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ANALYSIS OF GROUND WATER QUALITY AND WATER LEVEL DATA AND THE
EFFECTS OF RECHARGE ON GROUND WATER QUALITY AT SMELTERVILLE FLATS,
IDAHO

A Thesis Presented in Partial Fulfillment of the Requirement for the
DEGREE OF MASTER OF SCIENCE
Major in Hydrology

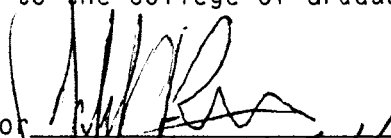
In the
COLLEGE OF GRADUATE STUDIES
UNIVERSITY OF IDAHO

by
Stephen P. Swope
September, 1990

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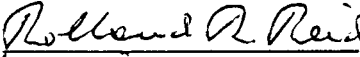
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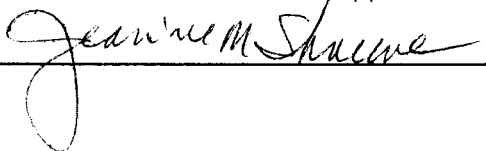
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Committee Members  Date 9/28/90

Roy E. Williams Date 9/28/90

Department Administrator  Date 11-16-90

College Dean  Date 12-12-90

College of Graduate Studies Final Approval and Acceptance:
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ABSTRACT

The Smeltermville Flats are located in the Coeur D'Alene River Valley in Northern Idaho. Mine wastes from zinc, silver and lead mines were discharged into the river and have been deposited in thicknesses up to seven feet over a large area of the Flats causing significant water quality degradation in the underlying aquifer. Water levels and water quality were monitored in ten pairs of piezometers (10 shallow and 10 deep) through two spring recharge events to study the effects of hydrology on water quality.

Heavy metal concentrations measured in the shallow wells were consistently higher than those measured in the deep wells. Despite a significant difference in water quality between the shallow and deep sets of piezometers, dissolved constituents change congruently in the deep and shallow piezometers. Zinc concentrations in the shallow wells varied widely across the Flats. Zinc concentrations could be correlated with depth in the deep piezometers implying the existence of a downward concentration gradient away from the wastes above the aquifer.

A linear relation between zinc and cadmium concentrations and to a lesser extent between zinc and lead concentrations supports the use of zinc as an indicator of contamination by the mine waste. While overall zinc concentration correlates positively with electrical conductivity collectively, well by well correlation is not consistent. Zinc concentration correlates negatively with pH in the deep wells but this correlation is not conclusive in the shallow wells.

Variations in zinc concentrations are associated with antecedent precipitation and therefore recharge more than with water level rise. Therefore remediation efforts should focus on decreasing recharge.

A conceptual model of heavy metal influx has been established consisting of three stratigraphic layers. Infiltrating ground water passes through the first layer and dissolves heavy metal ions. The heavy metal bearing water then moves downward through the second layer and mixes with horizontally migrating ground water of lower zinc concentration in the third layer. Some of this water eventually enters the South Fork of the Coeur D'Alene River.

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CHAPTER 1: INTRODUCTION

Statement Of The Problem

For almost eighty years prior to 1968, tailings from mines located in the Silver Valley of Northern Idaho were discharged into the South Fork of the Coeur D'Alene River . The river water quality has been degraded seriously by this process. Some of these tailings were carried downstream into Coeur D'Alene Lake; other deposits are located on the valley floor mixed with other alluvial material. Whereas tailings no longer discharge directly into the river, the deposits on the Smeltonville Flats continue to contaminate ground water and the South Fork through leaching of toxic heavy metals such as lead, zinc, and cadmium. Determining the effects of recharge on the leaching of these metals is critical to predicting the effects of alternative reclamation efforts. In particular, a proposed revegetation plan will add 20 to 40 inches of irrigation water to this site the first year and 50 to 80 the second year.

The shallow aquifer beneath Smeltonville Flats discharges directly into the South Fork of the Coeur D'Alene River. Mink (1971) and Calcott (1989) show that ground water discharging from the shallow aquifer in the western end of the Flats is the source of greatest metals increase to river.

Ten pairs of piezometers were installed in a 12 acre area owned by the U. S. Bureau of Land Management on the Smeltonville Flats in 1988 by Kunkel. This study is a continuation of a study initiated by Kunkel and is directed towards the evaluation of recharge on shallow ground water quality under the Smeltonville Flats.

Purpose

The purpose of this study is to facilitate remedial action and future investigations of in situ leaching of the metal content of wastes on the Smeltonville Flats by gaining a better understanding of the hydrologic controls on ground water quality in the shallow aquifer.

Objectives

The general objective is to determine the interrelationships among water quality variables and the possible effects of recharge on ground water quality in the shallow aquifer underlying the Smeltonville Flats. The specific objectives include:

1. Create a database of water level, water quality, and precipitation information from 1989 and 1990.
2. Present the spatial and temporal distribution of water level and water quality data.
3. Identify spatial and temporal trends in water levels and water quality.
4. Evaluate the use of zinc concentrations and other water quality parameters as indicators for other dissolved heavy metals.
5. Identify relationships between recharge, water level rise, and water quality.

Study Methods

The study methods employed may be divided into water level and water quality measurements which were completed in the field, and subsequent

statistical analysis. Water levels and water quality were measured weekly from January 26 to May 27, 1990 for a total of sixteen times. Water levels were measured with a steel tape and chalk during both study periods.

During the 1988-1989 study period, ground water was sampled in the following manner. Three well volumes were removed with an ISCO peristaltic pump before the well was sampled. For each sample, approximately 500 ml of water was removed and placed in an acid-washed beaker. Electrical conductivity and temperature were measured in the field with a YSI model 33 SCT meter. A Sargent Welch meter was used to measure pH. The samples were then filtered through 0.45 micron filter paper with a millipore filtration apparatus and placed in a sterilized 135 ml poly-bottle. The pH was reduced to 2 by the addition of fifteen drops of nitric acid. The samples were then sent to the U. S. Bureau of Mines Lab and analyzed on an ICP. The procedure during the 1990 study period was identical except that an Orion Research SA 250 was used to measure pH, and the samples were then sent to Acme Analytical Labs in Vancouver B.C. for analysis. The detection limits for the ICPs used in 1989 and 1990 are given in table 1.1. During the 1990 study period, one sample per week was duplicated and analyzed by the same lab. Splits were not performed.

Statistical correlation analysis was performed on the StatView® statistical package to determine the interrelation between parameters.

TABLE 1.1, DETECTION LIMITS OF ICPS USED IN ANALYSIS 1989, 1990

Ion	1989, mg/l	1990, mg/l
Ag	0.01	0.01
Al	0.01	0.1
As	0.1	0.05
Ca	0.001	0.1
Cd	0.01	0.01
Cu	0.01	0.01
Fe	0.007	0.1
K	0.1	0.1
Mg	0.001	0.1
Mn	0.001	0.01
Na	0.05	0.1
Ni	0.01	0.01
Pb	0.05	0.1
Sb	0.1	0.05
Zn	0.005	0.01

Previous Investigations

Galbraith (1971) concluded that water passing through mine wastes could leach heavy metals. This process is initiated by the oxidation of sulfides and is aided by the action of micro-organisms. The metals accumulate in plants growing over the water source and bio-accumulate in animals grazing on the plants.

Reece (1974) studied the feasibility of leaching of metals from sediments collected along the South Fork of the Coeur D'Alene River. Laboratory experiments determined the effects of temperature, particle

size, contact time, aeration, and repeated wetting and drying on acid water production from local ores.

Norbeck (1974) mapped the distribution of alluvium and mine waste in the valley of the South Fork of the Coeur D'Alene River. The thickness of the mine waste and alluvium was determined using well logs, seismic refraction, electrical resistivity, and depth soundings. In addition he prepared a water table map and sampled 49 wells for pH, EC, and metals content. Zinc mass transport was estimated using Darcy's Law and water quality data from one Bunker Hill Company Well.

Morilla (1975) incorporated a finite element, steady state, mathematical model to investigate the movement of ground water through the Page tailings pile. The quantity of recharge to the tailings pile and the location and fluctuation of the regional water table were found to be the factors controlling the size and shape of the ground water mound.

Marcy (1979) investigated the chemistry of the unconfined mine waste on the Smeltonville Flats and its impact on the Coeur D'Alene River. The sediments were determined to contain high concentrations of lead and zinc; however, no correlation between metals concentration and physical appearance could be found. Pyrite oxidation was found to occur during the dry season when minerals are in contact with oxygen. Winter rains and rising ground water levels were discovered to flush the mobilized oxidation products into the ground water.

Norton (1980) installed a network of monitor wells and soil pits to determine the effect of the tailings on the Coeur d'Alene River. The lower extent of the mine wastes was found to coincide with the the top of the river gravel at a depth of 5 to 10 feet. Metals were also discovered to be concentrated in smaller size fraction of the mine wastes. Norton

determined that ground water quality in individual piezometers is affected predominantly by the mineralogical character of the material in the vicinity of the piezometer screen.

Dames and Moore (1988) synthesized previously collected and analyzed data from the Bunker Hill Superfund site to provide a unified picture of hydrogeological conditions. Ground water recharge to the upper aquifer was determined to come from upgradient tributary aquifer systems as well as leakage from the South Fork of the Coeur D'Alene River, leakage from the lower aquifer, and direct recharge. They note that leaching of the tailings can occur either as ground water rises into the tailings or by recharge of precipitation through the tailings.

Calcott (1989) repeated a study of the chemistry of the South Fork of the Coeur D'Alene River undertaken by Mink in 1971. A statistical comparison of the two data exhibited a decrease in zinc, cadmium and lead concentrations since Mink's study. Ground water seeps were established to be the major source of metal ions entering the river.

Adams (1989) characterized the lower aquifer underlying the Smeltonville Flats through long term water level measurements and large scale hydraulic stress testing. A clay aquitard, where it exists, was found to be effective in isolating the upper and lower aquifers.

Towatana (1990) showed a positive correlation between iron, calcium and magnesium concentrations in the sediments with sediment pH. Because of the presence of carbonate gangue minerals (siderite, ferrodolomite, and ankerite) in the tailings, Towatana suggests that the gangue minerals may buffer pH. He notes that water pH plays a minor role in controlling metal solubility. Towatana's results on sediment quality provide input into the present study on water quality.

Kunkel (in preparation) measured water levels and sampled water quality in the upper aquifer underneath the Smeltonville Flats during the fall of 1988 and the spring of 1989. The transmissivity of the upper aquifer was determined to be approximately 60,000 ft²/day and the specific yield was calculated at 0.04.

CHAPTER 2: SITE DESCRIPTION

Description Of The Study Area

The Smeltonville Flats lie two miles west of Kellogg, Idaho in the east-west trending Silver Valley of the Coeur D'Alene Mountains of Northern Idaho (figure 2.1). The South Fork of the Coeur D'Alene River flows east to west through the valley. The study area occupies a small area of the Flats owned by the U. S. Bureau of Land Management (figure 2.2).

Geography

The South Fork of the Coeur D'Alene River forms the valley and drains part of the Coeur D'Alene Mountains which are part of the Bitterroot range. The terrain is rough with thirty degree hill sides and half-mile wide valleys. The Smeltonville Flats are sparsely vegetated because of a lack of moisture and fertilization (Lombard, personal communication). The average annual precipitation for Kellogg, Idaho is 30.4 inches. The monthly rainfall data for the study period are given in figure 2.3. Most of the precipitation falls as snowfall during the winter as shown by the number of days in which the average daily air temperatures was below freezing (figure 2.4).

Bed Rock

The Coeur D'Alene river basin is underlain by Precambrian Belt series rocks. The Belt Series consists of a slightly metamorphosed, thick sequence of fine grained sedimentary rocks originally laid down in a large geosyncline and later folded and faulted (Hobbs and others, 1965). The bed

FIGURE 2.1, GENERALIZED LOCATION MAP OF THE STUDY AREA

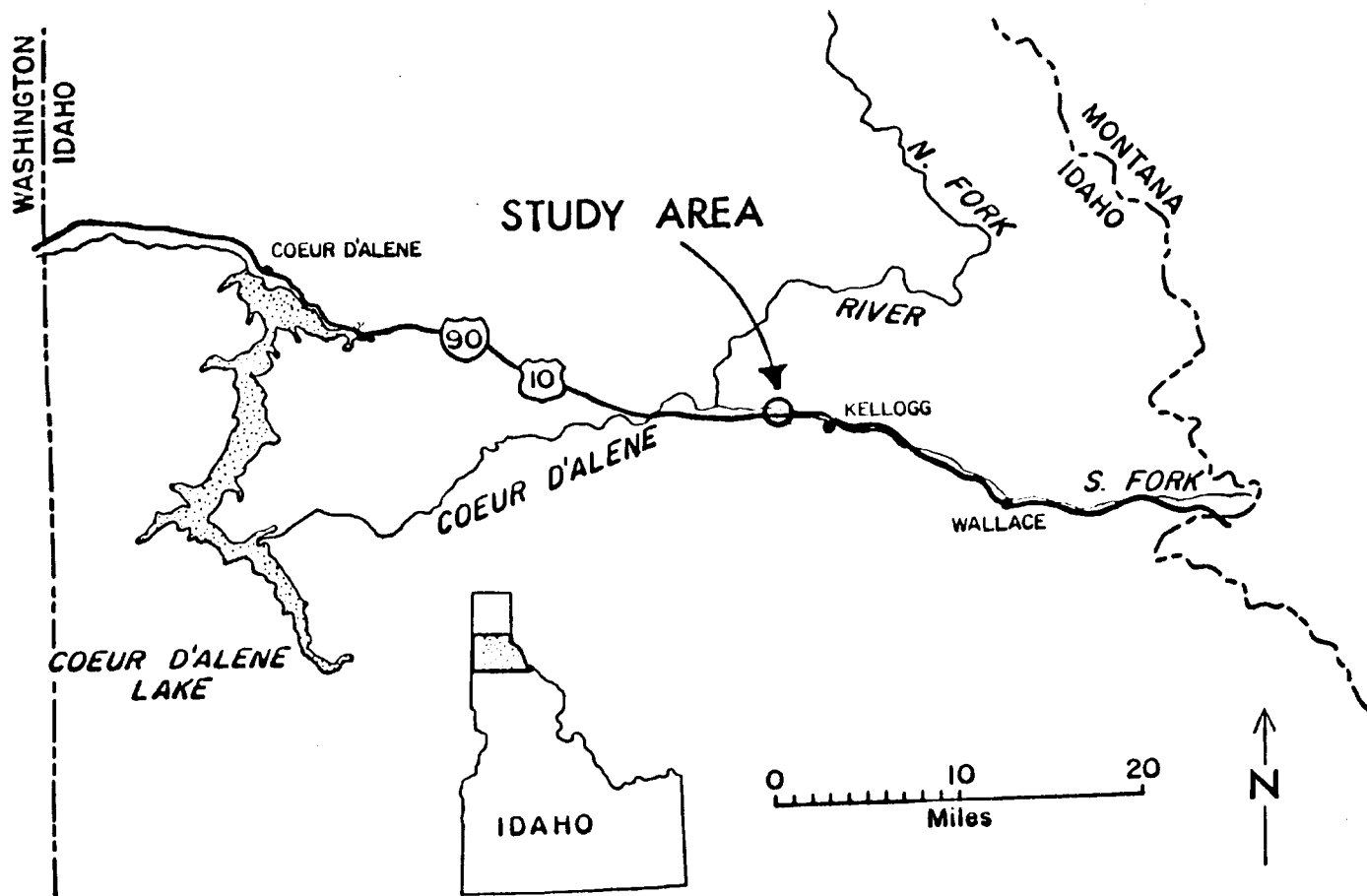


FIGURE 2.2, BLM STUDY AREA LOCATION MAP

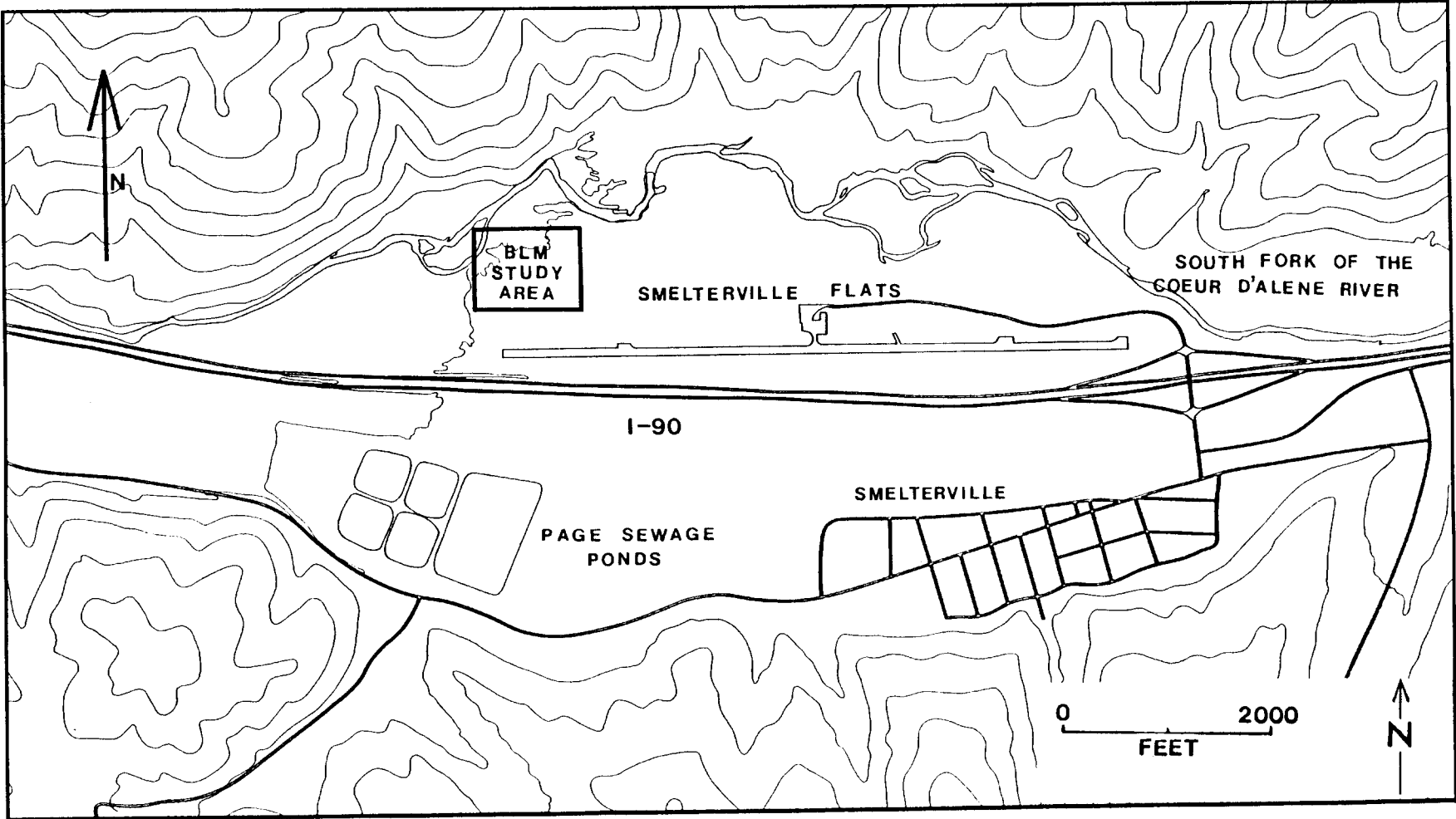


FIGURE 2.3, MONTHLY PRECIPITATION FOR KELLOGG, IDAHO FOR THE STUDY PERIOD (NATIONAL WEATHER SERVICE)

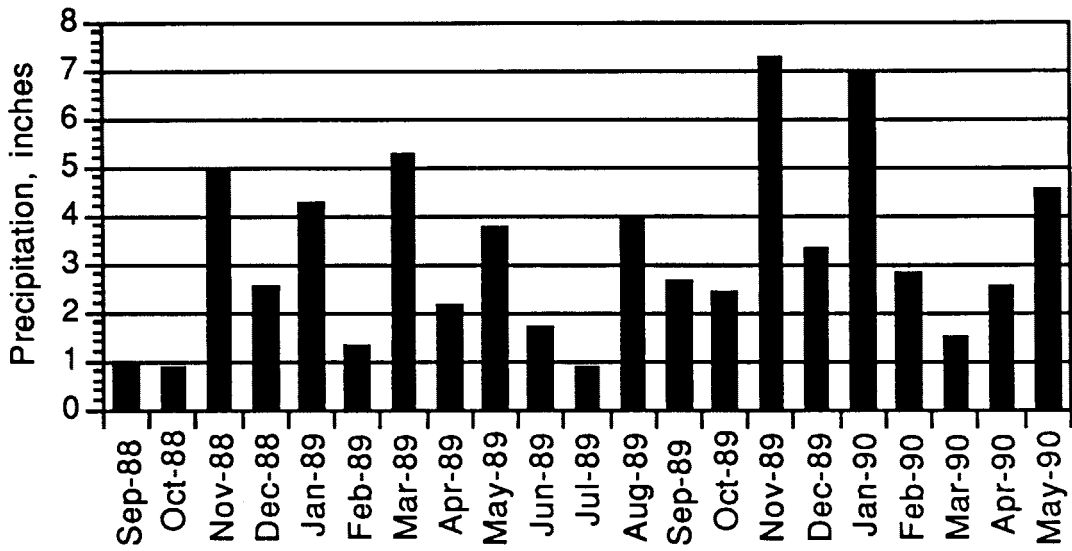
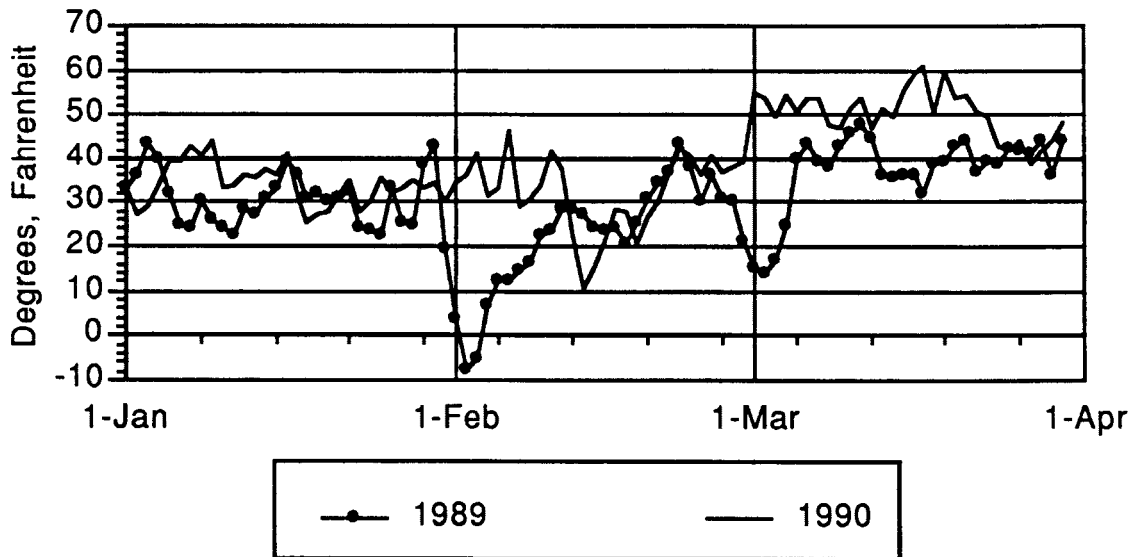


FIGURE 2.4, AVERAGE DAILY TEMPERATURE DURING THE 1988-1989 AND 1990 STUDY PERIODS (NATIONAL WEATHER SERVICE)



rock does not affect the hydrogeology of the upper aquifer except where it acts as a no-flow boundary (Trexler, 1975).

Alluvium

Most of the valley is underlain by fluvial and lacustrine deposits consisting of silt, sand, and gravel. Zero to six feet of heterogeneous mine wastes mixed with alluvium overlie the natural sediments.

Mine Wastes

Mine wastes occupy the upper five to seven feet of upper aquifer at the Smeltonville Flats. Most of the metals are located in a discontinuous, silty-clay layer located three to five feet below the surface (Norbeck, 1974; Kunkel, in preparation). The thickness of this layer is highly variable ranging from zero to two feet across the Flats. Metal concentrations within the silty layer are also highly variable (Norbeck, 1974). The hydraulic conductivity of this layer has been approximated to be 0.001 ft/day by Kirschner (in preparation).

Hydrogeology

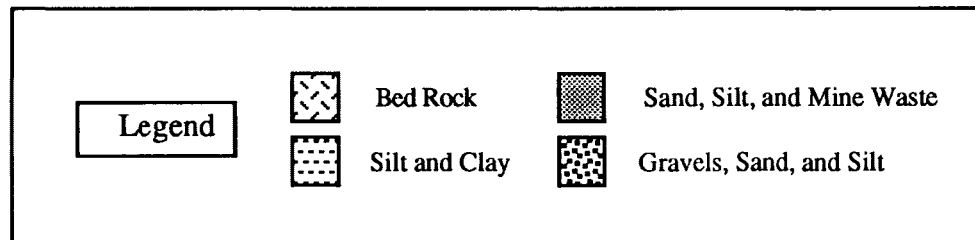
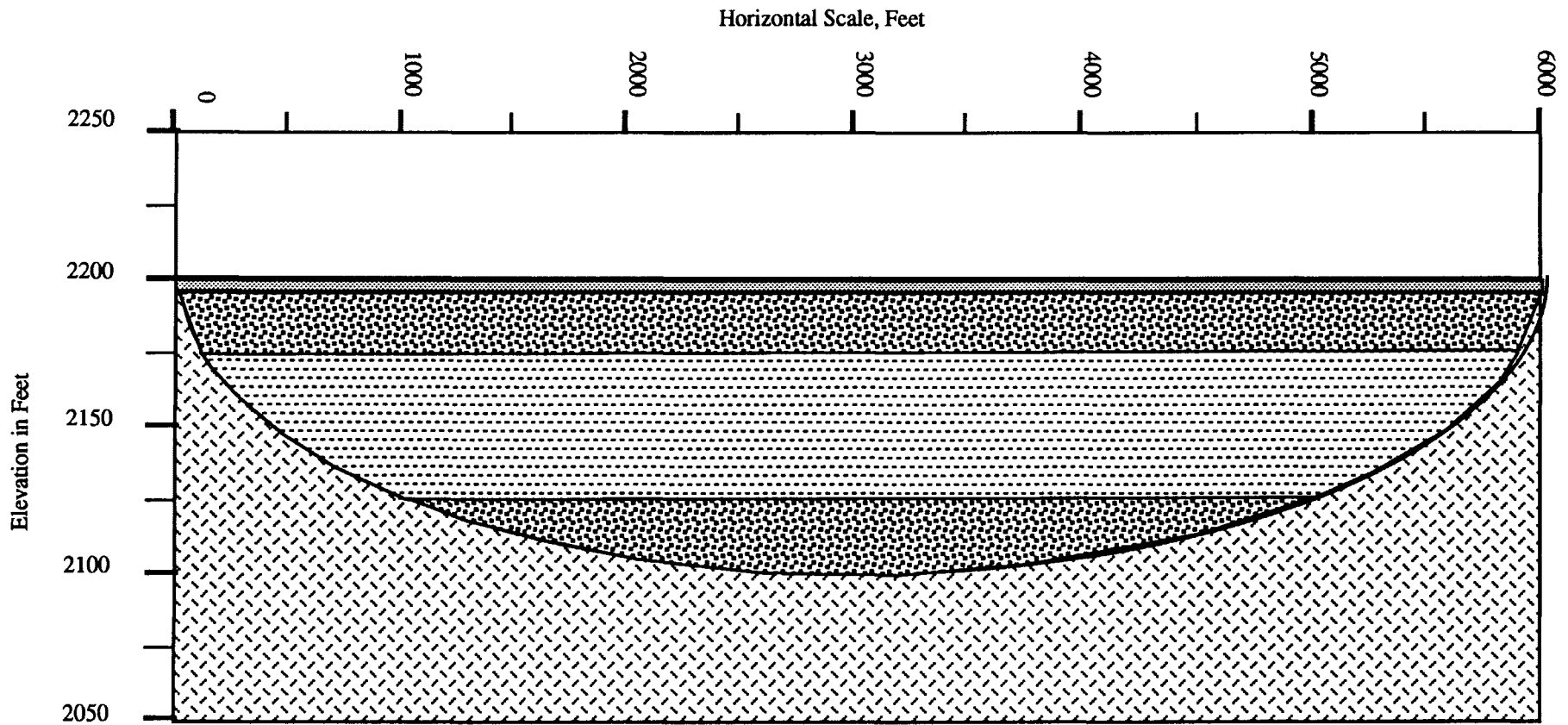
The South Fork of the Coeur D'Alene River flows across the Smeltonville Flats from east to west and is in direct hydraulic communication with the upper aquifer (Kunkel, in preparation). The river is fed primarily by snow melt and thus the maximum discharge occurs in April, May, and June.

