Supplemental Modeling and Analysis Report

Atlas Corporation Moab Mill, Moab, Utah

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1 .0 Introduction

The purpose of this report is to provide additional numerical modeling and data evaluation for the Atlas tailings pile near Moab, Utah. A previous report (Tailings Pile Seepage Model: The Atlas Corporation Moab Mill, Moab, Utah, January 9, 1998) prepared for the Nuclear Regulatory Commission (NRC) by Oak Ridge National Laboratory/Grand Junction (ORNL/GJ) presented the results of steady-state modeling of water flow and subsequent discharge to the underlying groundwater system. At the request of the Fish and Wildlife Service (FWS), this model was expanded to evaluate the impact of drainage from the tailings pile in addition to recharge from precipitation in a transient mode simulation. In addition, the FWS requested transient simulations of contaminant transport in the alluvial aquifer. Subsequently, NRC requested an evaluation of additional hydrologic issues related to the results presented in the Tailings Pile Seepage Model (ORNL/GJ 1998a) and the Limited Groundwater Investigation (ORNL/GJ 1998b). Funding for the report was provided by the U.S. Department of Energy. The following section lists the individual tasks with subsequent sections providing the results. A map for the Atlas Moab Mill site is presented in Fig. 1.1.

1.1 Project Scope

The scope of this report was based on requests by'the FWS and NRC during a January 15 conference call with ORNL/GJ. Listed below are the individual tasks that are addressed in this report.

<u>FWS REOUESTED TASKS</u>

- **Task FWS-1:** Transient simulations of pile drainage.
- **Task** FWS-2: Transient simulations of the contaminant concentrations discharging from the pile.
- **Task** FWS-3: Impact of tailings pile removal on contaminant flux discharging to the alluvial aquifer and the Colorado River.

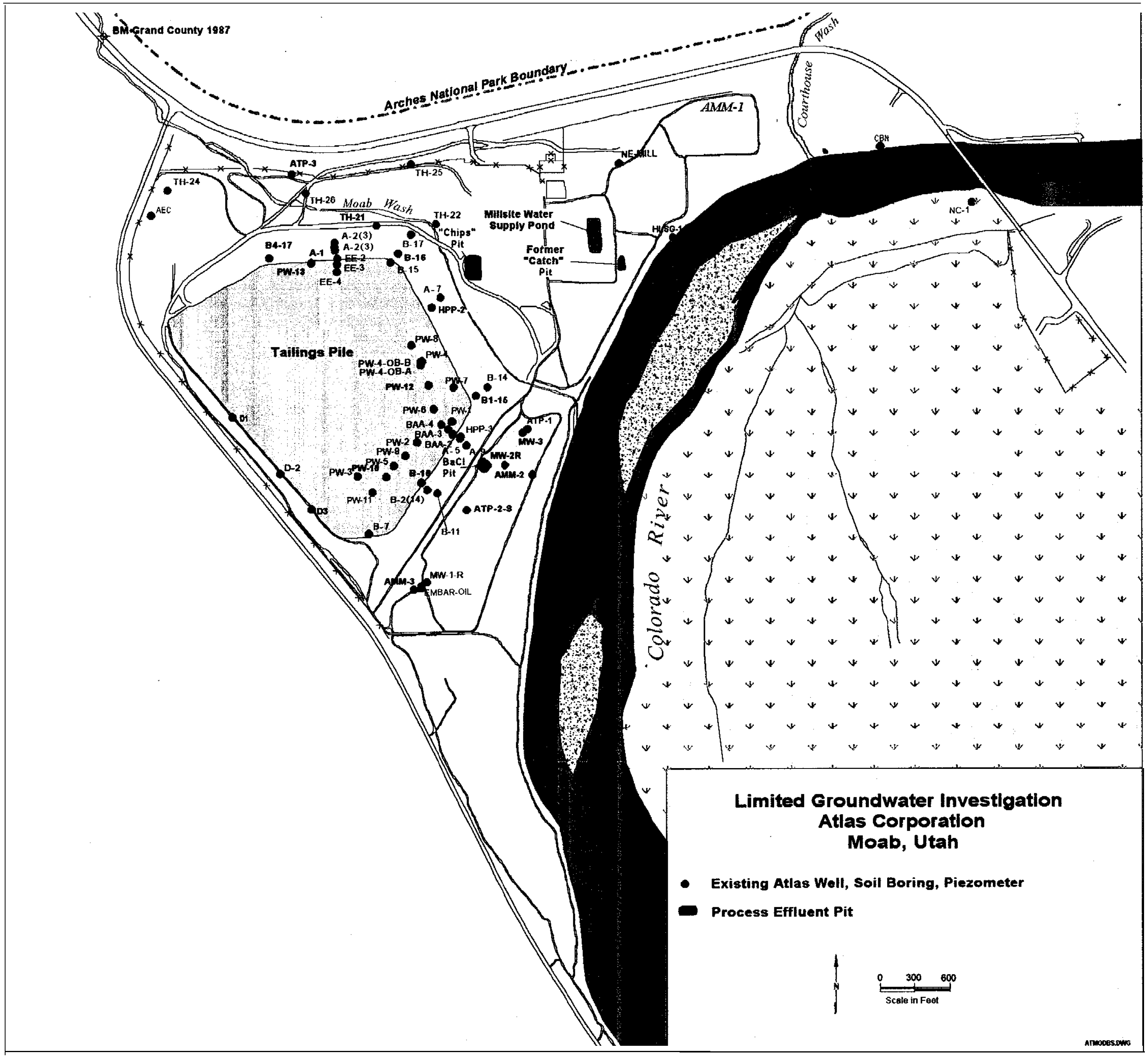

Fig. 1.1. Location map of the Atlas Mill Site.

NRC REQUESTED TASKS

- **Task NRC-1:** Sensitivity analysis of the hydrologic parameters used in the model.
- **Task NRC-2:** Impacts of retardation on contaminant migration in the alluvial groundwater.
- **Task NRC-3:** Transient effects of river stage fluctuation.
- **Task NRC-4:** Review of historical water level and water quality data and the subsequent impact on seepage rates from the tailings pile.
- **Task NRC-5:** Impact of construction activities during tailings pile removal on contaminant discharge to the groundwater.

Each of these tasks are addressed but at varying levels of detail. The bulk of this report discusses the results of transient numerical modeling for the drainage of the tailings pore water and contaminant transport simulations. Because'of time and budget limitations, several of the tasks are addressed only in limited detail. In particular, ORNL/GJ acknowledges that the sensitivity analysis task (Task NRC- 1) has not been adequately addressed.

2.0 Groundwater and Contaminant Transport Modeling

2.1 Modeling Constraints

The information presented in this and the previous reports (ORNL/GJ 1998a, b) is preliminary and is intended to provide an order of magnitude estimate of the geochemical and hydrologic processes at the site. Further work, particularly regarding sensitivity analysis of the model and impacts of contaminant retardation as well as heterogeneities in the tailings pile, variable saturation of the pile, and transient river effects is needed to improve the reliability of the model predictions.

2.2 Drainage Modeling

The existing two-dimensional model (Fig. 2.1) used in' the previous simulations (ORNL/GJ 1998a) was modified for the pile drainage simulations (Task FWS-1). Based on recent and historic soil borings drilled through the pile, very fine-grain slimes located at the base of the pile were included in the simulation. It was assumed that the slimes cover the entire bottom of the tailings pile. Boring logs indicate that there are areas where the slimes are absent but there is insufficient data to construct a reliable map of their extent and thickness. The same permeability and unsaturated hydraulic characteristics (0.0003 ft/d [10^{-7} cm/s]) used for the clay cover were used to represent the slimes. It should be noted that the tailings material above the slimes is mostly fine to very fine-grained sand.

Boundary conditions consisted of mixed conditions of constant head or flux boundaries. The lateral boundaries consisted of constant head values for the alluvial aquifer immediately upgradient of the tailings pile and the river elevation downgradient of the pile. The lateral boundaries above the water table were set as “no flux” boundaries. Head values were based on water-level measurements from monitoring wells or surveyed river elevations taken during December 1997. The lower boundary, which was'also set as a “no flux' boundary, may not be completely accurate considering the evidence of vertical flow from the underlying salt formations -- as indicated by the elevated chloride concentrations downgradient of the pile (ORNL/GJ 1998b). Nevertheless, any vertical flow should have little impact on transport calculations through the cover and pile. The upper boundary was set as a 'fixed flux value that corresponds to the estimated yearly infiltration rate which was estimated to be 0.0002 ft/yr based on a fixed percentage of the average yearly rainfall of 8 in/yr (Blanchard, 1990). This recharge rate, resulting from precipitation, is an estimate and is subject to a range of interpretations.

Initial conditions consisted of saturated moisture contents for the tailings material based on the assumption that the slimes and tailings were saturated when placed in the impoundment. Simulations were run in the transient mode with small incremental time steps that increase based on the convergence criteria. Moisture content and vertical flux values for water discharging through the pile were recorded during the simulations.

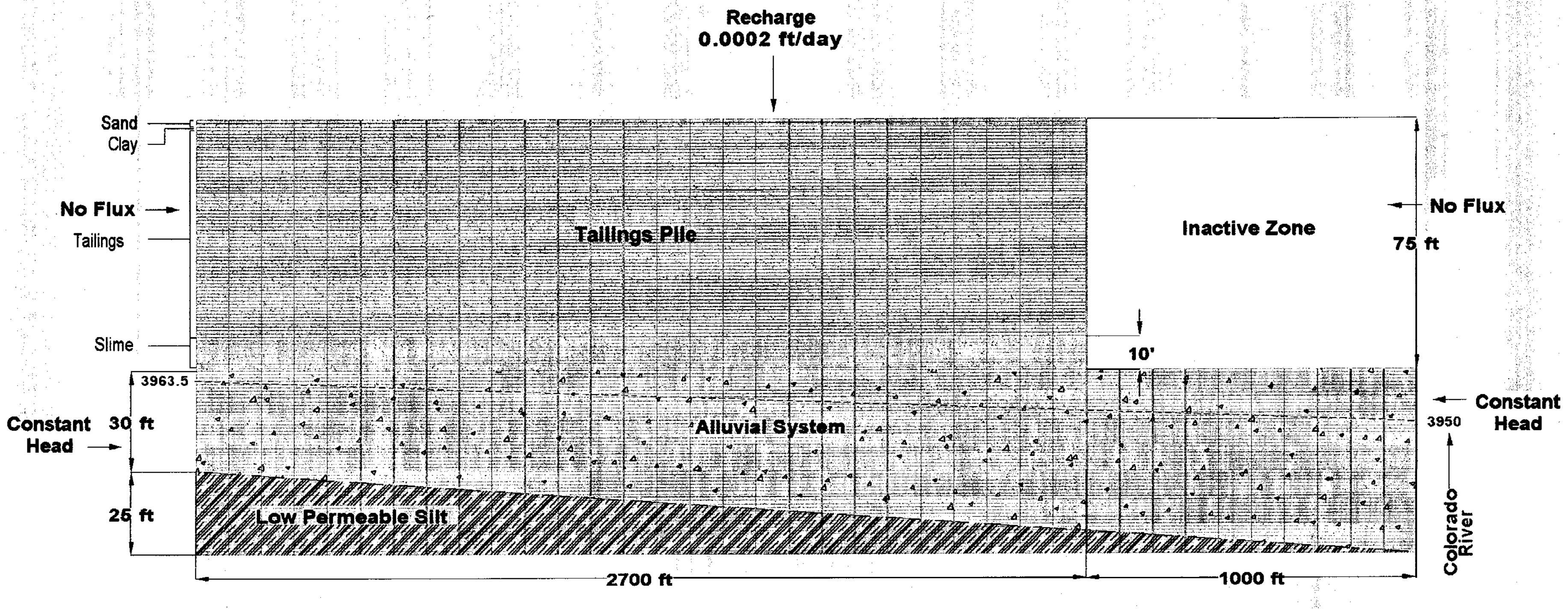

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Fig. 2.1. Model domain for flow simulations.

Figures 2.2 and 2.3 show the vertical flux and saturation as a function of time for the center of the fine-grain sand tailings and at the base of the slimes immediately above the alluvial aquifer. The graphs show that the bulk of the pile drainage occurs within the first 100 years. Steady-state conditions, defined as the point in time where the flux at the base of the pile matches the recharge rate, occur after 238 years. The relatively flat nature of the curves (Figs. 2.2 and 2.3) between 100 and 238 years represents continued drainage of bore water in the tailings and slimes but at a rate of approximately 5 percent of the recharge flux from precipitation.

2.3 Contaminant Transport Simulations

Two separate contaminant transport simulations were conducted for this investigation. The first simulation (Section 2.3.1) consisted of the transport of contaminants from the pile into the alluvial aquifer for a period of 41 years (Task FWS-2). Forty-one years represents the available time for transport since the initial placement of tailings in the impoundment in 1956. The second simulation (Section 2.3.2) assumed that the sources of contamination, the tailings pile and all other potential sources, were removed (Task FWS-3). This simulation predicts the time required for contaminant levels in the aquifer to return to pre-1956 levels.

For all simulations performed, contaminant concentrations were normalized to the average oontaminant concentrations in the tailings pile pore water. It was assumed that the contaminants were conservative, therefore, Kd values were set to zero: Based on published values (Freeze and Cherry 1979) of the coefficients of dispersivity for a sand aquifer, the longitudinal dispersivity was set at 0.5 ft^2/d and the transverse dispersivity was set at 0.05 ft^2/d. Future sensitivity analyses should be conducted to evaluate the importance of these parameters on the contaminant transport simuiations.

2.3.1 Plume Simulations

Initial groundwater flow conditions consisted of a saturated tailings pile at a normalized contaminant concentration of 1 .O. Contaminant concentrations in the underlying alluvium were

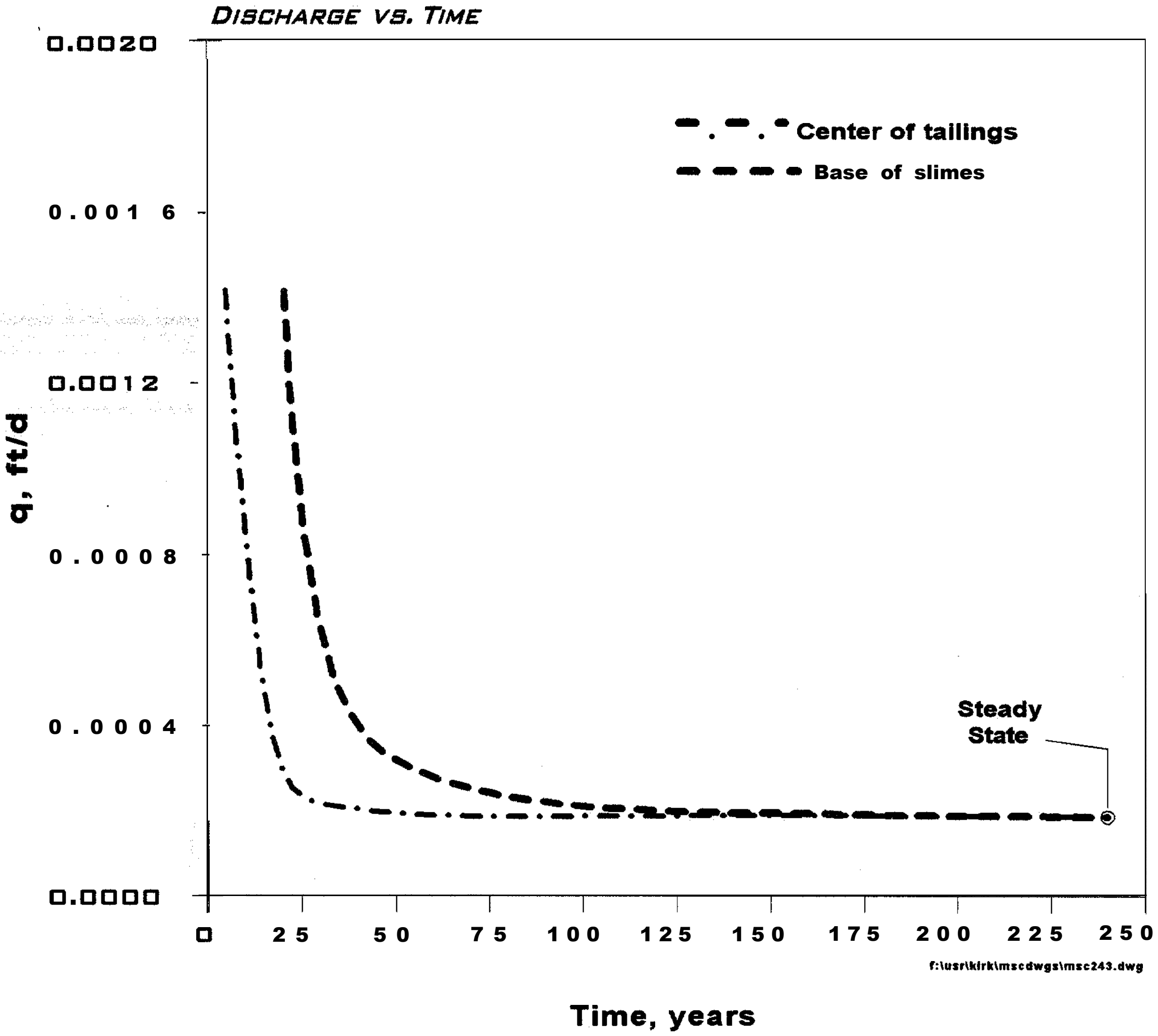

Figure 2.2. Flux rates in the tailings pile during desaturation.

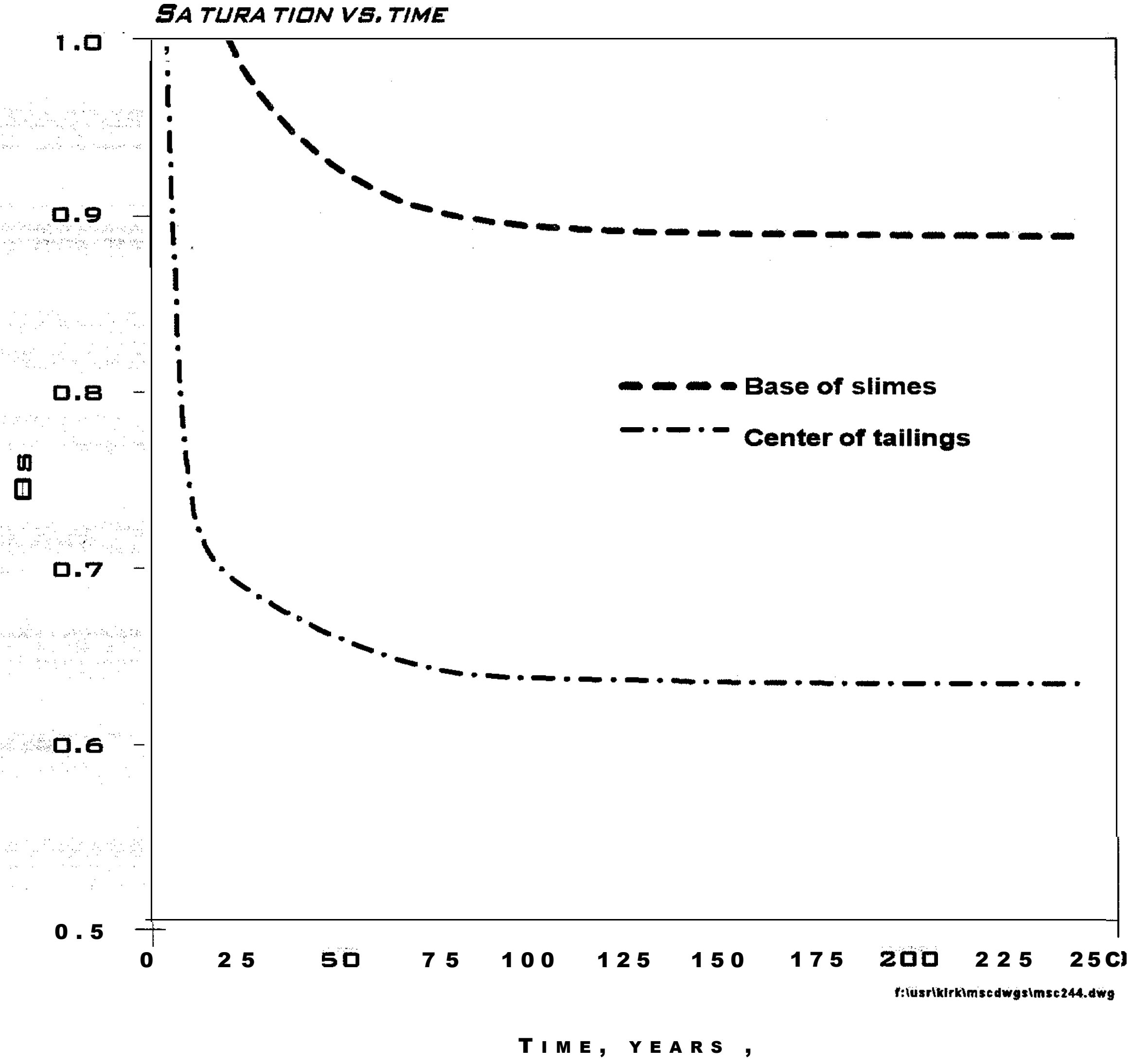

Figure 2.3. Moisture contents (Θs) changes with time in tailings pile based on numerical modeling simulation.

set to zero.

