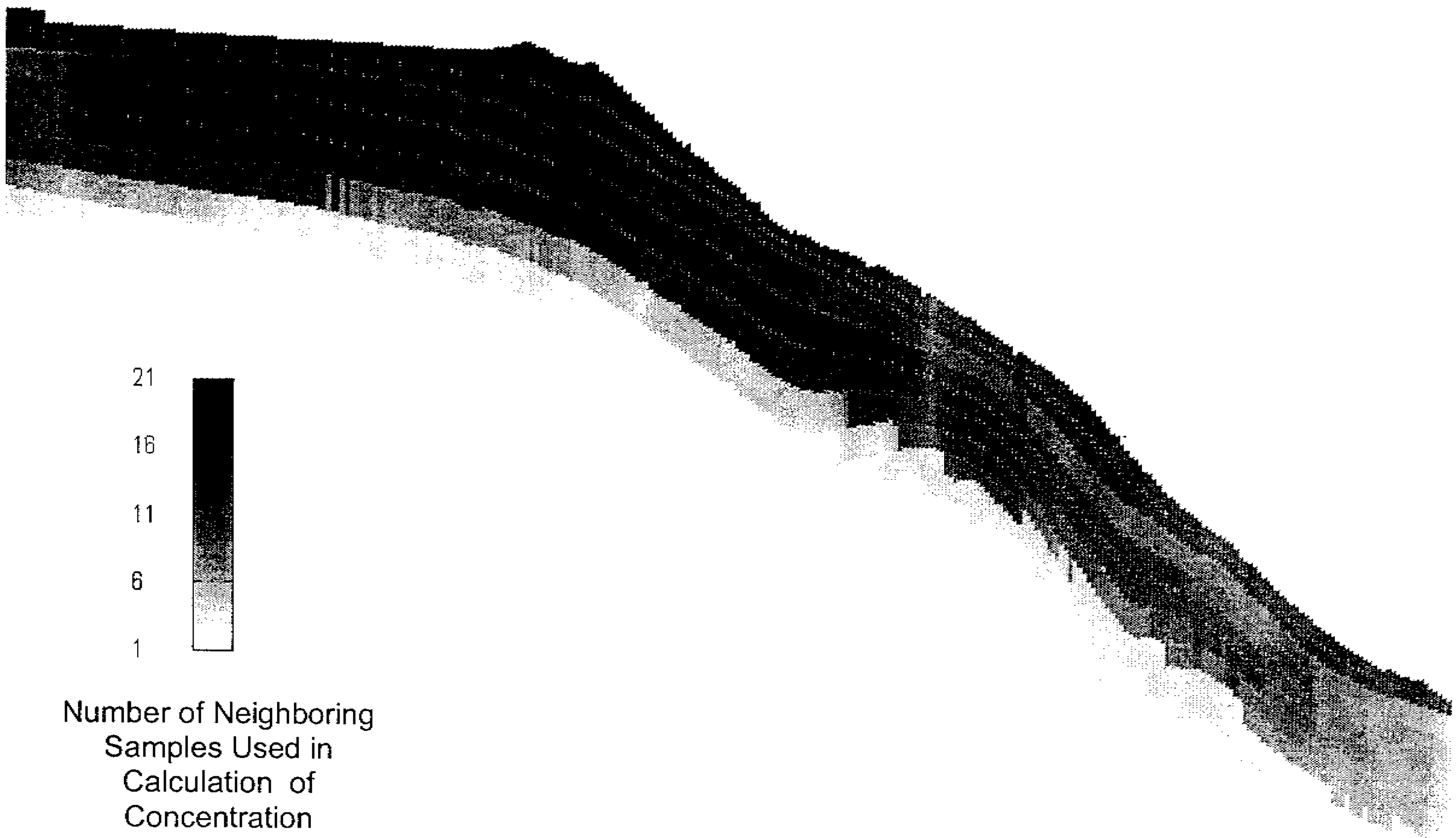

Figure 7c: Number of sample data values used to calculate initial concentration of nitrate in each model cell.

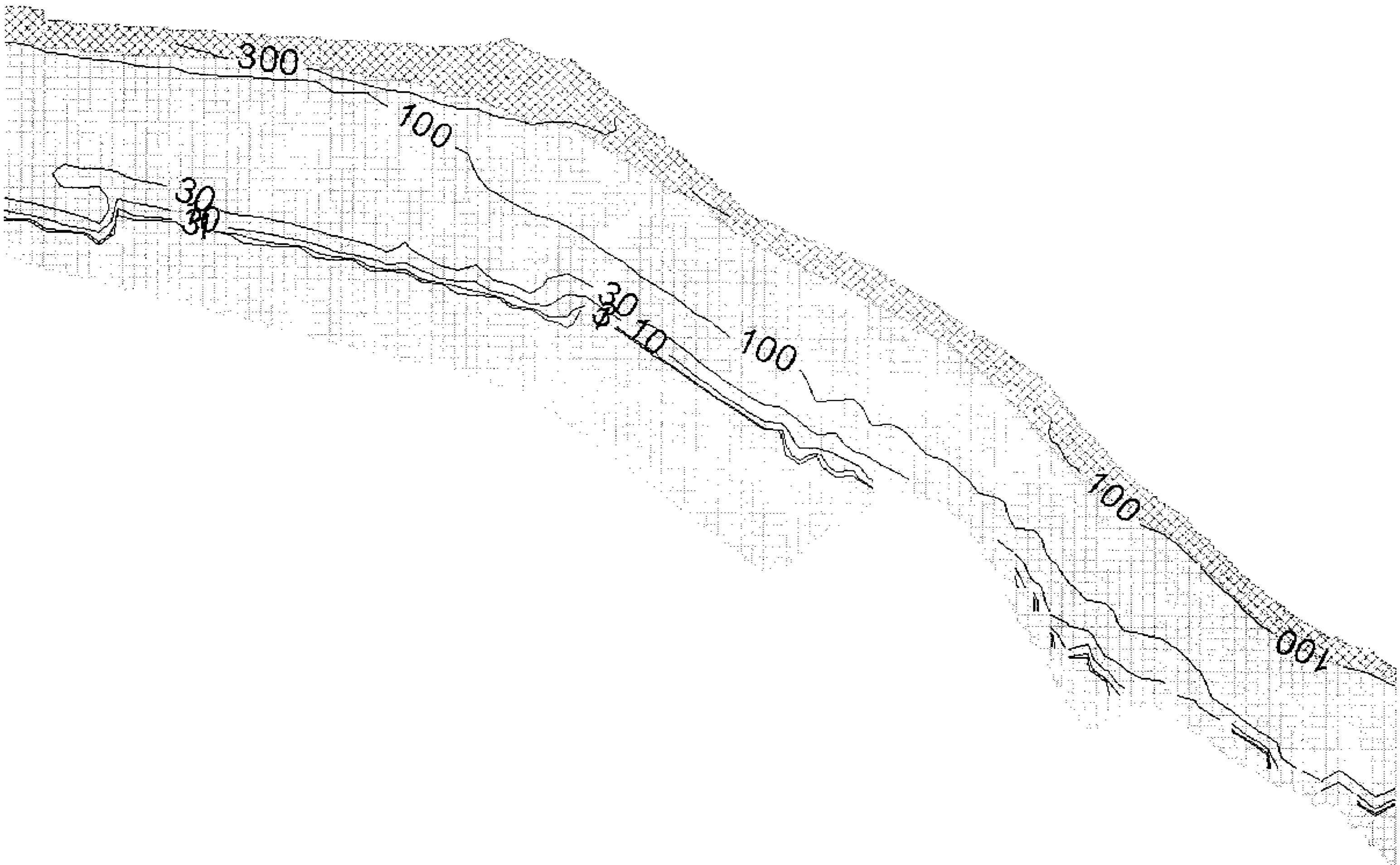

Figure 8a: Contoured uranium activities (pCi/L) based on February 1998 sampling data, ignoring samples collected greater than a 12-foot depth away.