Three hydrostratigraphic units have been identified under the Smeltonville Flats by Adams (1989): an upper aquifer, an aquitard, and a lower aquifer (figure 2.5). The upper unconfined gravel aquifer is a 15 to

30 feet thick heterogeneous mixture of alluvium, and mine and mill wastes and has a transmissivity of between 40,000 ft²/day and 90,000 ft²/day (Kunkel in preparation). Specific yield ranges from 0.02 to 0.09. A generalized stratigraphic column is presented in figure 2.7. The aquifer is recharged through direct recharge of precipitation, groundwater inflow from adjacent tributary valleys and, in the eastern portion of the flats, flow from the South Fork (Towatana 1990). The upper aquifer, which is the focus of this study, discharges directly into the Coeur D'Alene River.

A 30 to 60 foot thick clay aquitard separates the two aquifers. An upward gradient exists between the shallow aquifer and the deep aquifer across this confining layer (Adams, 1989). The lower aquifer consists of silty sand, gravel, and cobbles. Transmissivity in the lower aquifer ranges from 60,000 ft²/day to 80,000 ft²/day and storativity is on the order of 5×10^{-5} (Adams, 1989).

Figure 2.5, Generalized North-South Cross Section of the Smelerville Flats (after Kunkel, in preparation)



Wells

Pairs of piezometers were installed at ten locations over the Smeltonville Flats. Well locations are detailed in fig 2.6. At each location, one piezometer was completed close to the tailings layer at an approximate depth of five feet. The other was drilled five feet away and completed at a depth of approximately 22-24 feet. All the wells are completed over a two foot interval. In addition three other wells, MP1A, MP2A, and well B, were completed over the full thickness of the aquifer.

All of the wells were installed by hollow stem auger using two inch flush threaded polyvinyl chloride (PVC). The bottom two feet is 40 slot saw cut well screen with a PVC cap on the bottom. The annulus adjacent to the slotted interval was backfilled with 20-30 mesh silica sand and the rest of the annulus was filled with bentonite chips. Concrete pads and six inch lock boxes were added to protect the wells. Generalized diagrams of well construction are shown in figures 2.7 and 2.7 and well completion information is given in table 2.1.

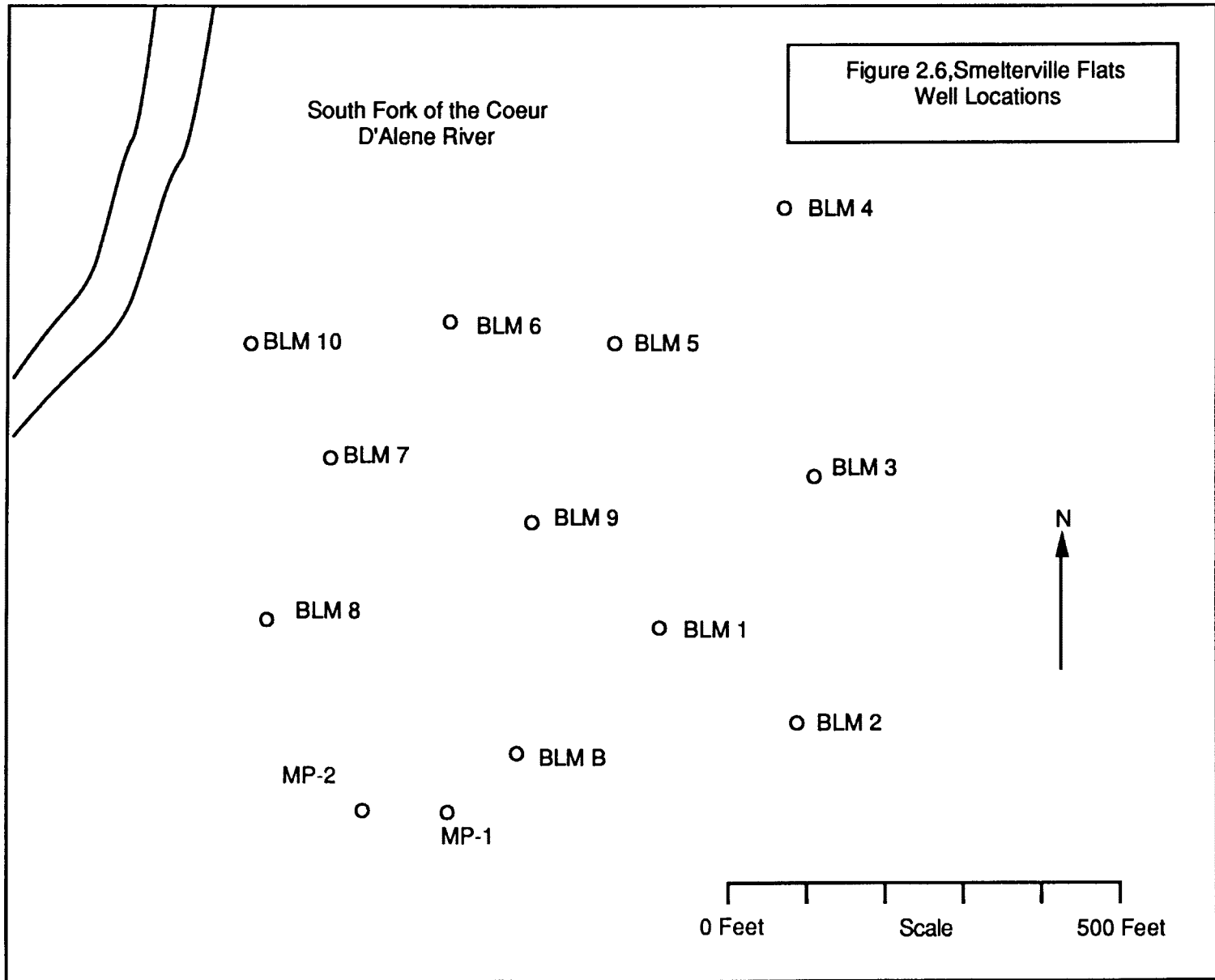
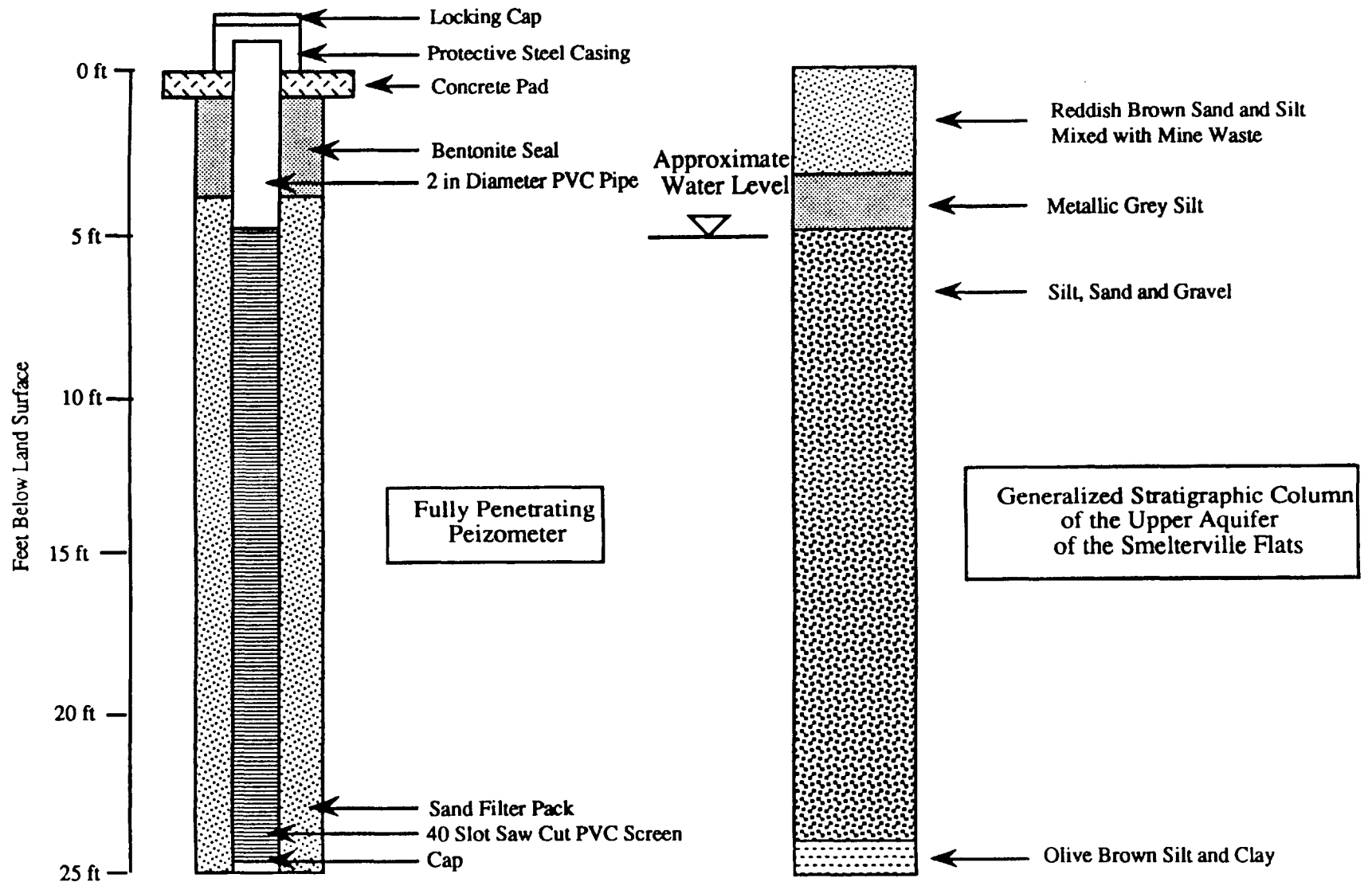


TABLE 2.1, WELL COMPLETION INFORMATION

Well	Total Depth feet	Sand Pack Interval,feet	Perforated Interval,feet	Measuring Point Elevation, feet	Measuring Point height above land, ft
BLM 1C	7	3.5-7	5 - 7	2205.60	
BLM 1D	24	20-24	22-24	2205.64	2.10
BLM 2C	6.5	3.5-6.5	4.5-6.5	2206.89	2.46
BLM 2D	24	20.5-24	22-24	2206.61	2.13
BLM 3C	6	3 - 6	4 - 6	2205.62	2.21
BLM 3D	24	20.5-24	22-24	2205.48	2.23
BLM 4C	6	3 - 6	4 - 6	2204.46	2.15
BLM 4D	26	19-26	24-26	2204.33	2.21
BLM 5C	6.5	3.5-6.5	4.5-6.5	2204.93	2.42
BLM 5D	25	22-25	23-25	2204.88	2.21
BLM 6C	6.5	3.7-6.5	4.5-6.5	2204.19	2.29
BLM 6D	25.5	22.5-25	23.5-25.5	2203.97	2.08
BLM 7C	7	4 - 7	5 - 7	2203.04	2.29
BLM 7D	26	22-26	24-26	2203.19	2.33
BLM 8C	7	4 - 7	5 - 7	2204.38	2.04
BLM 8D	26	21-26	24-26	2204.23	2.21
BLM 9C	6	3 - 6	4 - 6	2204.51	2.21
BLM 9D	6.5	3.7-6.5	4.5-6.5	2204.47	2.04
BLM 10 C	6.5	3.7-6.5	4.5-6.5	2202.2	2.17
BLM 10 D	25.5	22-25.5	23.5-25.5	2202.26	2.02
Type B	24	3-24	4-24	2204.31	2.19
MP1A	26	23-24	22-26		
MP2A	24	22-23	20-24		

Figure 2.7, Fully Penetrating Monitor Well and Generalized Stratigraphic Column



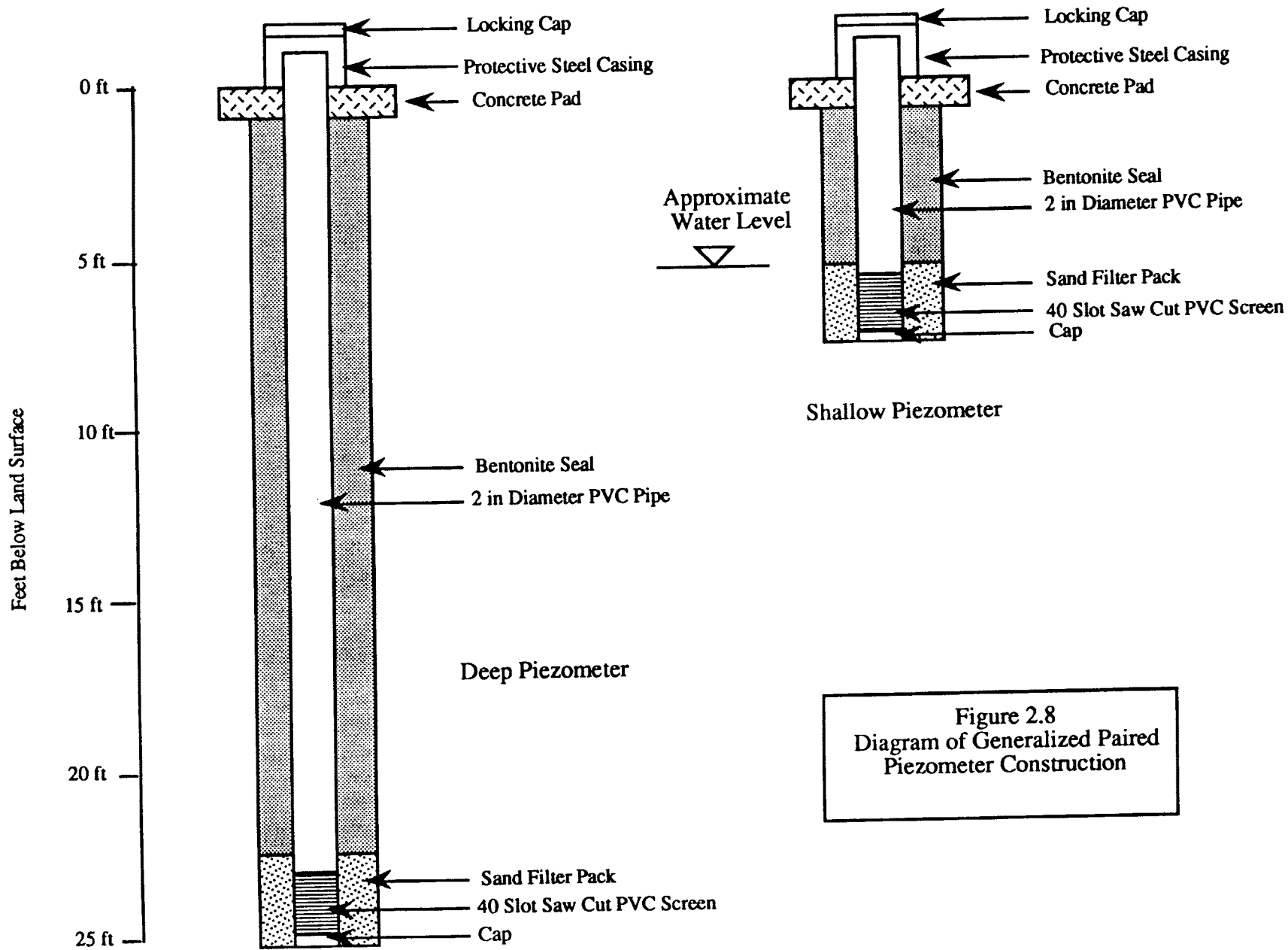


Figure 2.8
 Diagram of Generalized Paired
 Piezometer Construction

CHAPTER 3: WATER LEVEL DATA, WINTER 1988-SPRING 1989 AND SPRING 1990

Introduction

Water level and water quality data for the study area were monitored eight times from September 1988 to June 1989 by Kunkel and sixteen times from January 1990 to June 1990 by the author. The following analysis includes a presentation of the data and a comparison of Kunkel's study to the present data. The data have been divided into subdivisions of horizontal, vertical, and temporal trends to facilitate presentation.

Horizontal Trends in Water Levels

The horizontal hydraulic gradient across the site is sub-parallel to the river and on the order of 0.0047, or 25 feet per mile. Shallow well water level data from April 13, 1990 are presented in figure 3.1 as representative of spring conditions. There was little change in gradient or head configuration throughout the study periods of both years. The Coeur D'Alene River is in direct communication with the aquifer (Kunkel, in preparation) and is a gaining stream in that part of the valley for the entire study period. All of the water level data for the study period are given in tables 3.1 and 3.2.

TABLE 3.1, WATER LEVEL ELEVATIONS IN FEET ABOVE M.S.L., SHALLOW WELLS, 1990 STUDY PERIOD

	BLM 1D	BLM 2D	BLM 3D	BLM 4D	BLM 5D	BLM 6D	BLM 7D	BLM 8D	BLM 9D	BLM 10D
26 Jan	2198.87		2199.47	2198.22	2198.49	2197.30	2196.64	2196.55	2198.09	2196.21
2 Feb	2198.7		2198.99	2198.07	2198.00	2197.14	2196.51	2196.41	2197.91	2196.10
8 Feb	2199.59		2198.92	2197.96	2197.90	2197.07	2196.42	2196.33	2197.79	2196.03
17 Feb	2197.85		2199.15	2198.29	2198.05	2197.25	2196.64	2196.57	2198.05	2196.17
23 Feb	2198.76		2198.98	2198.06	2197.92	2197.24	2196.35	2196.53	2198.46	2195.80
1 Mar	2198.88		2199.17	2198.26	2198.04	2197.32	2196.70	2196.60	2198.07	2196.25
7 Mar	2198.9		2199.23	2198.34	2198.12	2197.39	2196.76	2196.68	2198.13	2196.35
16 Mar	2198.9		2199.15	2198.30	2198.77	2197.33	2196.71	2196.61	2198.11	2195.95
25 Mar	2199.13		2199.45	2198.58	2198.33	2197.60	2196.96	2196.81	2198.35	2196.17
30 Mar	2199.03		2199.34	2198.47	2198.24	2197.52	2196.90	2196.80	2198.26	2196.11
13 Apr	2199.6		2199.92	2199.08	2198.80	2198.09	2197.44	2197.35	2198.81	2196.63
19 Apr	2200.02		2200.36	2199.59	2199.24	2198.54	2197.91	2197.81	2199.24	2197.10
28 Apr	2199.91		2200.26	2199.45	2199.10	2198.32	2197.69	2197.58	2199.11	2196.83
4 May	2199.42		2199.75	2198.84	2198.62	2197.88	2197.69	2197.14	2198.62	2196.45
11 May	2199.43		2199.79	2198.91	2198.64	2197.89	2197.26	2197.17	2198.64	2196.45
27 May	2199.95		2200.28	2199.39	2199.13	2198.38	2197.82		2199.16	2196.92

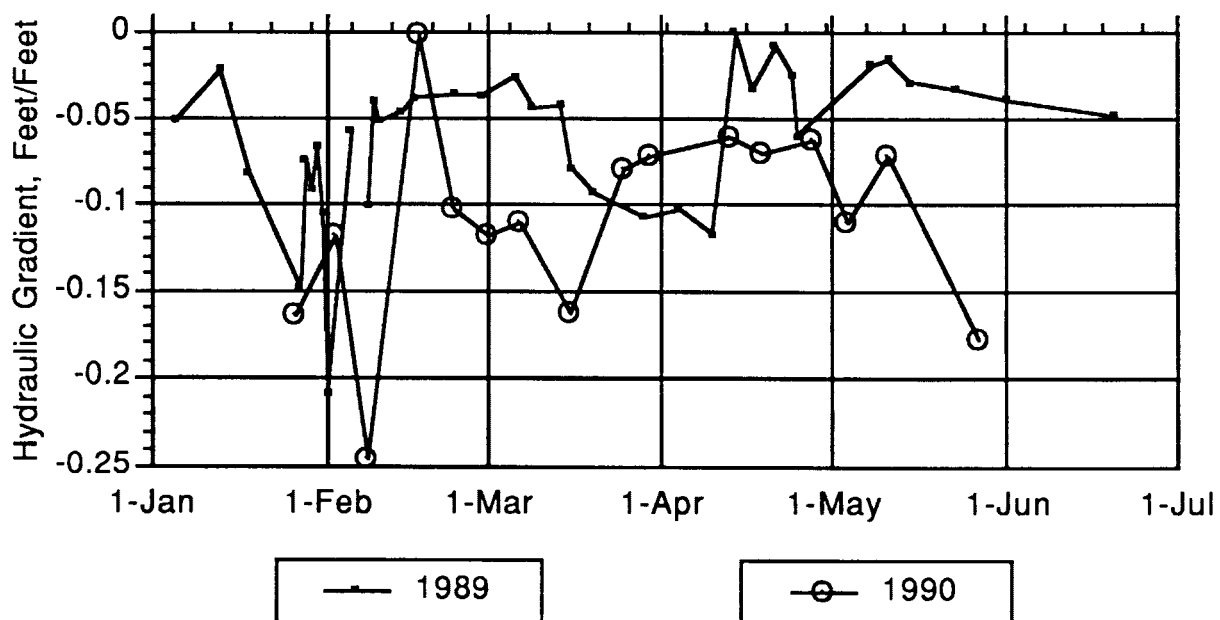
TABLE 3.2, WATER LEVEL ELEVATIONS IN FEET ABOVE M.S.L., DEEP WELLS, 1990 STUDY PERIOD

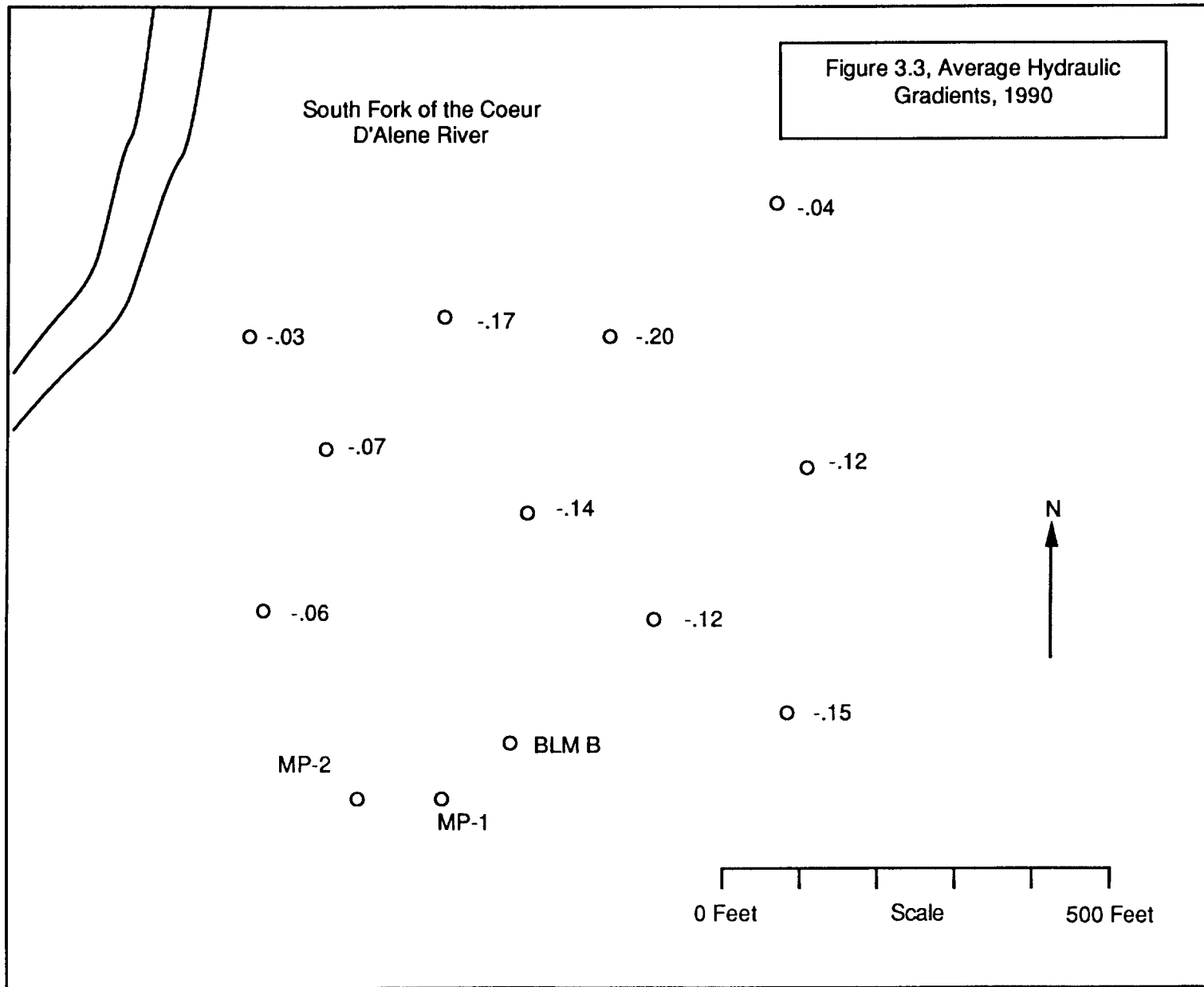
	BLM 1D	BLM 2D	BLM 3D	BLM 4D	BLM 5D	BLM 6D	BLM 7D	BLM 8D	BLM 9D	BLM 10D
26 Jan	2198.91	2199.26	2199.13	2198.21	2197.90	2197.19	2196.62	2196.49	2197.97	2195.94
2 Feb	2198.59	2199.11	2198.90	2198.04	2197.74	2197.04	2196.49	2196.33	2197.82	2195.82
8 Feb	2198.46	2198.99	2198.78	2197.93	2197.64	2196.93	2196.39	2196.24	2197.65	2195.77
17 Feb	2198.75	2199.31	2199.06	2198.19	2197.89	2197.15	2196.62	2196.50	2197.92	2195.92
23 Feb	2198.56	2199.13	2198.90	2198.04	2197.75	2196.47	2196.24	2196.63	2198.42	2196.16
1 Mar	2198.74	2199.27	2199.06	2198.24	2197.94	2197.18	2196.67		2197.93	2195.98
7 Mar	2198.77	2199.32	2199.13	2198.33	2198.01	2197.27	2196.74	2196.60	2197.98	2196.07
16 Mar	2198.75	2199.31	2199.10	2198.24	2197.96	2197.21	2196.62	2196.54	2197.96	2195.99
25 Mar	2198.99	2199.55	2199.36	2198.54	2198.22	2197.48	2196.93	2196.73	2198.18	2196.23
30 Mar	2198.89	2199.43	2199.24	2198.46	2198.13	2197.40	2196.88	2196.73	2198.10	2196.20
13 Apr	2199.44	2200.01	2199.82	2199.05	2198.70	2197.95	2197.42	2197.30	2198.67	2196.73
19 Apr	2199.86	2200.41	2200.26	2199.55	2199.16	2198.41	2197.87	2197.66	2199.11	2197.21
28 Apr	2199.95	2200.33	2200.16	2199.33	2198.98	2198.19	2197.64	2197.49	2198.96	2196.91
4 May	2199.26	2199.84	2199.64	2198.82	2198.54	2197.73	2197.20	2197.07	2198.47	2196.52
11 May	2199.28	2199.87	2199.68	2198.84	2198.51	2197.77	2197.22	2197.09	2198.50	2196.55
27 May	2199.81	2200.37	2200.16	2199.33	2199.02	2198.24	2197.71		2199.00	2197.00

Vertical Trends in Water Levels

During the entire 1988-1989 study period a downward vertical gradient of average magnitude 0.05 feet existed between the upper and lower piezometers across the site (figure 3.2). In 1990, the average downward hydraulic gradient was on the order of 0.1. The largest gradients occur in February of both years. Figure 3.3 shows the distribution of average hydraulic gradient over the study period.