Figure 2.4 illustrates the contaminant plume in the alluvial aquifer after 41 years. The simulations predict a mature plume that reached the river several years prior to the end of the 41-year simulation period. This is consistent with contaminant plume maps based on water sample results presented in the ORNL/GJ groundwater report (ORNL/GJ 1998b).

The model predicts that the contaminants emanating from the tailings pile are diluted by 60 percent by the groundwater. Although the 60 percent dilution rate is consistent with mixing simulations for ammonia, the extent of retardation by aquifer sediments and the extent of oxidation of ammonia to nitrate is unknown, therefore, reducing the reliability of the ammonia simulation. In a similar fashion, sulfate simulations are questionable because the solubility limits of several of its salts are probably exceeded. The mixing simulations are, perhaps, best served by the uranium data due to the conservative nature of the uranyl carbonate ion in this geochemical environment. For uranium mixing calculations, however, a 60 percent dilution results in a reduction of the tailings pore water concentration of 23.5 mg/l to 9.4 mg/l in the alluvial groundwater downgradient of the pile. The actual average uranium concentration in the alluvial groundwater is 4.62 mg/l--approximately one-half the amount predicted by the model. Thus, these results suggest that the initial input of contaminated water is high by a factor of two during the first 30 years of the simulation. Most likely, the initial condition of total saturation is not correct and a lower saturation value should be used for future simulations. Using a lower saturation value will permit a more accurate simulation of the concentrations that are now being measured. Relative concentrations, as described in the next two paragraphs, are also affected by the choice of initial saturation conditions. The relative concentrations predicted later are probably too high but still within a factor of 2 or 3 of the actual values.

A simulation was conducted to evaluate the long-term contaminant concentrations near the river based on the assumption that the tailings pile is not removed. Figure 2.5 shows the normalized contaminant concentrations at a node in the center of the groundwater contaminant plume adjacent to the Colorado River. This node is only one foot thick. Actual contaminant concentrations as measured in a monitoring well would be lower because the well is screened over

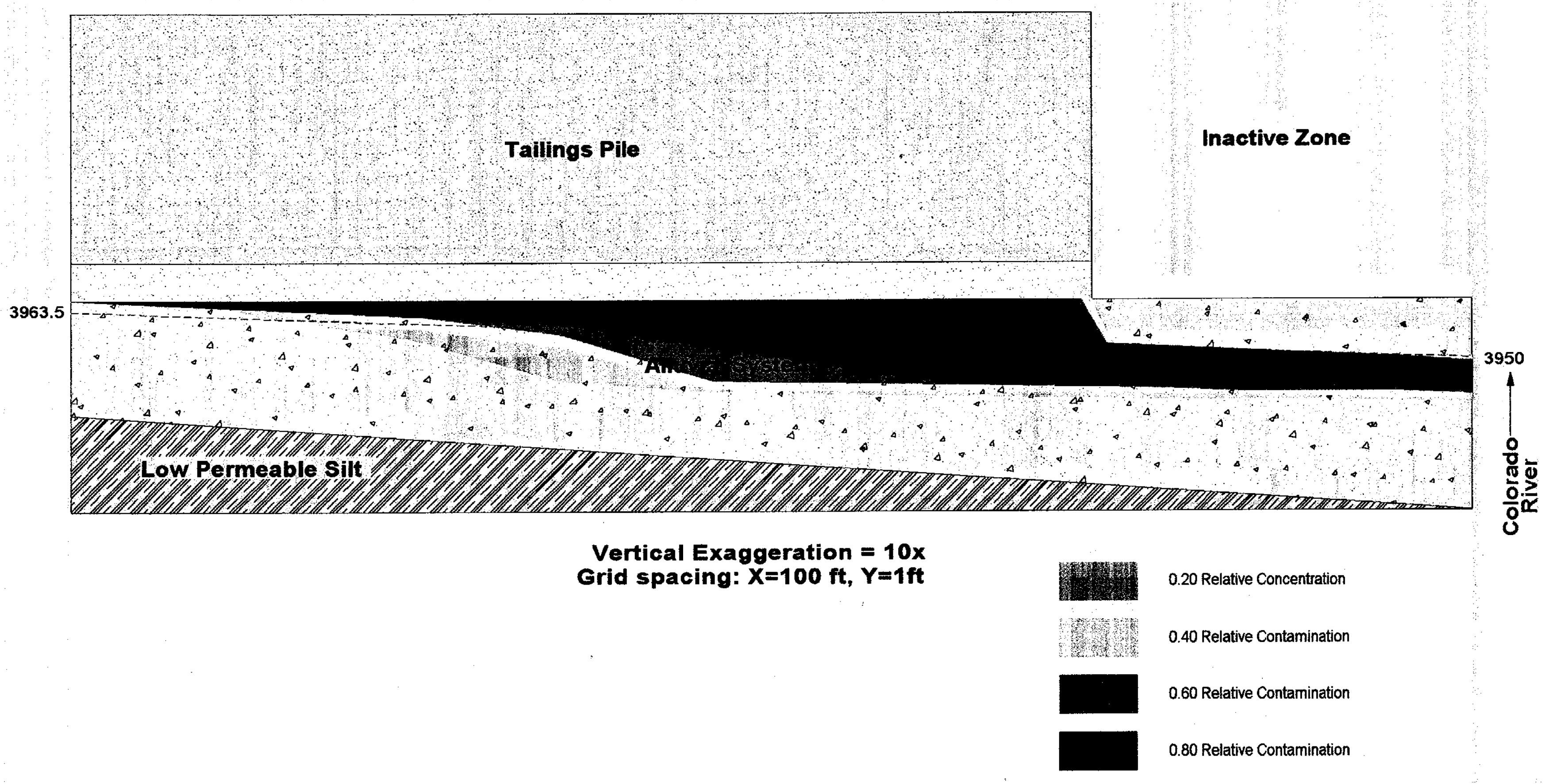

Fig. 2.4. Normalized contaminant plume after 41 years.

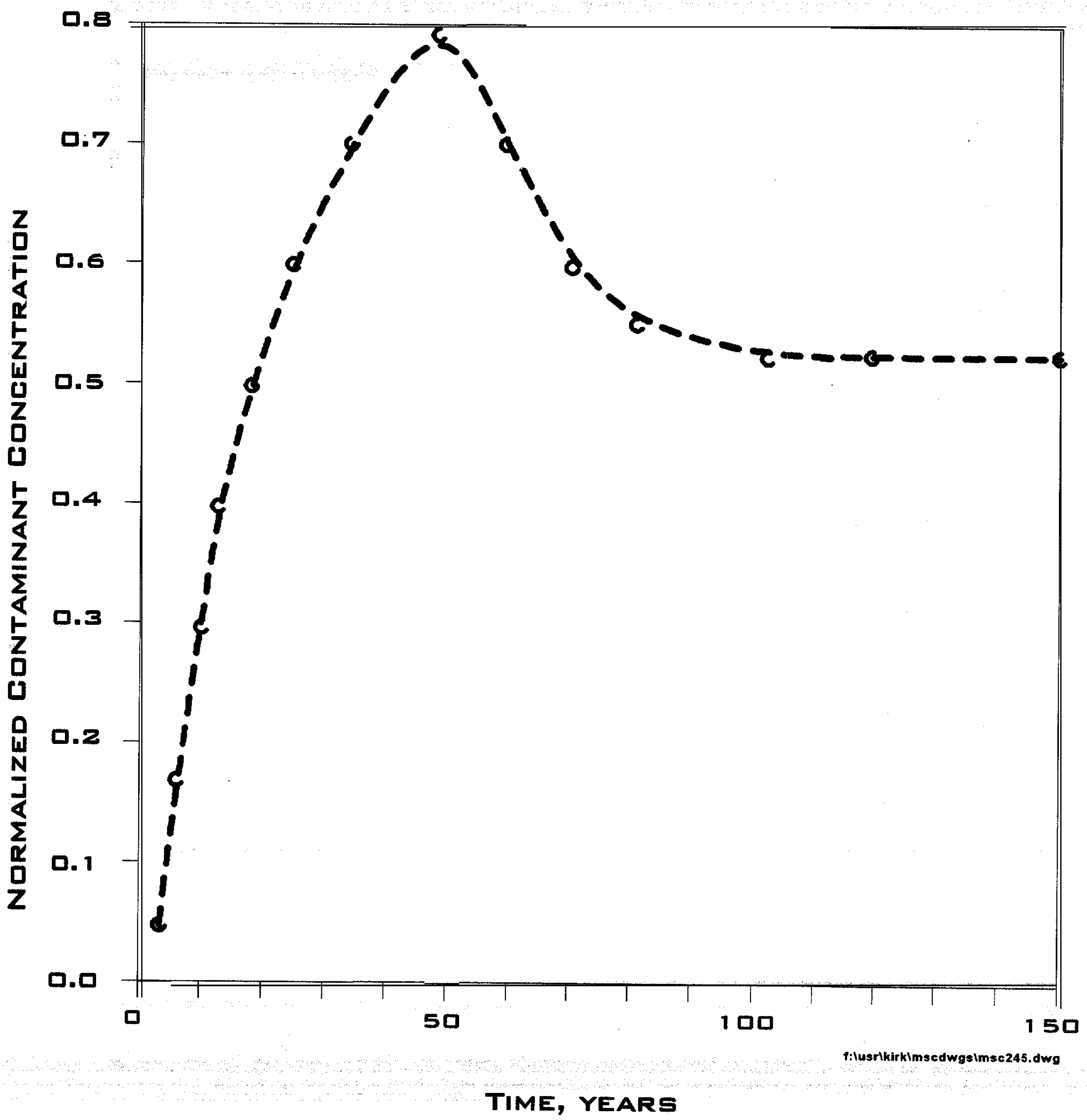

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Figure 2.5. Normalized contaminant concentration at a selected node adjacent to river.

several nodes that exhibit Power contaminant concentrations.

The model simulation predicts that after 50 years, the decline in the contribution of contaminants due to the drainage of tailings pore water begins to impact concentrations at the river (see Figs. 2.2 and 2.3). Because 41 years have passed' since the tailings were first placed in the impoundment, these results suggest that contaminant concentrations at the river will continue to increase for 9 more years. The simulation further suggests that the peak of the contamination is located near the downgradient edge of the tailings pile. This result is consistent with the trend analysis conducted in Section 5.0 that indicates that there is no discernable trend in contaminant concentrations.

2.3.2 Source Removal Simulations

The source removal simulation assumed that after 5 1 years of contaminant release from the tailings pile and subsequent transport by the alluvial aquifer, the source of contamination was completely removed by remedial actions. after 41 years of contaminant transport, an additional 10 years of continuous input of contaminants was simulated based on the assumption that tailings removal will require approximately 10 years to complete. During these 10 years, contaminant flux rates were consistent with existing rates under the no source removal scenario.

-Figures 2.6 through 2.8 show the extent of the plume at 10, 16 and 27 years after source removal. After 35 years, the model predicts that contaminant concentrations near the river will be less than 10 percent of what was present in the initial tailings pile pore water. Results of the simulations are consistent with average linear groundwater flow velocities for the alluvial aquifer as reported previously (ORNL/GJ 1998a). Finally, using an average linear velocity of 107 ft/yr (ORNL/GJ 1998a) and approximately 3800 feet of travel distance, 3 5.5 years would be required to clean the aquifer. This value, however, is unrealistic because this simulation does not consider the effect of molecular diffusion of contaminants from permeable zones into adjacent low permeable zones and subsequent diffusion back to permeable zones as the concentration gradient reverses. The net result of these factors is that there will be an increased amount of time before the aquifer

10 years after source is removed

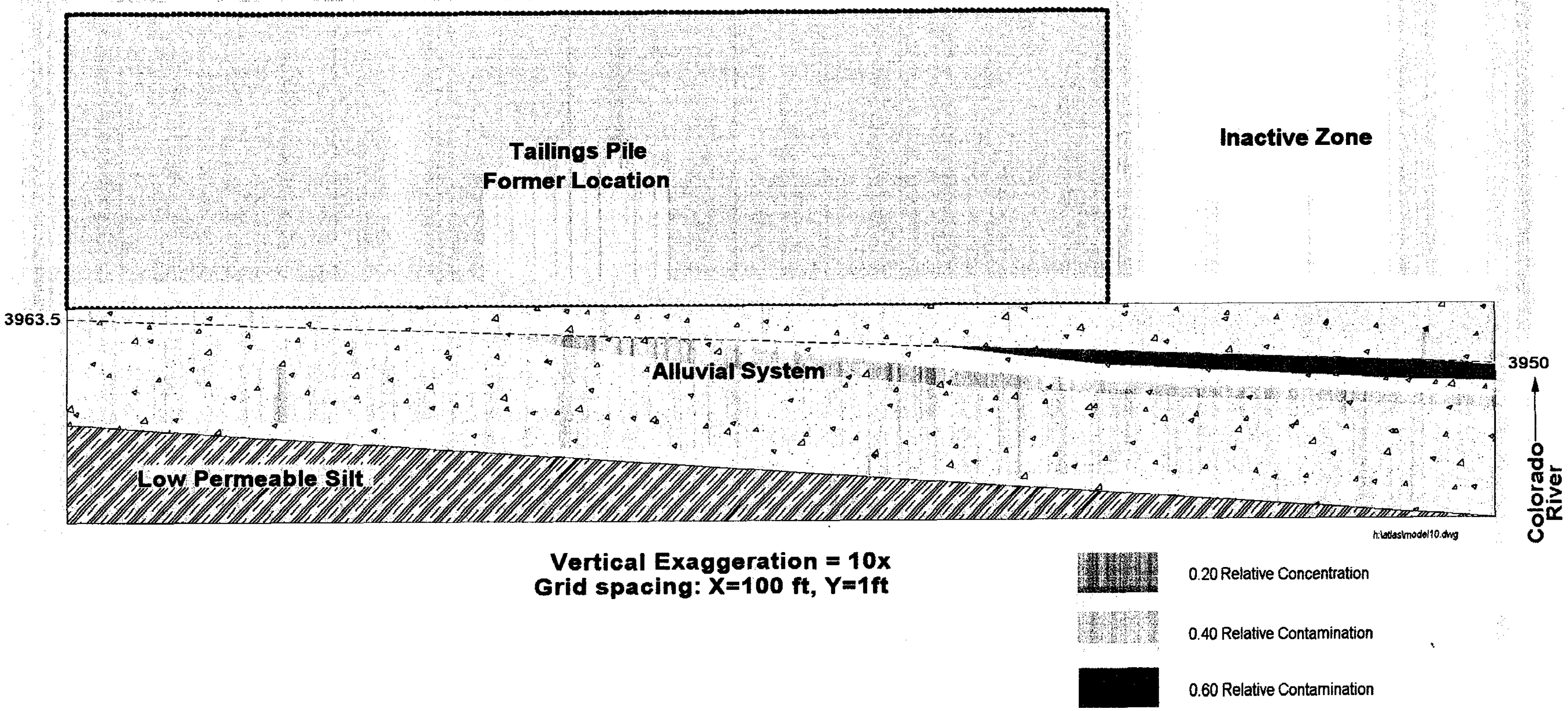

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Fig. 2.6. Extent of groundwater contaminant plume 10 years after source removal.

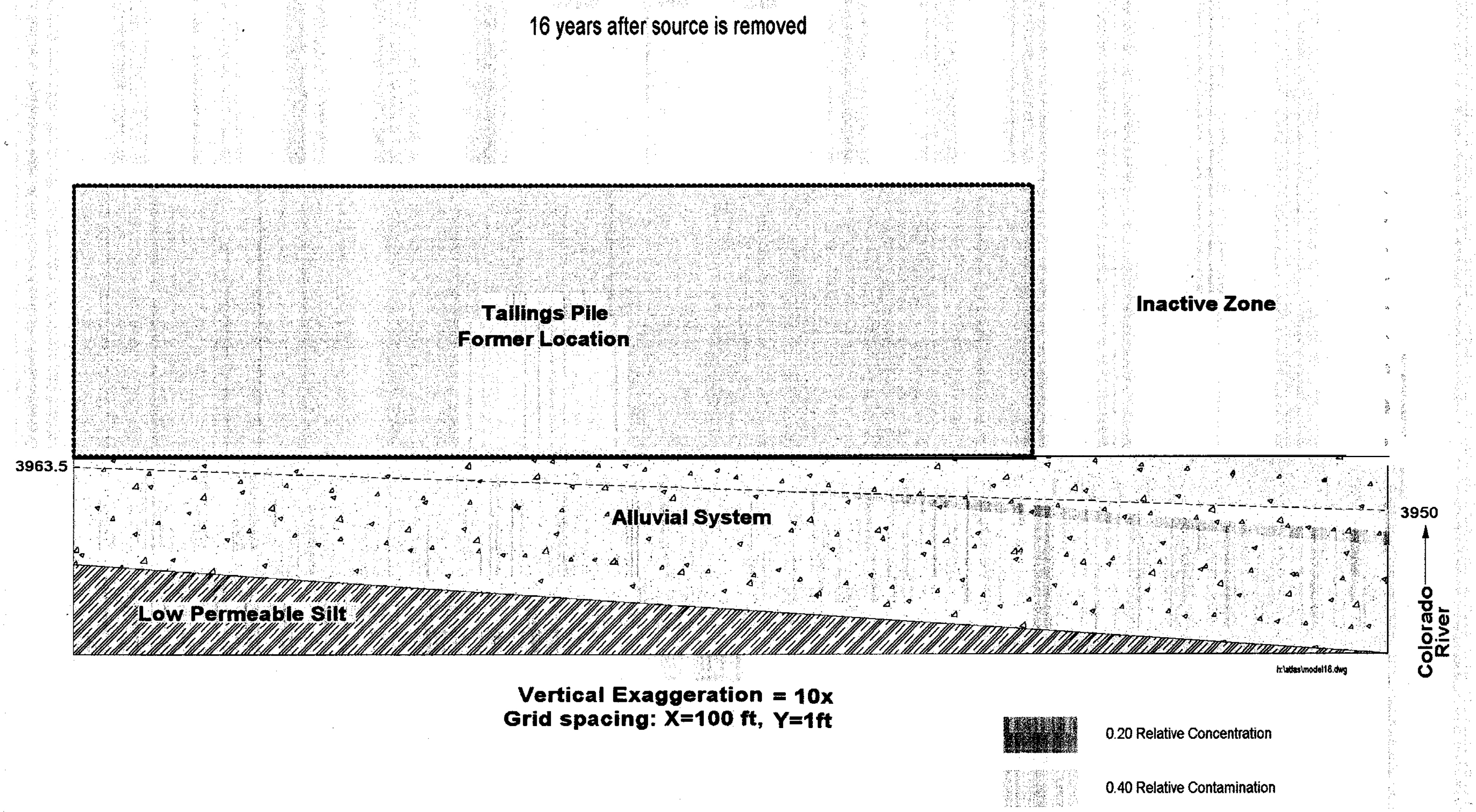

Fig. 2.7. Extent of groundwater contaminant plume 16 years after source is removed.