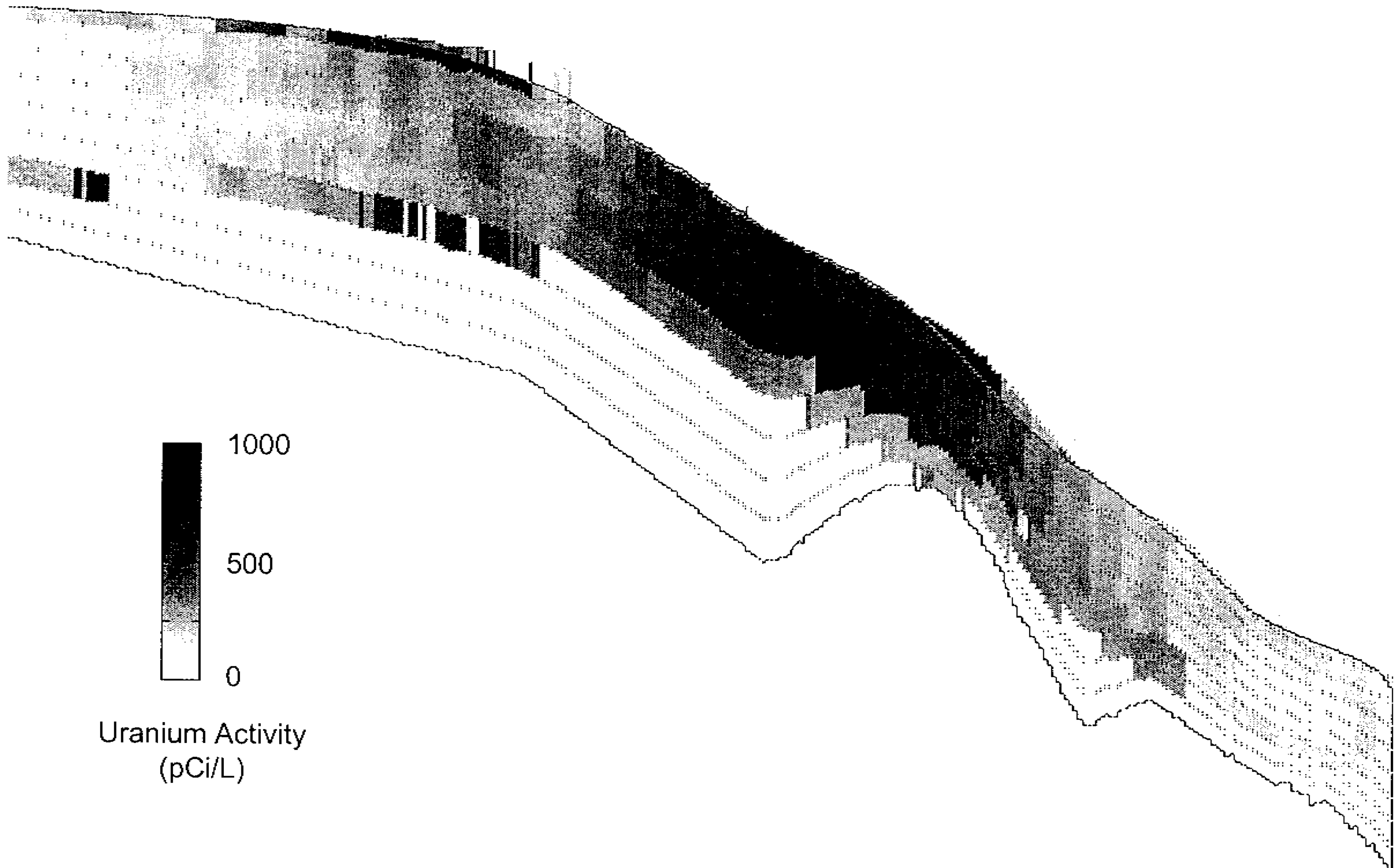

Figure 8b: Uranium activities (pCi/L) based on February 1998 sampling data, ignoring samples collected greater than a 12-foot depth away.