FIGURE 3.2, AVERAGE VERTICAL HYDRAULIC GRADIENT: 1988-1989 AND 1990 STUDY PERIODS.





Temporal Trends in Water Level Data

Water levels increased and peaked in late April and again in early May of 1989 in all wells . Figure 3.4 exhibits water level data for well BLM 9C for the 1988 - 1989 and 1990 study periods. Well location 9 was chosen as a representative well because of its location in the middle of the study site. Because of the high transmissivity of the aquifer, all of the wells exhibit a similar pattern. In 1990, the peak water level occurred in mid-April and late May. The water level data in figure 3.4 do not reflect changes in precipitation because water levels are controlled by regional ground water trends, not precipitation infiltrating directly into the Flats. Comparison between river data for 1989 (figure 3.5) and water levels for the same year shows the response of water levels to basin wide hydrology.

FIGURE 3.4, WATER LEVEL COMPARISON, BLM 9C, 1988-1989 AND 1990 STUDY PERIODS

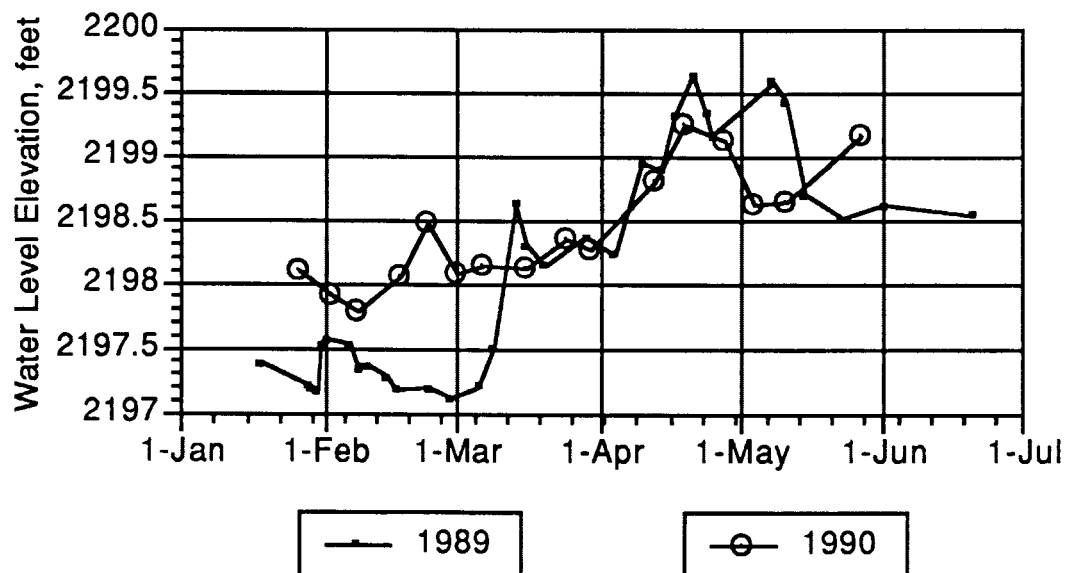
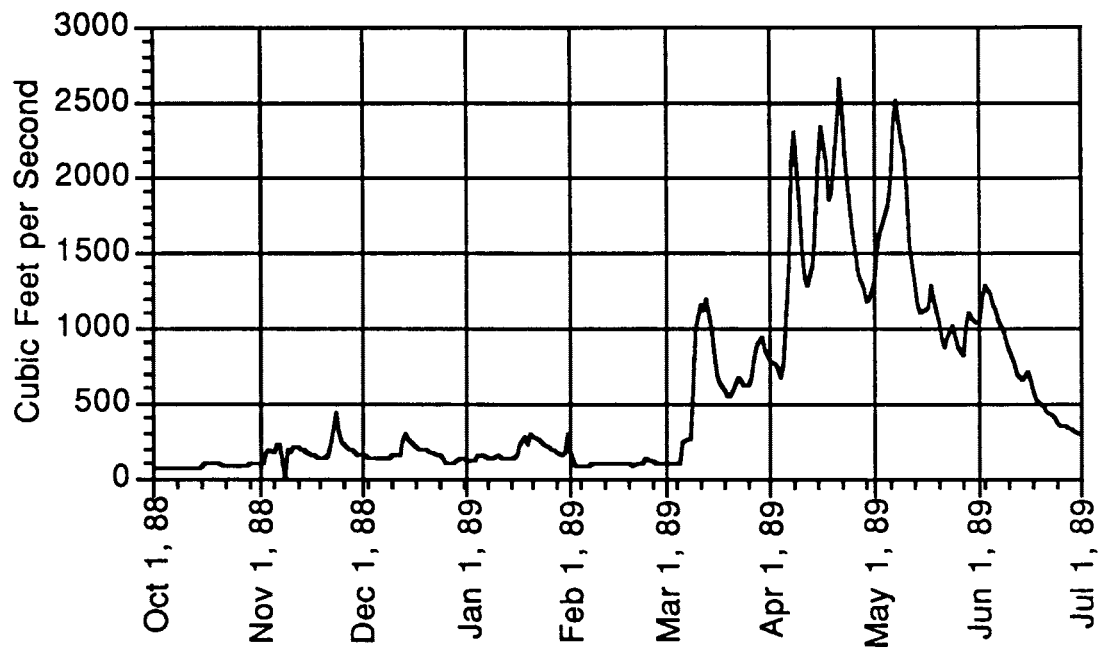


FIGURE 3.5, FLOW IN THE SOUTH FORK OF THE COEUR D'ALENE RIVER,
(HARENBERG AND OTHERS, 1989)



CHAPTER 4: WATER QUALITY DATA, WINTER 1988 TO SPRING 1989 AND SPRING 1990

Introduction

Water quality was sampled eight times from September 1988 to June 1989 by Kunkel and weekly from January to June 1990 by the author. Temperature, pH, and electrical conductivity were measured in the field. The elements included in the analysis and the corresponding detection limits are given in table 1.1. Table 4.1 gives the ranges of concentrations measured for the two study periods and the Idaho maximum concentration limits (MCL) where applicable. The maximum concentrations set for iron, manganese, and zinc are to provide acceptable aesthetic and taste characteristics whereas the maximum concentrations set for cadmium, chromium, lead, antimony and arsenic are set according to health standards (State of Idaho, 1989). All of the elements for which an MCL has been set except copper were over the limit at some time during the study.

Of the elements included in the analysis, only zinc, cadmium and lead concentrations are discussed here. The other analyzed elements are either too close to detection limits or form multiple species in the pH range of the Smeltonville Flats. A change in species could result in precipitation or other reactions which are not predictable. Data for those elements not detailed here are given in Appendix 2. Concentrations of cadmium and lead are only presented briefly because they correlate with zinc (see chapter 5) and therefore their behavior can be deduced from that of zinc.

Earth science data generally is log normally distributed: thus a natural log transform of the data was calculated before it was averaged (Symader and Thomas, 1982). The application of the natural log

transformation to the Smeltonville Flats water quality data is proved to be valid in Appendix 1. The deep and shallow sets of piezometers are assumed to be separate populations and are looked at individually.

TABLE 4.1, MAXIMUM AND MINIMUM CONCENTRATION RANGES,
1989 AND 1990 STUDY PERIODS

Element	Maximum Concentration, mg/l		Minimum Concentration, mg/l		Maximum Conc. Limit
	1989	1990	1989	1990	
Al	NA	2.4	NA	B/D	
As	N/A	0.29	N/A	B/D	.05
Ca	192	186.	26	B/D	
Cd	7.46	3.46	B/D	B/D	.01
Cr	0.07	0.24	B/D	B/D	0.05
Cu	0.34	0.4	B/D	B/D	1.0
Fe	141	100.6	0.055	B/D	0.3
K	15.4	22.7	1	B/D	
Mg	138	180.	11	14.4	
Mn	78.6	105	0.054	B/D	0.05
Na	491.	513.	3.4	1.8	
Ni	0.4	0.27	B/D	B/D	
Pb	3.94	2.9	B/D	B/D	0.05
Sb	0.1	0.21	0.1	B/D	0.01
Zn	1758	1976	0.34	1.68	5.0

NA = Not analyzed for

B/D = Below Detection limits

Zinc Concentrations

Zinc concentrations measured during the study periods ranged from 0.34 to 1758 mg/l (tables 4.2 and 4.3). Zinc concentration is consistently higher in the shallow wells for both years (figures 4.1 to 4.4). In addition to large variations in zinc concentrations over the site there are also variations in the zinc concentrations in individual wells. Trends in zinc concentrations in some of the deep set of wells appear to be similar as opposed to concentrations in the shallow wells, which are not.

The lack of similarity in the trends between wells is attributed to the sinuous flow paths common in fluvial deposits and multiple sources of contaminants and recharge. Because these effects are not quantifiable, an attempt has been made to remove the effects by averaging all the data taken on a particular day. Thus average zinc concentrations show the general trends in the water quality data.

Throughout this study zinc concentrations will be used as an indicator for the effects of the mine tailings following the practices of Kunkel (in preparation) and Riley (1990). Their reasons include 1) zinc does not exhibit multiple valency and is therefore stable in solution within the pH conditions at the site (Moore and Ramamoorthy, 1984). 2) zinc is present throughout the site in concentrations that can be measured accurately on the ICP and is therefore easier to correlate across the site.

TABLE 4.2, ZINC CONCENTRATIONS IN MG/L, SHALLOW WELLS, 1990 STUDY PERIOD

	1C	2C	3C	4C	5C	6C	7C	8C	9C	10C
26 Jan	478		47.72	41.92	1976.17	29.88	93.65	59.32	245.17	727.83
2 Feb	527.09		31.17	39.49		24.66	101.46	54.11	98.12	931.61
8 Feb	561		29.28		1827.44	24.96	92.21	66.2	136.75	791.53
17 Feb	538.42		35.37	43.4	1789.35	28.19	94.44	60.04	249.66	642.65
23 Feb	600.39		28.51	39.45	1809.33	25.91	92.72	52.19	181.58	683.91
1 Mar	581.08			46.07	740.44	24.21	81.47	53.37	166.09	609.09
7 Mar	579.53		27.78	31.93	757.43	22.85	79.98	55.57	146.58	696.95
16 Mar	523.92		23.24	32.12	544.07	23.82	76.57	48.09	156.29	720.06
25 Mar	520.39		26.87	42.76	578.54	26.85	90.46	67.94	131.98	727.89
30 Mar	451.55		21.66	44.15	412.17	25.49	84.43	61.96	117.28	494.63
13 Apr	393.47		23.6	59	228.37	20.44	68.31	63.02	100.11	184.17
19 Apr	394.22		24.25	56.28	220.98	21.28	66.66	59.42	92.09	157.1
28 Apr	375.07		32.75	59.12	203.49	20.78	71.19	62.29	89.06	174.88
4 May	92.41		18.52	41.51	265.92	18.53	66.65	49.96	83.71	299.48
11 May	324.58		16.41	37.86	240.21	18.47	60.81	47.78	64.07	148.31
27 May	231.43		20.32	46.08	621.43	17.04	52.96		79.43	887.85

TABLE 4.3, ZINC CONCENTRATIONS IN MG/L, DEEP WELLS, 1990 STUDY PERIOD

Deep	1D	2D	3D	4D	5D	6D	7D	8D	9D	10D
26 Jan	26.66	25.27	12.51	1.68	15.02	11.82	12.12	18.31	14	13.42
2 Feb	27.45	26.51	12.48	6.26	15.46	12.94	12.09	21.86	14.11	11.71
8 Feb	27.62	28.52	13.24	14.8	15.91	12.33	12.41	19.97	14.92	11.42
17 Feb	29.97	26.69	12.76	7.14	19.79	11.09	11.38	19.32	10.9	11.19
23 Feb	28.51	26.15	11.58	6.43	21.24	11.76	11.94	19.71	14.49	15.8
1 Mar	26.08	24.58	11.62	6.51	16.66	11.82	11.92	20.07	13.9	12.35
7 Mar	26.72	25.06	11.17	5.7	19.81	10.82	11.24	18.25	12.76	13.84
16 Mar		25.86	10.85	5.64	16.45	10.41	11.59	18.02	12.51	12.53
25 Mar	31.4	28.37	13.21	6.96	18.58	12.26	12.72	20.4	14.95	15.62
30 Mar	30.98	27.49	12.44	6.36	15.92	11.02	11.48	18.39	13.14	12.01
13 Apr	23.76	21.51	10.37	5.38	12.87	9.12	10.11	16.92	11.38	8.3
19 Apr	23.81	19.2	8.34	4.41	13.1	8.01	8.93	15.84	10.22	8.12
28 Apr	23.08	20.94	10.34	5.15	12.88	9.12	10.5	17.24	11.2	8.83
4 May	20.71	19.16	10.61	5.19	12.72	9.55	10.03	17.21	10.97	8.5
11 May	19.6	18.23	8.5	4.47	9.98	7.56	8.63	14.52	9.5	7.25
27 May	18.82	17.07	7.94	4.88	11.28	6.15	7.39		8.17	8.98

FIGURE 4.1, ZINC CONCENTRATIONS, SHALLOW WELLS, 1990

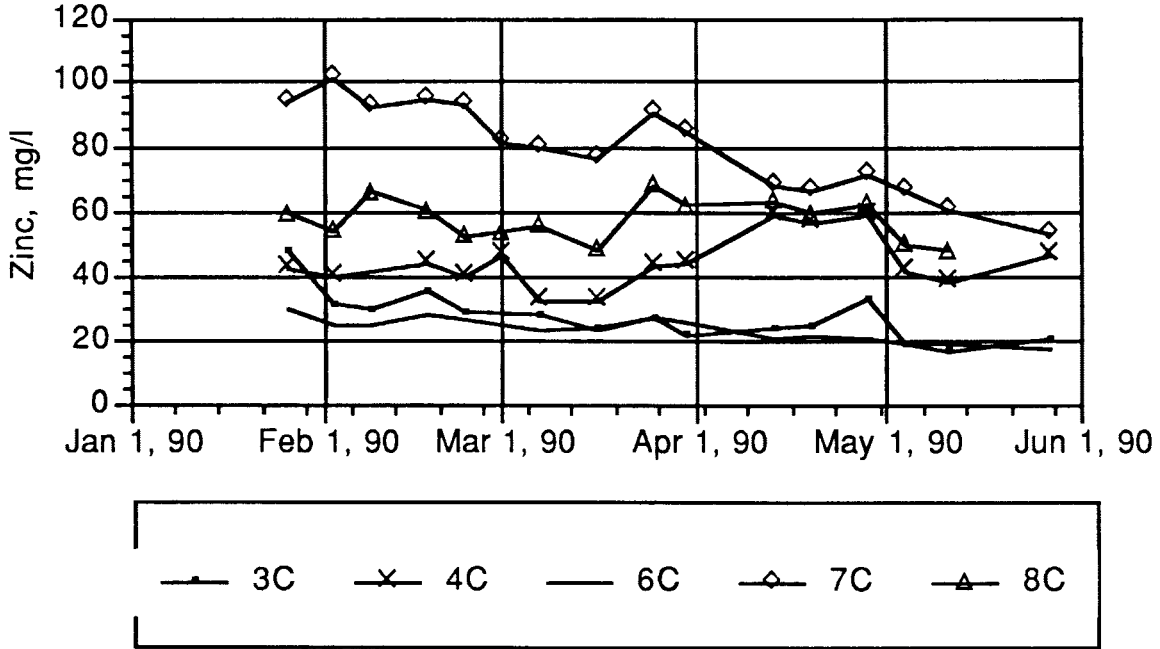


FIGURE 4.2, ZINC CONCENTRATIONS, SHALLOW WELLS, 1990

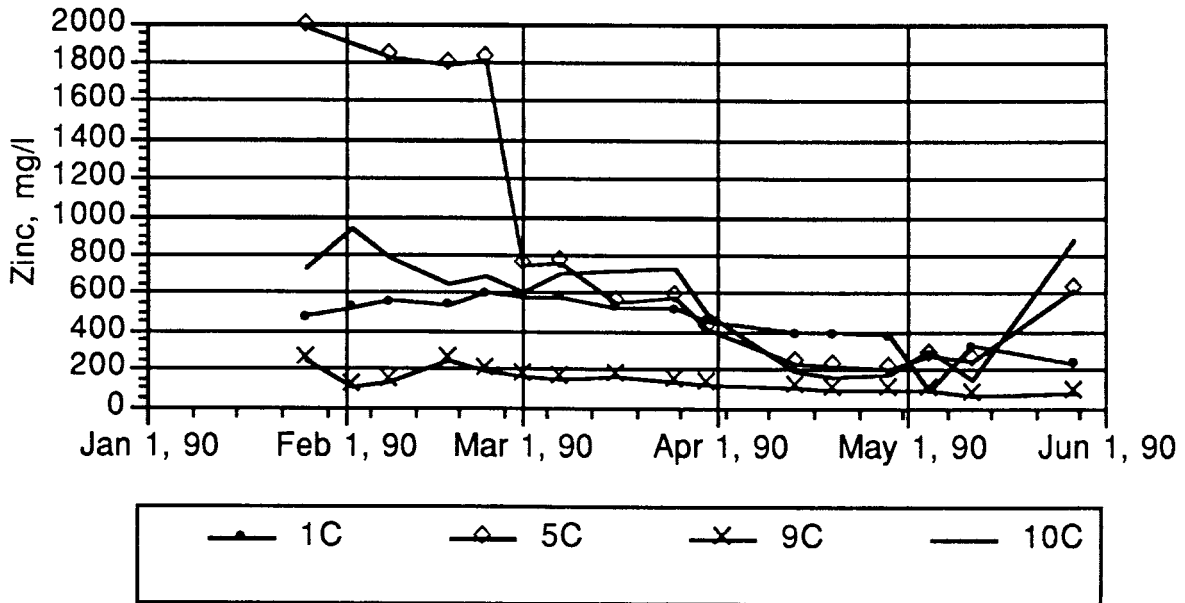


FIGURE 4.3, ZINC CONCENTRATIONS, DEEP WELLS, 1990

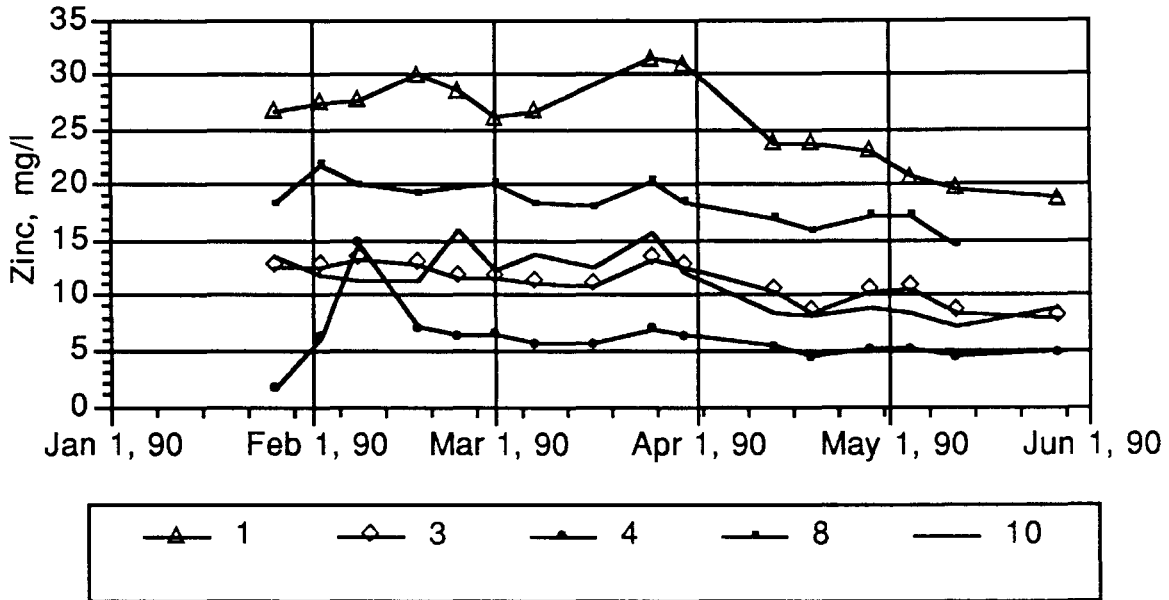
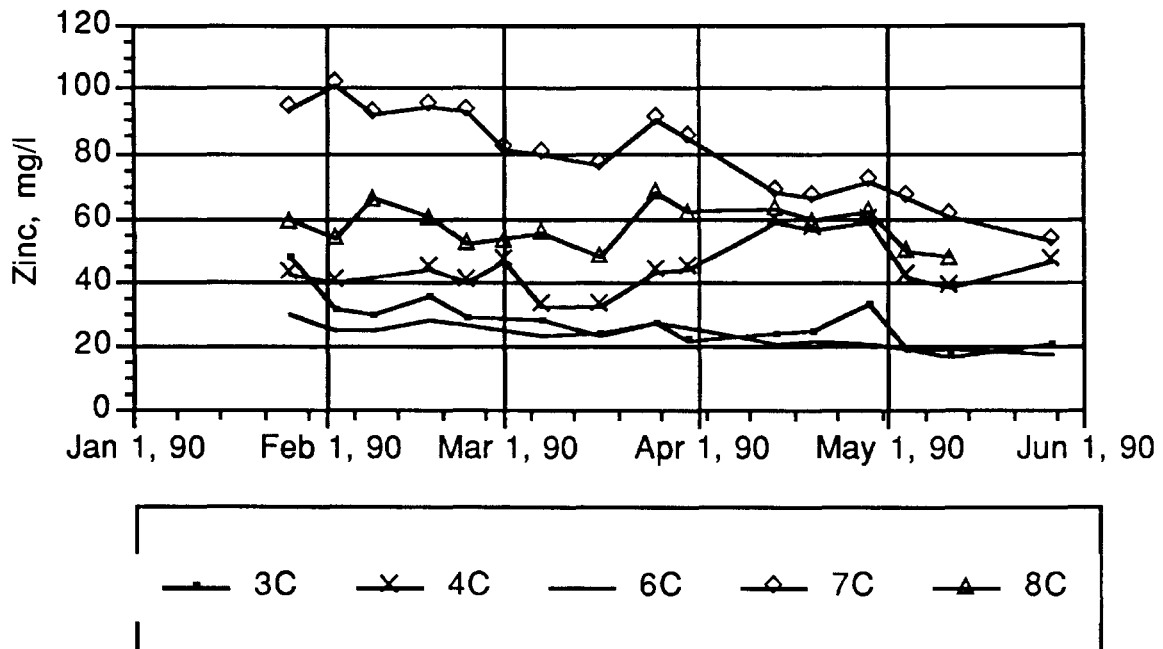