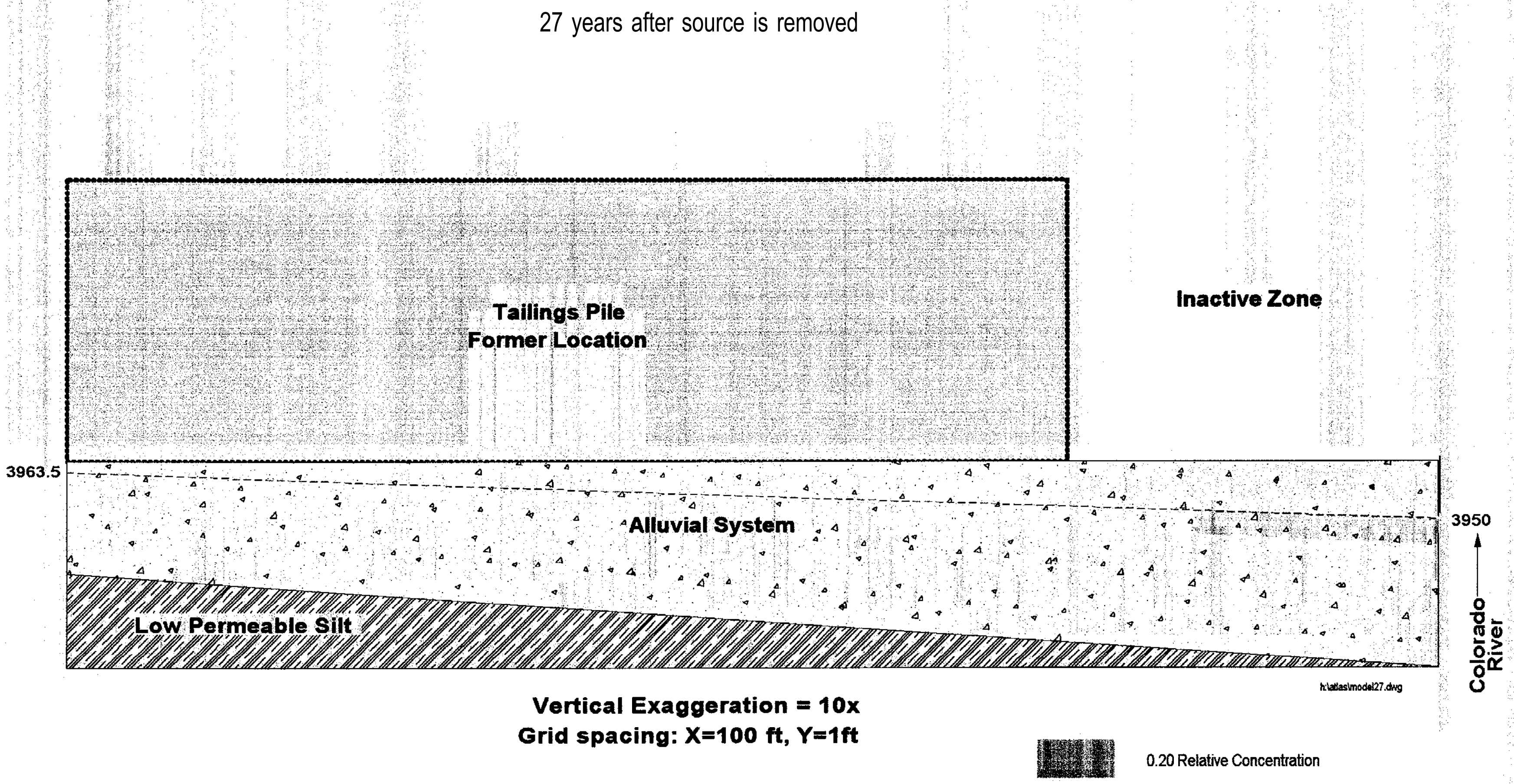

Fig. 2.8. Extent of groundwater contaminant plume 27 years after source removal.

completely cleans itself Results from other tailings pile removal projects should be evaluated to improve the estimate for cleaning the aquifer.

3.0 Sensitivity Analysis

The purpose of a sensitivity analysis is to quantify the uncertainty in the calibrated model caused by uncertainties in the estimate of aquifer parameters, initial conditions, boundary conditions, and contaminant concentrations (Task NRC-l). A sensitivity analysis is an essential step in all modeling applications. During a sensitivity analysis, values for hydraulic conductivity, storage, recharge, and boundary conditions are systematically changed within previously established plausible ranges. The magnitude of changes in head and contaminant concentrations from the calibrated solution is a measure of the sensitivity to that particular parameter.

Because of the limited time frame available to conduct this modeling of the Atlas site, it was not possible to conduct a sensitivity analysis. ORNL/GJ recommends that future Work be performed to complete this task. If this recommendation is followed, the most important hydraulic parameters will be identified. Additional field Work Can then be proposed to better define the most important parameters.

4.0 Retardation of Contaminants

No specific studies have been performed to address retardation of contaminants (Task NRC-2). However, in general, the oxidized, sandy, gravelly, highly alkaline nature of the alluvial aquifer will promote migration of the contaminants, particularly those found as anions: uranium, molybdenum, sulfate, and nitrate. Ammonium is a special case because it is apparently being converted to nitrate due to the oxidizing nature of the alluvial system. In addition, sulfate species may be near their solubility limits. The discussion below, therefore, focuses on uranium because its geochemistry in this type of environment is well understood. Because of their similar behavior, this discussion can also be applied, in a general way, to molybdenum.

The distribution of uranium species is highly dependent on the carbonate concentration. The third graph in Fig. 4.1 (Waite and Payne 1993) is probably not too dissimilar from what might be expected for the groundwater at the Atlas site. Thus, $[UO_2(CO_3)_2]^{2-}$ and UO_2CO_3 may be important species. However, the speciation is so dependent on the partial pressure of carbon dioxide that it is difficult to generalize. For example, Duff and Amrhein (1996) state that "in the presence of dissolved carbonates, U(W) forms several strong carbonate complexes: $(UO_2)_2CO_3(OH)^{3-}$, UO_2CO_3, $UO_2(CO_3)_2^{2-}$, $UO_2(CO_3)_3^{4-}$." Nevertheless, it is concluded that uranium in the alluvial aquifer will be in the form of one of several negatively-charged carbonate species.

As can be inferred by the previous discussion, adsorption decreases with decreasing pH and increasing alkalinity. The reason for this effect is that formation of the dicarbonate species is increasingly favored and bicarbonate ion competes for available adsorption sites (van Geen et al. 1994). Soil and mineral surfaces are general&negatively-charged. Thus, the negatively-charged or neutral carbonate species have little propensity to sorb on the soil minerals,

This conclusion is supported by Duff and Amrhein (1996) who concluded that "with increasing carbonate alkalinity, U(VI) most likely formed negatively charged carbonate complexes which did not strongly adsorb to the soil or goethite in the study. Therefore, U(VI) adsorption to soils dominated by permanently charged clays is not a likely factor controlling U(VI) solubility . . . "

To summarize, conditions at the Atlas site appear to be favorable to the formation of carbonate complexes of U(VI). Such complexes are not strongly adsorbed by soil materials and are, therefore, relatively mobile in the environment. Extensive sampling and analysis regarding uranium speciation and' the effects of other ions would be needed to apply a geochemical model that would more accurately simulate uranium mobility.

5.0 Trend Analysis of Groundwater Contamination Data

NRC requested that historical water quality data be reviewed and that a trend analysis be provided (Task NRC-4). Several wells at the site have been sampled and analyzed on a regular basis since 1987. The objective of the statistidal analysis presented in this section is to detect changes or

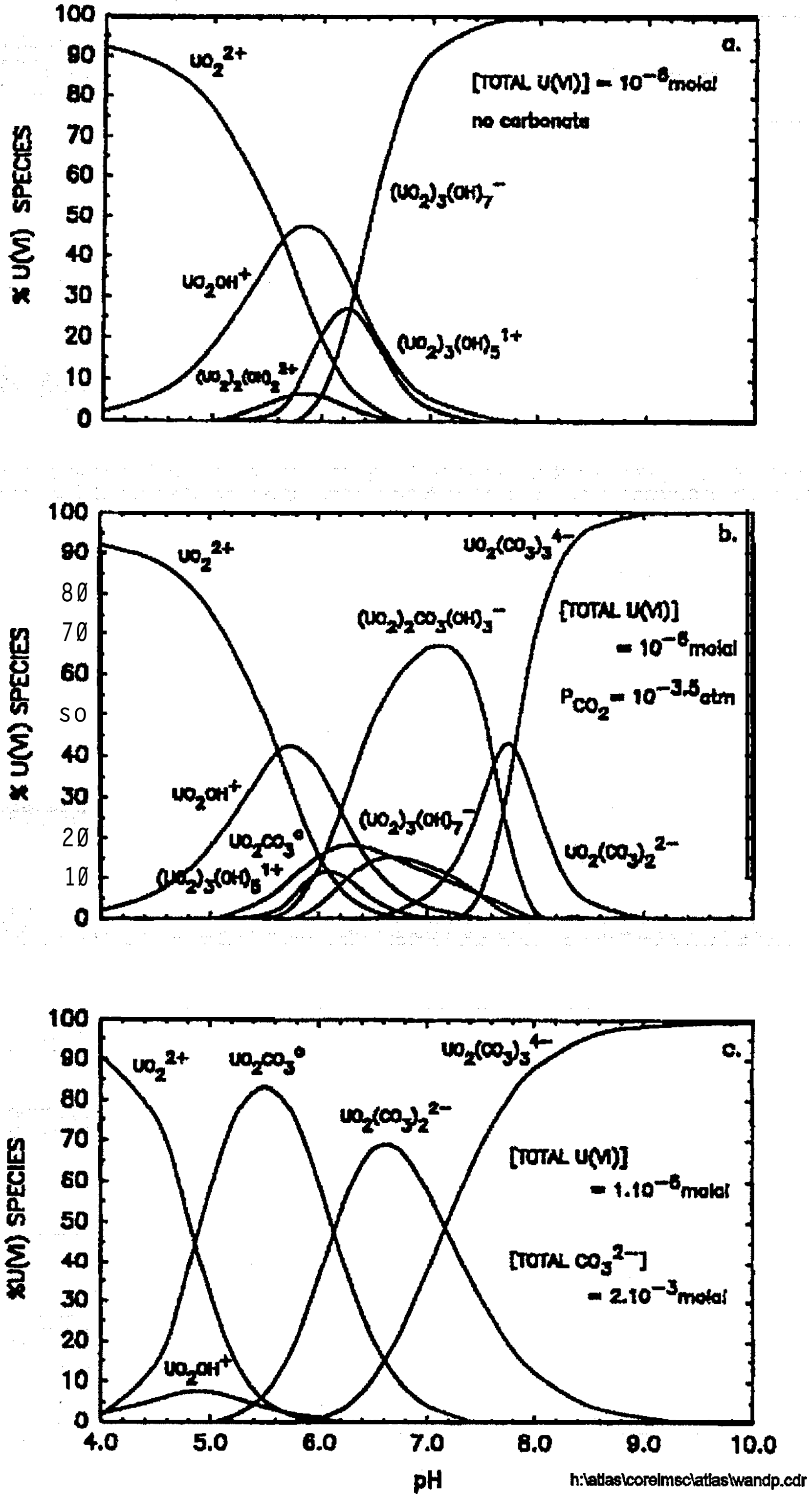

Figure 4.1. **Speciation of 10^{-6}M U(VI) as a Function of pH.** a) in the absence of carbonate, b) in equilibrium with the atmosphere (**P_{CO_2} = $10^{-3.5}$ atm**), c) in **solutions** containing 2 **mM** total carbonate. *(From Waite and Payne, 1993)*

trends in contaminant levels. For the groundwater chemistry data collected, the nonparametric Mann-Kendall test for trend analysis was conducted. This procedure is particularly useful because missing values are allowed and the data need not conform to any particular distribution. Also, data reported as trace or less than the detection limit can be used by assigning them a common value that is smaller than the smallest measured value in the data sets (Gilbert, 1987). Tests were conducted with the null hypothesis being no trend in the data. The null hypothesis is rejected if the probability value (p) corresponding to the computed Mann-Kendall statistic (s) is less than a specified significance level. For the Atlas site, both 90 and 95 percent confidence levels were selected to evaluate the data. The use of a 90 percent confidence interval reflects the high variability inherent in environmental data and is intended to provide an indication of trends but at a lower confidence interval.

If the p value is less than 0.05 or 0. I, then the evidence is insufficient to reject the null hypothesis that there is no trend in, the data. Mann-Kendall- tests were conducted on selected analytes from a total of 4 wells located downgradient of the tailing pile (Fig. 5.1). Results are presented in Table 5.1. The statistical and analytical data are presented in Appendix A. Of the eight analytes tested, four yielded a trend that was within the 90 percent confidence interval. Of these four, two showed downward or decreasing concentrations while two showed an upward trend. The remaining four analytes showed no trend within a 90 percent confidence interval. For concentrations that exhibited a trend within the 95 percent confidence interval, two wells showed a downward trend and one well showed an upward trend.

The Mann-Kendall test on uranium data from well ATP-2-S showed no trend within the 90 percent confidence interval. However, the characteristics of the data for this well show a repeated increase and decrease in concentration values which results in an uncertainty in the statistical analysis. Time was not available to conduct further statistical tests, but it is recommended that the Seasonal Kendall test be conducted on this data set. Using this analysis, the cyclic trend can be removed and it is expected that a statistically significant downward trend in uranium concentrations for ATP-2-S will emerge.

Although there is some indication of a downward trend for a few analytes, the data taken as a

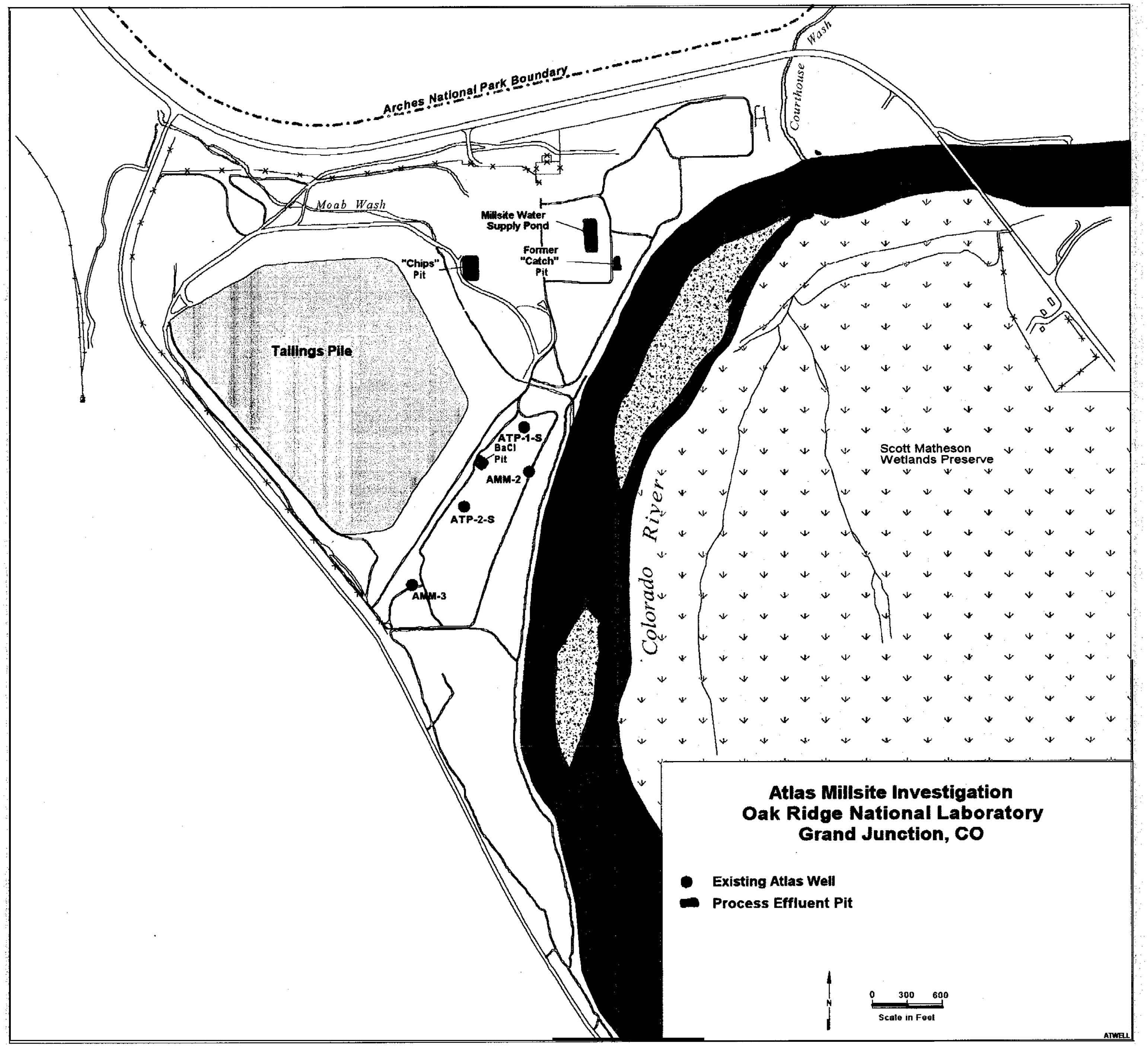

Fig. 5.1 Location of wells used in the Mann-Kendall tests.

'whole indicated no reliable trend in concentrations. 'Thus, there is not consistent evidence for a trend, in the groundwater contaminant concentrations downgradient of the pile.

Table 5.1 Statistical analysis of water quality trends based on groundwater samples from downgradient wells

Well	Analyte	P-Value	Trend
AMM-2	Nitrate	0.153	none
AMM-2	Uranium	0.171	none
AMM-3	Molybdenum	0.624	none
AMM-3	Uranium	0.004	up
ATP-1-S	Uranium	0.006	down
ATP-2-S	Molybdenum	0.063	up
ATP-2-S	Nitrate	0.000	down
ATP-2-S	Uranium	0.165	none

Consequently, there is no strong evidence that contaminant levels in the groundwater are decreasing due to a decrease in the contaminant concentrations in the tailings pile or because of reduced discharge rates. Additional evaluation of geochemical factors is needed to provide a comprehensive understanding of the observed contaminant concentrations downgradient of the tailings pile. Such an evaluation would include calculation of the solubility limits of selected analytes within the tailings pore water and measurement of geochemical factors that affect the migration of the contaminants.

6.0 River Fluctuations on Contaminant Discharge Rates

The NRC requested an evaluation of how fluctuating river stages affect groundwater discharge of contaminants into the Colorado River (Task NRC-3). Specifically, as the Colorado River stage rises during spring runoff, how are contaminant flux rates fi-om the alluvial groundwater to the river affected? Although' there was insufficient time to fully analyze the issue, there are reasons why the contaminant flux values presented in the ORNL/GJ groundwater report (ORNL/GJ

1998b) are a reasonable estimate of a yearly average. First, the hydraulic gradient across the Atlas site reflects average boundary conditions for the aquifer. For example, Canonie (1994) reported a hydraulic gradient across the Atlas site of 0.004. A potentiometric map based on water level measurements taken by ORNL/GJ in December I997 also yielded a hydraulic gradient of 0.004 (ORNL/GJ 1998b). Second, a review of stream gage records for the nearest W.S.G.S. station at Cisco, Utah shows the daily discharge values since 1922 (Fig. 6-la). Figure 6-lb shows recent water levels for January of this'year. At the time of the ORNL/GJ field effort(December 1997), the Colorado river was discharging approximately 5000 cfs. If this discharge value is compared with the historical flow, there are brief periods (two or three months) of peak flow that exceed that discharge rate, but the bulk of historical river discharge values are below 5000 cfs. For peak discharge rates associated with spring runoff, groundwater discharge rates will decrease in response to the higher river levels. This decrease in groundwater discharge rates during late spring and early fall is offset by higher groundwater discharges in the late fall and winter in response to lower river levels. Consequently, the contaminant discharge values based on December1997 hydrologic data are a reasonable estimate of an average yearly value.

A more definitive approach to address this question would be to vary the downstream constant head boundary of the contaminant transport model to represent on-site river stage data. Then the model could be used to calculate the resulting time dependent contaminant flux rates. Time and budget were not available to perform this task. Nevertheless, as described above, there would probably not be a substantial change regarding the present description of the contaminants in the alluvial aquifer.