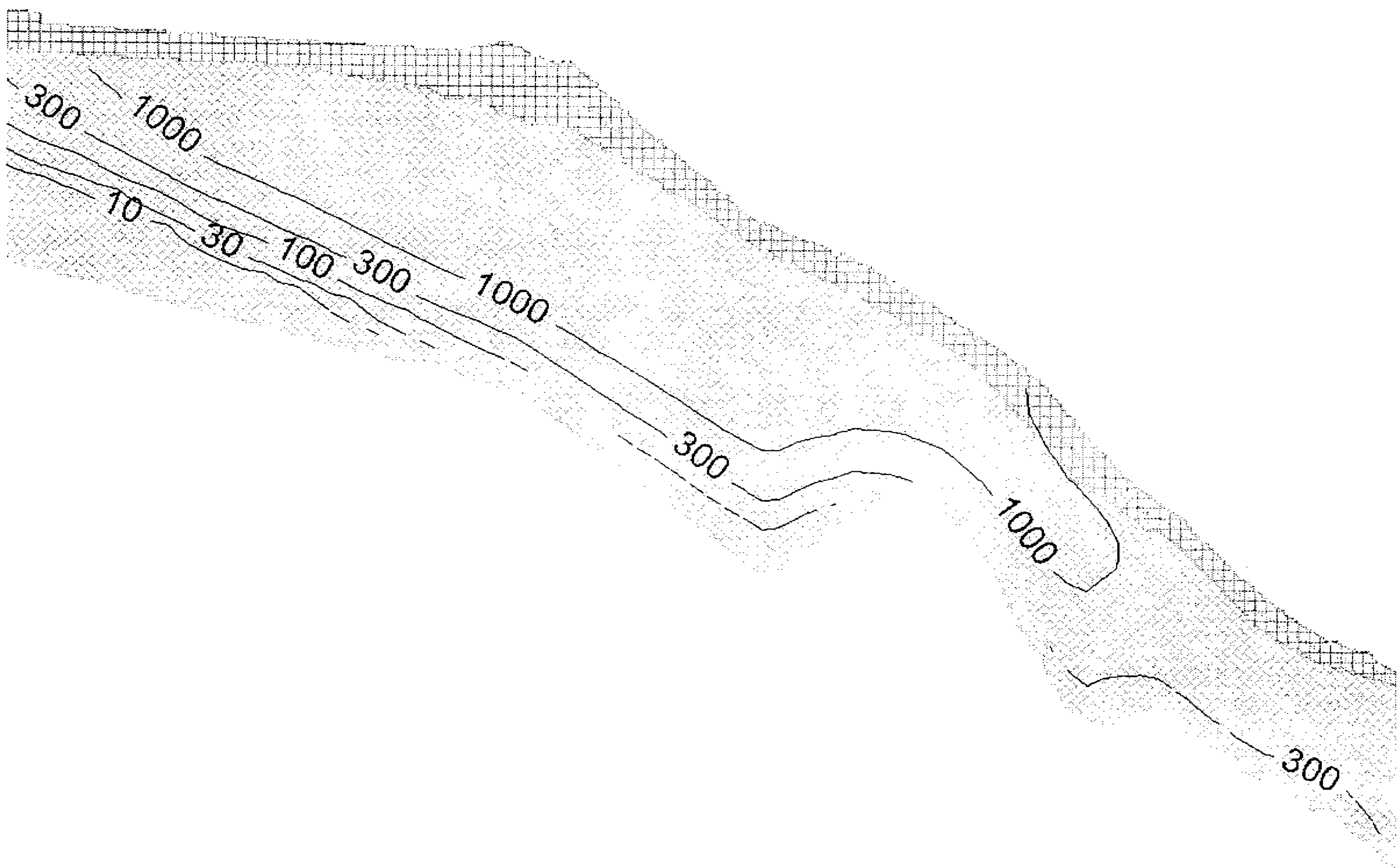

Figure 9a: Contoured nitrate concentrations (Nitrate as N in mg/L) predicted by model given leakage from SEPs at 6,000 mg/L. First 27 years (1954-1981) no ITS in place. Next 14 years (1981-1995) ITS active in current configuration (ITS keyed to bedrock) with 6,000 mg/L source in ponds. Final 3 years (1995-1998) SEPs source of water with 0.0 mg/L concentration of nitrate.

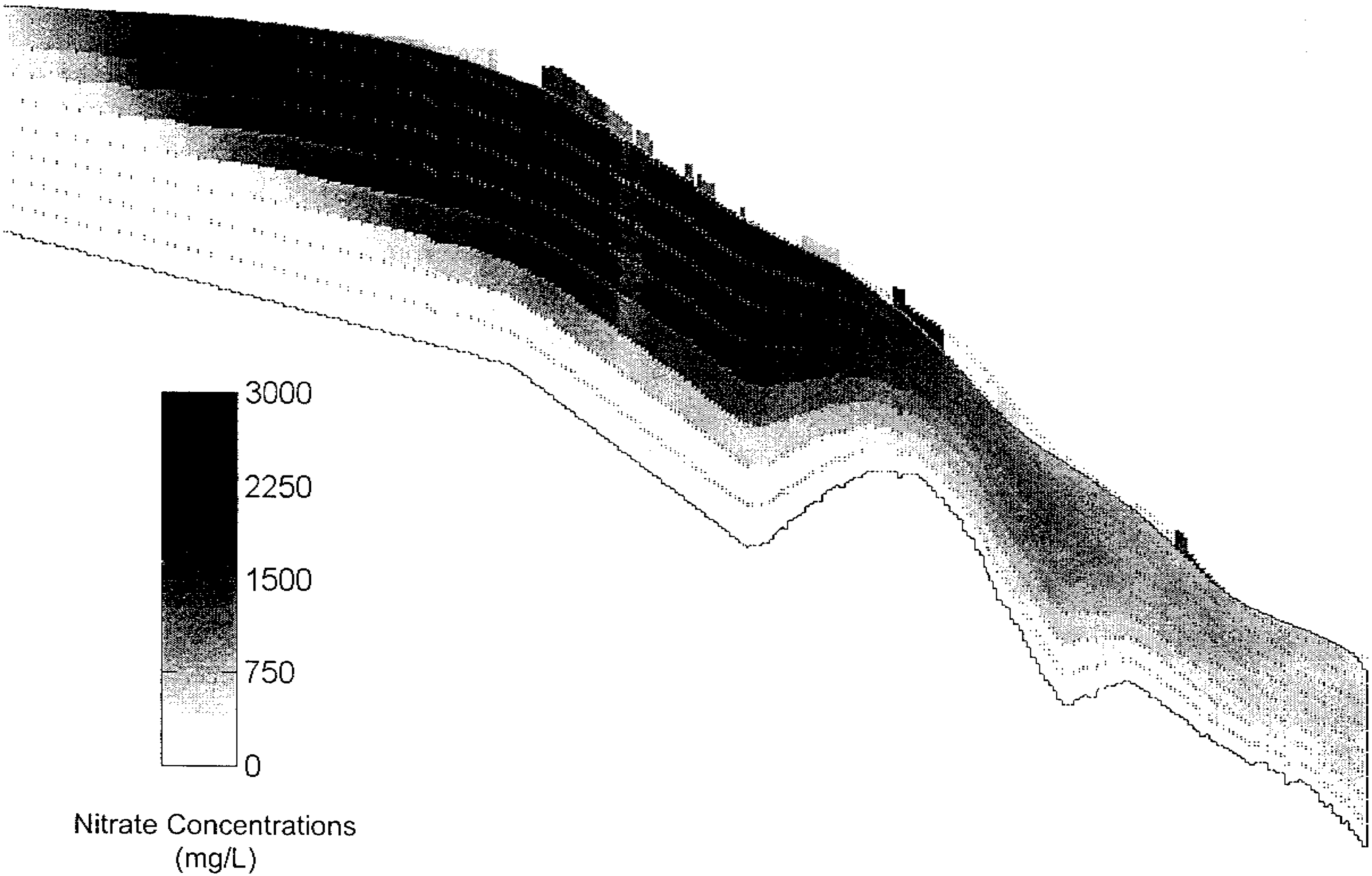

Figure 9b: Nitrate concentrations (Nitrate as N in mg/L) predicted by model given leakage from SEPs at 6,000 mg/L. First 27 years (1954-1981) no ITS in place. Next 14 years (1981-1995) ITS active in current configuration (ITS keyed to bedrock) with 6,000 mg/L source in ponds. Final 3 years (1995-1998) SEPs source of water with 0.0 mg/L concentration of nitrate.