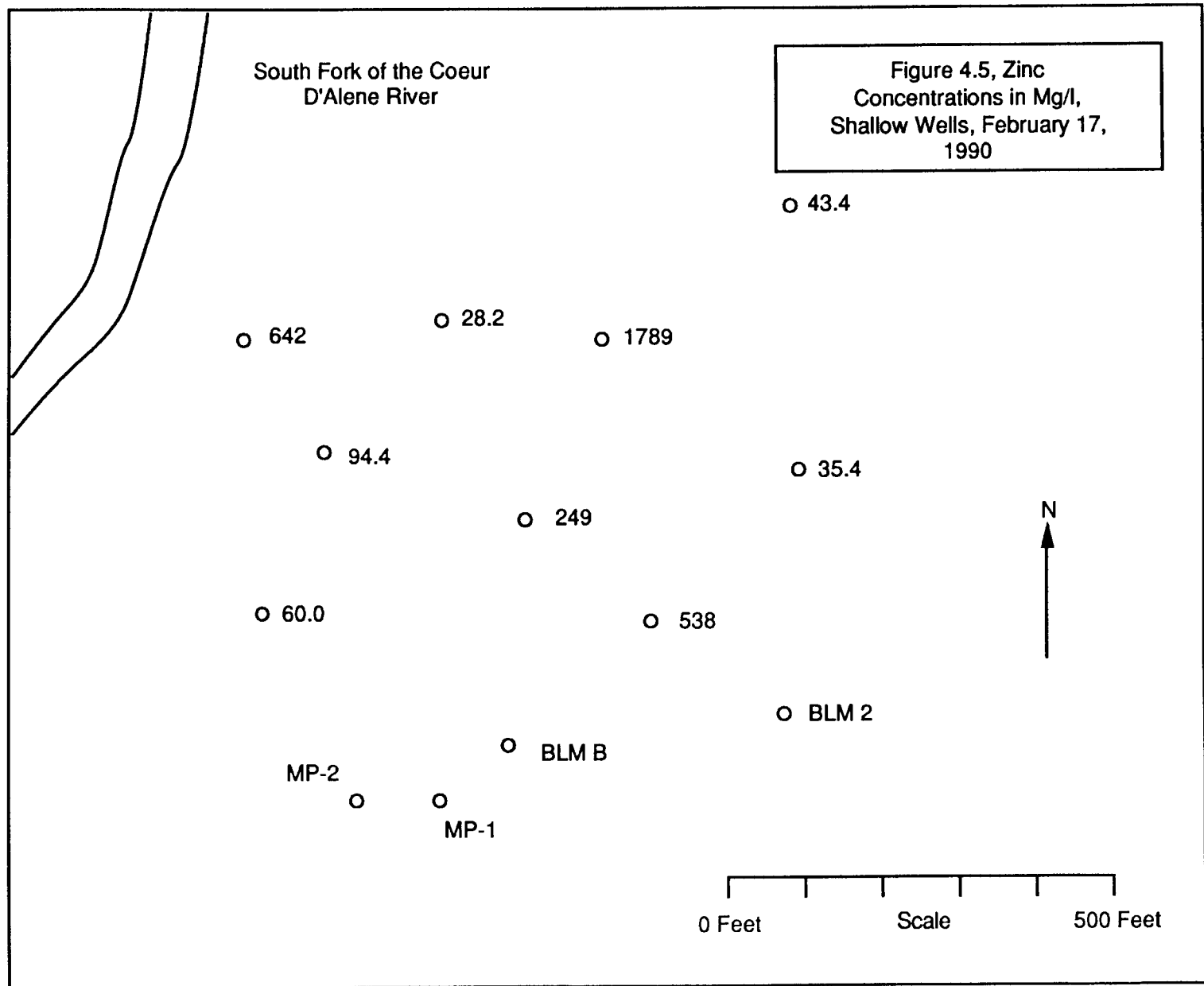
FIGURE 4.4, ZINC CONCENTRATIONS, DEEP WELLS, 1990

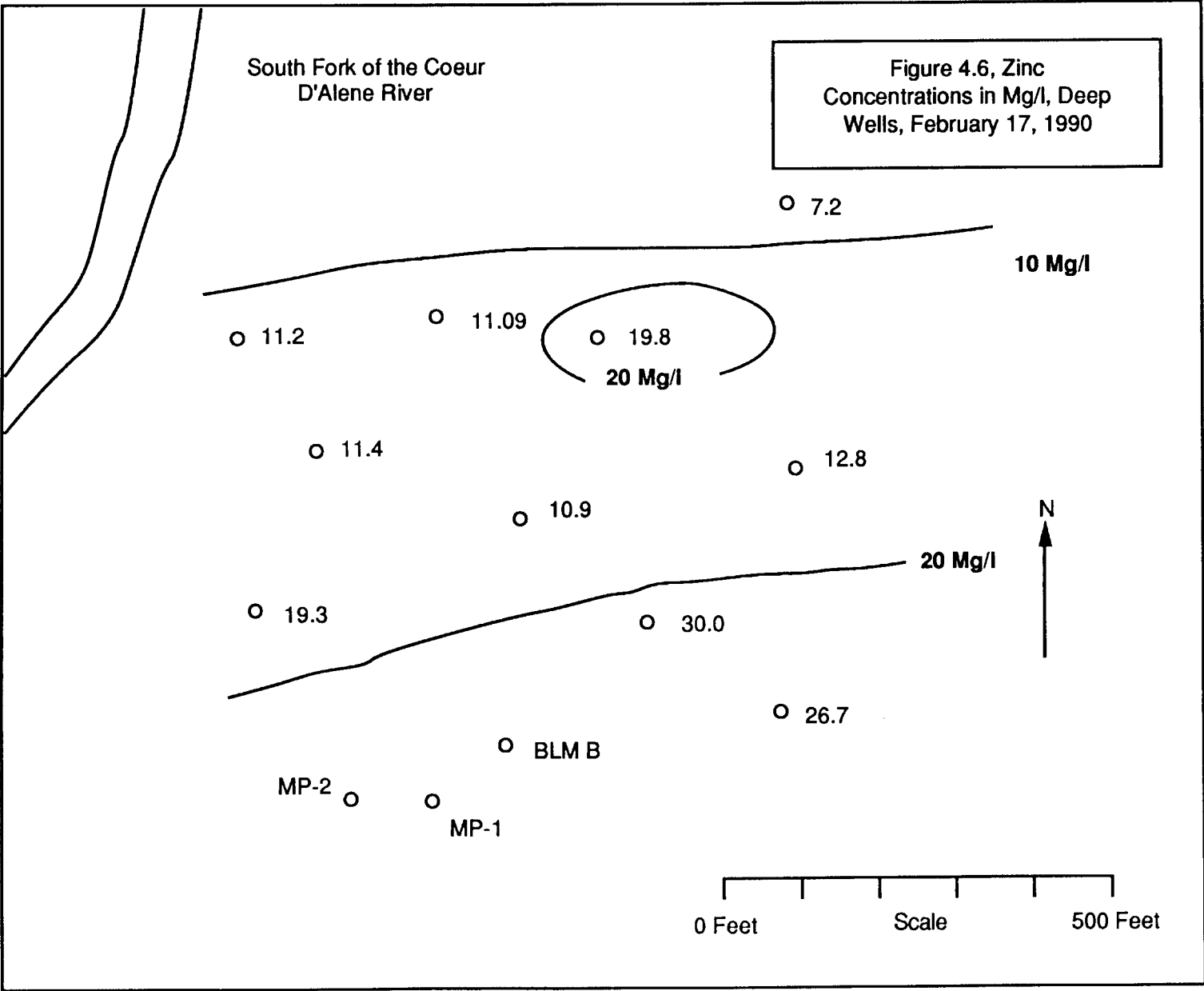


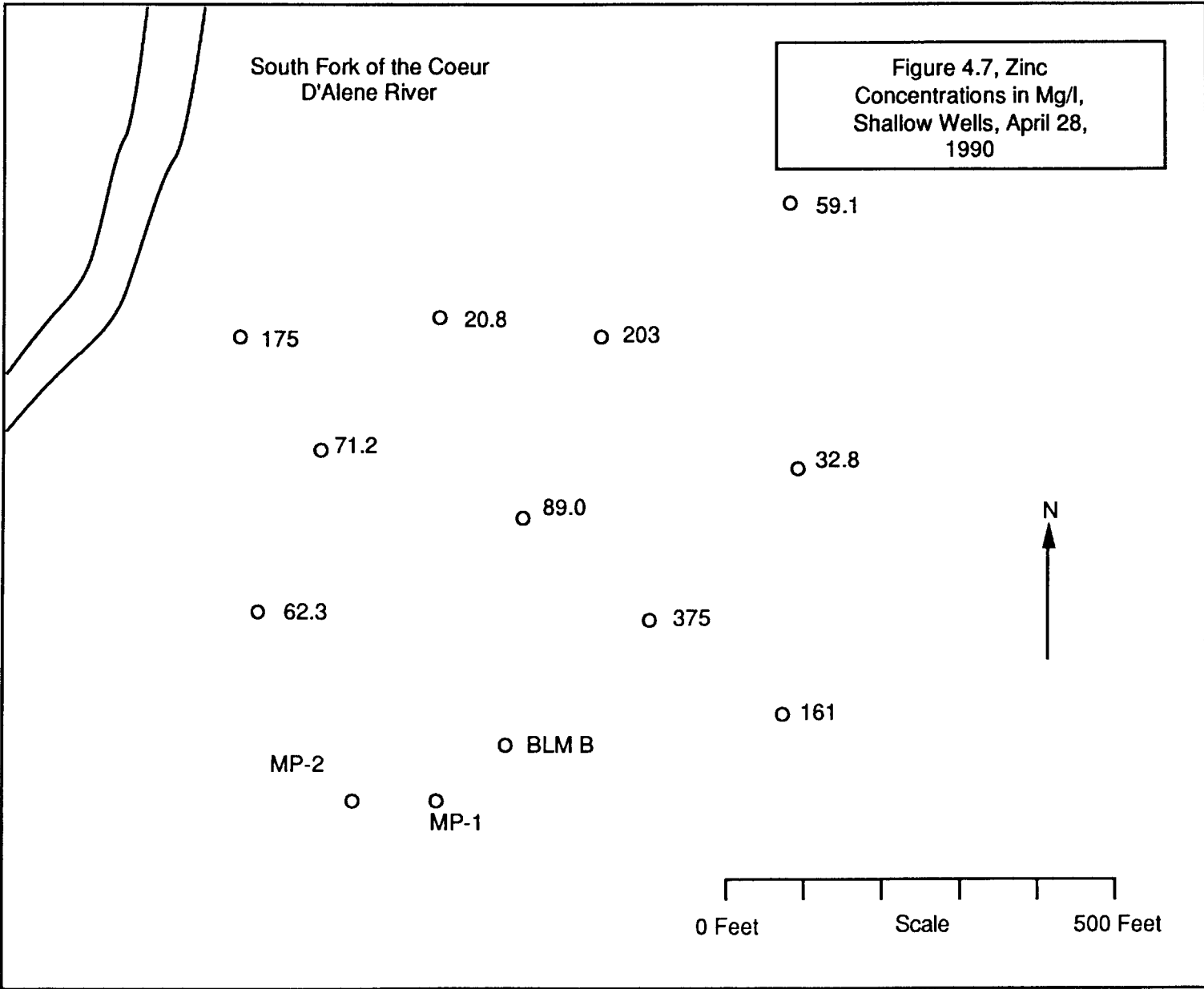
Horizontal Trends in Zinc Concentration

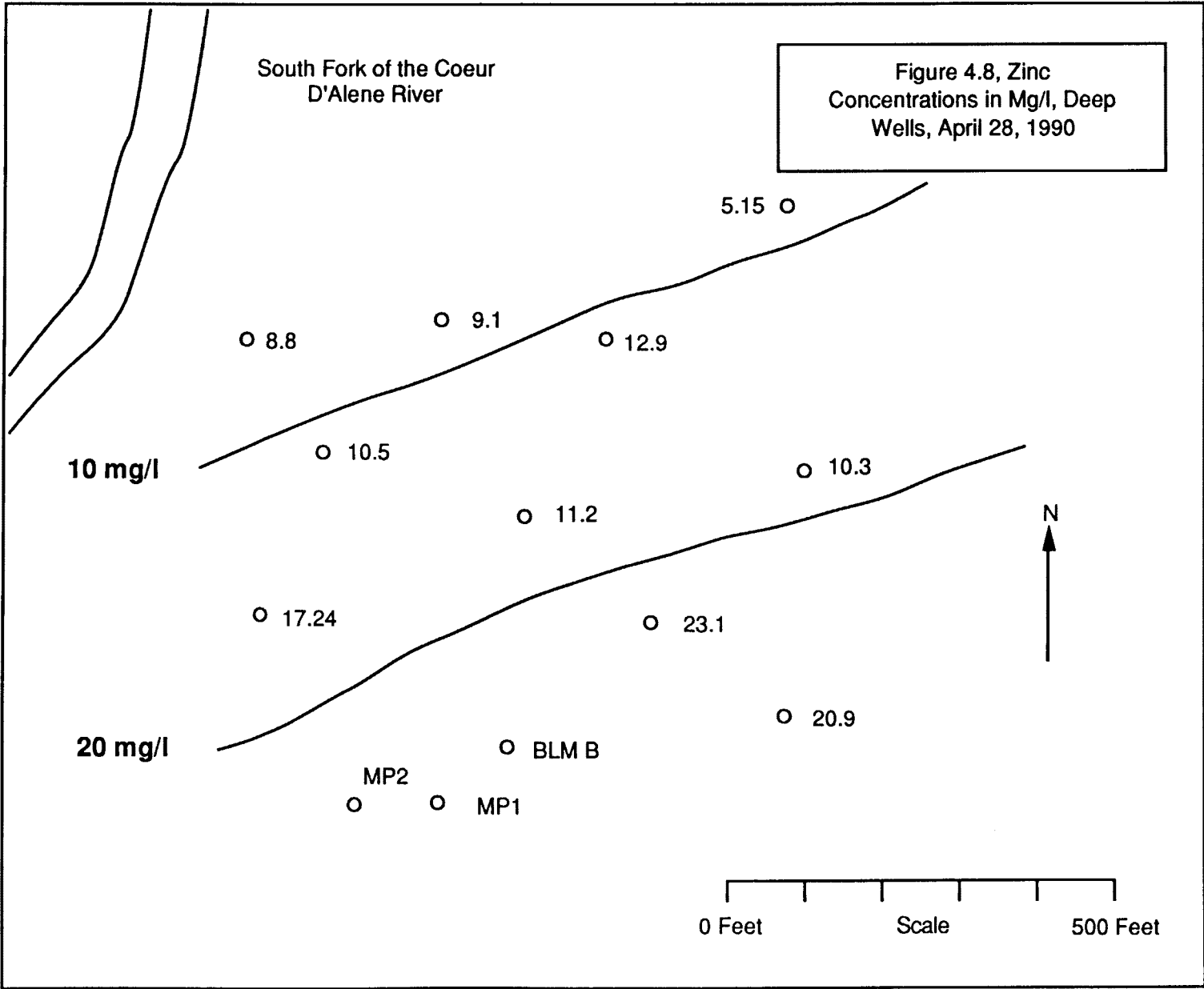
Zinc concentrations in the shallow wells show no horizontal trend as indicated by representative zinc concentrations from February 17 and April 28, 1990 (figures 4.5 and 4.7). This is because the dissolved concentrations are controlled primarily by the metals concentration in the tailings adjacent to the well (Norton, 1980). The metals concentrations in the tailings are known to be very heterogeneous (Norbeck, 1974), therefore making the water quality heterogeneous. An apparent contradiction exists between the high transmissivity of the upper aquifer and the heterogeneity of the water quality. However the upper part of the aquifer is overlain by fine grained tailings which are mixed into the upper part of the aquifer thus decreasing the transmissivity of that portion of the aquifer. Also some of the shallow piezometers may be completed in the mine waste layer. The differences in transmissivity may also explain the greater congruency in the changes in concentrations in the deeper wells as compared to the shallow wells discussed earlier in this chapter.

Zinc concentrations in the deep wells are generally higher in wells further from the river during the entire sampling period as indicated by figures 4.6 and 4.8. This apparent horizontal concentration gradient is approximately perpendicular to the hydraulic gradient, which is approximately parallel to the river. This trend in concentrations may be due to the erosion and reworking of the source of contamination near the river. If this is the case then concentrations in the shallow wells would be expected to show the same trend since they are closer to the tailings rich layer. However this is not supported by the concentrations in the shallow wells where two of the of the wells with high zinc concentrations (5C and 10C) are closest to the river.









Another possible explanation for the apparent trend in the deep wells is that the wells closer to the river are diluted by cleaner river water. Dilution by the river is unlikely, however, because the hydraulic gradient is toward the river. Other explanations for the observed concentration patterns are presented in the next section.

Vertical Trends in Zinc Concentration

Zinc concentrations are consistently higher in the shallow piezometers than in the deep piezometers. This is because the source of metals is in the top 0-5 feet of the sediments.

This vertical chemical gradient is also recognizable to a lesser extent in the deep wells. The deeper wells were completed at various depths below the water table (table 2.1). Therefore metals concentration can be correlated with well completion depth below the water table at a given time. A sample correlation is given in figure 4.9. Tables 4.4 and 4.5 present the coefficients of determination for all of the correlations. Coefficients of determination range from 0.427 to 0.815; the slopes and intercepts are consistent between the two years. The negative slopes imply the continued existence of the vertical concentration gradient at the depth of completion of the deep wells, approximately 20 feet. This gradient is distinct enough to be discerned in a network of wells spread over ten acres with only a 5 foot range in completion depths. The apparent horizontal concentration gradient in the previous section is probably a result of the wells with deeper completion depths being closer to the river.

Temporal Trends in Zinc Concentration

Maximum average zinc concentration was reached in late February in 1990 but not until early April in 1989 (figure 4.10). Zinc concentrations increased over the 1989 study period but decreased over the 1990 study period (figure 4.11). Possible explanations for this trend are discussed in Chapter 6. The average zinc concentration trends in the shallow sets of piezometers are very similar to those in the deep sets of piezometers for both years. This congruency between shallow and deep wells is seen in all of the water quality variables measured.

FIGURE 4.9, CORRELATION OF ZINC CONCENTRATION VERSUS THE DEPTH FROM THE WATER TABLE TO THE TOP OF THE SAND PACK, DEEP WELLS, JANUARY 26, 1990 ($R^2 = 0.74$)

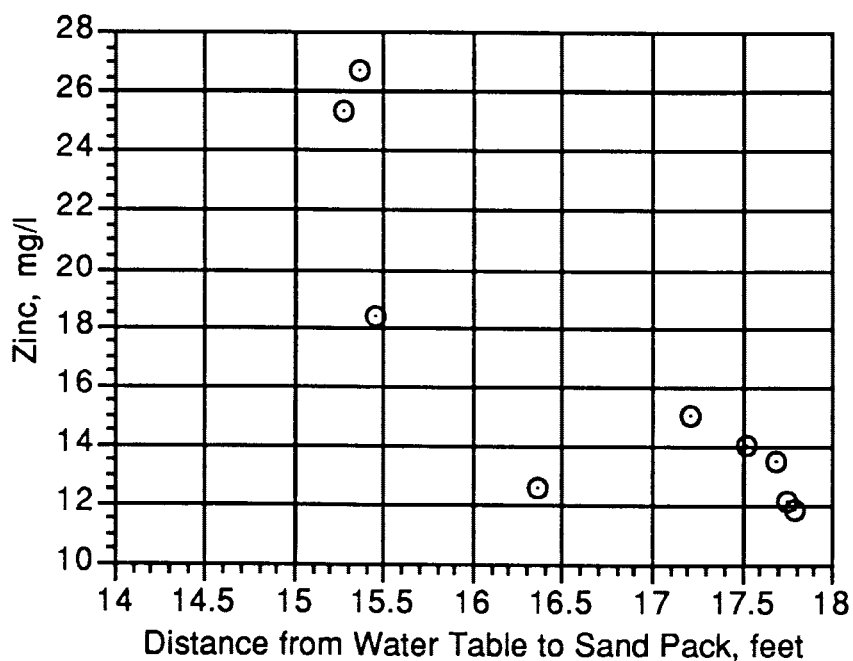


TABLE 4.4, COEFFICIENTS OF DETERMINATION FOR THE NATURAL LOG OF ZINC
VERSUS DEPTH OF SAND PACK FROM WATER LEVELS, DEEP WELLS, 1989

Date	R ²	Constant	Slope
Oct 5	0.75	5.62	-0.25
Dec 16	0.72	5.47	-0.24
Jan 6	0.76	5.45	-0.23
Jan 18	0.74	6.08	-0.26
Feb 23	0.71	7.00	-0.31
Apr 7	0.74	8.55	-0.34
Apr 25	0.68	8.00	-0.31
June 1	0.72	7.84	-0.31
June 20	0.54	6.44	-0.24

All correlations significant at the 0.05 level.

BLM 4 D removed as outlier

TABLE 4.5, COEFFICIENTS OF DETERMINATION FOR THE NATURAL LOG OF ZINC
VERSUS DEPTH TO SAND PACK FROM WATER LEVELS, DEEP WELLS, 1990

Date	R ²	Constant	Slope
26 Jan	0.74	6.82	-0.24
2 Feb	0.80	7.24	-0.26
8 Feb	0.79	7.24	-0.27
17 Feb	0.73	7.96	-0.31
23 Feb	0.42	6.11	-0.19
1 Mar	0.70	6.96	-0.25
7 Mar	0.58	6.71	-0.23
16 Mar	0.57	6.49	-0.22
25 Mar	0.69	7.15	-0.25
30 Mar	0.77	7.72	-0.29
13 Apr	0.81	7.78	-0.29
19 Apr	0.72	7.77	-0.29
28 Apr	0.79	7.80	-0.29
4 May	0.84	7.09	-0.26
11 May	0.83	7.61	-0.30
27 May	0.57	7.72	-0.28

All correlations significant at the 0.05 level except 23 Feb.
BLM 4 D removed as outlier

FIGURE 4.10, AVERAGE ZINC CONCENTRATION OVER TIME, 1989

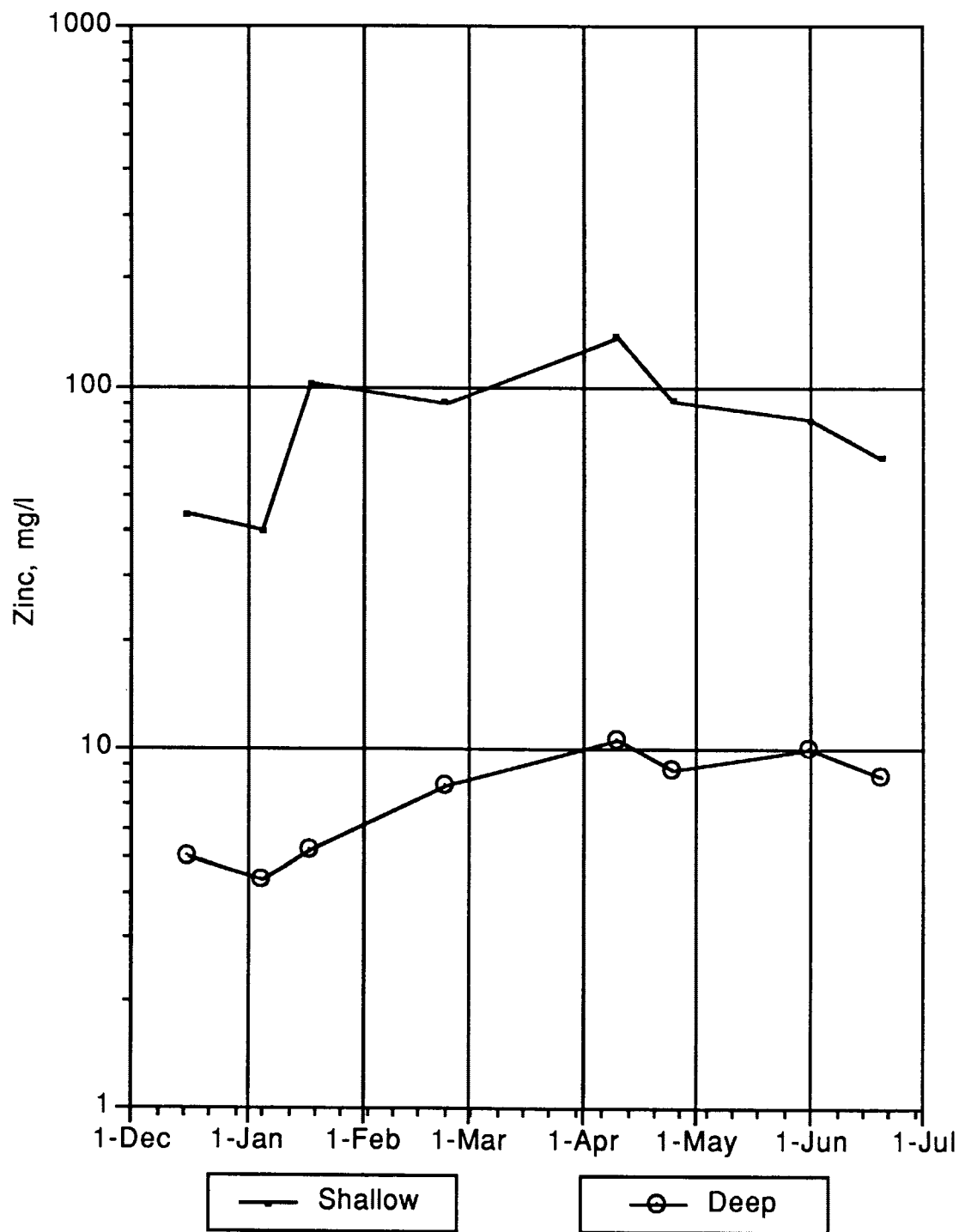
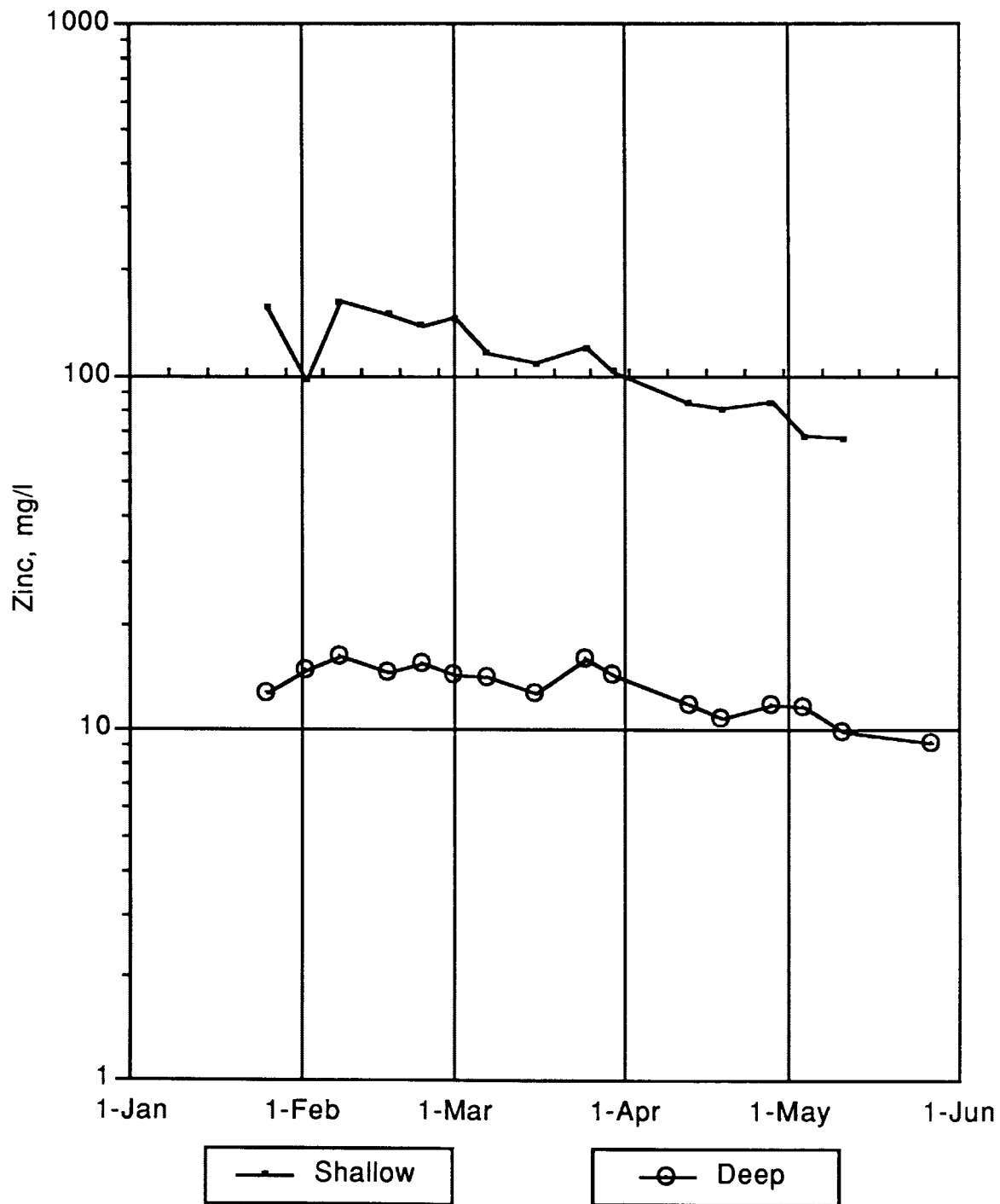


FIGURE 4.11, AVERAGE ZINC CONCENTRATION OVER TIME, 1990



Cadmium and Lead

Cadmium concentrations range from 3.46 mg/l to below the detection limit of 0.02 mg/l. Cadmium concentrations increased in the deep wells and decreased in shallow wells through the 1989 study period (figure 4.12). Cadmium concentrations in the shallow wells generally decreased through the 1990 study period (figure 4.13). Concentrations in the deep wells were generally below the detection limit until mid-March. All cadmium data for the 1989 study period are given in tables 4.6 and 4.7.