7.0 Review of Historical Water Level Data

NRC requested that the historical water level data from the Atlas monitoring wells be reviewed with respect to the tailings pile dewatering program that began in mid-1990. In particular, the impact on water levels in the tailings pile and the implications to seepage rate estimates was to be addressed (Task NRC-4). Water-level data reviewed for this evaluations were obtained from the Canonie report (1994) and are presented in Appendix B. Interim water level data collected by

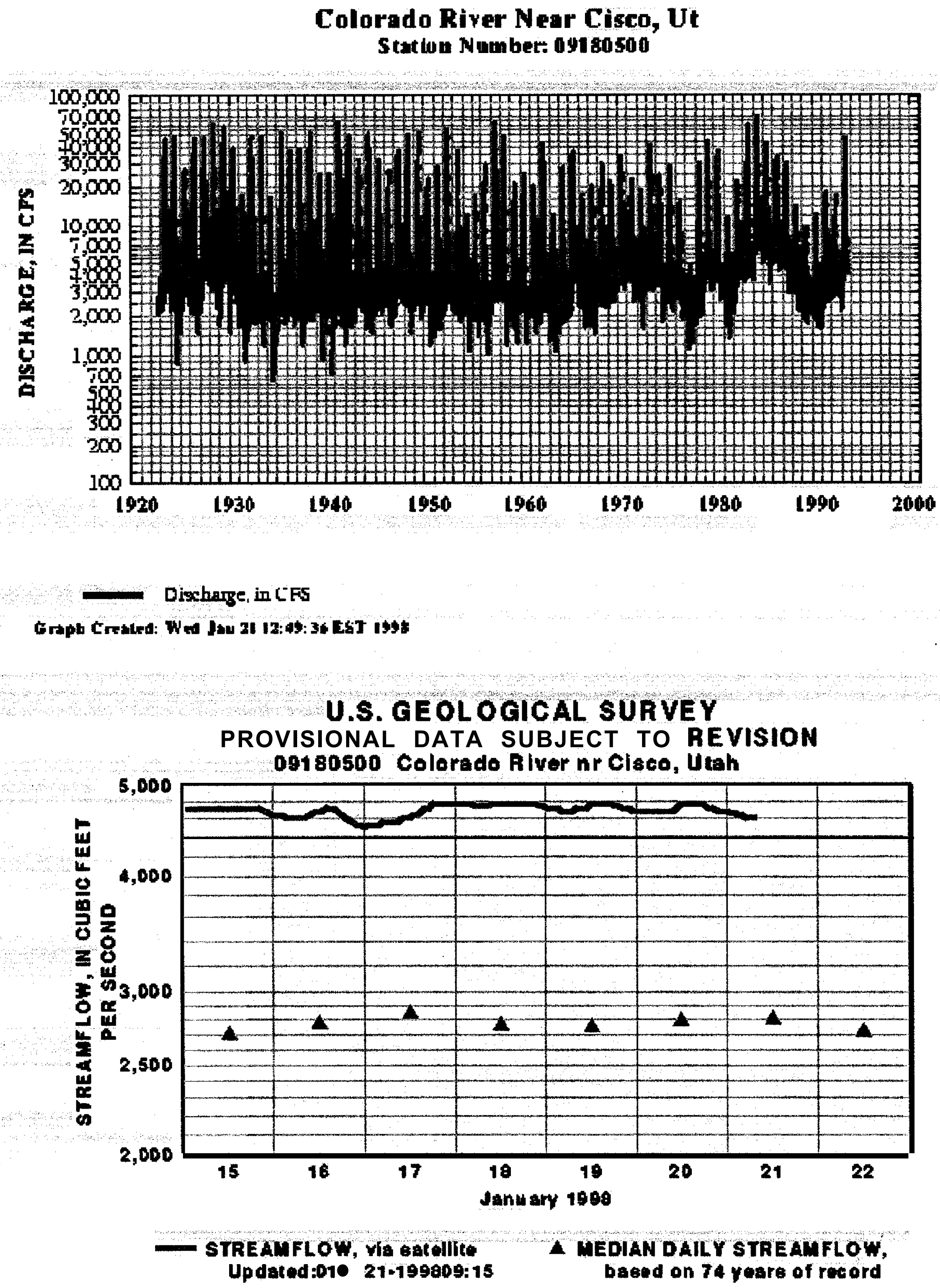

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Figure 6.1. (a) Flow records since 1922 for the Colorado River at Cisco, UT and (b) recent flow records.

Atlas since the Canonie report were not available to be included in the following discussion.

Graphs B- 1 through B-4 in Appendix B compare individual alluvial wells located downgradient of the tailings pile with river stage elevations from 1989 to 1994. Fluctuations in monitoring well water levels correspond to river stage fluctuations indicating that there is hydraulic connection between the river and the alluvial aquifer downgradient of the tailings pile.

Graph B-5 in Appendix B shows a comparison of the water elevation in the pond at the top of the tailings pile to the river stage from 1989 to 1994. As expected, there is no discernable correlation between the two, indicating no hydraulic connection.

Graph B-6 in Appendix B compares water levels in wells drilled into the tailings pile with river stage levels. There is a large variation in water levels among these wells. A source of the variation be that the wells are completed in different lithologic units. Review of the well completion information presented in the Canonie report (1994) and the Dames & Moore reports (1973 and 1981) provided the data presented in Table 2. As shown in Table 2, the wells represented in Graph B-6, are completed within the alluvium, the sand tailings, and the slimes. Water level data in Table 2 is from January 1989, June 1990, and February 1994 and were used to calculate the change is head values before and after the dewatering program began. The largest decline in water level is observed in well B-4 and is representative of conditions before the dewatering program began. Although this'well shows no influence from the river (Graph B-5 in Appendix B), it yields the greatest decline in water levels. However, there is no obvious explanation for this decline based on the available data. Comparing water levels in wells A-9 and BAA-4 shows a higher water level in well BAA-4, which is underlain by slimes, compared with A-9 that is screened in both the sand and alluvium. This difference in water levels may be due to the low permeable slimes acting as an aquitard resulting in perched water in the vicinity of well BAA-4.

As shown in Table 2, there is a larger average decline in water levels for the 17 months prior to the initiation of the dewatering program than for the 42 months after pumping began. This evidence indicates that the pumping is having little or no effect on the dewatering of the tailings

Table 2. Well completion, lithology, and water level data for wells located on the Atlas Tailings Pile

Well number	Surface elevation	Screen interval, ft	Total depth, ft	Lithology	Water elevation, 1/14/89	Water elevation, 6/11/90	Elevation difference, 1/89 to 6/90	Water elevation, 2/25/94	Elevation difference, 6/90 to 2/94
B-4	4,040	70 to 80	110	Alluvial well, no indication of slimes	4,035	4,024	-11	4,022	-2
EE-4	4,053.6	39.2 to 41.2	?	Based on B-15 log Sand tailings well, no slimes	4,020	4,017	-3	4,016	-1
A-9	4,007.9	29 to 49	50	Sand tailings, alluvial well, no indication of slimes	3,978	3,976	-2	3,973	-3
B-7	4,046.3	80 to 82	119	Completed well in slime tailings	3,973	3,972	-1	3,972	0
BAA-4	4,052.3	51.7 to 53.7	N/A	Based on B-l Screened in sand tailings with 5 A of slime below	4,015	4,010	-5	4,008	-2

All data compiled from Canonie report (1994) and Dames & Moore reports (1973 and 198 1).

pile. It appears that ‘natural drainage prior to pumping yielded the larger water-level decline. Canonie (1994) reported that the remedial wells pump at a combined total of approximately 3 gpm when averaged over the period from July 1990 to February 1994. Assuming that the pores drained to the residual moisture content of 0.63 (ORNL/GJ 1998a) and that all of the decline in water levels is due solely to pumping, the resulting drop in water levels in the tailings pile in response to pumping would be 0.73 ft over this 42-month period or 0.21 ft per year.

If it is assumed that water level declines in monitoring wells completed in the sand tailings are due to the discharge of water into the underlying aquifer, then it is possible to estimate the recent discharge of tailings pore water. This estimate of discharge would be in addition to discharge occurring in response to infiltration due to precipitation. For this evaluation, recharge rates in response to water level declines were estimated before and after dewatering began. Wells EE-4 BAA-4, both completed in the sand tailings, exhibited water level declines. From 1989 to 1990, water levels declined three and five feet, respectively. Multiplying these water level declines by the surface area of the pile (3868103 ft^2), the porosity of the sand tailings (0.66)[ORNL/GJ 1998a], the drainable portion of the porosity as predicted by the numerical simulation (0.16)[ORNL/GJ 1998a], and dividing by the time required for the water level decline (17 mo.), a discharge rate of 12 to 20 gpm results. If water level declines from 1990 are used, and the drainable portion of the porosity is adjusted to 0.23 to reflect the increased drainage time, then the recharge rate due to drainage of the tailings pore water ranges from 2.5 to 5.0 gpm. This recharge rate is comparable to the value (6.7 gpm) predicted using the uranium mixing calculation

8.0 Impact of Moving Tailings

NRC expressed the concern that excavation of the tailings pile could result in a “pulse” of contaminated water entering the groundwater system (Task NRC-5). The additional source of the water, according to the NRC, that could cause this pulse was attributed to dust suppression/ control measures used during tailings pile excavation activities. To address this concern, ORNL/GJ discussed the dust suppression/control measures used by the DOE with Don Metzler, a hydrologist with the DOE in Grand Junction. According to Mr. Metzler, the volume of water typically used for dust suppression during tailings pile excavation above the water table would not result in a “pulse” of’contamination to the groundwater system if proper management of construction/excavation activities is provided. Water added for dust suppression during excavation would only penetrate a few centimeters into the tailings and evaporation losses would be significant. Further, low velocities associated with unsaturated transport would be insufficient to move the moisture to any significant depth before the tailings were excavated. However, for excavation activities below the water table, DOE has found that dissolution of contaminants may be increased by the remedial action (D. Metzler, U. S. DOE Grand Junction Office – personal communication with F. Gardner, 2/3/98).

9.0 Conclusions

Results of the modeling simulations have resulted in estimates of the time for the pore water in the tailings pile to drain and for the amount of time needed for the groundwater system to clean up after total source removal. In addition, several issues raised by the FWS and NRC were addressed. Listed below are the individual conclusions from the modeling and data analysis.

a Model simulations indicate that the bulk of the pore water in the tailings drains after 100 years with 238 years required to reach steady state conditions

- The model predicts that the contaminant plume entering the river is mature-- a finding consistent with site characterization data.
- Simulations predict that the peak contaminant concentration reaches the river 50 years after emplacement of the tailings (9 years from the present) and then declines to a steady rate after approximately 100 years.
- Source removal simulations indicate that it would require a minimum of 35 years for the aquifer to clean up to pre-1956 levels.
- Retardation of uranium and molybdenum in the alluvial aquifer is not believed to be significant.

a Statistical trend analysis of the downgradient water quality indicates that there is no consistent evidence for a trend in, the data. The contaminant transport modeling is consistent with this finding.

- River fluctuations are not believed to have a large impact on average contaminant discharge estimates presented in the initial ORNL/GJ groundwater investigation report (ORNL/GJ 1998b).

- Historical water levels indicate that the present dewatering system is having minimal impact on the water balance in the tailings pile.
- Excavation and removal of tailings is not expected to adversely impact groundwater quality.

Based on the analysis presented in this and the previous ORNL/GJ reports, there is evidence supporting a total discharge rate from 6.7 to 20 gpm (ORNL/GJ 1998 a, b). Uranium mixing simulations and post dewatering water-level declines in the tailings pile support the lower discharge rate. Ammonia mixing simulations and pre-dewatering water level declines in the tailings pile support the higher discharge rate. Additional data and sensitivity analysis are needed to better define the actual discharge rate of water from the tailings pile to the underlying groundwater system.

10.0 References

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APPENDIX A

STATISTICAL ANALYSIS OF HISTORICAL WATER QUALITY DATA

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                                                       PROB.  OF  EXCEEDING
                        MANN                           THE ABSOLUTE VALUE
                       KENDALL                         OF THE  Z  STATISTIC
                          S           Z                 (TWO-TAILED TEST)
STATION   SEASON   STATISTIC   STATISTIC        N          IF   N  >  10

   1         1        97.00       1.43082       34               .153

                                  SEN  SLOPE
                             CONFIDENCE INTERVALS

STATION      SEASON        ALPHA      LOWER  LIMIT      SLOPE      UPPER  LIMIT

   1            1          .050         -.180           .500        2.353 1.667
                           .100          000            . 500        1.429
                           .200         :ooo            .500         1.136
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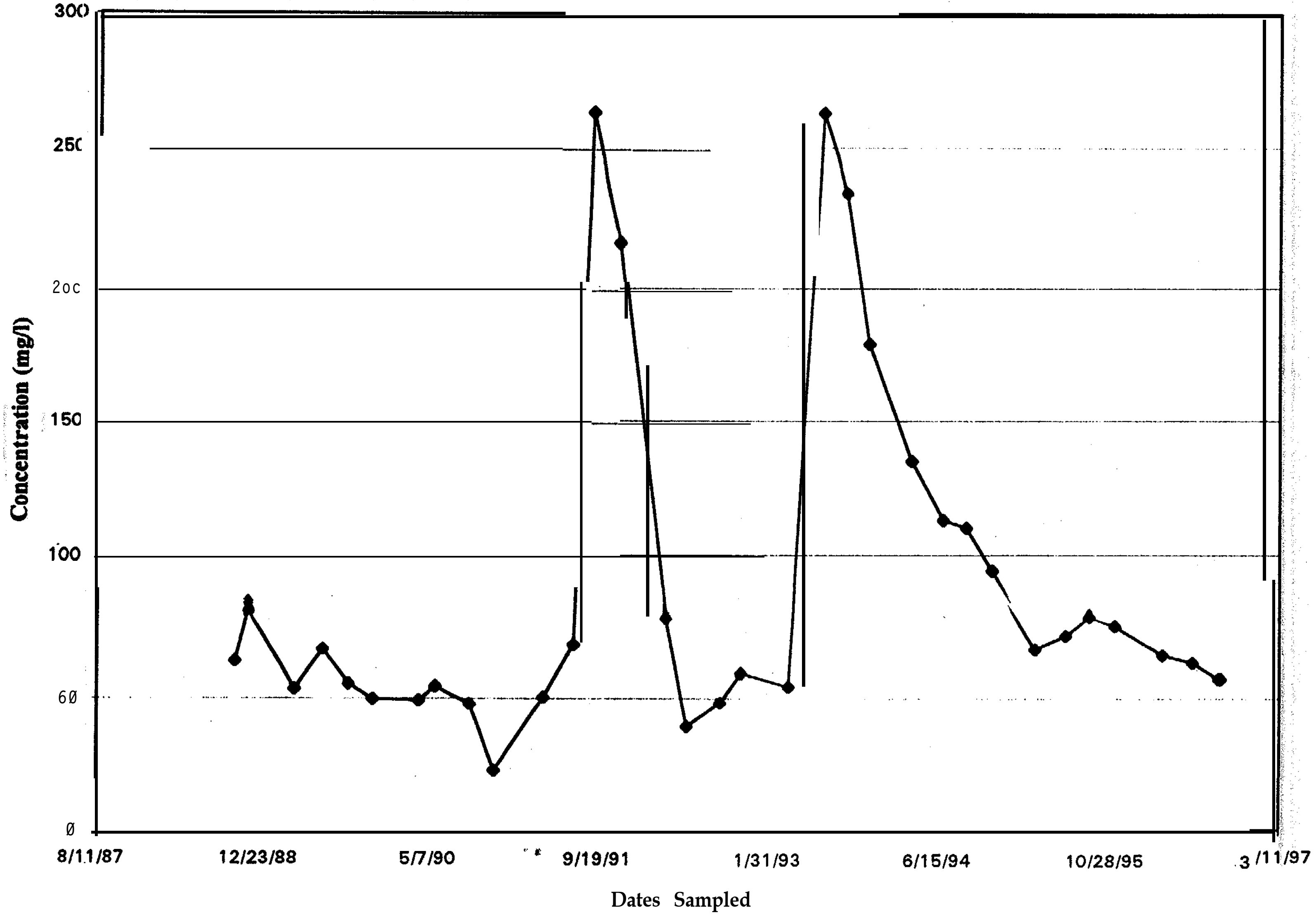
File: J:\FOX\GENSTAT\AMM2_NIT.CSV

					Linear Regression		
Minimum	**Maximum**	**Mean**	**Median**	**Std Dev**	**Slope**	**R-Sqr**	**Num**
0.00	265.00	88.97	65.00	65.19	3.48483	0.04	34

Nitrate Concentrations
Monitoring Well AMM-2



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                                                     PROB. OF  EXCEEDING
                       MANN                            THE ABSOLUTE VALUE
                      KENDALL                          OF THE Z STATISTIC
                         s              Z               (TWO-TAILED TEST)
STATION'   SEASON   STATISTIC   STATISTIC    N           IF  N  > 10

    1         1        42.00      1.35320     20               .176


                                 SEN SLOPE
                            CONFIDENCE INTERVALS

  STATION      SEASON        ALPHA     LOWER LIMIT     SLOPE     UPPER LIMIT
     1            1          .010        -.013         .013         .057
                             .050         ,000         .013         .050
                             .100         .000         .013         .050
                             .200         .000         .013         .031
```

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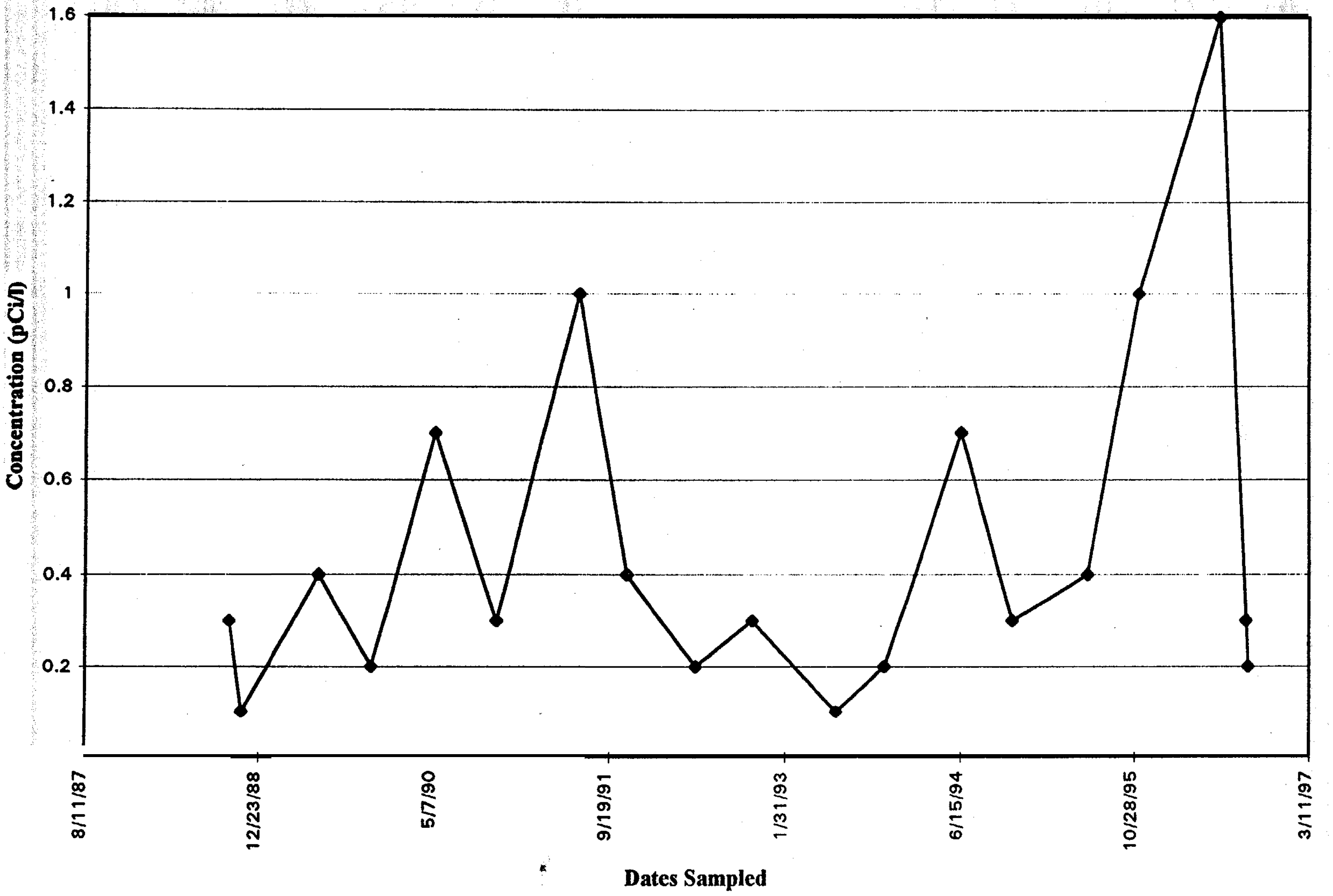
File: J:\FOX\GENSTAT\AMM2_RA6.CSV

					Linear Regression		
Minimum	Maximum	Mean	Median	Std Dev	Slope	R-Sqr	Num
0.00	1.60	0.44	0.30	0.38	0.06732	0.14	20

RA226 Concentrations
Monitoring Well AMM-2



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                                                        PROB.  OF  EXCEEDING
                         MANN                           THE  ABSOLUTE  VALUE
                        KENDALL                         OF  THE  Z  STATISTIC
                           S_           Z                (TWO-TAILED  TEST)
"STATION    SEASON    STATISTIC   STATISTIC      N         IF  N  >  10

    1          1        32.00      1.00825      20             .313

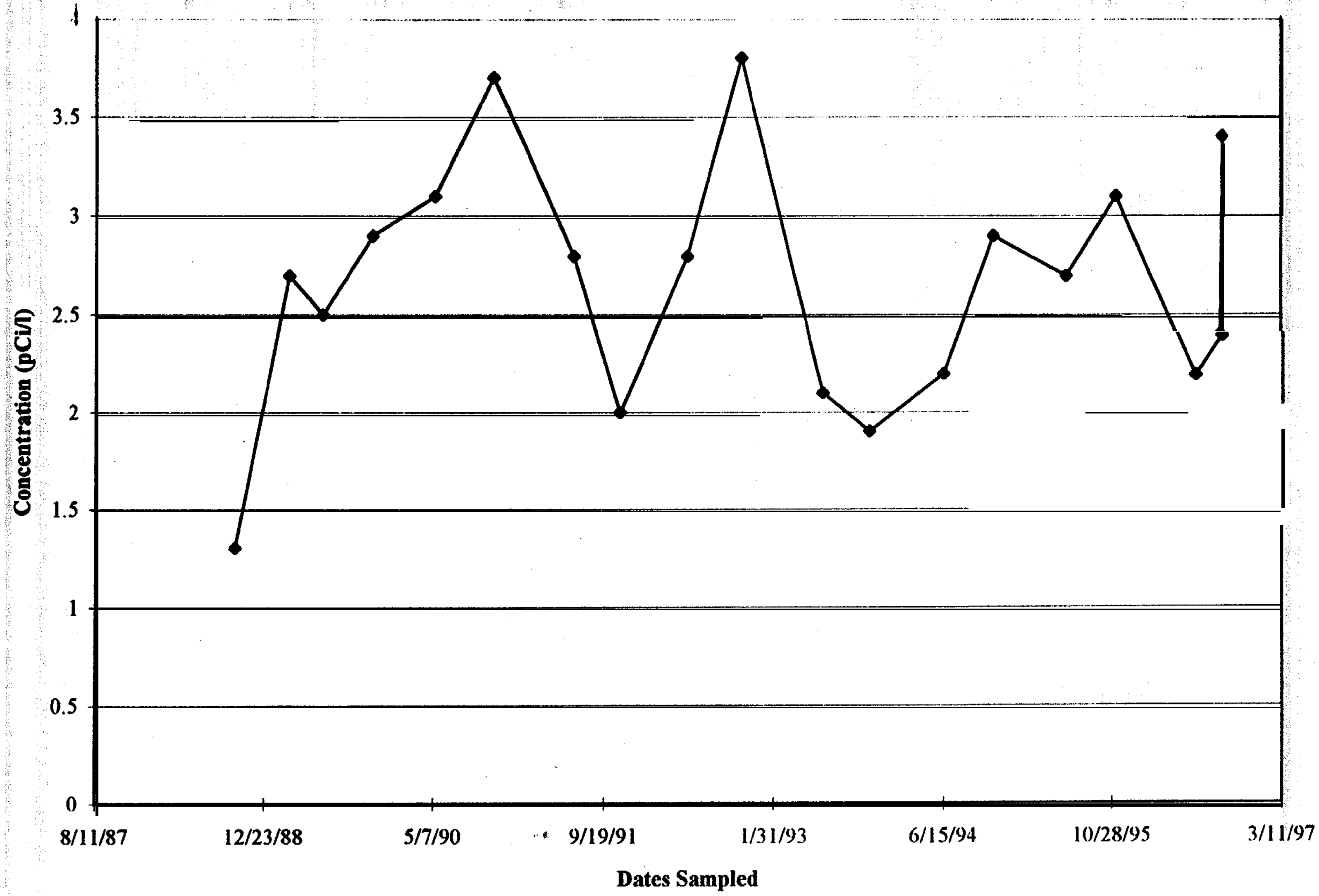
                                   SEN  SLOPE
                              CONFIDENCE  INTERVALS

 STATION       SEASON       ALPHA     LOWER  LIMIT     SLOPE      UPPER  LIMIT
    1             1         .010         -.040         .038          .150
                            .050         -.027         .038          .111
                            .100         -.019         .038          .100
                            .200         -.009         .038          .083
```