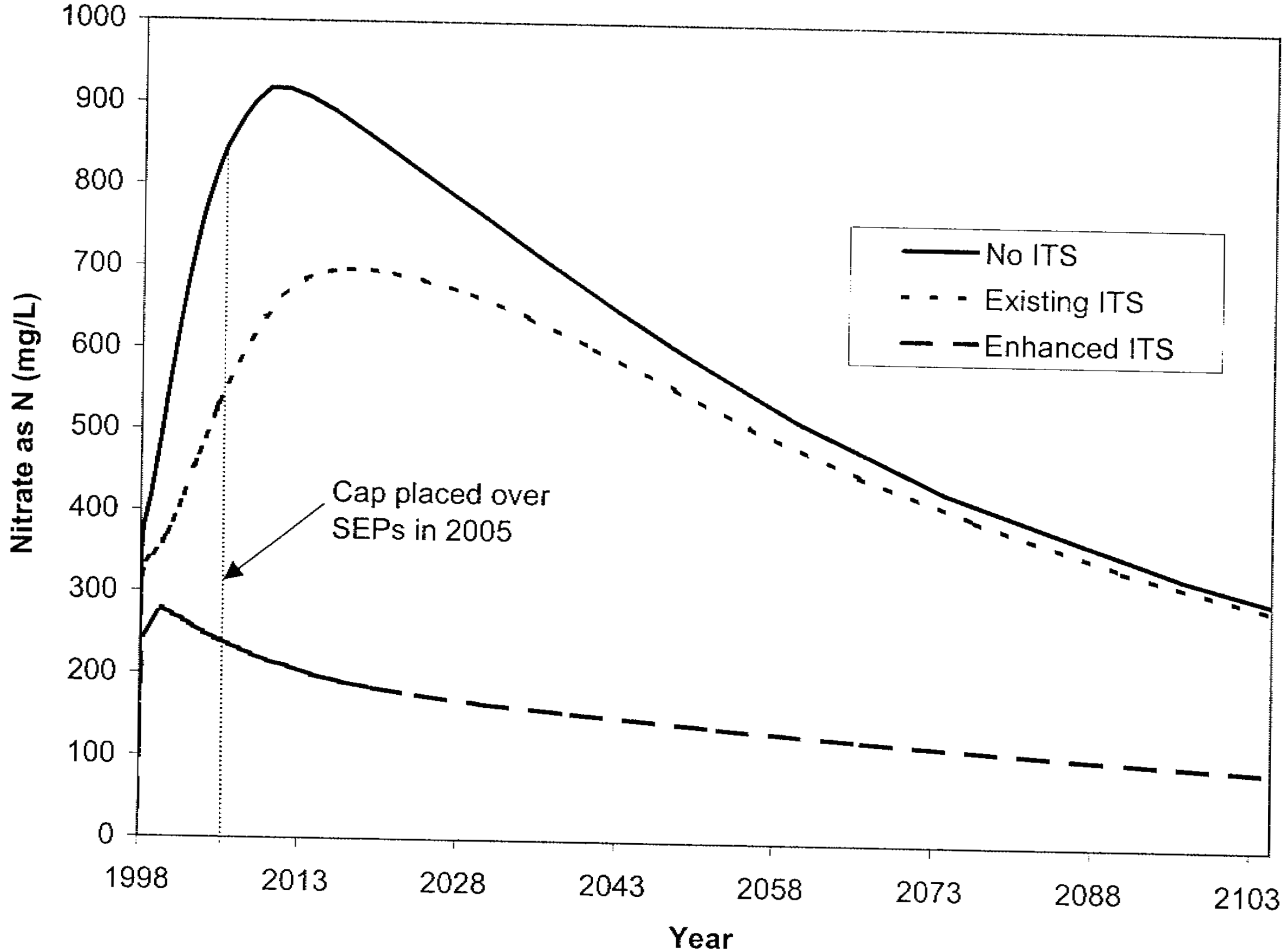

Figure 10: Simulated nitrate concentrations in weathered bedrock adjacent to North Walnut Creek

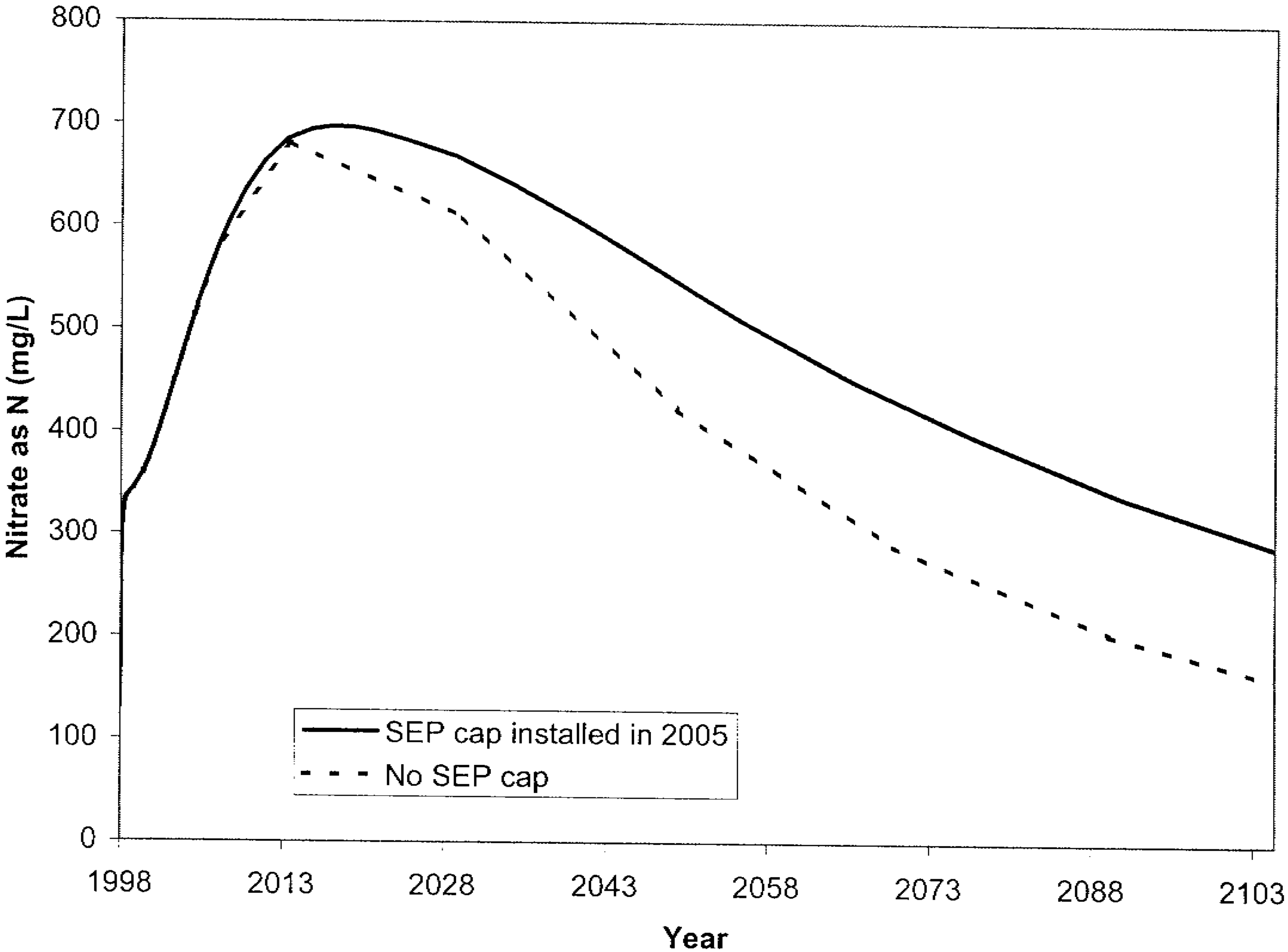

Figure 11: Simulated nitrate concentrations in weathered bedrock adjacent to North Walnut Creek
Alternative: Existing ITS