Lead concentrations were generally at or below detection limits except in well 5C (figure 4.14). Lead concentrations for the 1990 study period are given in tables 4.8 and 4.9.

**FIGURE 4.12, CADMIUM CONCENTRATIONS IN MG/L, WELLS 10C AND 10D,
1989 STUDY PERIOD**

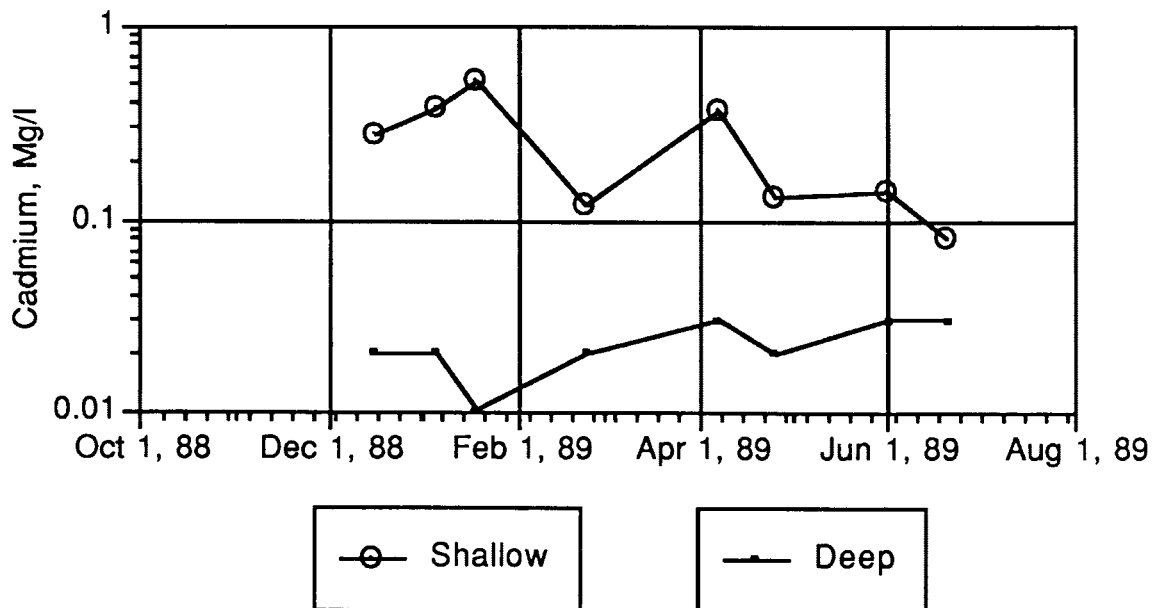


FIGURE 4.13, CADMIUM CONCENTRATIONS IN MG/L, WELLS 10C AND 10D, 1990 STUDY PERIOD

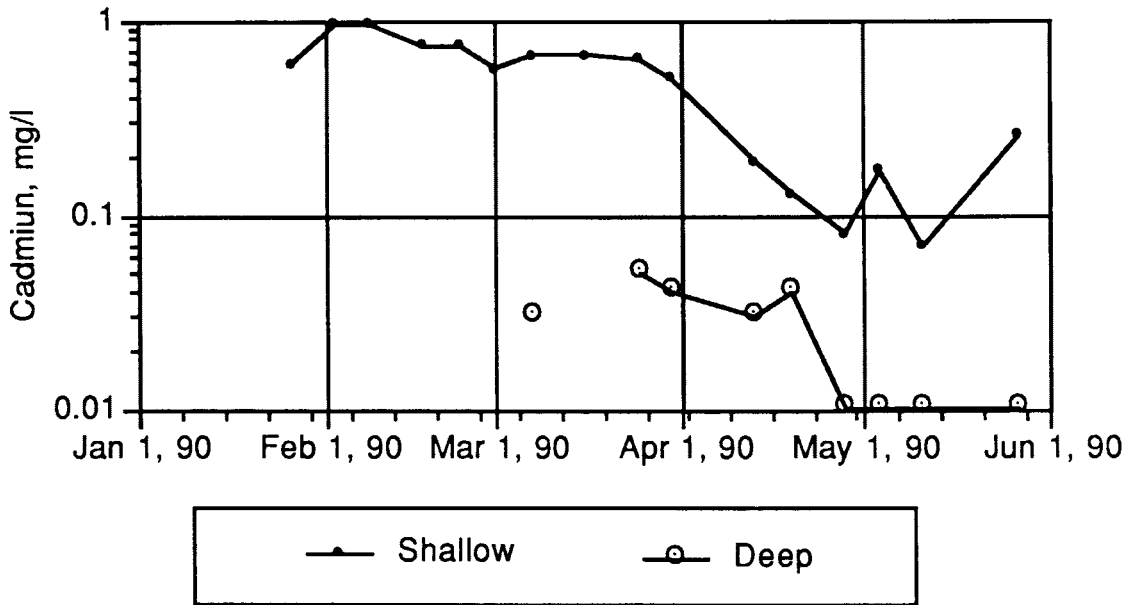


FIGURE 4.14, LEAD CONCENTRATIONS FOR WELL 5C, 1989 AND 1990 STUDY PERIODS

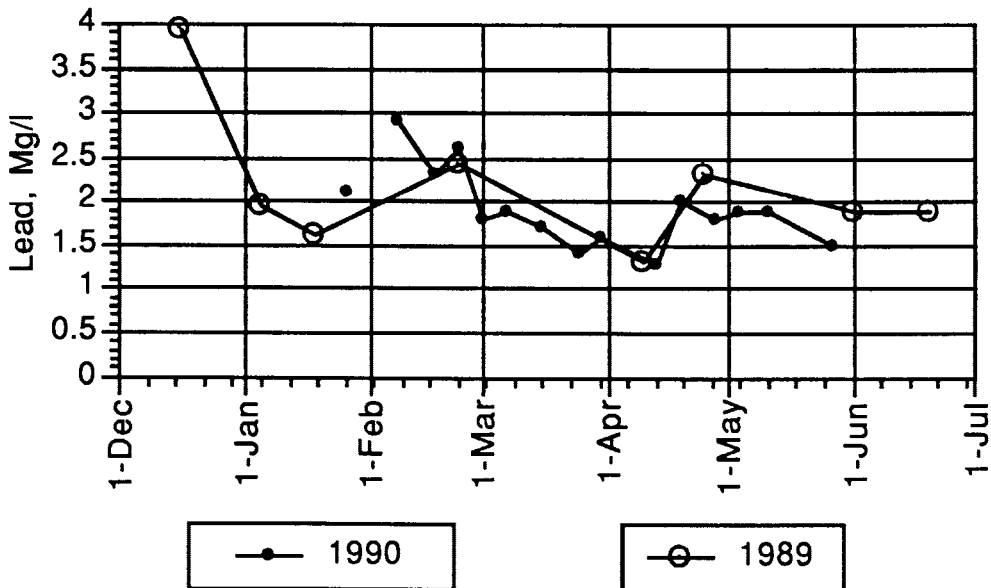


TABLE 4.6, CADMIUM CONCENTRATIONS IN MG/L , SHALLOW WELLS, 1990
STUDY PERIOD

Shallow Wells	BLM 1C	BLM 2C	BLM 3C	BLM 4C	BLM 5C	BLM 6C	BLM 7C	BLM 8C	BLM 9C	BLM 10C
26-Jan	2.14		0.2	<.02	1.09	0.11	0.57	0.43	0.97	0.6
2-Feb	2.75		0.13	<.02		0.07	0.61	0.38	0.28	0.96
8-Feb	3.05		0.1	<.02	0.92	0.08	0.54	0.43	0.48	0.96
17-Feb	3.16		0.15		3.46	0.11	0.55	0.48	0.99	0.74
23-Feb	2.88		0.1	<.02	2.9	0.09	0.59	0.39	0.7	0.74
1-Mar	2.70			0.04	1.03	0.12	0.54	0.43	0.66	0.57
7-Mar	2.54		0.1	0.02	0.79	0.08	0.54	0.44	0.57	0.66
16-Mar	2.48		0.08	0.02	0.49	0.1	0.49	0.37	0.56	0.67
25-Mar	2.39		0.14	0.07	0.48	0.13	0.6	0.53	0.48	0.63
30-Mar	2.13		0.1	0.05	0.38	0.13	0.56	0.48	0.42	0.51
13-Apr	1.91	0.35	0.13	0.13	0.23	0.12	0.49	0.62	0.38	0.19
19-Apr	2.02	0.36	0.16	0.23	0.24	0.12	0.47	0.61	0.32	0.13
28-Apr	1.85	0.28	0.08	0.15	0.15	0.08	0.42	0.48	0.21	0.08
4-May	1.58		0.06	0.01	0.21	0.07	0.41	0.37	0.2	0.17
11-May	1.57		0.04	0.01	0.21	0.06	0.39	0.43	0.19	0.07
27-May	1.17	0.23	0.06	0.13	0.28	0.05	0.34		0.25	0.26

TABLE 4.7, CADMIUM CONCENTRATIONS IN MG/L , DEEP WELLS, 1990 STUDY
PERIOD

Deep Wells	BLM 1D	BLM 2D	BLM 3D	BLM 4D	BLM 5D	BLM 6D	BLM 7D	BLM 8D	BLM 9D	BLM 10D
26-Jan	0.19	0.19	<.02	<.02	<.02	<.02	<.02	0.07	<.02	<.02
2 Feb	0.2	0.2	<.02	<.02	<.02	<.02	<.02	0.06	<.02	<.02
8-Feb	0.2	0.22	<.02	<.02	<.02	<.02	<.02	0.09	<.02	<.02
17-Feb	0.21	0.19	<.02	<.02	0.03	<.02	<.02	0.09	<.02	<.02
23-Feb	0.22	0.21	<.02	<.02	0.03	<.02	<.02	0.08	0.03	<.02
1-Mar	0.24	0.22	0.02	0.02	0.05	<.02	<.02	0.1	<.02	<.02
7-Mar	0.21	0.22	<.02	<.02	<.02	<.02	<.02	0.1	<.02	0.03
16-Mar	<.02	0.23	<.02	<.02	0.04	<.02	<.02	0.09	0.02	<.02
25-Mar	0.27	0.28	0.06	0.03	0.07	0.03	0.05	0.14	0.07	0.05
30-Mar	0.27	0.25	0.07	0.02	0.07	0.06	0.05	0.13	0.07	0.04
13-Apr	0.24	0.24	0.07	0.02	0.05	0.05	0.06	0.12	0.05	0.03
19-Apr	0.24	0.21	0.03	0.03	0.07	0.02	0.06	0.11	0.06	0.04
28-Apr	0.17	0.13	0.01	0.01	0.01	0.01	0.01	0.07	0.01	0.01
4-May	0.15	0.13	0.01	0.01	0.01	0.01	0.01	0.06	0.01	0.01
11-May	0.14	0.14	0.01	0.01	0.01	0.01	0.01	0.03	0.01	0.01
27-May	0.14	0.11	0.01	0.01	0.01	0.01	0.01		0.01	0.01

TABLE 4.8, LEAD CONCENTRATIONS IN MG/L , SHALLOW WELLS, 1990 STUDY PERIOD

Shallow Wells	BLM 1C	BLM 2C	BLM 3C	BLM 4C	BLM 5C	BLM 6C	BLM 7C	BLM 8C	BLM 9C	BLM 10C
26-Jan	0.2		0.2	0.2	2.1	0.4	0.3	<0.2	0.6	0.4
2-Feb	<0.2		<0.2	<0.2		<.2	0.5	0.2	0.5	<0.2
8-Feb	0.3		<0.2		2.9	<.2	<0.2	<0.2	0.4	<0.2
17-Feb	<0.2		<0.2		2.3	<.2	0.2	0.3	<0.2	<0.2
23-Feb	0.2		<0.2	0.4	2.6	0.2	<0.2	<0.2		0.2
1-Mar	<0.2				1.8	<.2	0.2	<0.2		0.4
7-Mar	<0.2		<0.2		1.9	<.2	<0.2	<0.2		<0.2
16-Mar	0.2		<0.2		1.7	<.2	<0.2	<0.2	0.2	0.3
25-Mar	0.2		0.1	0.1	1.4	0.2	0.2	0.2	0.1	0.4
30-Mar	0.3		0.2	0.1	1.6	0.1	0.2	0.4	0.4	0.2
13-Apr	0.4	0.2	0.1	0.1	1.3	0.1	0.1	0.1	0.1	0.1
19-Apr	0.4	0.5	0.6	0.6	2	0.4	0.6	0.4	0.3	0.5
28-Apr	0.3	0.2	0.6	0.3	1.8	0.1	0.3	0.2	0.3	0.3
4-May	0.1		0.2	0.1	1.9	0.1	0.1	0.2	0.1	0.1
11-May	0.1		0.1	0.1	1.9	0.1	0.3	0.1	0.1	0.1
27-May	0.1	0.1	0.1	0.1	1.5	0.1	0.1		0.1	0.1

TABLE 4.9, LEAD CONCENTRATIONS IN MG/L , DEEP WELLS, 1990 STUDY
PERIOD

Deep Wells	BLM 1D	BLM 2D	BLM 3D	BLM 4D	BLM 5D	BLM 6D	BLM 7D	BLM 8D	BLM 9D	BLM 10D
26-Jan	<0.2	0.3	<0.2	0.8	<.02	0.3	0.3	0.2	<0.2	0.5
2 Feb	<0.2	0.3		0.3	<.02	<0.2	<0.2	0.3	<0.2	<0.2
8-Feb	<0.2	<0.2			<.02	0.2		<.02	<0.2	<0.2
17-Feb	<0.2	<0.2		0.2	<.02	<0.2		<.02	<0.2	0.6
23-Feb	<0.2	<0.2	0.2	0.2	0.2	<0.2	0.4	0.3	<0.2	<0.2
1-Mar	<0.2	<0.2			<.02	<0.2		<.02	<0.2	<0.2
7-Mar	<0.2	<0.2	0.2		<.02	<0.2		0.2	<0.2	<0.2
16-Mar		<0.2		0.2	<.02	0.2		<.02	<0.2	<0.2
25-Mar	0.2	0.5	0.1	0.2	0.1	0.2	0.2	0.1	0.2	0.1
30-Mar	0.5	0.3	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1
13-Apr	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
19-Apr	0.3	0.2	0.2	0.1	0.1	0.3	0.3	0.1	0.1	0.1
28-Apr	0.1	0.3	0.3	0.5	0.1	0.2	0.1	0.1	0.1	0.1
4-May	0.1	0.1	0.1	0.3	0.4	0.3	0.2	0.2	0.4	0.3
11-May	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
27-May	0.1	0.1	0.1	0.4	0.5	0.4	0.5		0.6	0.5

Electrical Conductivity Data

Electrical conductivity (EC) values measured during the study periods range from 180 to 3600 $\mu\text{mhos/cm}$. Precision in EC measurements is approximately ± 100 $\mu\text{mhos/cm}$ above 500 $\mu\text{mhos/cm}$, and ± 10 $\mu\text{mhos/cm}$ below 500 $\mu\text{mhos/cm}$. The average EC trends are shown in figures 4.15 and 4.16. Maximum average EC was reached in late February in 1990 but not until early April in 1989. Reasons for this discrepancy are discussed in Chapter 6. The general trends of EC in the shallow and deep wells are very similar both years; EC is consistently higher in the shallow wells. Electrical conductivity data for the 1990 study period are given in tables 4.10 and 4.11.

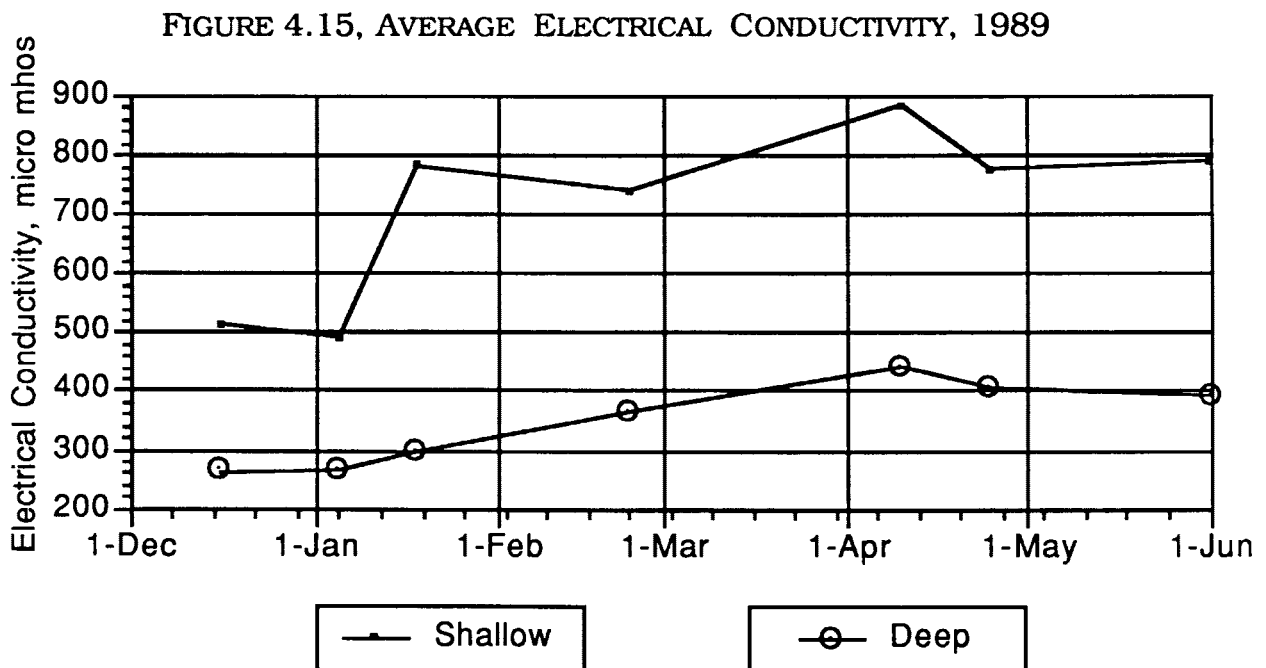


FIGURE 4.16, AVERAGE ELECTRICAL CONDUCTIVITY, 1990

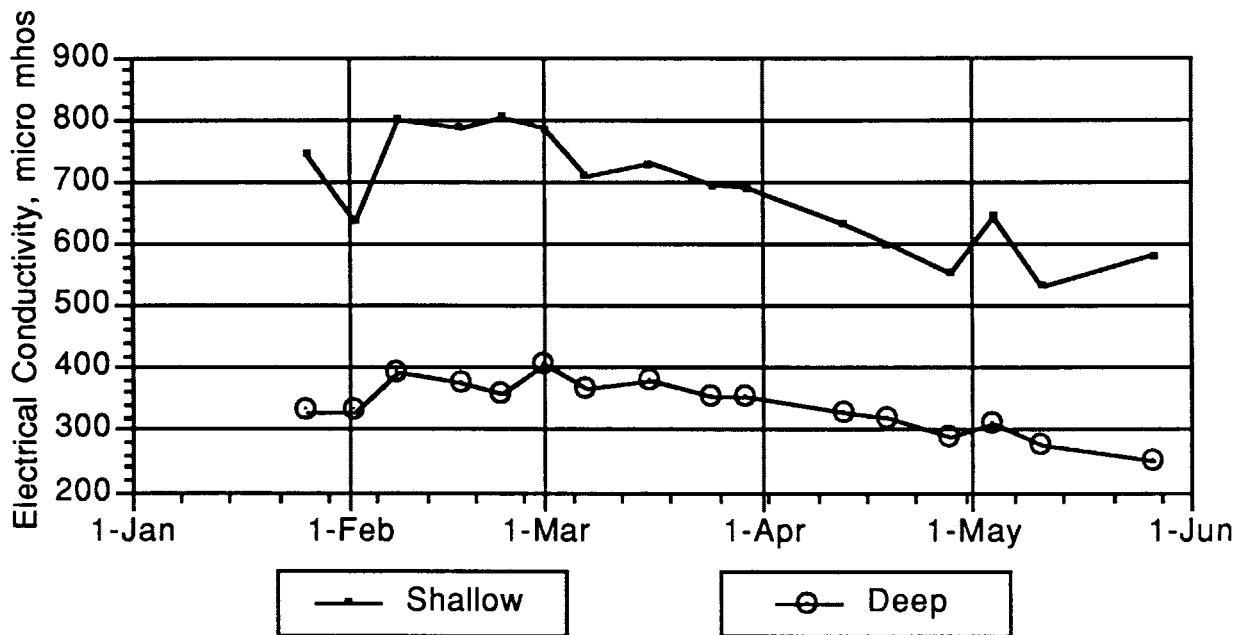


TABLE 4.10, ELECTRICAL CONDUCTIVITY DATA IN MICRO MHOS, SHALLOW WELLS, 1990 STUDY PERIOD

Shallow Wells	BLM 1C	BLM 2C	BLM 3C	BLM 4C	BLM 5C	BLM 6C	BLM 7C	BLM 8C	BLM 9C	BLM 10C
26-Jan	1100		315	465	3200	380	550	550	750	1550
2-Feb	1150		380	600		315	550	550	550	1950
8-Feb	1200		360		3200	370	600	500	600	1800
17-Feb			370	600	3100	410	600	600	800	1800
23-Feb	1300		380	500	3200	410	600	600	750	1600
1-Mar	1350		390	600	2000	420	600	550	750	1700
7-Mar	1250		370	480	1500	390	600	600	600	1600
16-Mar	1200		370	500	1400	410	600	600	700	1800
25-Mar	1100		340	500	1400	390	600	600	600	1700
30-Mar	1100		350	600	1200	400	600	600	600	1450
13-Apr	1000		350	700	900	400	500	600	600	1000
19-Apr	1000		330	750	800	375	500	500	600	900
28-Apr	900		320	700	700	350	460	550	460	850
4-May	800		310	700	900	370	460	600	480	2500
11-May	800		290	700	800	330	430	500	410	900
27-May	700		300	600	1200	310	420		470	1400

TABLE 4.11, ELECTRICAL CONDUCTIVITY DATA IN MICROMHOS, DEEP WELLS,
1990 STUDY PERIOD

Deep Wells	BLM 1D	BLM 2D	BLM 3D	BLM 4D	BLM 5D	BLM 6D	BLM 7D	BLM 8D	BLM 9D	BLM 10D
26-Jan	415	380	315	210	350	265	320	390	370	320
2-Feb	315	450	300	270	345	320	320	360	330	300
8-Feb	500	520	390	400	360	340	350	400	370	330
17-Feb		460	340	290	390	360	370	440	400	350
23-Feb	410	480	290	300	390	350	350	440	300	320
1-Mar	600	600	350	290	390	360	380	450	390	350
7-Mar	490	490	330	280	360	330	350	420	340	340
16-Mar	600	500	340	270	370	340	365	370	380	340
25-Mar	500	460	310	250	340	310	350	420	350	320
30-Mar	500	400	340	240	350	310	350	430	360	320
13-Apr	450	450	290	225	320	290	320	400	330	280
19-Apr	440	425	280	210	310	280	320	400	320	270
28-Apr	400	385	260	190	290	250	290	350	280	250
4-May	415	415	285	200	310	280	310	380	300	270
11-May	370	390	250	185	270	240	270	340	265	240
27-May	370	350	240	140	270	230	210		270	250

pH Data

Measured pH values are between 4 and 7 throughout the two study periods although the average pH ranges between 5 and 6. Precision of the pH measurements is approximately ± 0.2 . Figures 4.17 and 4.18 present the average pH for the shallow and deep wells for 1989 and 1990. In 1989 there is not enough data to discern a trend in pH. In 1990, the average pH gradually increased from 5.3 to 6.1 in the deep wells and from 5.4 to 5.9 in the shallow wells. This may be due to the addition of buffered recharge water during the study period.

Although there appears to be a difference between the average pH in the shallow and deep wells, the only date which is statistically significant at the 0.05 level is June 1, 1989. All of the pH data for the 1990 study period are given in tables 4.12 and 4.13.