File: J:\FOX\GENSTAT\AMM2_RA8.CSV

Minimum	Maximum	Mean	Median	Std Dev	Linear Regression		
					Slope	R-Sqr	Num
0.00	3.75	2.52	2.65	0.82	0.13522	0.13	20

RA228 Concentrations
Monitoring Well AMM-2



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                                                    PROB.  OF  EXCEEDING
                       MANN                          THE  ABSOLUTE  VALUE
                      KENDALL                        OF  THE  Z  STATISTIC
                         s            Z               (TWO-TAILED TEST)
STATION    SEASON    STATISTIC   STATISTIC       N        IF  N  >  10

   1          1        -40.00     -1.36919,      19             .171


                                  SEN  SLOPE'
                             CONFIDENCE  INTERVALS

STATION      SEASON         ALPHA      LOWER  LIMIT      SLOPE       UPPER  LIMIT
   1            1            .050      -113.758      -42.308        60.468
                                        -95.044      -42.308        17.642
                             .100       -89.691      -42.308'        7.143
                             .200       -74.644      -42.308          .000
```

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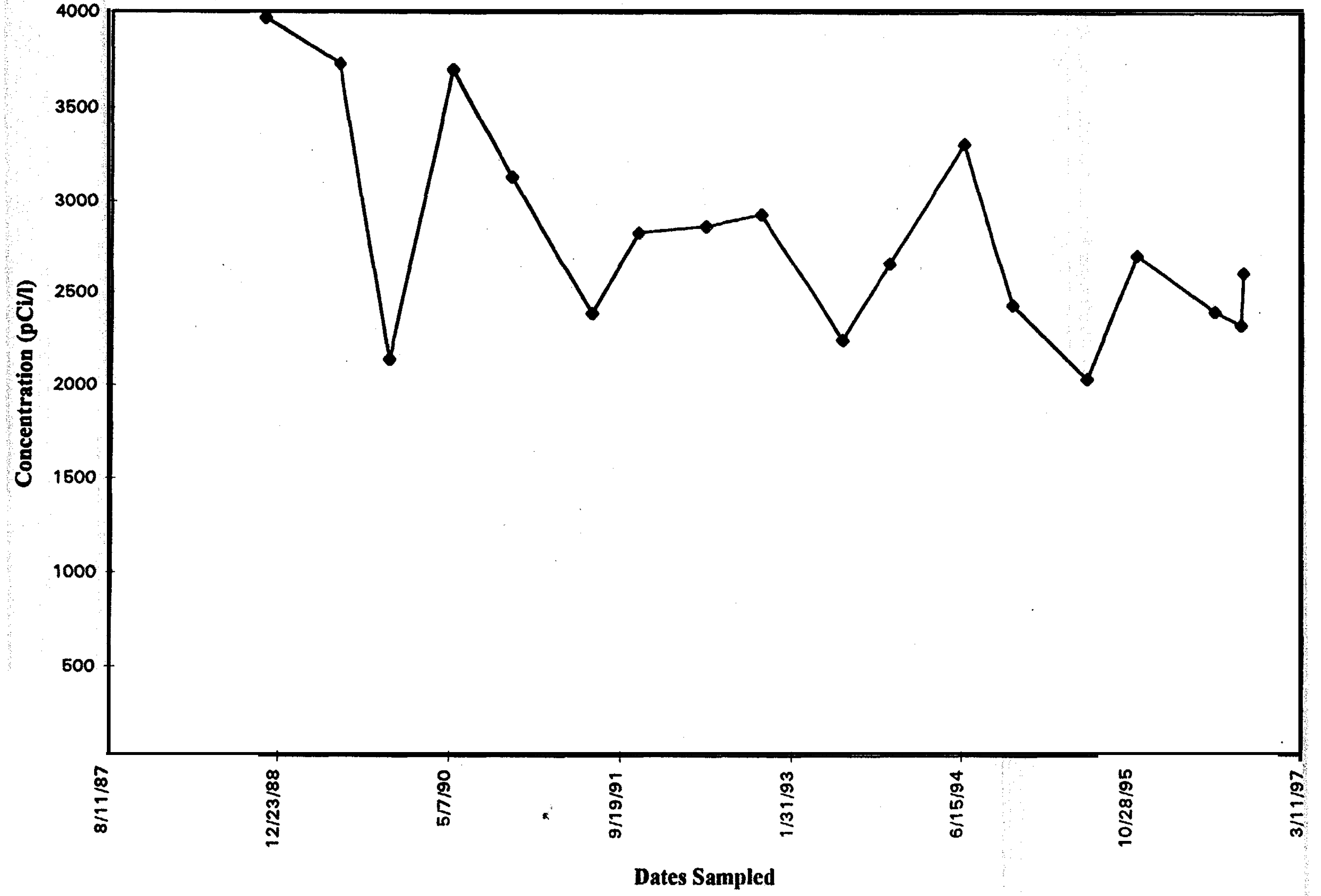
File: J:\FOX\GENSTAT\AMM2_URA.CSV

					Linear Regression		
Minimum	Maximum	Mean	Median	Std Dev	Slope	R-Sqr	Num
0.00	3900.00	2650.00	2700.00	813.86	0.58730	0.00	19

Uranium Concentrations
Monitoring Well AMM-2



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                         -MANN                          THE ABSOLUTE VALUE
                        KENDALL                         OF THE Z STATISTIC
                           S           Z                 (TWO-TAILED TEST)
STATION   SEASON      STATISTIC    STATISTIC      N         IF N > 10

   1         1          15.00        .49040      19            .624

                                  SEN SLOPE
                            CONFIDENCE INTERVALS

STATION      SEASON        ALPHA      LOWER LIMIT      SLOPE      UPPER LIMIT
   1            1           .010         -.015         .003          028
                            .050         -.010         .003         .024
                            .100         -.007         .003         .018
                            .200         -.005         .003         .014
```

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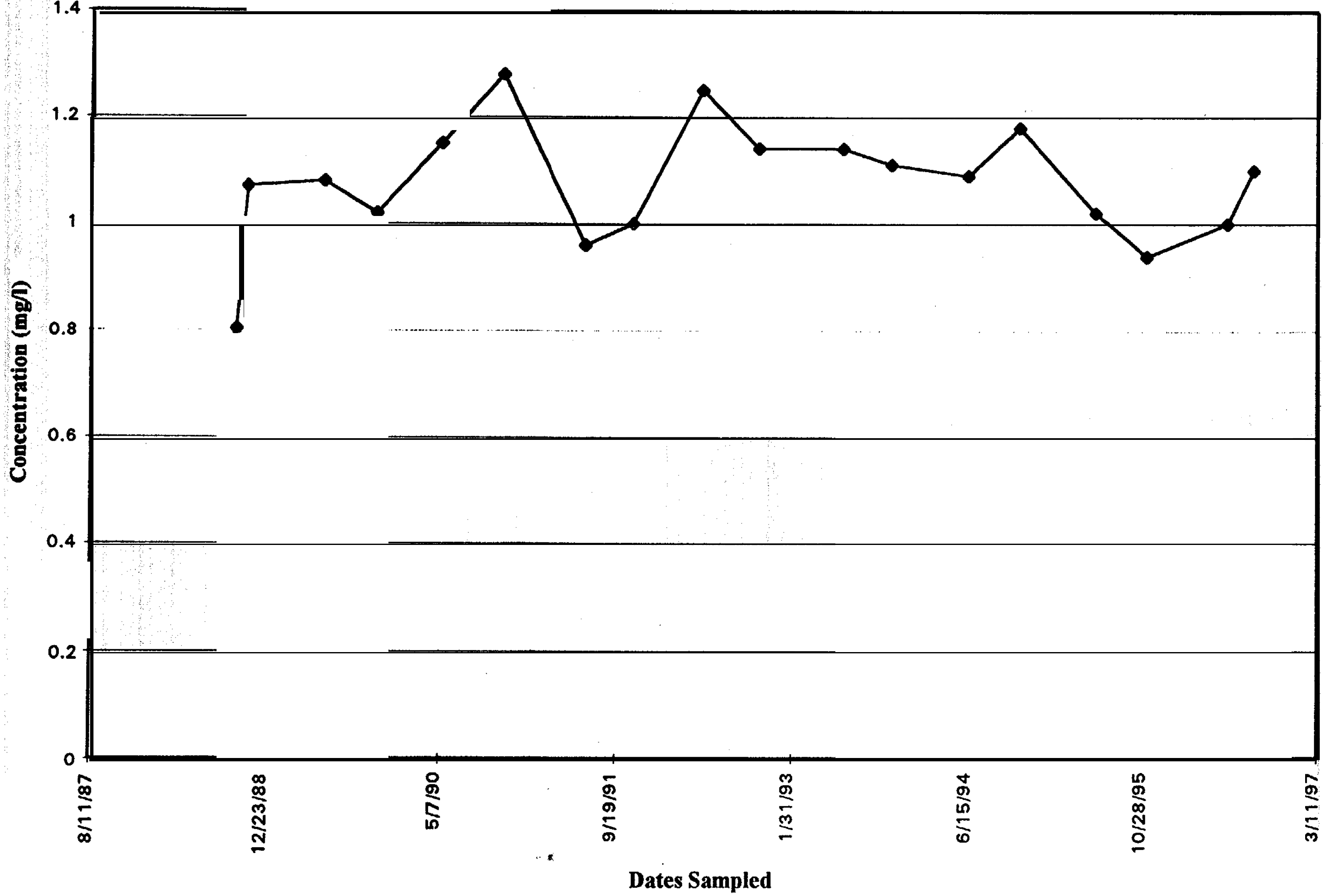
File: J:\FOX\GENSTAT\AMM3_MOL.CSV

					Linear Regression		
Minimum	**Maximum**	**Mean**	**Median**	**Std Dev**	**Slope**	**R-Sqr**	**Num**
0.00	1.28	1.02	1.09	0.26	0.02379	0.16	19

Molybdenum Concentrations
Monitoring Well AMM-3



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                                                   PROB. OF EXCEEDING
                       MANN                        THE ABSOLUTE VALUE
                      KENDALL                      OF THE Z STATISTIC
                         S           Z              (TWO-TAILED  TEST)
STATION   SEASON    STATISTIC   STATISTIC      N       IF N > 10

   1         1        29.00      .    96605   19          .324

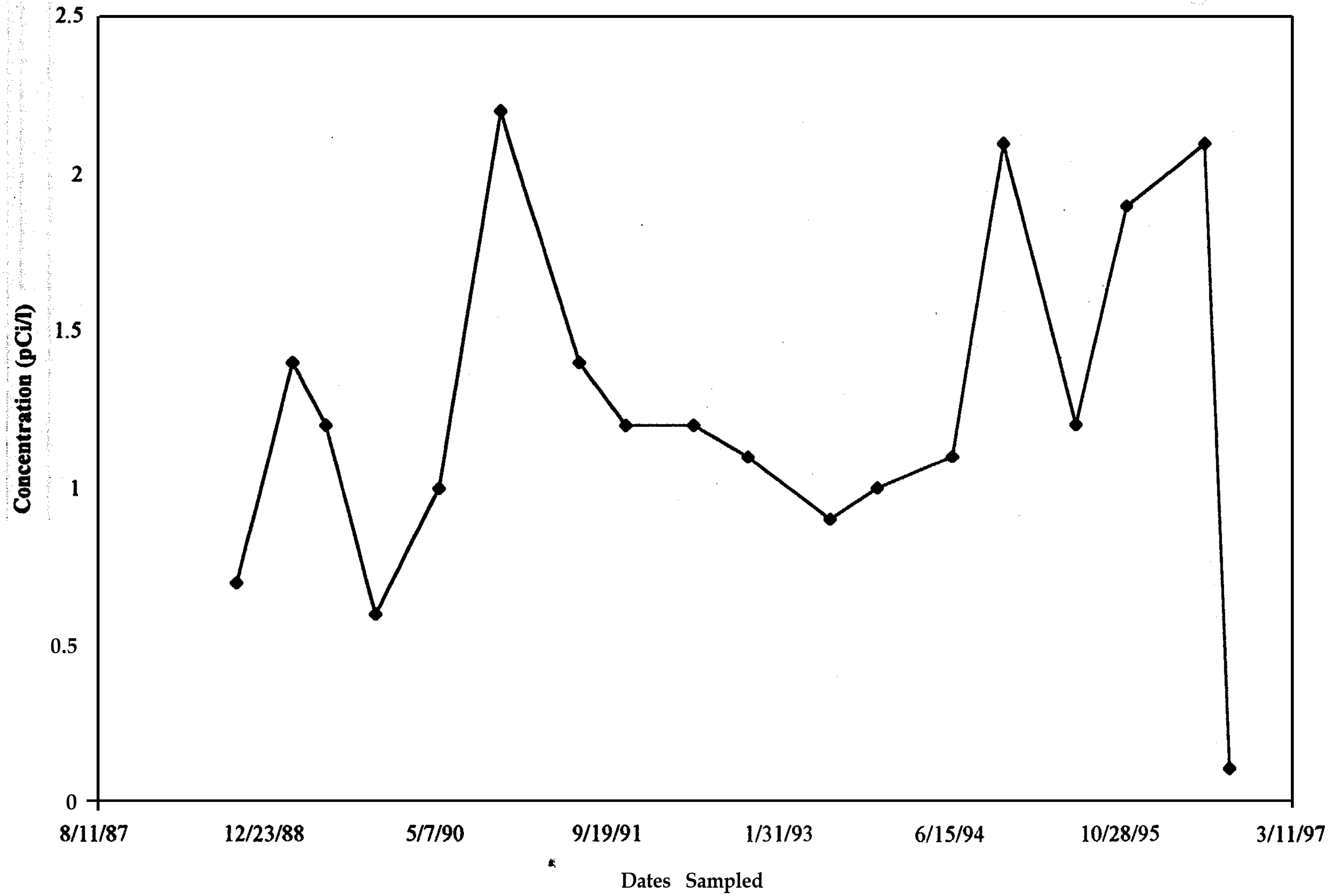
                                SEN SLOPE
                           CONFIDENCE INTERVALS

STATION     SEASON       ALPHA    LOWER LIMIT     SLOPE     UPPER LIMIT
   1           1          .010       -.035         .039        .110
                          .050       -.019         .039        .086
                          .100       -.014         .039        .082
                          .200       -.002         .039        . 078
```

File: J:\FOX\GENSTAT\AMM3_RA8.CSV

					Linear Regression		
Minimum	**Maximum**	**Mean**	**Median**	**Std Dev**	**Slope**	**R-Sqr**	**Num**
0.00	2.20	1.17	1.20	0.58	0.09310	0.12	19

RA228 Concentrations
Monitoring Well AMM-3



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--------------------------------------------------------------------------
                                                      PROB. OF EXCEEDING
                           MANN                       THE ABSOLUTE VALUE
                          KENDALL                     OF THE Z STATISTIC
                             S           Z             (TWO-TAILED  TEST)
STATION    SEASON    STATISTIC    STATISTIC    N        IF  N >  10"

   1          1        82.00       2.85902      19            .004

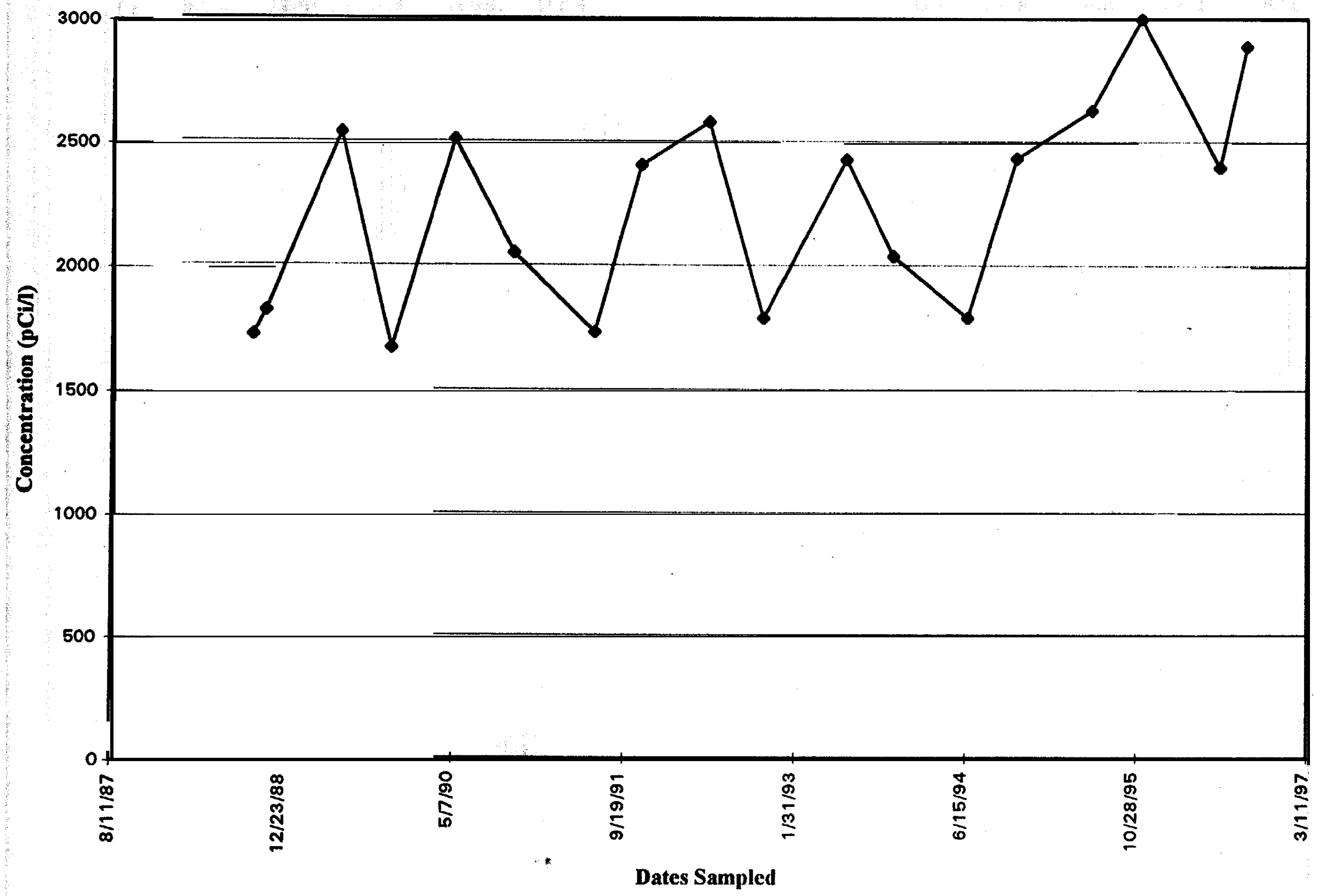

                                  SEN SLOPE
                              CONFIDENCE  INTERVALS

STATION       SEASON        ALPHA      LOWER  LIMIT      SLOPE       UPPER  LIMIT
   1             1           .010            .000      65.385      141.152
                             .050          16.667      65.385      112.500
                             .100          25.380      65.385      104.545
                             .200          33.769      65.385       96.913
```