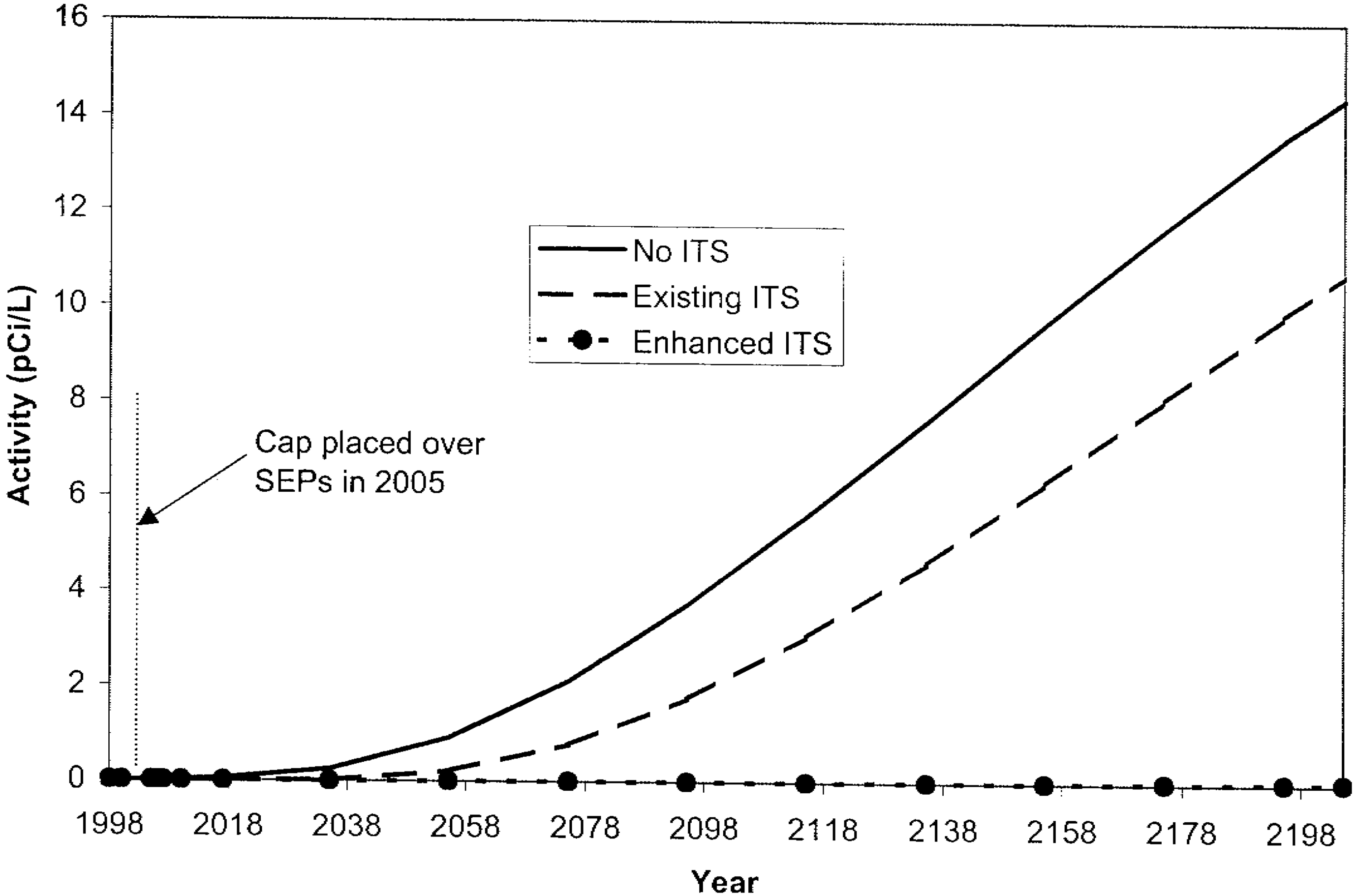

Figure 12: Simulated anthropogenic uranium activities in weathered bedrock adjacent to North Walnut Creek

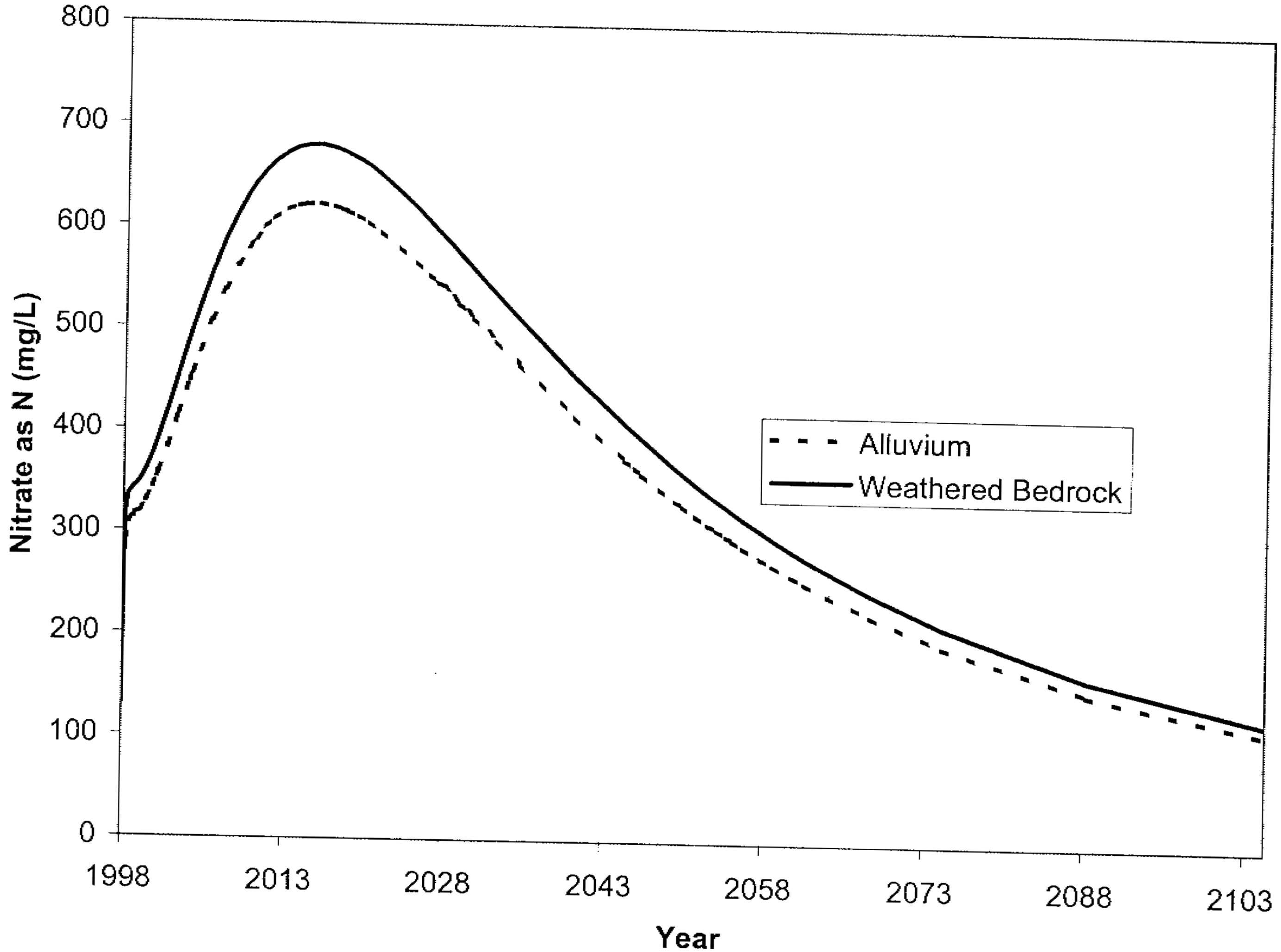

Figure 13: Simulated nitrate concentrations adjacent to North Walnut Creek
Alternative: Aggressive Flushing