FIGURE 4.17, AVERAGE PH IN PIEZOMETER, 1989

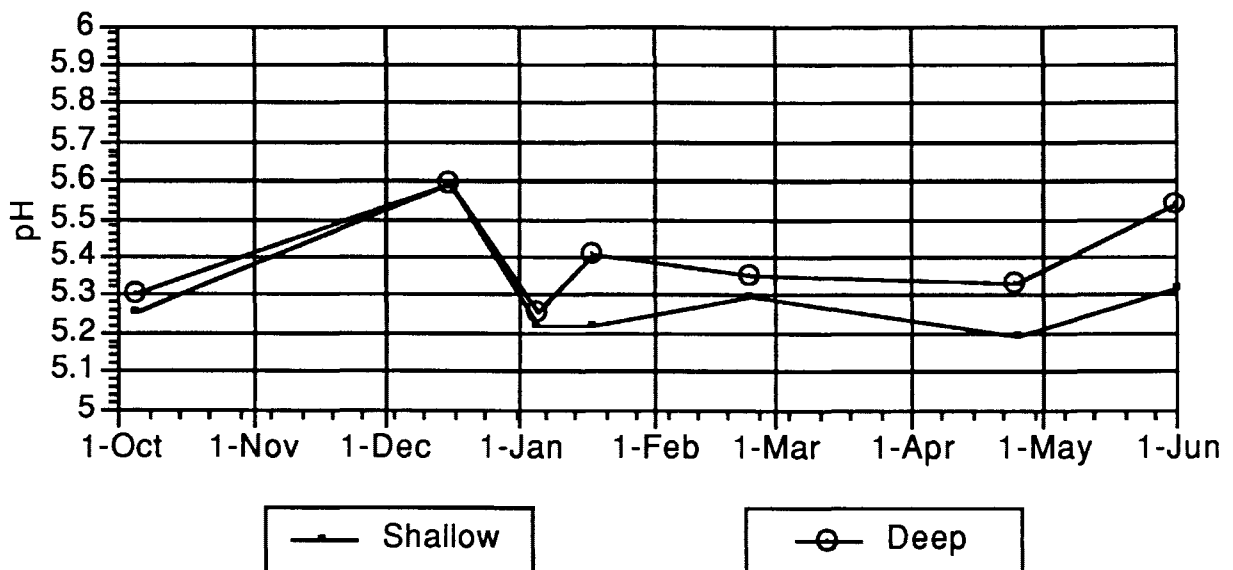


FIGURE 4.18, AVERAGE PH IN PIEZOMETER, 1990

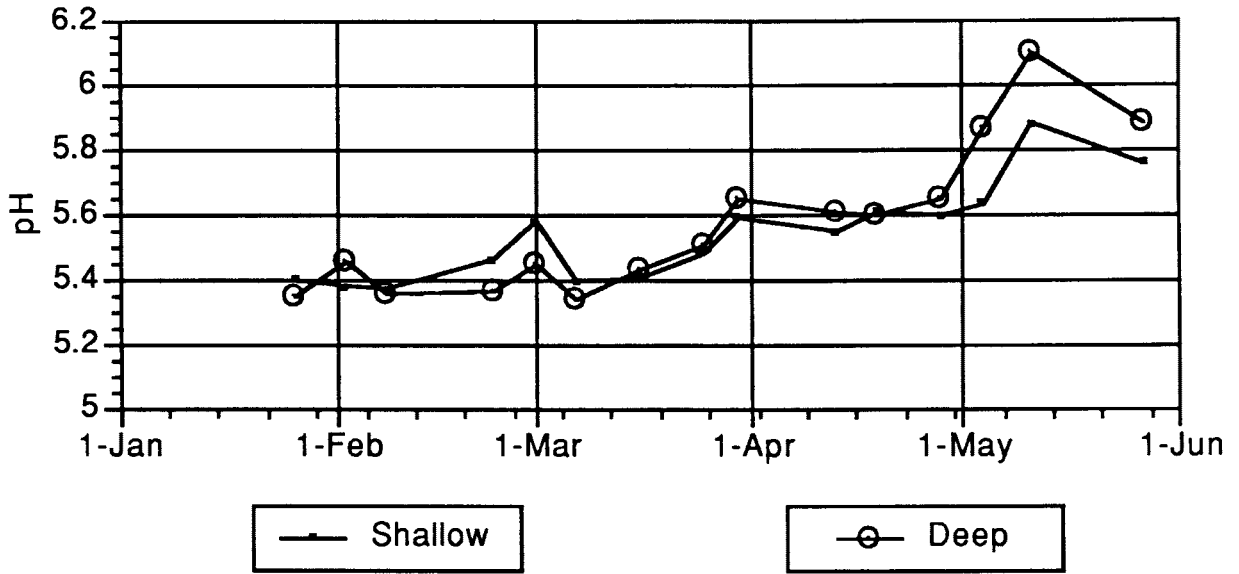


TABLE 4.12, PH DATA, SHALLOW WELLS, 1990 STUDY PERIOD

	BLM 1C	BLM 2C	BLM 3C	BLM 4C	BLM 5C	BLM 6C	BLM 7C	BLM 8C	BLM 9C	BLM 10C
26-Jan	5.06		6.43	5.33	5.02	5.28	5.01	4.85	5.8	5.8
2-Feb	4.86		6.94		5.16	5.27	5.13	5.1	5.28	5.28
8-Feb	5.14			5.47	5.14	5.14	5.07	4.93	6.03	6.03
17-Feb										
23-Feb	4.29		6.93	5.82	4.91	5.2	5.05	5.19	5.87	5.87
1-Mar	5.05		6.91	5.65	5.15	5.32	5.13	4.93	6.03	6.03
7-Mar	5.03		6.68	5.51	5.16	5.21	5.16	4.19	5.8	5.8
16-Mar	5.38		6.89	5.72	5.17	5.36	5.18	4.19	5.39	5.39
25-Mar	5.14		6.7	5.67	5.15	5.27	5.1	4.94	5.68	5.68
30-Mar	5.36		6.8	5.77	5.1	5.2	5.14	4.88	6.02	6.02
13-Apr	5.13		6.34	5.85	5.2	5.25	5.13	4.98	6.01	6.01
19-Apr	5.15		6.5	5.98	5.33	5.27	5.27	4.98	5.98	5.98
28-Apr	5.17		6.48	6.05	5.28	5.26	5.14	4.99	5.99	5.99
4-May	5.00		6.67	6.1	5.33	5.36	5.28	5.15	5.9	5.9
11-May	5.50		6.6	6.39	5.81	5.78	5.45	5.35	6.01	6.01
27-May	4.83		6.7	5.91	5.59					

TABLE 4.13, PH DATA, DEEP WELLS, 1990 STUDY PERIOD

Deep Wells	BLM 1D	BLM 2D	BLM 3D	BLM 4D	BLM 5D	BLM 6D	BLM 7D	BLM 8D	BLM 9D	BLM 10D
26-Jan	5.08	5.11	5.41	6.18	5.27	5.43	5.28	5	5.18	5.48
2 Feb	5.15	5.26	5.6	6	5.39	5.56	5.4	5.21	5.32	5.62
8-Feb	5.1	5.08	5.47	5.99	5.26	5.49	5.32	5.1	5.28	5.45
17-Feb										
23-Feb	5.08	5.05	5.67	6.03	5.35	5.39	5.29	5	5.19	5.55
1-Mar	5.18	5.18	5.48	6.3	5.39	5.53	5.37	5.17	5.3	5.59
7-Mar	5.16	4.19	5.49	6.2	5.41	5.55	5.34	5.2	5.27	5.59
16-Mar	5.22	5	5.5	6.11	5.34	5.54	5.37	5.19	5.3	5.72
25-Mar	5.26	5.08	5.57	6.3	5.48	5.6	5.45	5.27	5.35	5.66
30-Mar	5.27	5.08	5.54	7.1	5.48	5.56	5.9	5.2	5.31	6.01
13-Apr	5.3	5.2	5.54	6.84	5.54	5.64	5.45	5.27	5.35	5.89
19-Apr	5.34	5.28	5.62	7.01	5.6	5.71	5.49	5.28	5.47	5.15
28-Apr	5.3	5.22	5.59	6.9	5.62	5.69	5.62	5.25	5.41	5.89
4-May	5.23	5.49	5.61	7.01	5.61	5.87	6.83	5.49	5.71	5.79
11-May	5.6	5.4	5.82	7.4	6.44	6.06	6.25	5.4	5.75	6.85
27-May	5.01	5.61	5.86	6.89	5.84	6.06				

Water Temperature Data

Water temperatures increased from an average of 9-10 degrees centigrade to 14-15 degrees in both years. The water temperature was still increasing at the final sample of each study period (figures 4.19 and 4.20). The precision on the water temperature measurements is approximately ± 1 °C.

In 1989, the water temperature in the deep wells was warmer from January 6 to April 25. This difference is statistically significant at the 0.05 level. In 1990, the average water temperature in the deep wells was consistently one to two degrees warmer than the average temperature in the shallow wells until the end of March. This difference is also statistically significant at the 0.05 level. The thermal gradient gradually diminished during the month of April, 1990, possibly in response to the increase in air temperature or the decrease in recharge of cold snowmelt water. All water temperature data for the 1990 study period are given in tables 4.14 and 4.15.

FIGURE 4.19, AVERAGE WATER TEMPERATURE, 1989: SHALLOW AND DEEP WELLS

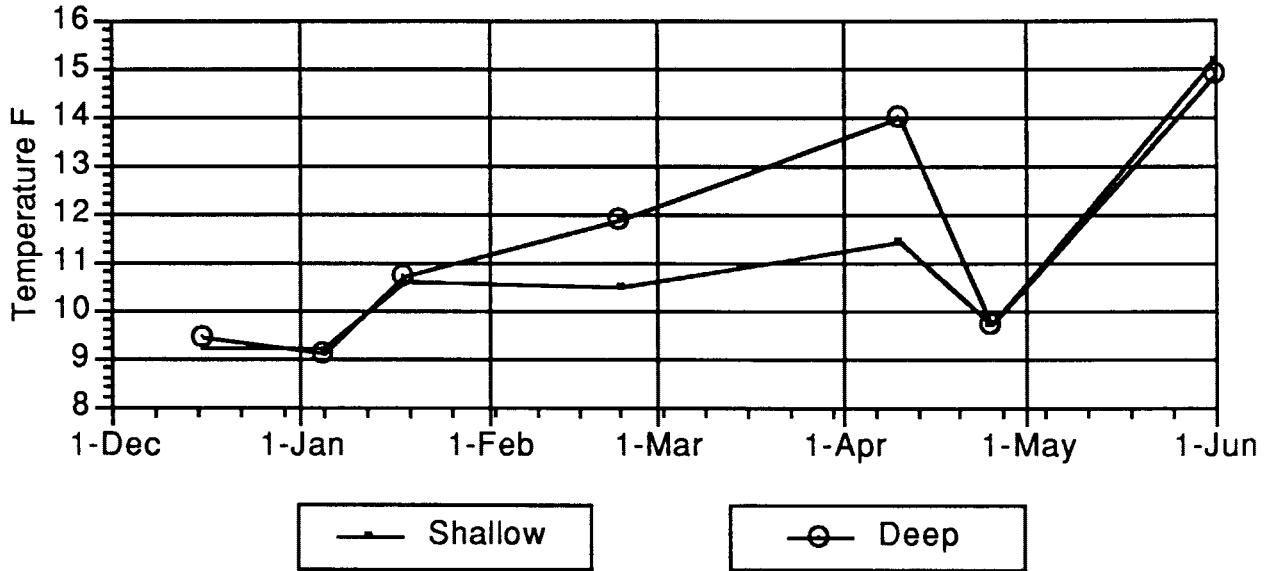


FIGURE 4.20 AVERAGE WATER TEMPERATURE, 1990: SHALLOW AND DEEP WELLS

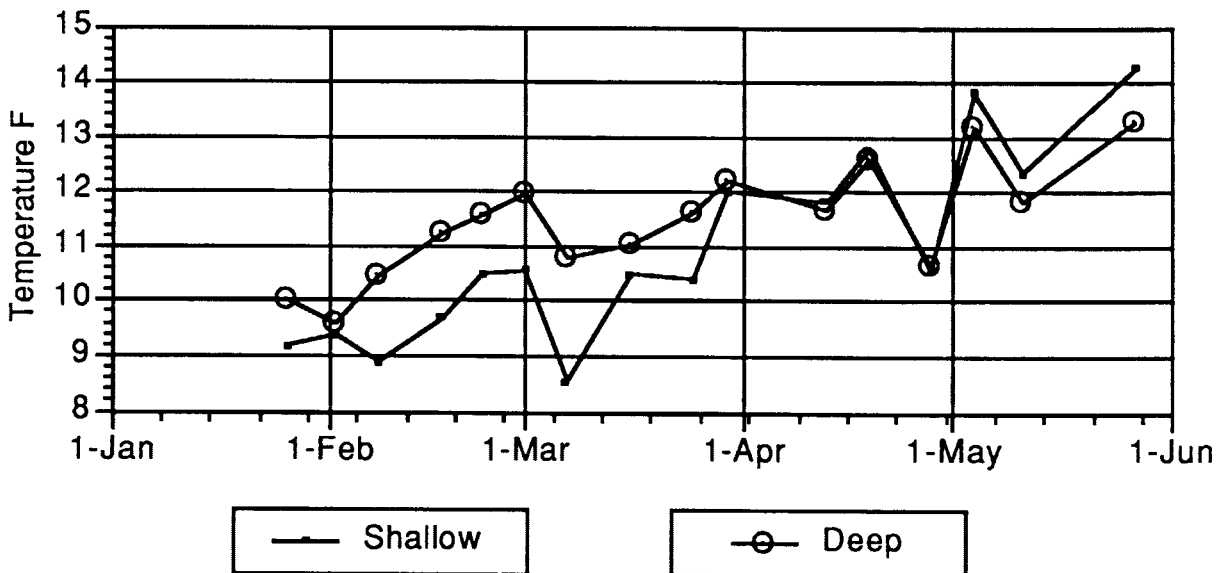


TABLE 4.14, WATER TEMPERATURE DATA IN DEGREES CENTIGRADE, SHALLOW WELLS, 1990 STUDY PERIOD

Shallow Wells	BLM 1C	BLM 2C	BLM 3C	BLM 4C	BLM 5C	BLM 6C	BLM 7C	BLM 8C	BLM 9C	BLM 10C
26-Jan	10.0		9	8.5	9	9	9	9	10	9
2-Feb	12.0		9	9		9	9	9	9	9
8-Feb	12.0		8		11	8	8.6	8.5	7	8
17-Feb			9	10	11.5	10	10	9	8	10
23-Feb	8.0		9	9	14	11	10	10.5	12	11
1-Mar	9.0		9	11	14.5	13.5	9	10	9	10
7-Mar	8.0		9	8	8	9	9	9	9	8
16-Mar	11.5		9	10	13	10	10	11	10	10
25-Mar	10.5		10	10	11.5	10	10	11.5	11	9
30-Mar	12.0		11	12	15	12	11	11.5	11.5	12
13-Apr	10.5		12	12	15	12	11	11.5	11	11.5
19-Apr	12.5		12	14	14	12	12	12	14	12.5
28-Apr	11.0		10	11.5	10	10	10.5	11	11	10
4-May	13.0		13	15	16	14	13	13	13	14.5
11-May	11.0		13	13	14	12	12	12	11	13
27-May	13.0		14	20	15	14	14		12	12

TABLE 4.15, WATER TEMPERATURE DATA IN DEGREES CENTIGRADE, DEEP WELLS, 1990 STUDY PERIOD

Deep Wells	BLM 1D	BLM 2D	BLM 3D	BLM 4D	BLM 5D	BLM 6D	BLM 7D	BLM 8D	BLM 9D	BLM 10D
26-Jan	9	9	9	10	10	10	11	11	11	10
2 Feb	11	9	9	9	9	9	10	10	10	10
8-Feb	10	13	13.5	10	9	10	10	10	9	10
17-Feb		10	11.5	11.5	11	12	12	11	10	12
23-Feb	11	10	11.5	11	12	12	12	12	12	12
1-Mar	11	11.5	11.5	12.5	12	13	12	12	12	12
7-Mar	10	11	10	11	10	11	11	12	11	11
16-Mar	11	10.5	11	11	10	11	12	11.5	11	11.5
25-Mar	13	10	11	12	11	11.5	12	12	12	11.5
30-Mar	12.5	11.5	11.5	12	12.5	13.5	12.5	12	12	12
13-Apr	11	11	11	12	11.5	12	12.5	12	11.5	12
19-Apr	13	11	12	12	13	13	12	13	14	13
28-Apr	11.5	10	10	10	10	11	11	11	11	11
4-May	12	12.5	13.5	13	13	13	15	13	15	12
11-May	11	12	13	11	12	12	12	12	11	12
27-May	12	14	14	16	12.5	15	12		12	12

CHAPTER 5: CORRELATIONS AMONG WATER QUALITY PARAMETERS

Introduction

Zinc concentrations have been used throughout this study to indicate the effects of tailings on water quality because of its single oxidation state and its abundance throughout the site. To prove the validity of this approach, zinc concentrations are correlated with cadmium and lead. These ions constitute the two greatest health hazards on the site.

A simpler approach than using zinc concentrations is to monitor an easily measured water quality characteristic, if one could be found to indicate the relative abundance of contaminants. Such an approach would greatly simplify research by reducing costs of and time between measurement and results. Water temperature, pH, and electrical conductivity are evaluated for use as such an indicator in this chapter.

In addition, the interrelation between ionic constituents and other water quality variables can provide insight into the chemical reactions which release contaminants into the ground water. Water temperature and pH are examined to investigate any such relationships.

Correlation of Zinc with Cadmium

The linear relation between the natural log of zinc and the natural log of cadmium concentrations in the deep wells is shown in figure 5.1. The R^2 value for this relation is 0.57. The relation becomes weaker as the concentrations approach the detection limit of cadmium. The R^2 values for all of the correlations are given in table 5.1. The association of zinc to cadmium concentration is not as simple in the shallow wells as in the deep

FIGURE 5.1, CORRELATION OF ZINC VERSUS CADMIUM CONCENTRATIONS, SHALLOW WELLS, 1990 STUDY PERIOD

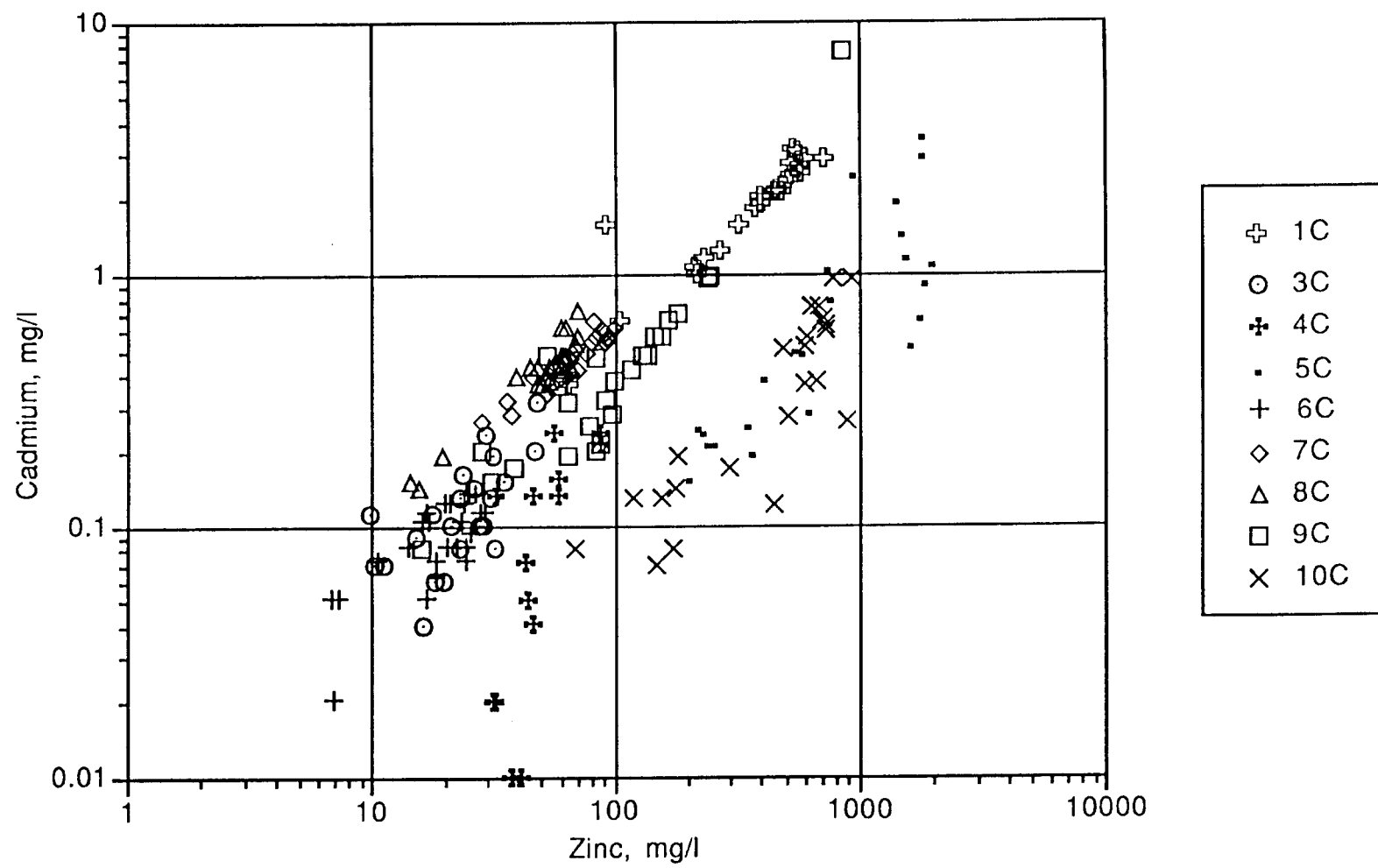
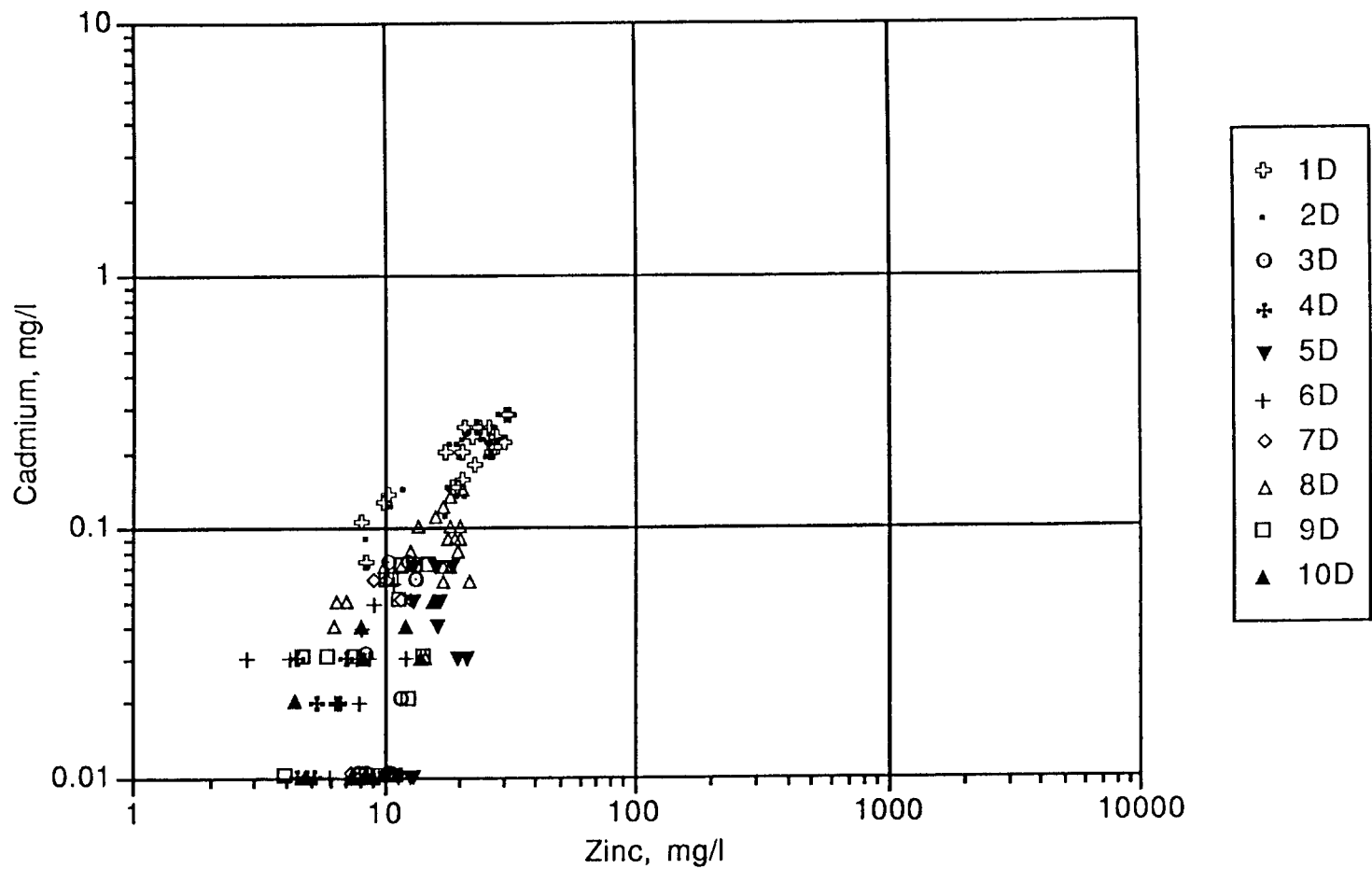


FIGURE 5.2, CORRELATION OF ZINC VERSUS CADMIUM CONCENTRATIONS, DEEP WELLS, 1990 STUDY PERIOD



wells (figure 5.2). When the natural logs of the concentrations in the shallow wells are compared, the wells can be divided into three sub-groups according to their slope and intercept. Wells 5C and 10C have the highest zinc concentrations and the largest zinc intercept value of 6.9. The second sub-group consists of well 4C which has an entirely different slope and intercept. The third sub-group is parallel to wells 5C and 10C and consists of wells 1C, 3C, 6C, 7C, 8C, and 9C.