File: J:\FOX\GENSTAT\AMM3_URA.CSV

					Linear Regression		
Minimum	Maximum	Mean	Median	Std Dev	Slope	R-Sqr	Num
0.00	3000.00	2165.79	2400.00	662.14	197.53097	0.43	19

Uranium Concentrations
Monitoring Well AMM-3



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                           MANN                          THE  ABSOLUTE  VALUE
                          KENDALL                        OF  THE  Z  STATISTIC
                             S          Z                 (TWO-TAILED  TEST)
STATION   SEASON    STATISTIC   STATISTIC       N           IF  N  >  10

   1         1        -44.00      -.80745      29              .420

                                  SEN  SLOPE
                             CONFIDENCE  INTERVALS

STATION     SEASON        ALPHA      LOWER   LIMIT   SLOPE      UPPER  LIMIT
   1           1           010          -.088         -.019        .043
                          .050                                     .025
                          .100          -.053         -.019        .020
                          . 200         -.047         -.019        .011
```

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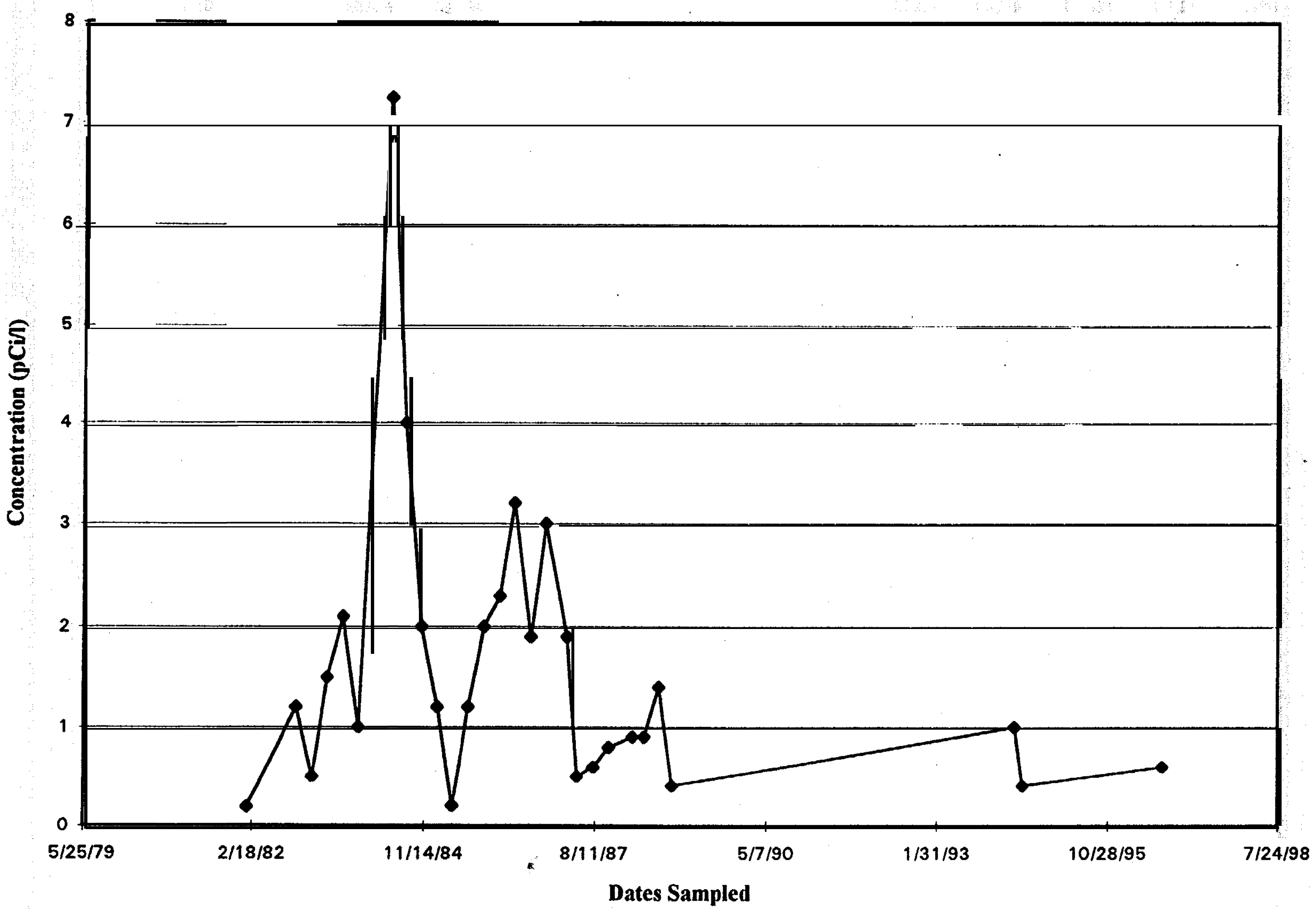
File: J:\FOX\GENSTAT\ATP1S_R6.CSV

					Linear Regression		
Minimum	Maximum	Mean	Median	Std Dev	Slope	R-Sqr	Num
0.00	7.30	1.52	1.20	1.44	-0.09141	0.03	29

RA226 Concentrations
Monitoring Well ATP-1-S



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                        MANN                        THE ABSOLUTE VALUE
                       KENDALL                      OF THE Z STATISTIC
                          s           Z              (TWO-TAILED TEST)
STATION   SEASON     STATISTIC   STATISTIC      N       IF N > 10

   1         1        -141.00     -2.77477      28         .006

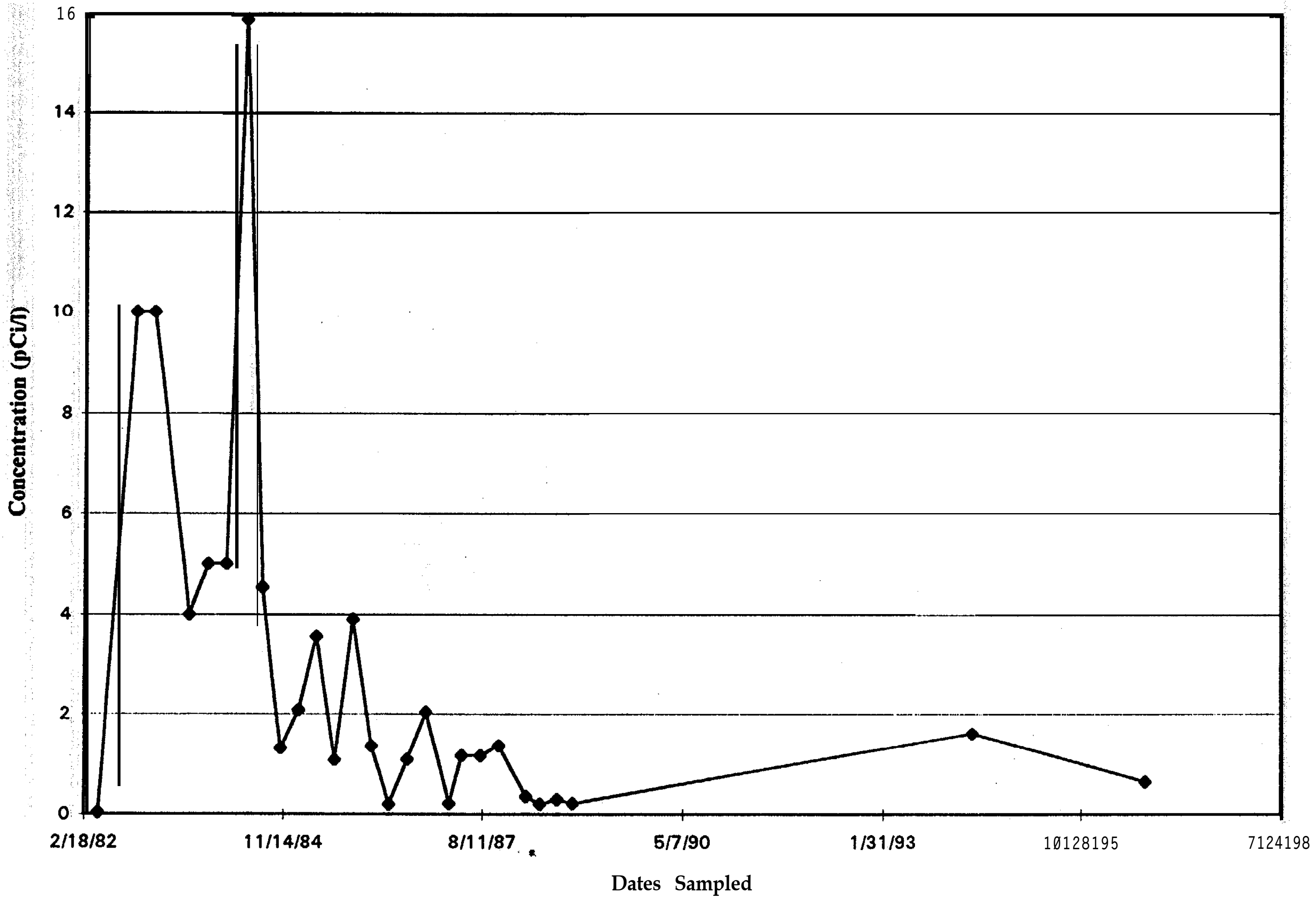

                               SEN SLOPE
                          CONFIDENCE INTERVALS

STATION     SEASON        ALPHA     LOWER LIMIT     SLOPE     UPPER LIMIT
   1           1           .010        -.300        -.170        .000
                           .050        -.278        -.170       -.045
                           .    100    -.265        -.170       -.065
                           .200        -.250        -.170       -.082
```

File: J:\FOX\GENSTAT\ATP1S_UR.CSV

					Linear Regression		
Minimum	**Maximum**	**Mean**	**Median**	**Std Dev**	**Slope**	**R-Sqr**	**Num**
0.00	45.90	3.86	1.20	8.51	-0.36212	0.06	28

Uranium Concentration
Monitoring Well ATP-1-S



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-----------------------------------------------------------------
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                         MANN                     THE ABSOLUTE VALUE
                        KENDALL                   OF THE Z STATISTIC
                           S          Z            (TWO-TAILED TEST)
STATION    SEASON     STATISTIC   STATISTIC     N      IF N > 10

   1          1          46.00     1.85999      17        .063

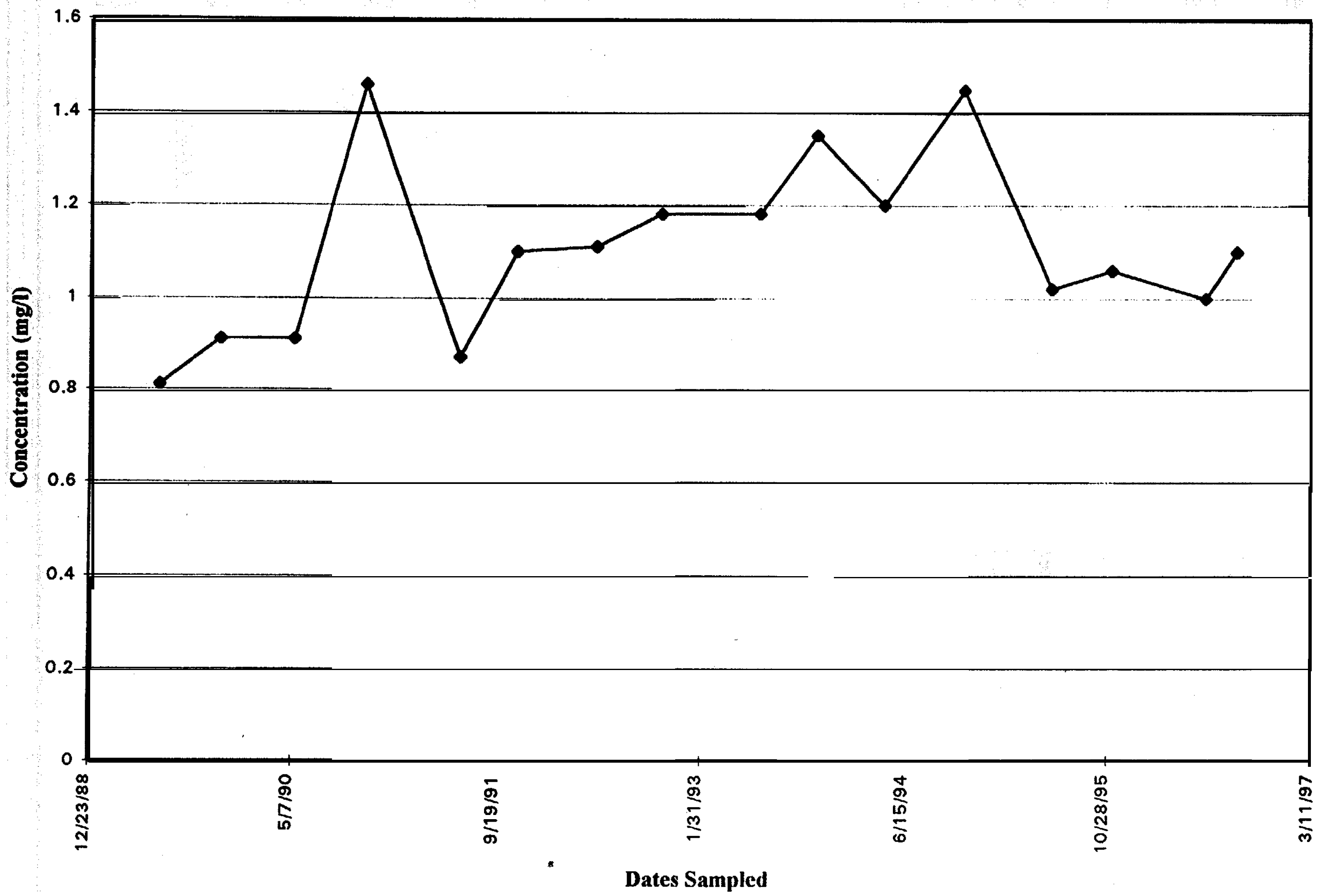
                                 SEN SLOPE
                           CONFIDENCE INTERVALS

STATION      SEASON      ALPHA    LOWER LIMIT    SLOPE     UPPER LIMIT
   1            1         .010       -.012        .020        .061
                          .050        .000        .020        .054
                          .100        .004        .020        .050
                          .200        .010        .020        .049
```

File: J:\FOX\GENSTAT\ATP2S_MO.CSV

					Linear Regression		
Minimum	Maximum	Mean	Median	Std Dev	Slope	R-Sqr	Num
0.00	1.45	1.05	1.10	0.32	0.03194	0.24	17

Molybdenum Concentrations
Monitoring Well ATP-2-S



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File:        J:\FOX\GENSTAT\ATP2S_NI.CSV
-------------------------------------------------------------------------
                                                    PROB. OF EXCEEDING
                         MANN                       THE ABSOLUTE VALUE
                        KENDALL                     OF THE Z STATISTIC
                           S          Z              (TWO-TAILED TEST)
STATION    SEASON     STATISTIC   STATISTIC     N        IF N > 10

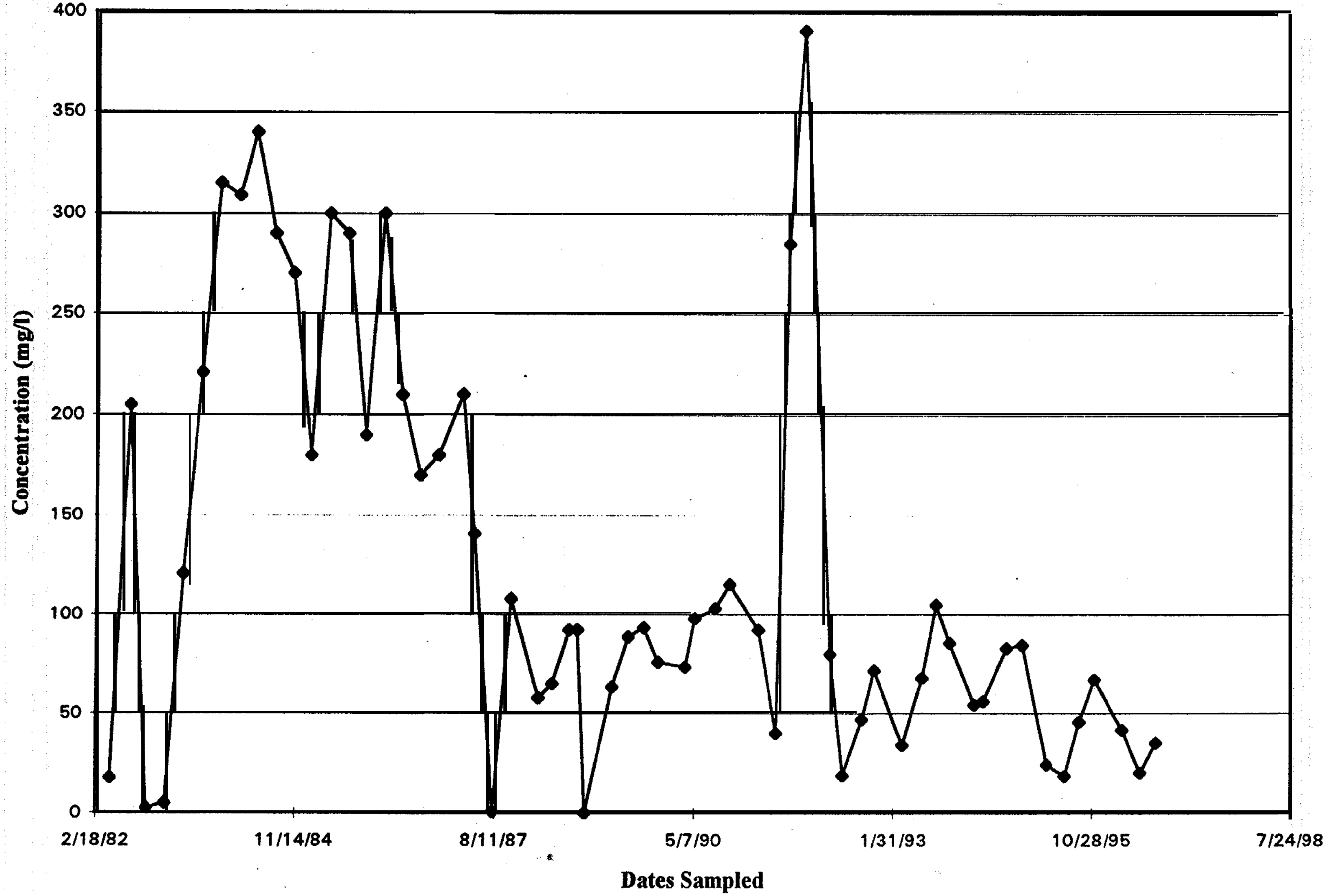
   1          1        -610.00    -3.88537      60          .000


                                SEN SLOPE
                          CONFIDENCE INTERVALS

STATION      SEASON        ALPHA     LOWER LIMIT     SLOPE     UPPER LIMIT
   1           1            .010       -4.513        -2.739      -1.059
                            .050       -4.032        -2.739      -1.500
                            .100       -3.765        -2.739      -1.719
                            .200       -3.500        -2.739      -2.055
```

File: J:\FOX\GENSTAT\ATP2S_NI.CSV

					Linear Regression		
Minimum	**Maximum**	**Mean**	**Median**	**Std Dev**	Slope	R-Sqr	Num
0.00	390.00	120.05	86.50	101.11	-2.55968	0.19	60



Nitrate Concentrations
Monitoring Well ATP-2-S

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-----------------------------------------------------------------------
                                                     PROB. OF EXCEEDING
                          MANN                       THE ABSOLUTE VALUE
                         KENDALL                     OF THE Z STATISTIC
                            S          Z              (TWO-TAILED TEST)
STATION   SEASON      STATISTIC    STATISTIC     N        IF N > 10