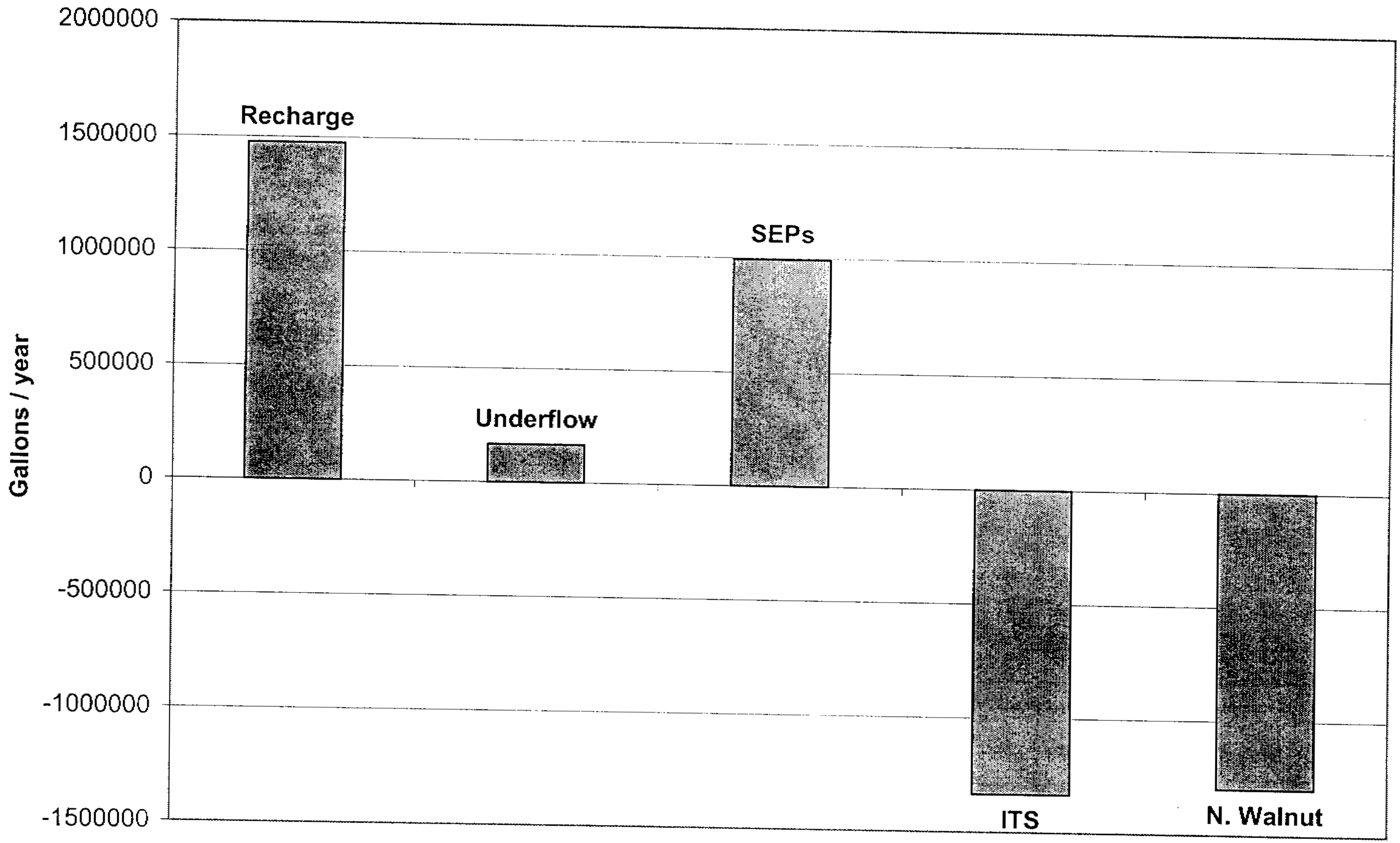

Figure 14: Water balance with no SEP cap

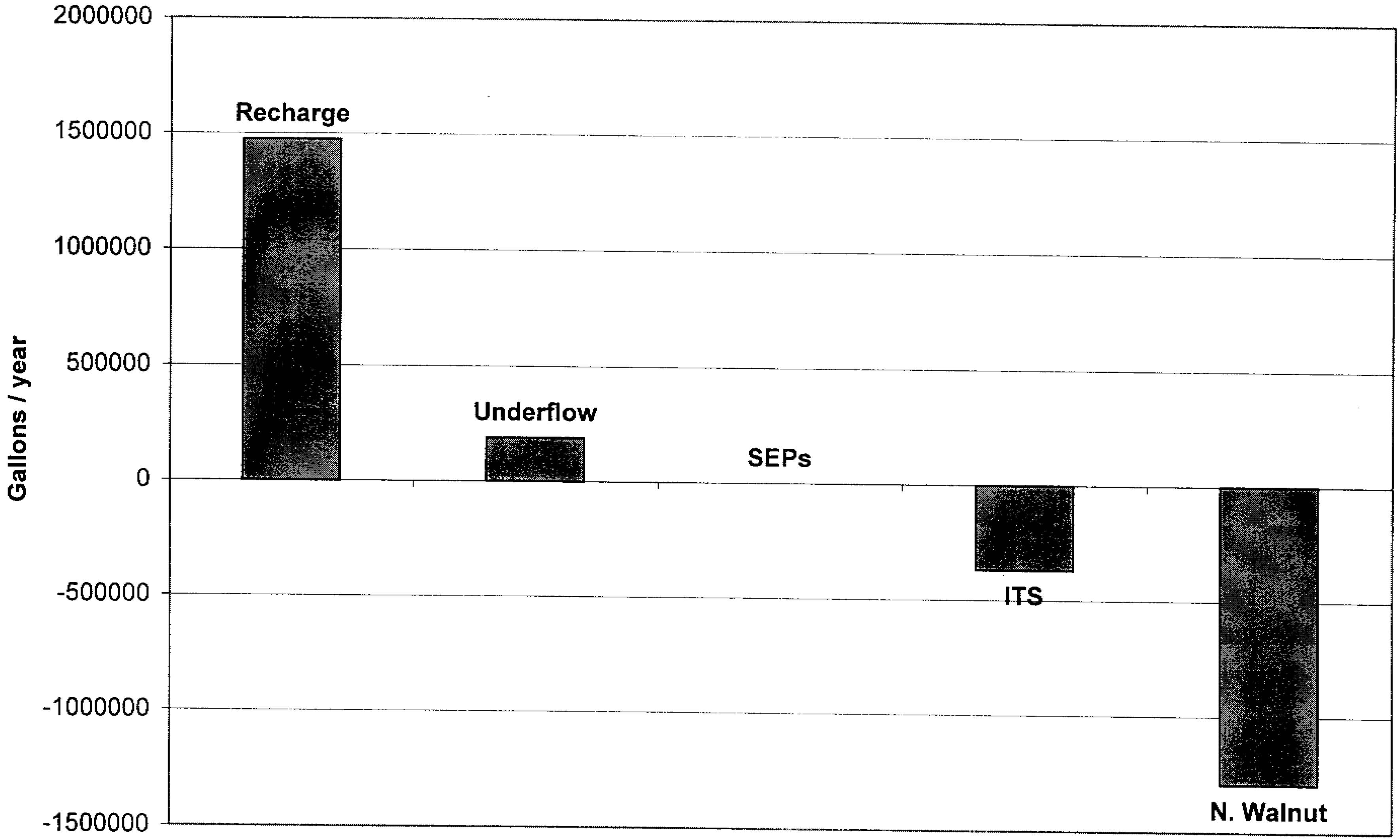

Figure 15: Water balance with SEP cap