Correlation of Zinc with Lead

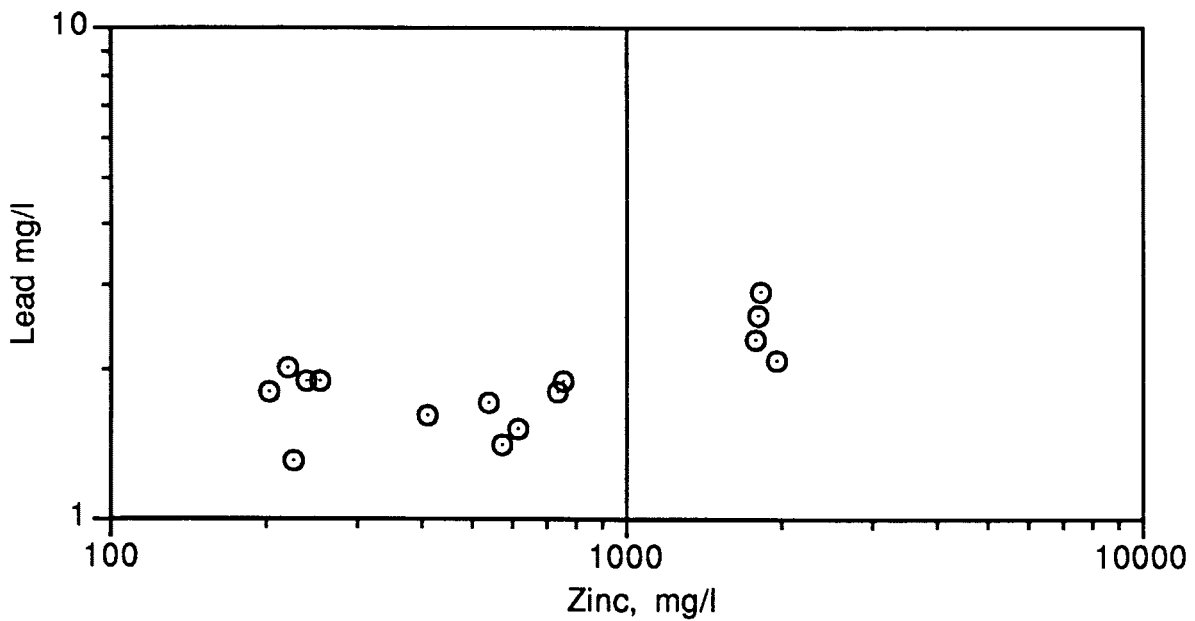
The relationship between zinc concentrations and lead is more difficult to establish because the concentrations of lead are close to the detection limit. Concentrations in 5C are consistently greater than 1 mg/l. If data from well 5C are used, then the linear correlation evident in figure 5.3 results. The relation between zinc and lead concentrations is much weaker than between zinc and cadmium concentrations resulting in a regression coefficients of 0.38. This may be an effect of the small number of points in the zinc/lead correlation.

TABLE 5.1, CORRELATION OF THE NATURAL LOG OF ZINC CONCENTRATIONS VERSUS THE NATURAL LOG OF CADMIUM AND LEAD CONCENTRATIONS

	R ²	Slope	Intercept
Zn vs Cd, Shallow	0.538	0.861	5.571
Zn vs Cd, 5C +10C	0.760	0.752	6.919
Zn vs Cd, 4C	0.642	0.156	4.261
Zn vs Cd, 1,2,3,6, 7,8,9C	0.933	0.950	5.245
Zn vs Cd, Deep	0.574	0.382	3.633
Zn vs Pb, 5C	0.377	2.382	4.833

All correlations significant at the 0.05 level

FIGURE 5.3, CORRELATION OF ZINC CONCENTRATION VERSUS LEAD CONCENTRATIONS, WELL 5C, 1989 AND 1990



Correlation of Electrical Conductivity with Zinc Concentration

Zinc correlates well with electrical conductivity in both the shallow and deep wells (figure 5.4 and 5.5) Coefficients of determination are over 0.9 and over 0.7 respectively for both years (Table 5.2). Slopes of the correlations are consistent between the shallow and deep wells over the two study periods. A change in intercept from -8.5 to -6.9 between 1989 and 1990 in the deep wells can be seen in figure 5.4. No change in intercept was detected in the shallow wells.

When each well is analyzed individually, the correlations of the 1989 data tend to be better than the 1990 data (tables 5.3 and 5.4). There are a number of possible explanations for the change in correlation from one year to the next.

One possible explanation for the inconsistency is that zinc might constitute a larger portion of the dissolved solids in 1989 and therefore exercise more control over EC. Table 5.5 displays average ratios of zinc concentrations to the concentrations of other major cations included in the analysis: Mn, Na, Ca, Mg, and Fe. Chloride and sulfate, the two major anions, were not analyzed for and therefore are not included. This may induce some error. The table indicates very little difference in the zinc to major constituents ratio between 1989 and 1990.

Another explanation is that those wells displaying the greatest range of zinc values correlate the best because the graphs are more elongate. This effect can be seen in the graphs of wells 5 and 6C (figures 5.6 and 5.7). Correlations for 5C are above 0.95 and display a wide range of data for both years. In 1989 the correlation for well 6C ($R^2=0.81$) is higher than in 1990 ($R^2=0.15$). This is reflected in the associated high range of data in 1989 in relation to 1990 presented in figure 5.7.

Despite the reproducibility problem in some wells, EC and zinc concentrations in wells 1C, 5C, 7C, 9C, 10C, 5D, and 10D correlate well for both years. If additional monitoring reveals a continued relationship, these wells may be employed in long term daily monitoring of metals concentration using a data logger and an electrical conductivity transducer. However, because of the wide variation in zinc concentrations compared to electrical conductivity, this method would best be employed to monitor relative changes in zinc concentration rather than to determine exact values.

FIGURE 5.4, CORRELATION OF ZINC CONCENTRATION WITH ELECTRICAL CONDUCTIVITY, SHALLOW WELLS

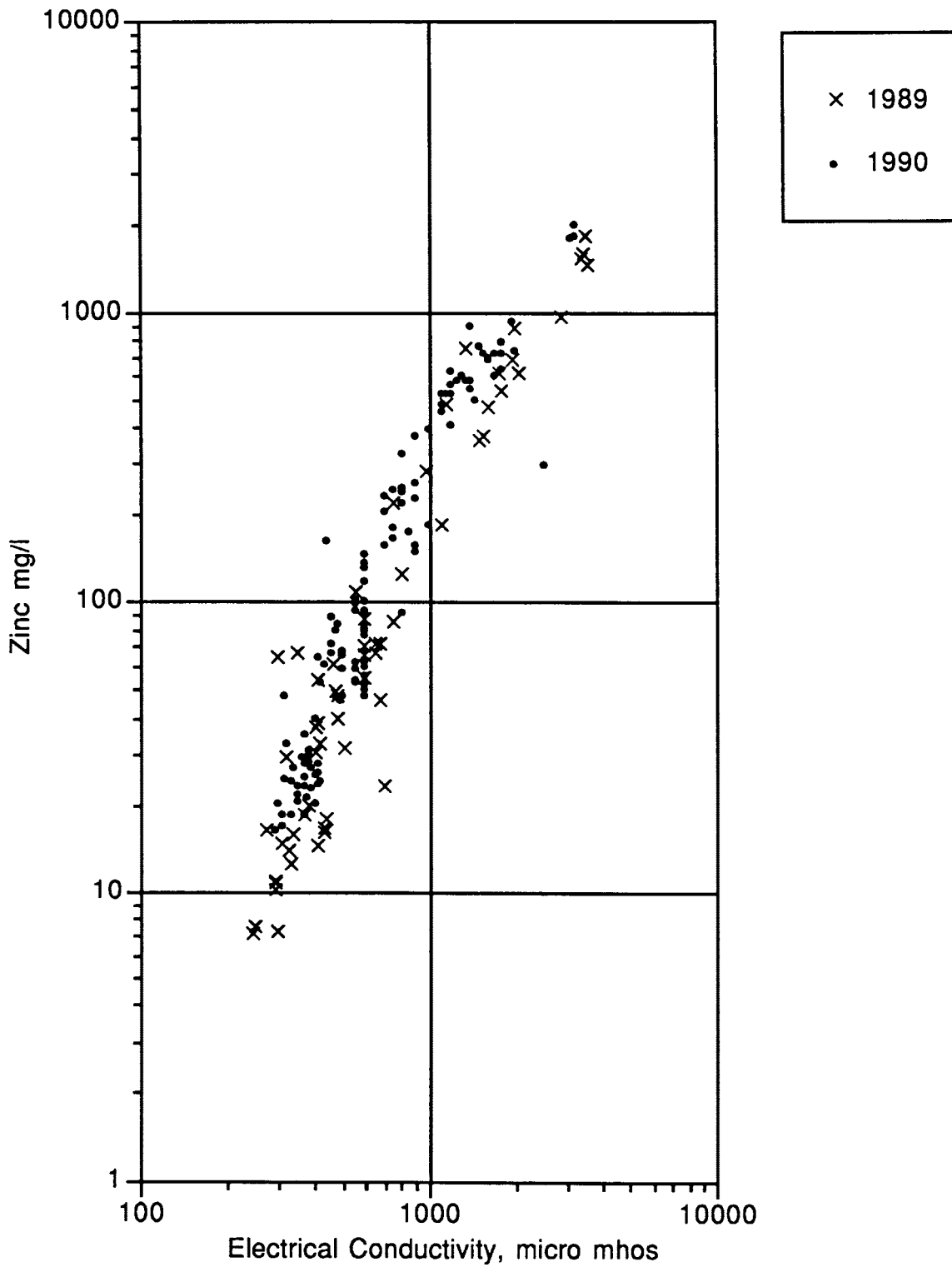


FIGURE 5.5, CORRELATION OF ZINC CONCENTRATION WITH ELECTRICAL CONDUCTIVITY, DEEP WELLS

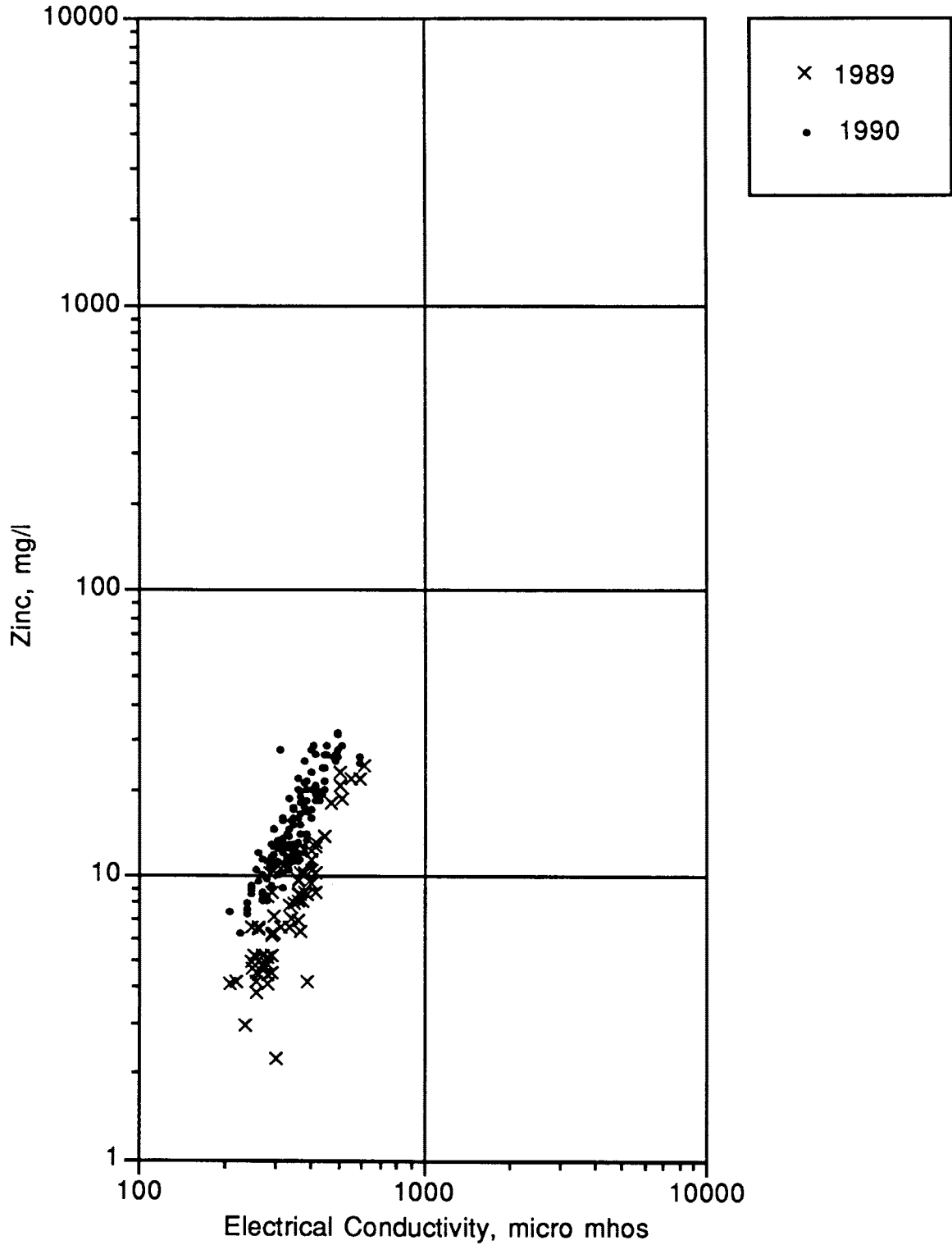


FIGURE 5.6, CORRELATION OF ZINC CONCENTRATION WITH ELECTRICAL CONDUCTIVITY, WELL 5C

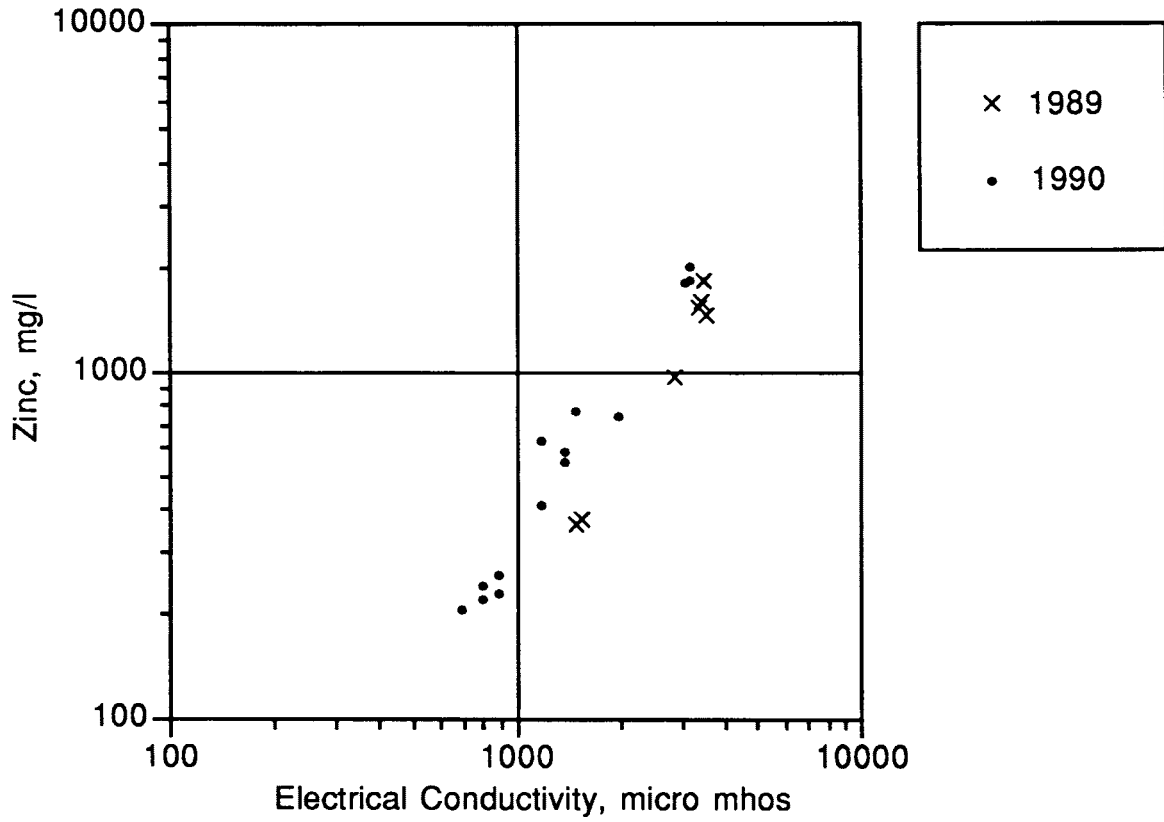


FIGURE 5.7, CORRELATION OF ZINC CONCENTRATION WITH ELECTRICAL CONDUCTIVITY, WELL 6C

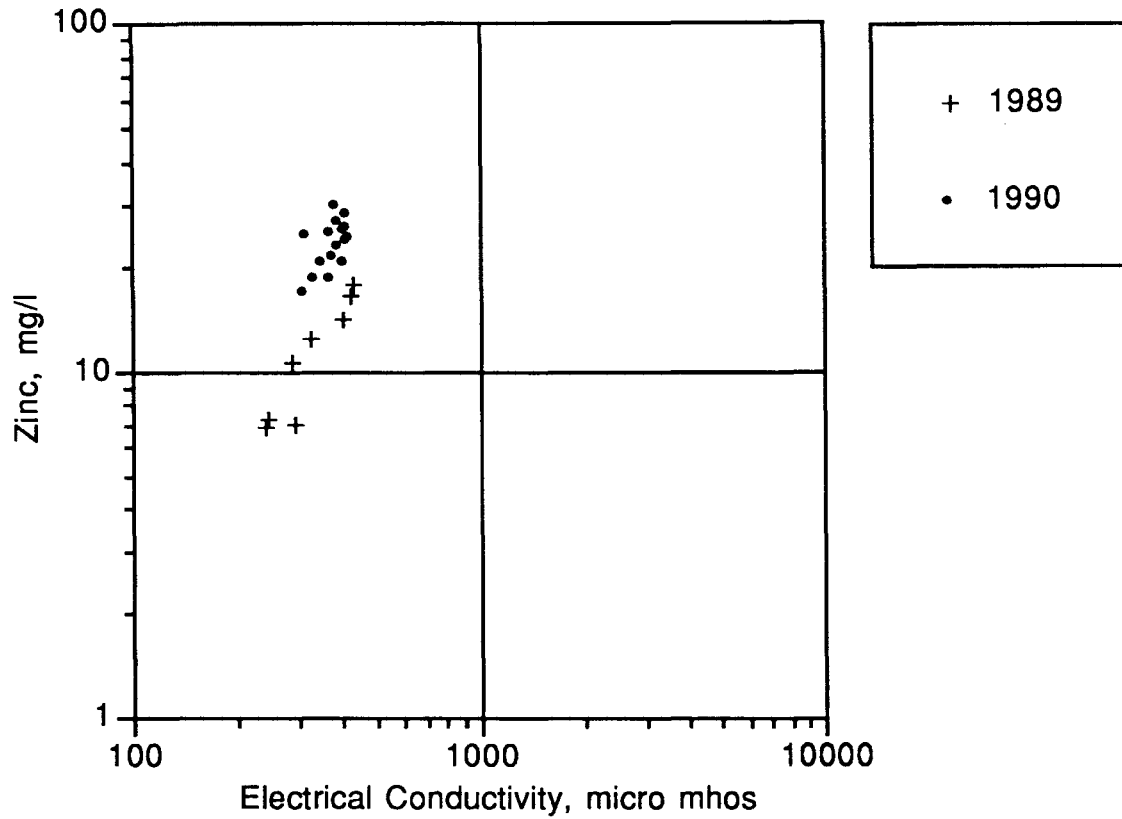


TABLE 5.2, COEFFICIENTS OF DETERMINATION FOR THE CORRELATION OF NATURAL LOG OF ZINC CONCENTRATION VS THE NATURAL LOG OF ELECTRICAL CONDUCTIVITY

Well	Adjusted R ²		Slope		Intercept		Probability	
	1989	1990	1989	1990	1989	1990	1989	1990
Shallow	0.908	0.908	1.976	2.07	-8.543	-8.758	0.0001	0.0001
Deep	0.737	0.744	1.817	1.64	-8.558	-6.936	0.0001	0.0001

Well 4 removed as outlier

TABLE 5.3, COEFFICIENTS OF DETERMINATION FOR THE CORRELATION OF
NATURAL LOG OF ZINC CONCENTRATION VS THE NATURAL LOG OF ELECTRICAL
CONDUCTIVITY IN THE SHALLOW WELLS

Well	R ²		Slope		Intercept		Probability	
	1989	1990	1989	1990	1989	1990	1989	1990
BLM 1C	0.96	0.649	1.60	2.014	-5.199	-7.988	0.0001	0.003
BLM 2C	0.976	0.002	2.15	-0.287	-9.855	5.861	0.090*	0.961*
BLM 3C	0.570	0.144	2.717	1.154	-13.10	-3.462	0.0118	0.162*
BLM 4C	0.094	0.439	1.968	0.776	-9.246	-1.187	0.504*	0.0071
BLM 5C	0.987	0.970	1.742	1.495	-6.9	-4.526	0.0001	0.001
BLM 6C	0.881	0.154	1.526	0.679	-6.469	-8.73	0.0006	0.148*
BLM 7C	0.991	0.602	1.322	1.021	-4.303	-2.047	0.0001	0.0007
BLM 8C	0.94	0.0	1.899	-0.031	-8.271	4.239	0.0014	0.932*
BLM 9C	0.959	0.847	1.877	1.863	-7.621	-7.09	0.001	0.0001
BLM 10C	0.897	0.62	2.651	1.631	-13.55	-5.79	0.0004	0.0005

TABLE 5.4, COEFFICIENTS OF DETERMINATION FOR THE CORRELATION OF
NATURAL LOG OF ZINC CONCENTRATION VS THE NATURAL LOG OF ELECTRICAL
CONDUCTIVITY IN THE DEEP WELLS

Well	R ²		Slope		Intercept		Probability	
	1989	1990	1989	1990	1989	1990	1989	1990
BLM 1D	0.771	0.207	1.23	0.444	-4.805	0.527	0.0171	0.1018
BLM 2D	0.869	0.205	1.399	0.543	-5.821	-0.142	0.0007	0.897
BLM 3D	0.353	0.5	1.314	0.846	-5.841	-2.434	0.1207	0.0032
BLM 4D	0.625	0.503	3.422	1.488	-19.23	-6.479	0.0611	0.0031
BLM 5D	0.903	0.79	1.885	1.655	-8.442	-6.915	0.001	0.009
BLM 6D	0.467	0.472	2.165	0.853	-10.78	-2.527	0.907	0.0047
BLM 7D	0.967	0.483	1.319	0.867	-5.75	-2.633	0.0001	0.004
BLM 8D	0.980	0.216	1.388	0.563	-5.888	-0.463	0.001	0.081
BLM 9D	0.942	0.242	1.571	0.586	-7.125	-0.884	0.0001	0.0626
BLM 10D	0.839	0.658	1.452	1.627	-6.651	-6.899	0.0014	0.0002

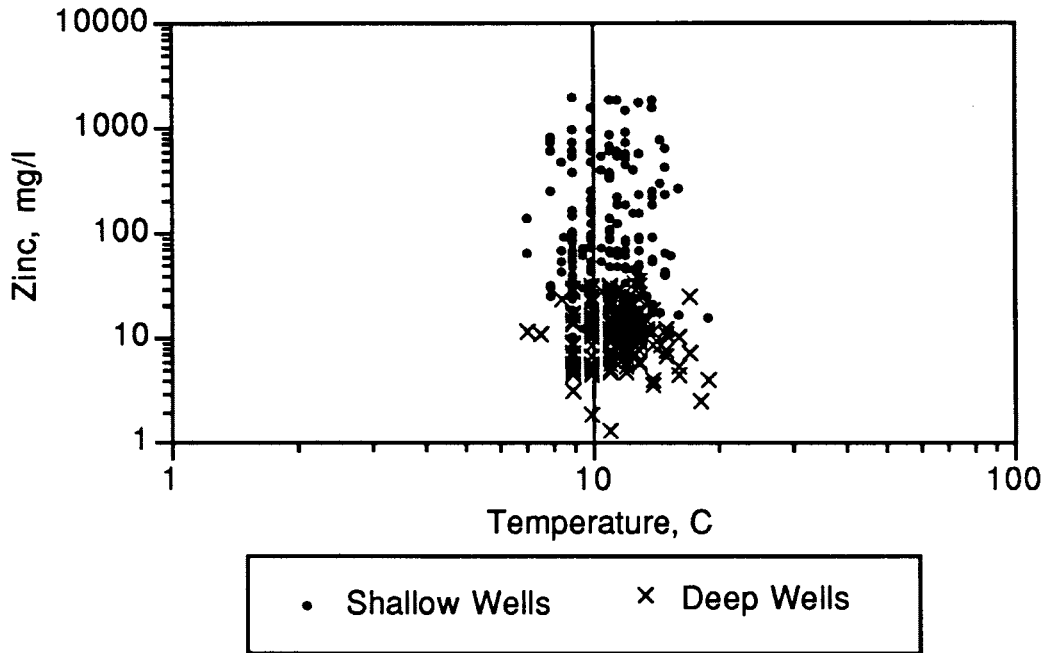
TABLE 5.5, AVERAGE RATIO OF ZINC CONCENTRATION TO THE SUM OF MANGANESE, SODIUM, MAGNESIUM, IRON, AND CALCIUM CONCENTRATIONS

	Shallow Wells		Deep Wells	
	1989	1990	1989	1990
1	2.2	2.20	0.14	0.20
2	N/A	N/A	0.14	0.19
3	0.23	0.30	0.10	0.15
4	0.26	0.27	0.04	0.09
5	1.95	2.10	0.10	0.18
6	0.15	0.23	0.07	0.14
7	0.47	0.63	0.08	0.15
8	0.29	0.40	0.11	0.17
9	0.75	0.96	0.09	0.15
10	1.09	1.40	0.07	0.15

Correlation of Water Temperature with Zinc Concentration

If the increase in zinc concentration occurs primarily with recharge, and the temperature of the infiltrating water is consistently different than the aquifer water, then zinc concentrations should be associated with a corresponding water temperature change. However, no statistically significant correlation exists between these two factors (figure 5.8).

FIGURE 5.8, CORRELATION OF ZINC CONCENTRATION WITH WATER TEMPERATURE



Correlation of pH with Zinc Concentration

If zinc enters the aquatic phase through the dissolution of zinc sulfate minerals as suggested by Marcy (1979), then an increase in zinc concentrations should be accompanied by a decrease in pH because of sulfuric acid generation. Towatana (1990) has hypothesized that this pH change would be buffered by carbonate gangue materials in the mine wastes. Figure 5.9 reveals the lack of correlation between zinc concentrations and pH in the shallow wells. Low coefficients of determination in table 5.6 further demonstrate this.

Figure 5.10 demonstrates the generally good negative correlation between zinc concentrations and pH in the deep wells. However, the generally poor coefficients of determination in table 5.7 imply a poor

ability to predict zinc concentrations from pH. No readily available explanation exists for the collinearity of zinc concentration and pH in the deep wells and the lack of collinearity in the shallow wells.