   1         1        -194.00      -2.09965     42          .036


                                  SEN SLOPE
                             CONFIDENCE INTERVALS

STATION     SEASON        ALPHA      LOWER LIMIT     SLOPE     UPPER LIMIT
   1           1           .010         -.050        -.020         002
                           ,050         -.040        -.020        :000
                           .100                      -.020         000
                           .200         -.030        -.020        -.007
```

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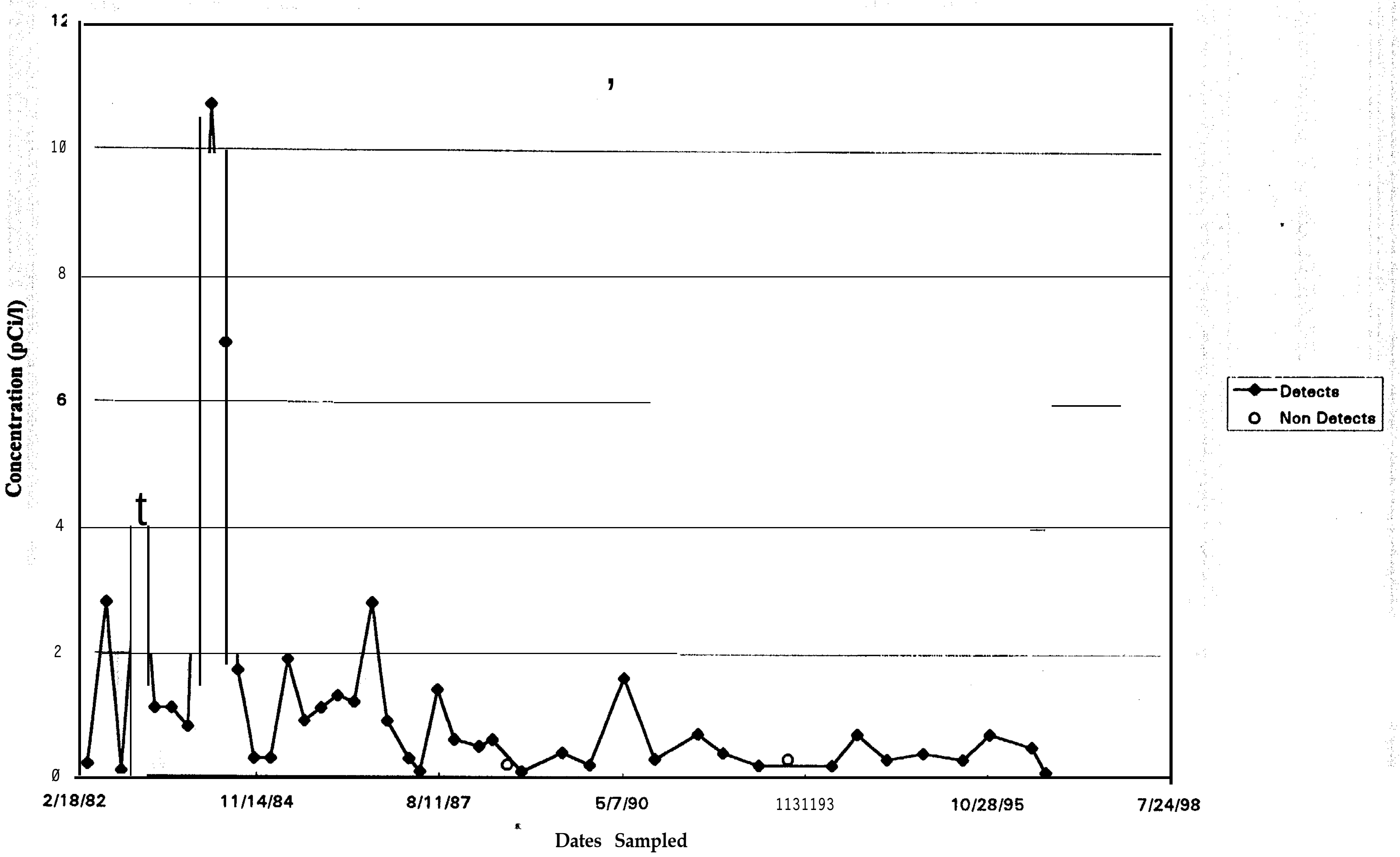
File: J:\FOX\GENSTAT\ATP2S_R6.CSV

Minimum	Maximum	Mean	Median	Std Dev	Linear Regression		
					Slope	R-Sqr	Num
0.00	10.80	1.23	0.60	1.94	-0.05548	0.12	42



RA226 Concentrations
Monitoring Well ATP-2-S

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-----------------------------------------------------------------------------
                                                     PROB.  OF-EXCEEDING
                           MANN                      THE  ABSOLUTE  VALUE
                          KENDALL                    OF  THE  Z  STATISTIC
                             S           Z            (TWO-TAILED  TEST)
STATION    SEASON    STATISTIC    STATISTIC      N        IF  N  >  10

   1          1         26.00       1.03392      17           .301

                                  SEN  SLOPE
                             CONFIDENCE  INTERVALS

STATION      SEASON       ALPHA     LOWER  LIMIT     SLOPE     UPPER  LIMIT
   1            1          .010        -.071          .037         .158
                           .050        -.048          .037         .121
                           .100        -.024          .037         .106
                           .200        -.009          .037         .083
```

File: J:\FOX\GENSTAT\ATP2S_R8.CSV

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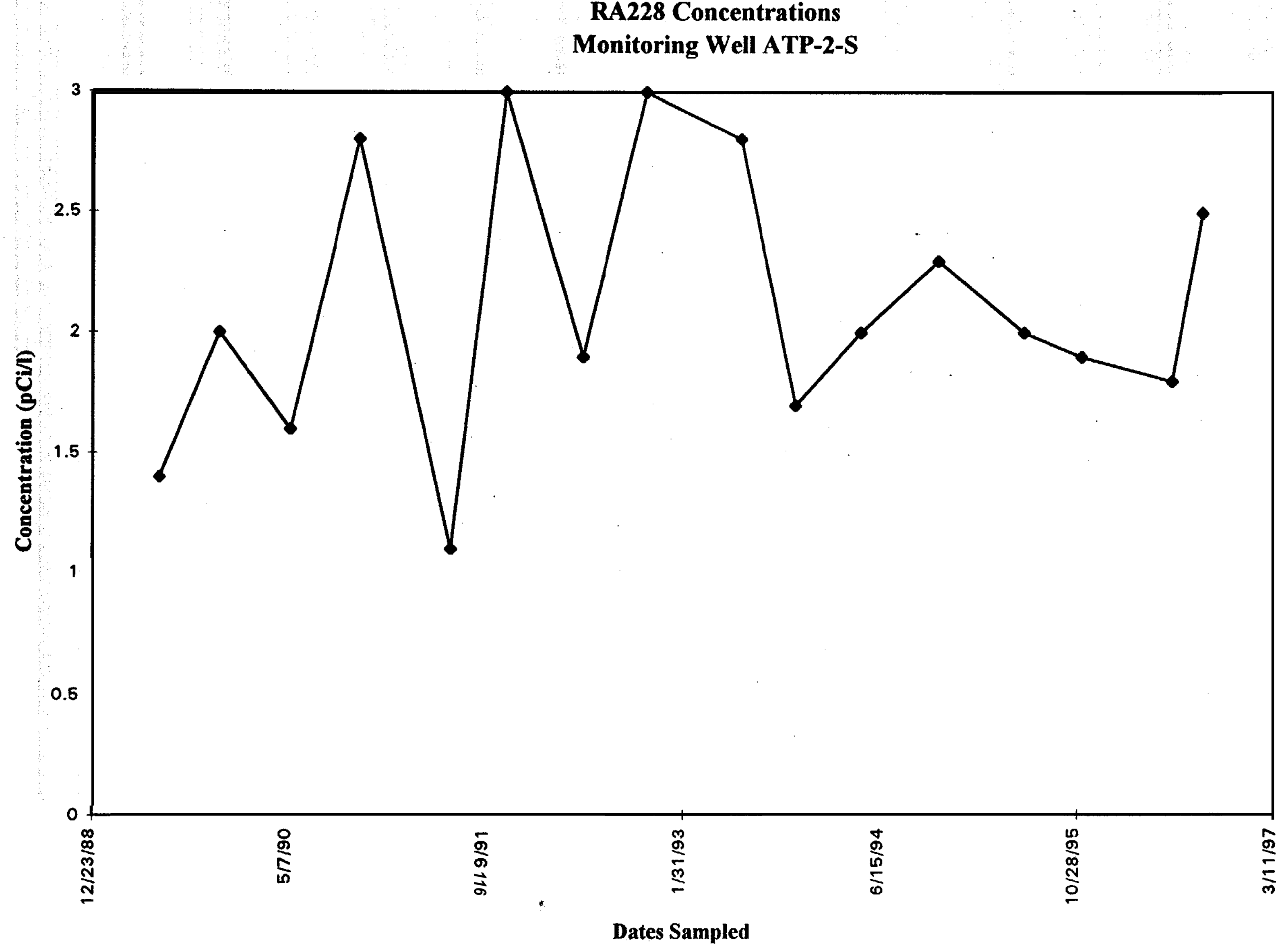
					Linear Regression		
Minimum	Maximum	Mean	Median	Std Dev	Slope	R-Sqr	Num
0.00	3.00	1.97	2.00	0.73	0.05612	0.12	17



RA228 Concentrations
Monitoring Well ATP-2-S

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--------------------------------------------------------------------------------
                                                          'PROB. OF EXCEEDING
                        MANN                               THE ABSOLUTE VALUE
                       KENDALL                             OF THE Z STATISTIC
                          S            Z                    (TWO-TAILED TEST)
STATION    SEASON    STATISTIC    STATISTIC       N            IF N > 10