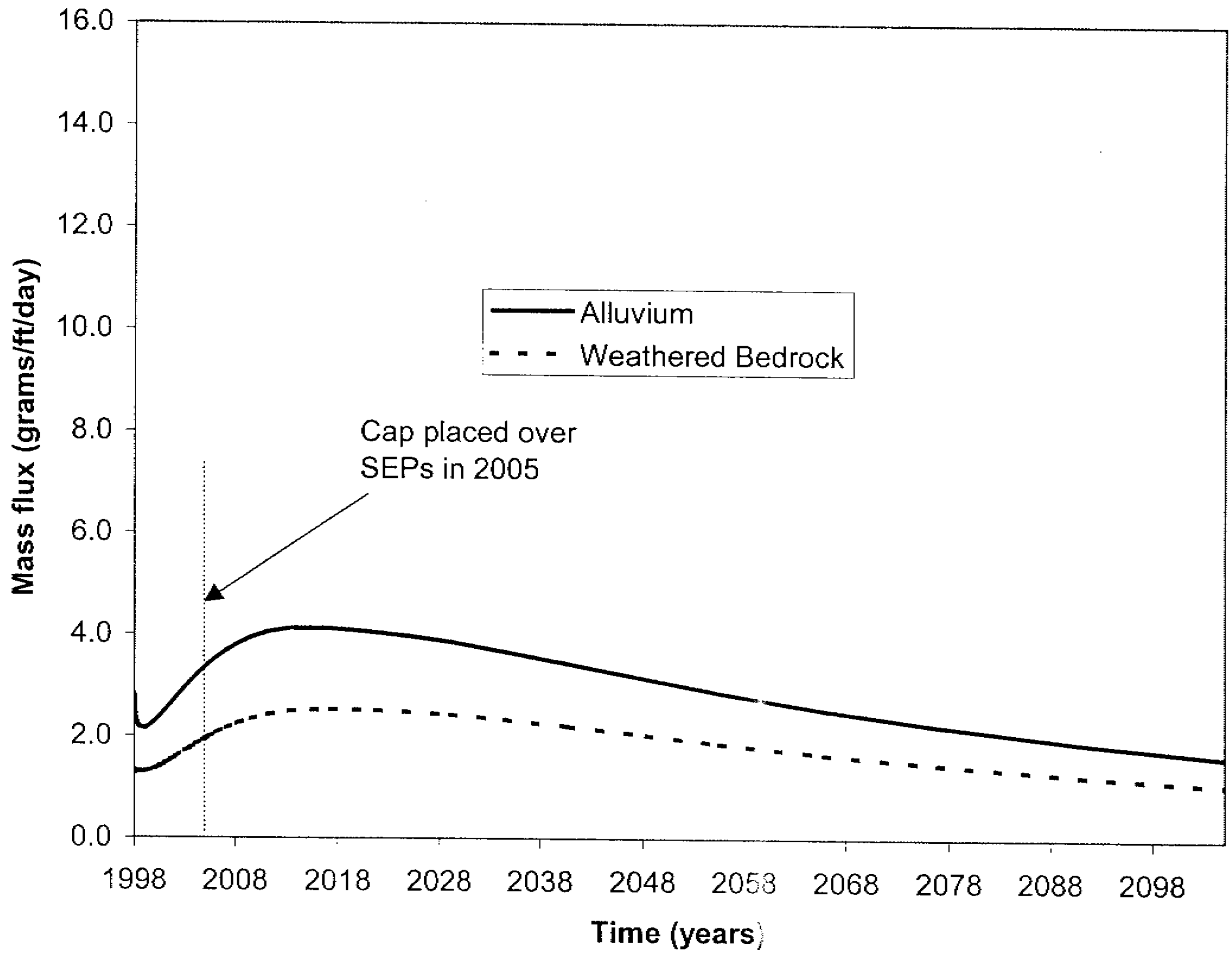

Figure 16: Simulated mass flux of nitrate to North Walnut Creek along centreline of nitrate plume
Scenario: With Existing ITS, SEP cap in 2005