   1          1       -143.00     -1.38991       45              .165


                                   SEN  SLOPE
                            CONFIDENCE    INTERVALS

STATION       SEASON         ALPHA      LOWER  LIMIT      SLOPE        UPPER  LIMIT
   1             1            . 010     -163.169        -56.696         57.143
                              .050
                              .100      -141.301 -125.989  -56.696 -56.696   12.158
                              .200      -115.074        -56.696         -2.769
```

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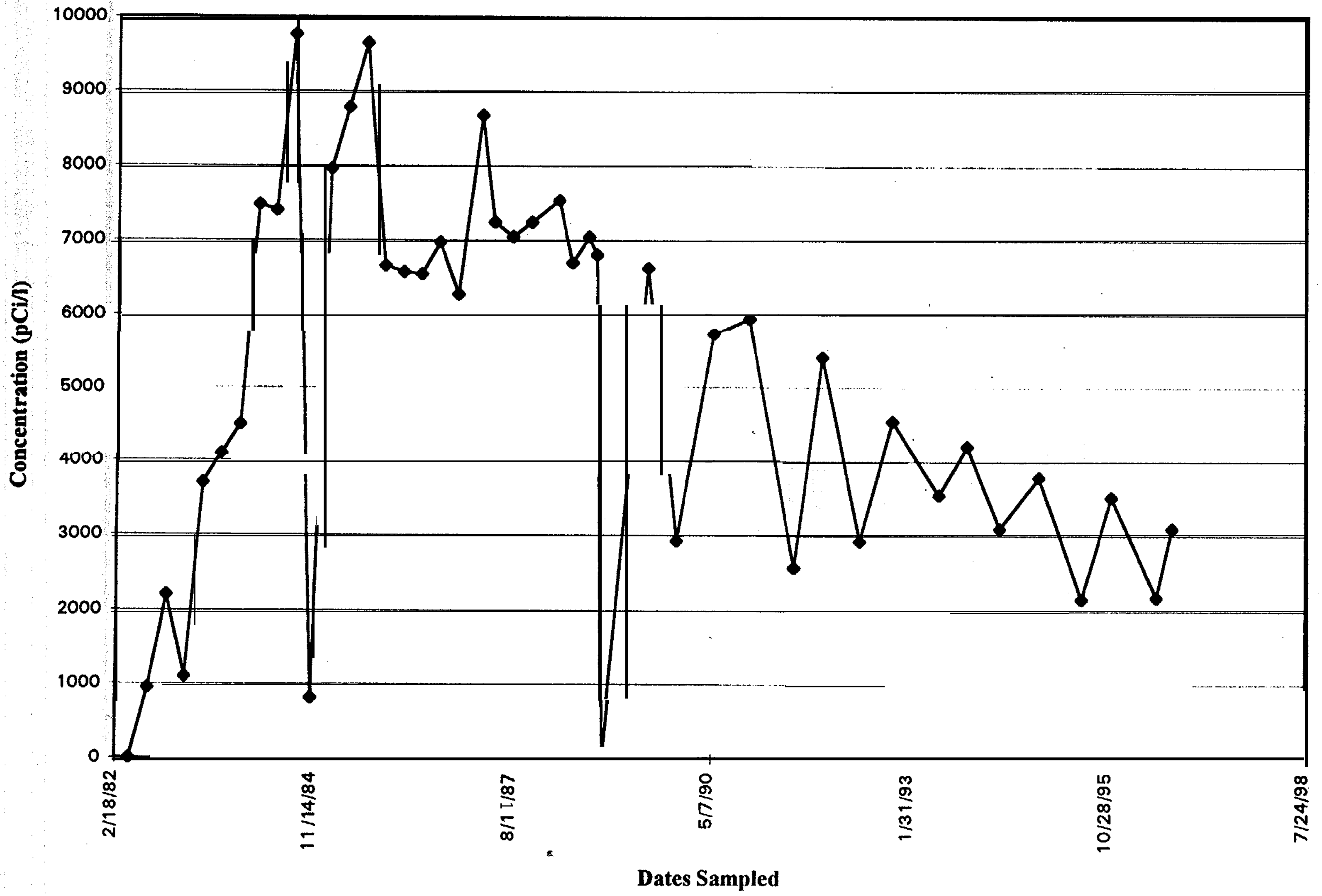
					Linear Regression		
Minimum	**Maximum**	**Mean**	**Median**	**Std Dev**	**Slope**	**R-Sqr**	**Num**
0.00	9800.00	4999.33	5400.00	2717.74	-32.59795	0.02	45

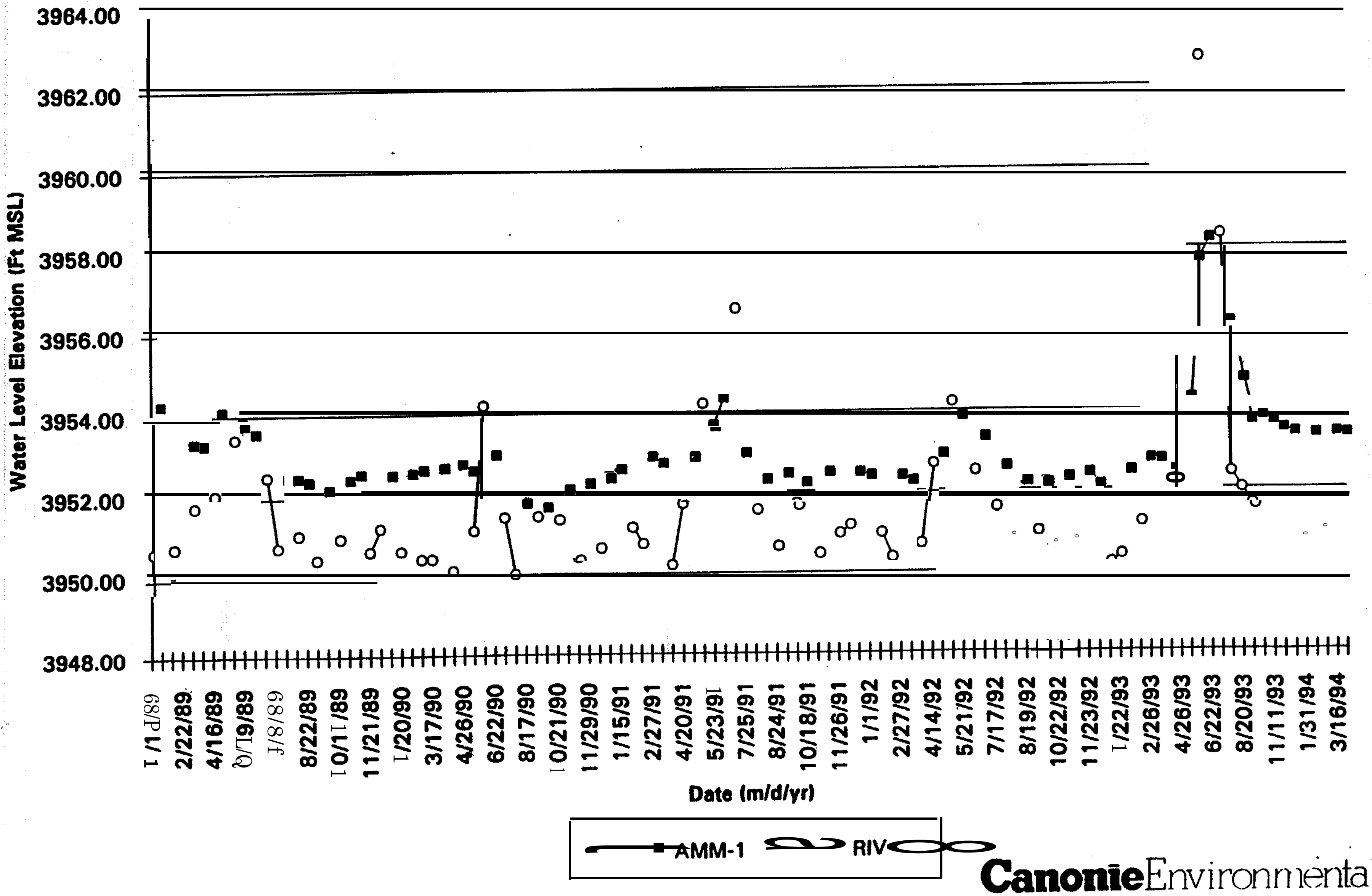
Uranium Concentrations
Monitoring Well ATP-2-S



APPENDIX B

HISTORICAL WATER LEVEL DATA

GRAPH B-1
WATER LEVEL COMPARISON BETWEEN WELL AMM-1 AND COLORADO RIVER



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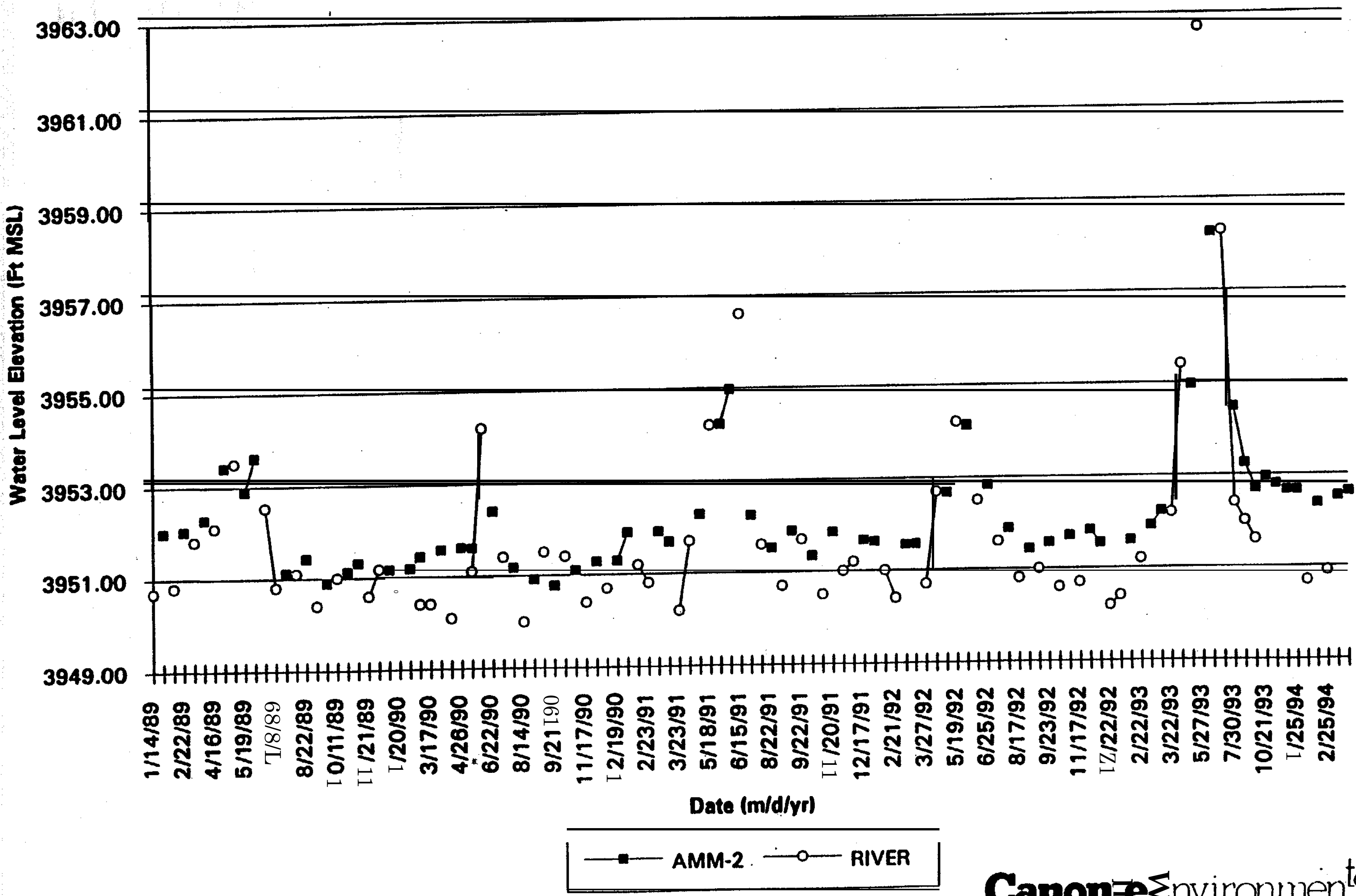
XSECTA.XLS GRAPHB1.XLC (6/29/94)

GRAPH B-2
WATER LEVEL COMPARISON BETWEEN WELL AMM-2 AND COLORADO RIVER



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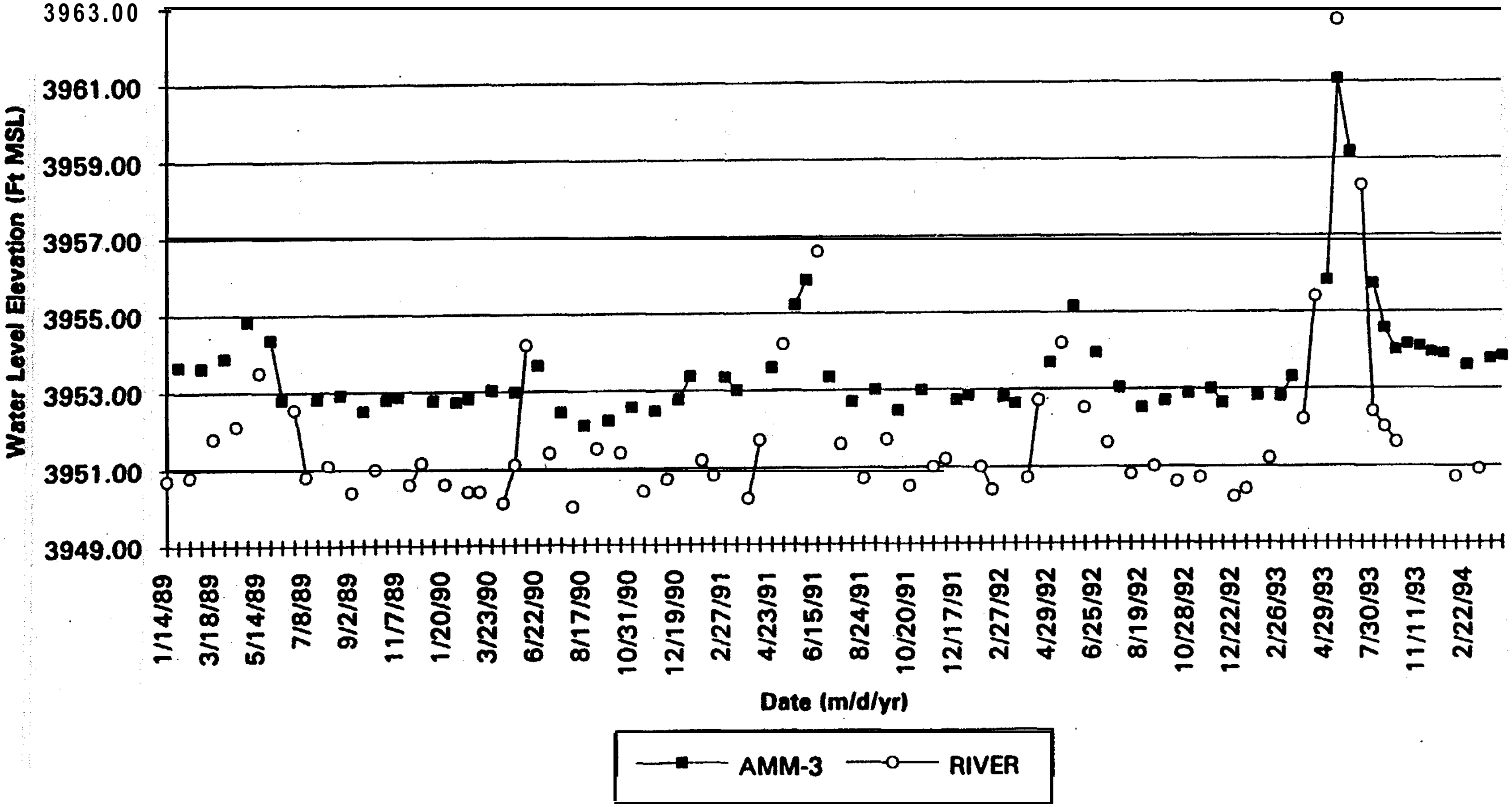
GRAPH B-3
WATER LEVEL COMPARISON BETWEEN WELL AMM-3 AND COLORADO RIVER



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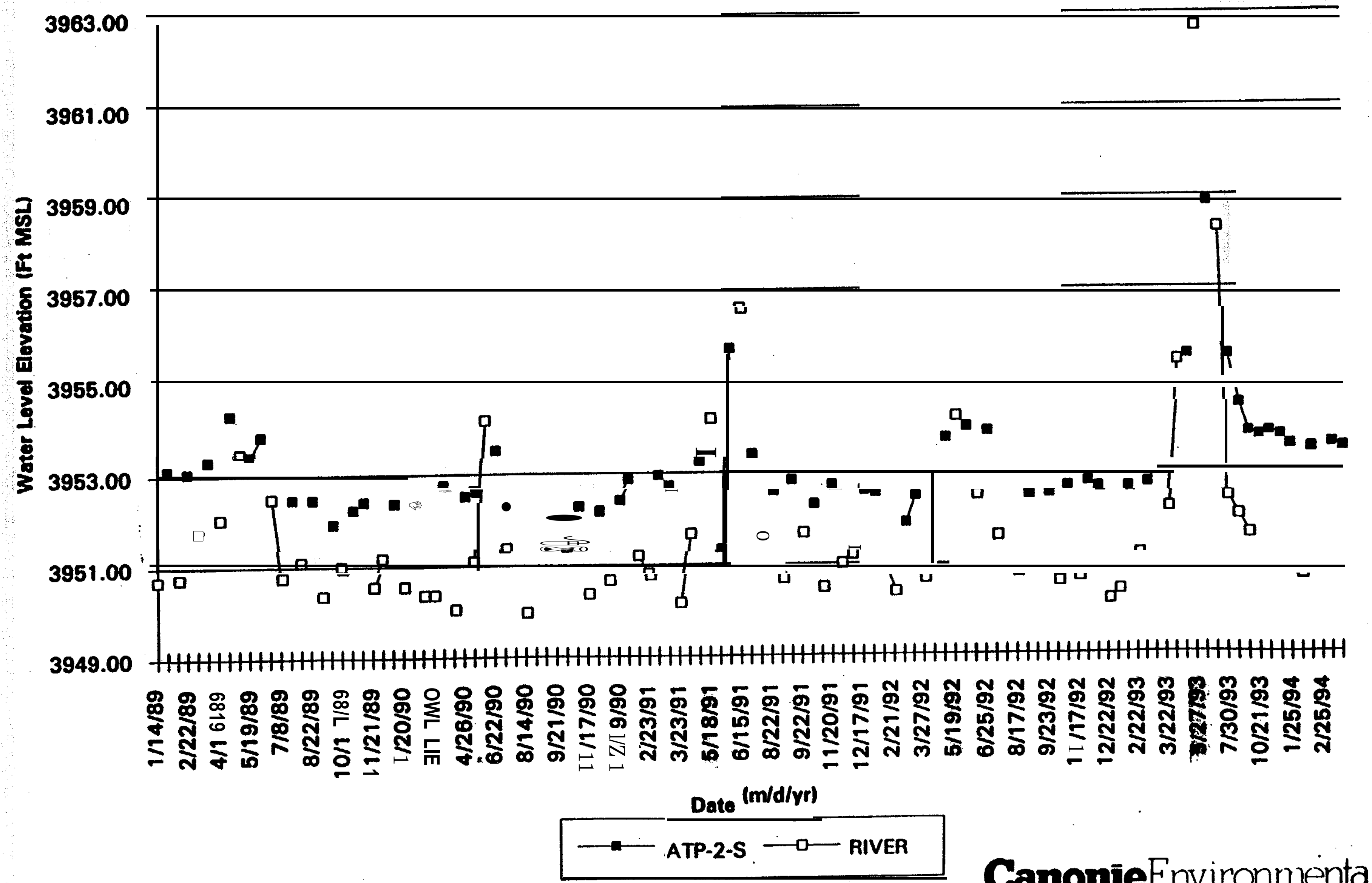
XSECTA.XLS GRAPHB3.XLC (6/29/94)

GRAPH B-4
Water Level Comparison Between Piezometer ATP-2-S and Colorado River



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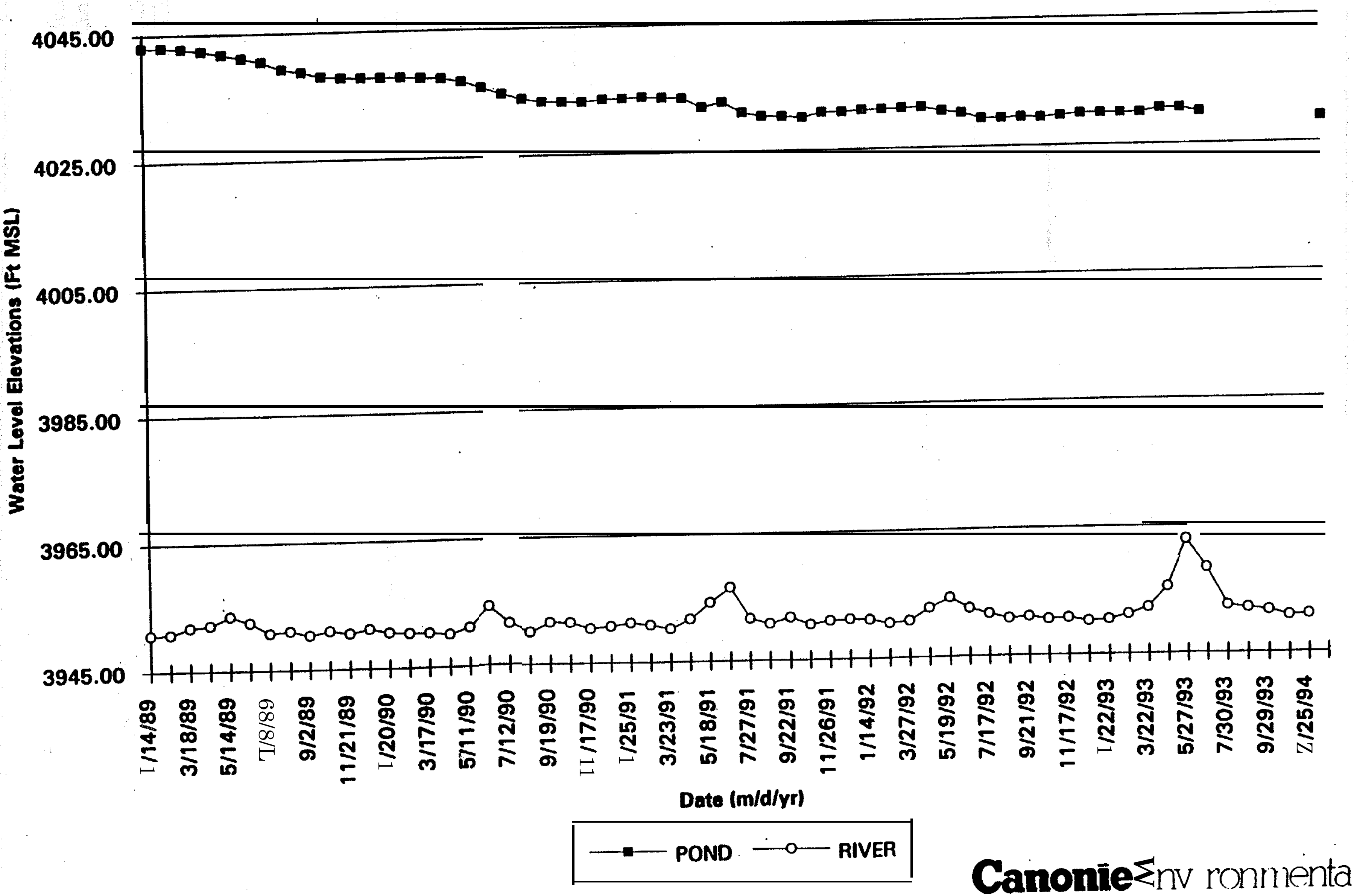
XSECTA.XLS Chart 16 (6/29/94)

GRAPH B-5
WATER LEVEL COMPARISON BETWEEN POND WATER LEVEL AND COLORADO RIVER



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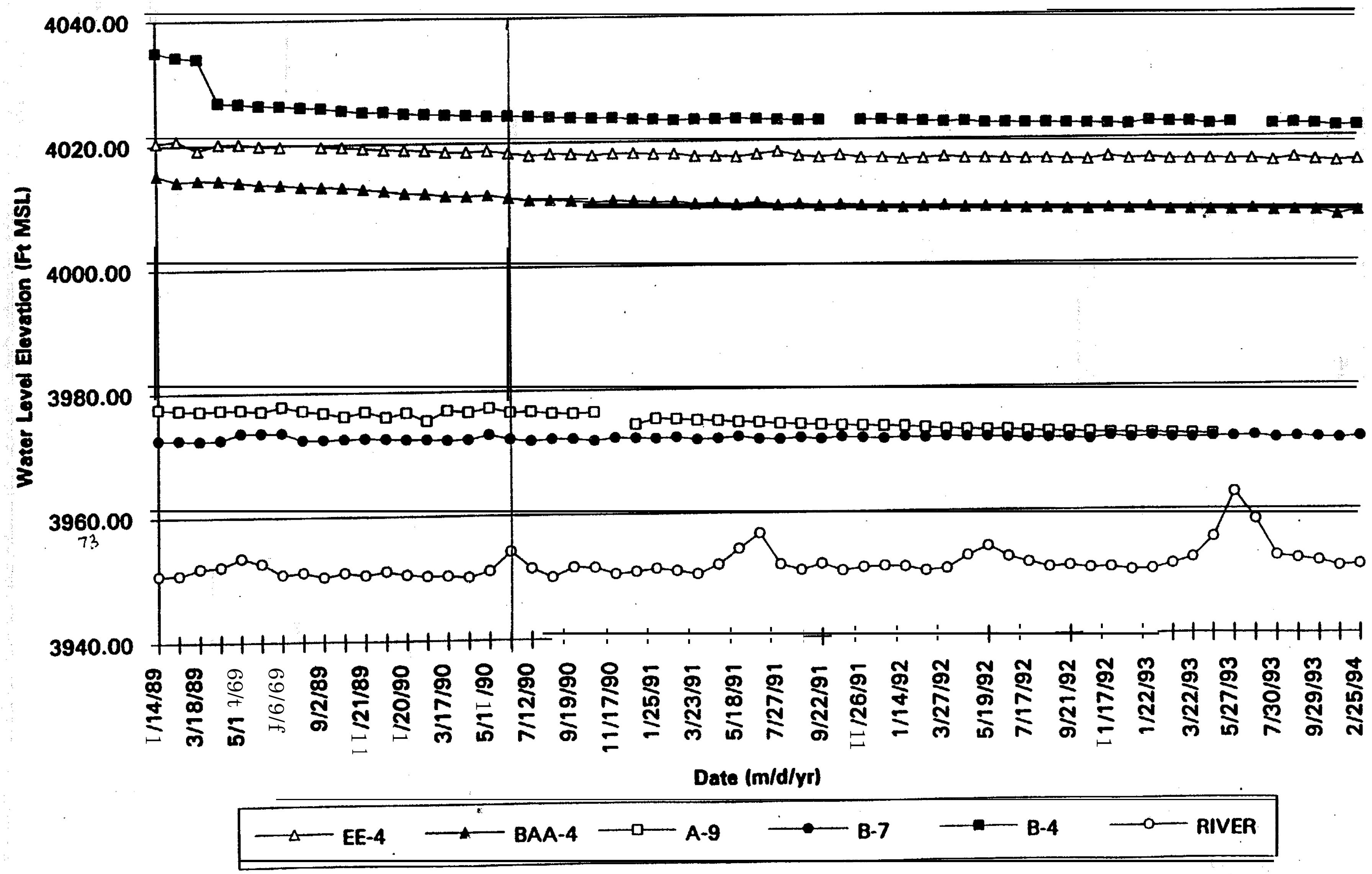
GRAPH B-6
Water Level Comparison Between Tailings Pile Piezometers and Colorado River



POND.XLS POND.XLS Chart 21 [6/29/94]

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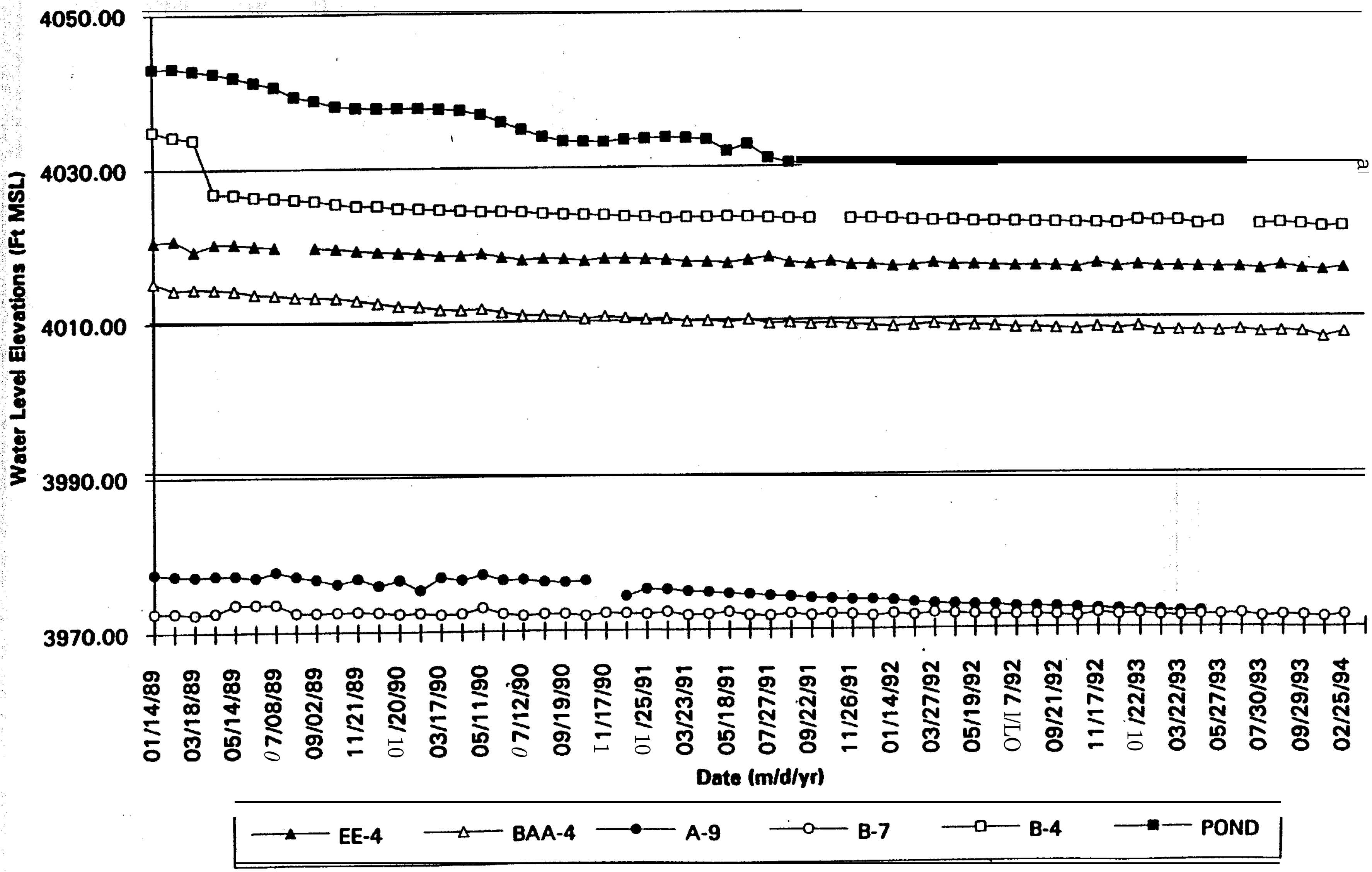
GRAPH B-7
Water Level Comparison Between Tailings Pile Piezometers and Pond Water Level



PONDELEV.XLS PONDELEV.XLS Chart 20 [6/29/94]

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