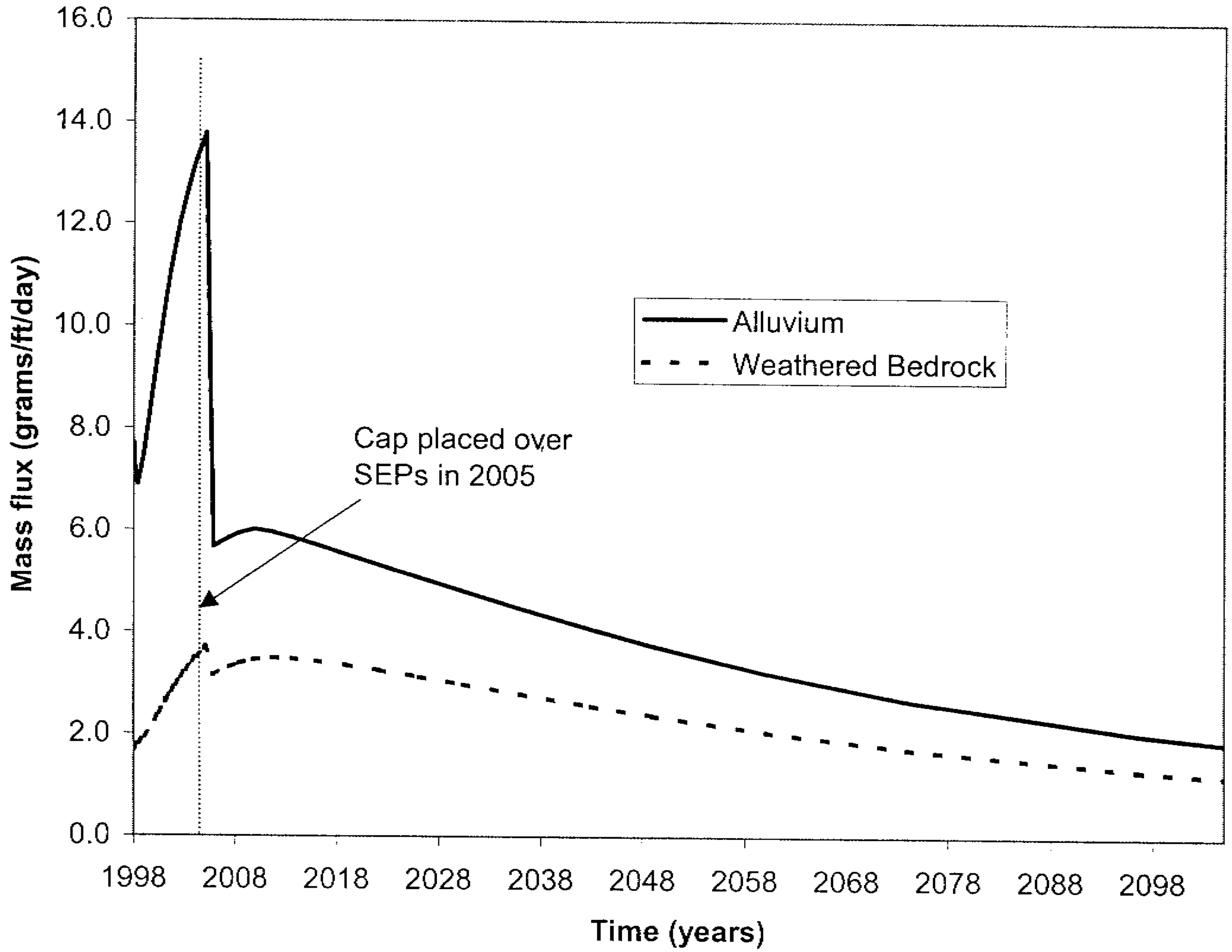

Figure 17: Simulated mass flux of nitrate to North Walnut Creek along centreline of nitrate plume
Scenario: No ITS, SEP cap in 2005

Table 1 – Calibrated values for groundwater flow parameters.

Hydrogeologic Unit	Hydrogeologic Property	Range of observed values	Value used in model
Alluvium	Horizontal Hydraulic Conductivity	.325 – 6.12 ft / d	1.5 ft/d
	Vertical Hydraulic Conductivity	.325 – 6.12 ft / d	1.5 ft/d
	Porosity	0.261 – 0.456	0.36
	Specific Storage		0.001 (ft^{-1})
	Specific Yield		0.2
Weathered Bedrock	Horizontal Hydraulic Conductivity	0.0025 – 2.23 ft / d	0.2 ft/d (model layer 3) to 1.6×10^{-3} ft/d (model layer 10)
	Vertical Hydraulic Conductivity	0.0025 – 2.23 ft / d	0.1 ft/d (model layer 3) to 7.8×10^{-4} ft/d (model layer 10)
	Porosity	0.317 – 0.436	0.38 (model layer 3) to 0.25 (model layer 10)
	Specific Storage		1.0×10^{-4} (ft^{-1})
	Specific Yield		0.02 (model layer 3) to 0.005 (model layer 10)
	Recharge from precipitation	0.4 – 2.2 inches/year	1.4 inches/year

Table 2 – Contaminant transport properties of alluvium and weathered bedrock.

Hydrogeologic Unit	Hydrogeologic Property	Range of observed values	Value used in model
Alluvium	Uranium Partitioning Coefficient (K_d)		1.05
	Nitrate Partitioning Coefficient (K_d)		0
	Longitudinal Dispersivity		150 ft.
	Soil Bulk Density	2.59 – 2.71 g / cm^3	2.65 g/cm^3
	Vertical Transverse Dispersivity		1.0 ft.
	Diffusion Coefficient		9.3×10^{-5} ft^2/d (1.0×10^{-10} m^2/s)
Weathered Bedrock	Uranium Partitioning Coefficient (K_d)	31.2 – 171.0 L / kg	0.9 – 2.5
	Nitrate Partitioning Coefficient (K_d)		0
	Soil Bulk Density	2.66 – 2.73 g / cm^3	2.69 g/cm^3
	Longitudinal Dispersivity		150 ft.
	Vertical Transverse Dispersivity		1.0 ft.
	Diffusion Coefficient		9.3×10^{-5} ft^2/d (1.0×10^{-10} m^2/s)

Table 3 – Site chronology used for simulations of historical development of nitrate plume.

Time Period	ITS configuration	Nitrate concentration in SEPs
1954 – 1981	No ITS	6,000 mg/L
1981 – 1995	Current ITS	6,000 mg/L
1995 – 1998	Current ITS	0 mg/L

/F100

ER/WM&I DDT

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Source/Driver: (Name & Number from ISP, IAG milestone, Mgmt. Action, Corres. Control, etc.)

Closure #: (Outgoing Correspondence Control #, if applicable)

Due Date

A. L. Primrose
Originator Name

GL FOR G. DiGregorio
QA Approval

J. E. Law
Contractor Manager(s)

Lane Butler
Kaiser-Hill Program Manager(s)

A. D. Rodgers
Kaiser-Hill Director

Document Subject:

TRANSMITTAL OF THE SUMMARY OF PHASE I ANALYSES OF THE REMEDIAL ALTERNATIVES FOR THE SOLAR PONDS PLUME – JEL-173-98

KH-00003NS1A

October 26, 1998

CEX-010-98

Discussion and/or Comments:

Enclosed is the "***Summary of Phase I Analyses of the Remedial Alternatives for the Solar Ponds Plume*** " for transmittal to the DOE (4 copies), the EPA (3 copies), and the CDPHE (3 copies). Four (4) additional copies are included for Kaiser-Hill distribution. This report summarizes the computer model development, modeling analyses, and other calculations that were conducted to quickly evaluate the alternatives remaining from the 1997 alternatives analysis and to determine which of these were the most feasible. It was not intended as a rigorous evaluation of contaminant flow within the complex hydrogeologic conditions present at the Solar Ponds Plume area, but as a conservative approach to screening potential remedial action. The model is a 2-D slice through the middle of the plume, with the highest concentrations applied to the entire plume area. The model was not rigorously tied back to the data and assumptions were made concerning concentrations within the plume.

When the model was developed, a more detailed evaluation of the remaining alternatives was planned as a second phase, which would have included sensitivity analyses of the ITS underflow. However, no alternatives were identified during the initial stage of the analysis to be carried forward for this second phase evaluation. The two curves, which represent the bounding conditions of the underflow, were previously presented at meetings with the stakeholders and partly replace the sensitivity analysis.

While none of the modeled alternatives was carried forward, the collection and treatment alternative presently under consideration is similar to the enhanced ITS scenario.

As requested, the cost of additional modeling was investigated. However, additional data would be required to accurately develop the new model. These data would include collection and analysis of nitrate degradation products from numerous existing wells within the plume to define the degradation rate, and installation of a fence line of new wells to better determine spatial distribution of contaminants. Multi-port testing of bedrock hydraulic conductivities would be conducted to obtain vertical conductivity data. Cost of collecting these additional data is estimated at $100,000.