FIGURE 5.9, PH VERSUS ZINC CONCENTRATIONS, SHALLOW WELLS, 1990

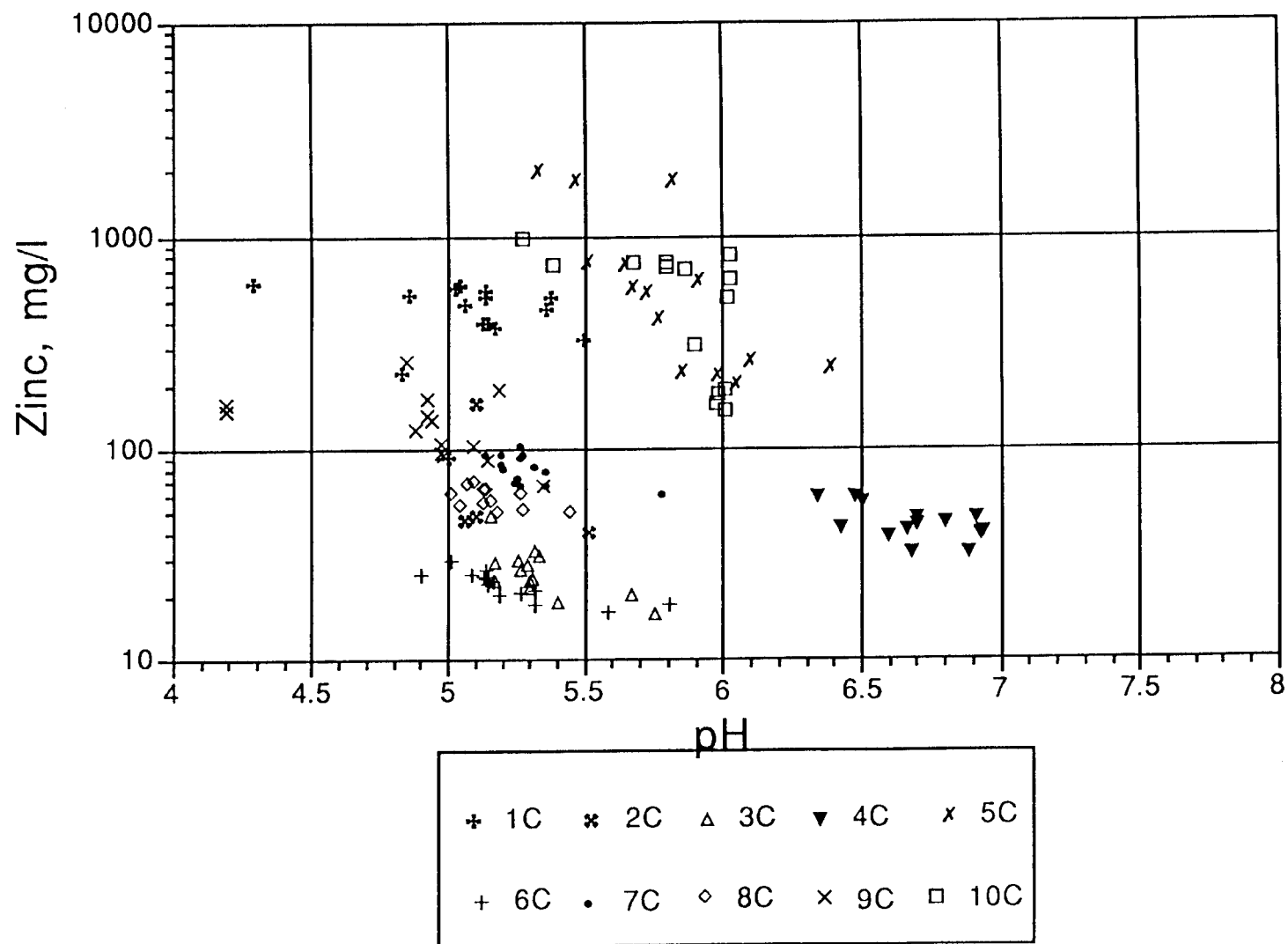


FIGURE 5.10, pH VERSUS ZINC CONCENTRATIONS, DEEP WELLS, 1990

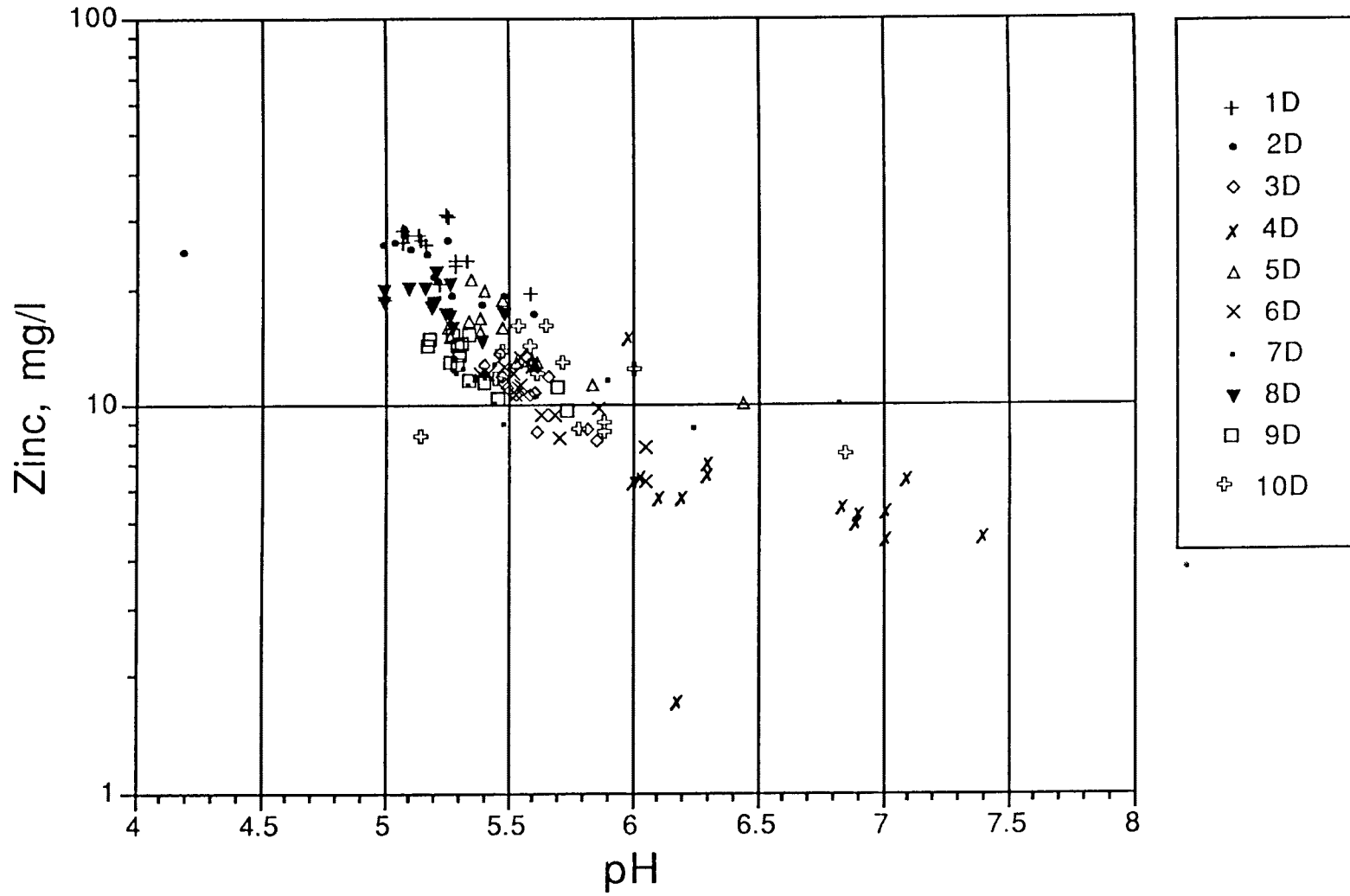


TABLE 5.6, CORRELATION OF THE NATURAL LOG OF ZINC CONCENTRATION WITH
PH

Well Location	R ²		Slope		Intercept		Probability	
	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep
BLM 1	0	0.07	-0.09	-0.29	6.48	4.74	0.84	0.16
BLM 2	0.16	0.75	-1.21	-0.86	10.4	7.64	0.60	0.00
BLM 3	0.56	0.54	-1.04	-0.97	8.80	7.84	0.01	0.00
BLM 4	0.34	0.49	-0.57	-0.22	7.62	3.15	0.03	0.01
BLM 5	0.59	0.58	-2.25	-0.54	19.3	5.72	0.00	0.00
BLM 6	0.68	0.75	-5.86	-0.90	6.19	7.38	0.00	0.00
BLM 7	0.35	0.31	-0.62	-0.15	7.63	3.25	0.03	0.04
BLM 8	0.29	0.29	-0.55	-0.44	6.89	5.18	0.05	0.05
BLM 9	0.20	0.63	-0.49	-0.69	7.22	6.22	0.10	0.00
BLM 10	0.55	0.20	-1.58	-0.23	15.3	4.07	0.04	0.12

CHAPTER 6: CORRELATION OF WATER QUALITY WITH HYDROLOGIC DATA

Introduction

Marcy (1979) and Dames and Moore (1988) have postulated that the contaminant influx into the upper aquifer results from the flushing action of infiltrating water and water levels rising into the tailings layer. This flushing action has also been proposed by Grimshaw and others (1976) for a similar site. Determining the relative contamination derived from each of these two factors is important in choosing a remediation plan. If recharge is the dominant mechanism of contaminant influx, then the leaching caused by the addition of irrigation water required by the present remediation plan potentially could degrade the water quality of the underlying aquifer and the South Fork of the Coeur D'Alene River. Therefore recharge and water level rise are studied for effects on zinc concentrations.

As in previous chapters, average zinc concentration is used instead of a well by well analysis in the following analyses because differences among wells are assumed to be caused by indeterminate local heterogeneities. The averaging process lessens the impacts of these heterogeneities.

Correlation of Water Quality with Hydrologic Variables

Zinc Concentration vs Water Levels

No direct relationship exists between water levels and zinc concentrations on the Smeltonville Flats. Figures 6.1-6.4 relate the average water level elevation to the average concentration of zinc in the

shallow (C) and deep (D) wells for both years. In general, metals concentrations follow the rise and fall of the water levels in 1989. However, the concentration peak appears to be slightly before the water level peak. In 1990, zinc concentrations fall with rising water levels. The different relationships in 1990 as opposed to 1989 suggest that other factors are more important in controlling the influx of heavy metals into the upper aquifer.

FIGURE 6.1, AVERAGE ZINC CONCENTRATION AND AVERAGE WATER LEVELS, SHALLOW WELLS, 1989

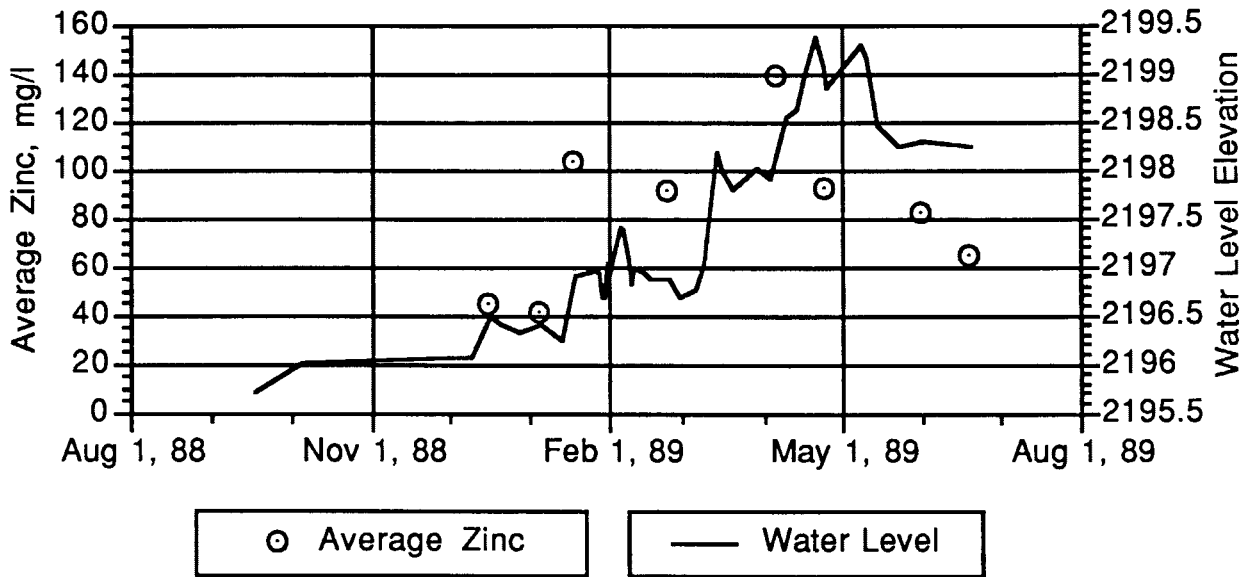


FIGURE 6.2, AVERAGE ZINC CONCENTRATION AND AVERAGE WATER LEVELS, DEEP WELLS, 1989

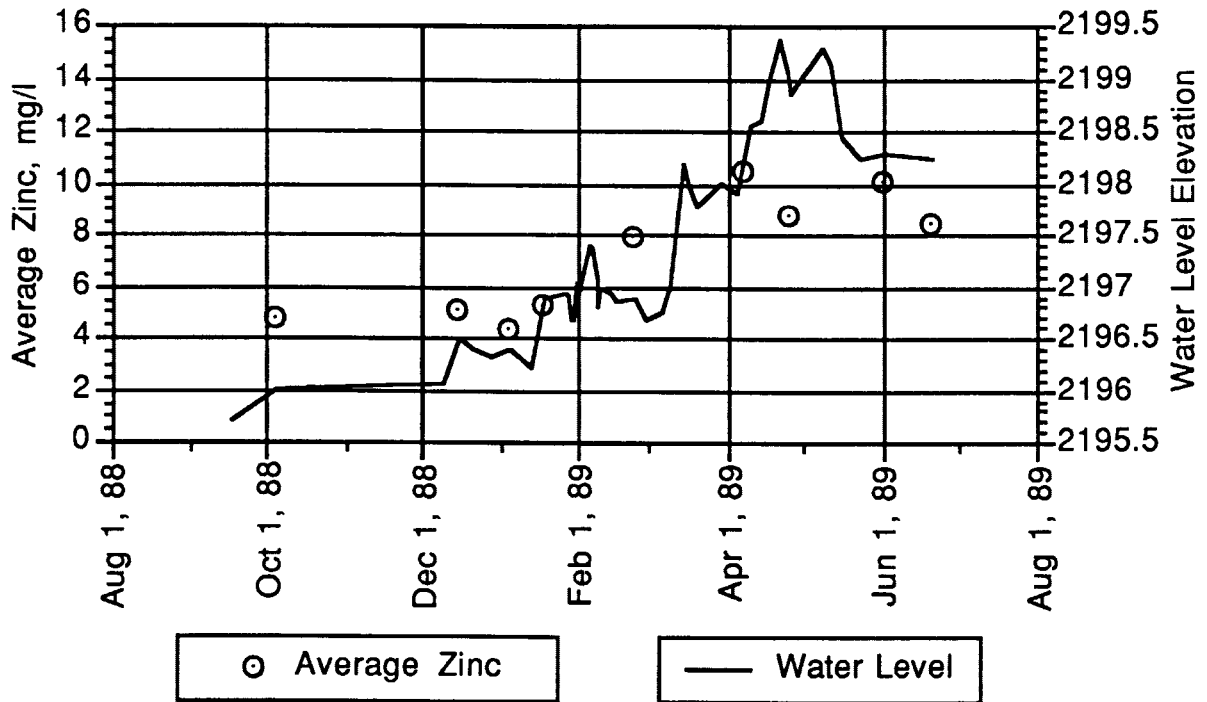


FIGURE 6.3, AVERAGE ZINC CONCENTRATION AND AVERAGE WATER LEVELS, SHALLOW WELLS, 1990

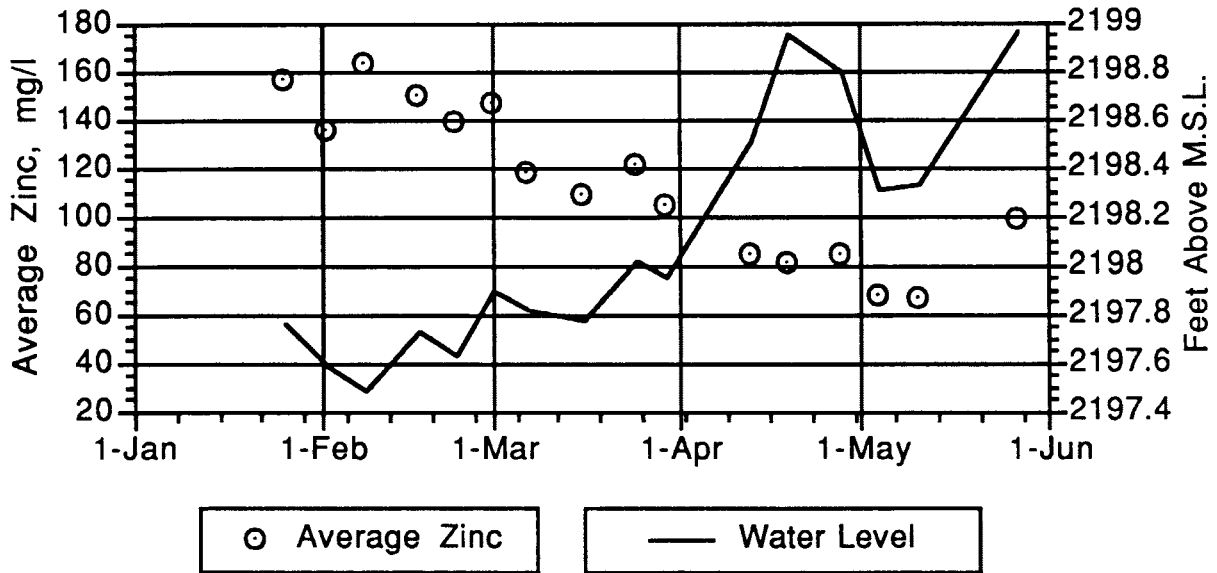
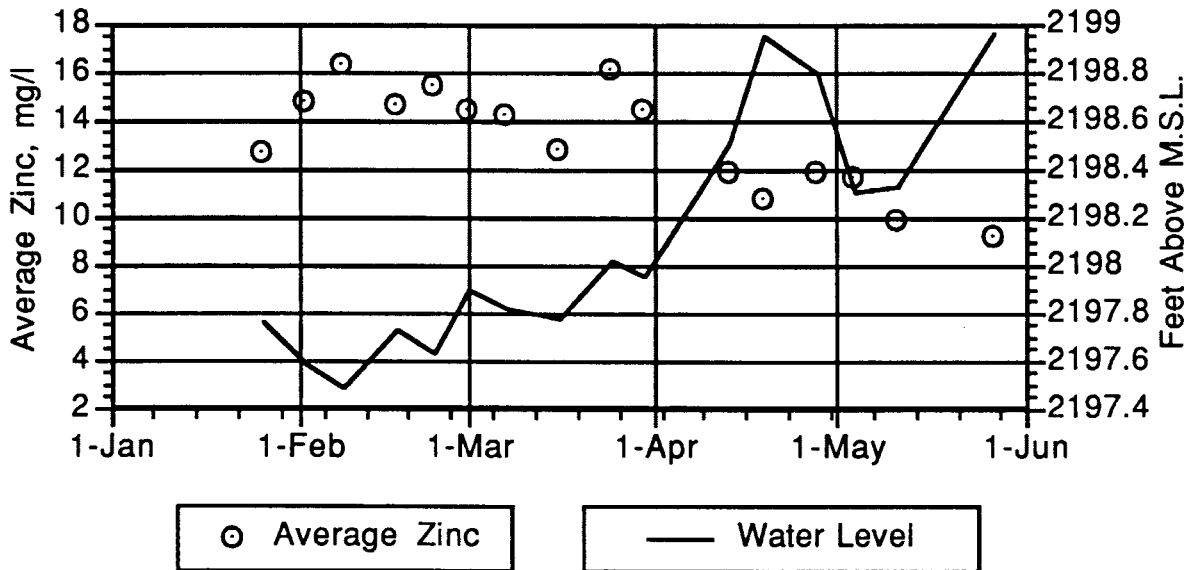


FIGURE 6.4, AVERAGE ZINC CONCENTRATION AND AVERAGE WATER LEVELS, DEEP WELLS, 1990



Antecedent Precipitation Index

Flushing action during infiltration from precipitation on the Flats is another possible mechanism for the increase in concentration of heavy metals in the shallow aquifer. Recharge was not measured directly during the study period; precipitation is the only applicable measured variable. In this section, an index of precipitation is developed to relate recharge from precipitation to changes in shallow ground water quality. The index includes consideration of previous precipitation, snow cover and melt, and the mixing of waters of different metal concentrations within the aquifer.

Antecedent Precipitation Index (API) provides an indication of how much precipitation has fallen prior to a particular day (Gregory and Walling, 1973). Antecedent precipitation index is concerned primarily with associated soil moisture conditions but it also may be used as an indication of recharge. The API used in this study takes the following form:

$$P_a = (P_{a_{d-1}}K) + P \quad (6.1)$$

where P_a = antecedent precipitation index

$P_{a_{d-1}}$ = index for the preceding day

P = rainfall in the preceding 24 hours

K = decay constant

The value of K is determined by trial and error and is generally on the order of 0.9 (Gregory and Walling, 1973).

The API equation assumes that water available for recharge comes only from rainfall. Because much of the daily recharge came from snow melt, a snow melt term must be added to the API equation. The Corps of Engineers (1956) equation for snow melt requires only the average daily temperature as input:

$$M = C(T_a - T_c) \quad (6.2)$$

where M = snow melt that day in inches of water

C = inches of snow melt per degree F of the average daily temperature over T_c (melt factor)

T_a = average temperature that day

T_c = temperature over which melt begins to occur

The variables C and T_c are determined by trial and error. The factors which affect the variables C and T_c are altitude and the amount of shade the site receives. The variable C generally varies between 0.05 and 0.15 and T_c varies between 24 and 32°F (Corps of Engineers, 1956). Combining the API and snow melt equations yields the following equation for antecedent precipitation:

$$P_a = (K * P_{a,d-1}) + C(T_a - T_c) \quad (6.3)$$

A computer spreadsheet model was developed to calculate the daily antecedent precipitation indices for the study period using this equation. The data required for the model (precipitation as rain, precipitation as snow, and average daily air temperature) were obtained from the National Weather Service station in Kellogg, Idaho. The daily API was calculated

beginning three months before each of the study periods because API is cumulative. The model then simultaneously correlated API for each sample date with the average zinc concentrations in the both the shallow and deep wells for each of the two years. The four correlation coefficients were averaged by calculating the hyperbolic arctangent of the correlation coefficients ($\tanh^{-1}(r^2)$), averaging them, and taking the hyperbolic tangent of the result (Graybill, 1961). The values of the variables K, C, and T_c were determined by selecting the combination of the variables which were inside the accepted range of variation and produced the highest average correlation coefficient. The results of the sensitivity analysis are given in tables 6.1, 6.2, and 6.3. Values of 0.988, 25°F and 0.13 were determined for K, T_c and C respectively resulting in the following equation:

$$P_a = (0.988 * P_{a,d-1}) + 0.13(T_a - 25^\circ F) \quad (6.4)$$

The decay constant (K) was increased above that suggested by Gregory and Walling to simulate the slow decrease in zinc concentrations due to mixing of the infiltrating water with cleaner aquifer water.

TABLE 6.1, SENSITIVITY ANALYSIS: R^2 FOR THE CORRELATION BETWEEN API AND THE AVERAGE NATURAL LOG OF ZINC CONCENTRATION, MELT FACTOR VARIATION

Decay Constant	Melt Temp F	Melt Factor	Shallow Data '89	Deep Data '89	Shallow Data '90	Deep Data '90	Average R^2
0.998	25	0.11	0.677	0.761	0.766	0.547	0.697
		0.12	0.712	0.749	0.764	0.548	0.702
		0.13	0.742	0.729	0.763	0.549	0.704
		0.14	0.765	0.701	0.763	0.549	0.704
		0.15	0.762	0.658	0.763	0.548	0.692

TABLE 6.2, SENSITIVITY ANALYSIS: R^2 FOR THE CORRELATION BETWEEN API AND THE AVERAGE NATURAL LOG OF ZINC CONCENTRATION, MELT TEMPERATURE VARIATION

Decay Constant	Melt Temp F	Melt Factor	Shallow Data '89	Deep Data '89	Shallow Data '90	Deep Data '90	Average R^2
0.998	22	0.13	0.763	0.580	0.763	0.546	0.675
	24		0.768	0.674	0.763	0.549	0.698
	25		0.742	0.729	0.763	0.549	0.704
	26		0.688	0.756	0.766	0.548	0.699
	28		0.582	0.759	0.764	0.540	0.674

TABLE 6.3, SENSITIVITY ANALYSIS: R^2 FOR THE CORRELATION BETWEEN API AND THE AVERAGE NATURAL LOG OF ZINC CONCENTRATION, DECAY CONSTANT VARIATION

Decay Constant	Melt Temp F	Melt Factor	Shallow Data '89	Deep Data '89	Shallow Data '90	Deep Data '90	Average R^2
0.980	25	0.13	0.786	0.374	0.784	0.478	0.639
0.985			0.796	0.602	0.787	0.528	0.695
0.988			0.742	0.729	0.763	0.549	0.704
0.990			0.680	0.795	0.721	0.547	0.696
0.992			0.604	0.839	0.626	0.510	0.666
0.995			0.478	0.860	0.214	0.227	0.512

Zinc Concentration vs API

In general, the API model is able to predict the broad trends and smaller peaks in the temporal distribution of zinc concentrations. The curves generated by the API data and the natural log of zinc concentrations are compared in figures 6.5-6.8. The correlation coefficients (R^2) of the natural log of zinc concentration versus API range from 0.549 to 0.763 with an average of 0.704 (table 6.4). The slopes of the shallow and deep wells are consistent over the two years although the intercept of the deep wells varies. The similarity in slope (but not intercept) means that the model effectively predicts the incidence of higher and lower relative zinc concentration in the aquifer but not necessarily the exact concentration. Additional years of data are needed to determine whether the variation in slope is significant and to validate the model. Other controls on zinc concentration must also

exist as evidenced by the failure of the API model to predict a zinc concentration peak in late March of 1990 in both the shallow and deep wells.

The correlation of zinc concentration with antecedent precipitation index (API) implies that recharge is primary in controlling the concentration of zinc in solution in the upper aquifer. Therefore, reducing recharge should reduce zinc levels. Conversely, increasing recharge should increase zinc concentrations. The extent to which increased or reduced recharge will affect the water quality can be estimated using the following equations:

Shallow wells:

$$\text{Zinc (mg/l)} = \text{EXP}(0.109((0.998*Pa_{d-1})+0.13(T_a-25^\circ\text{F}))+3.35) \quad (6.4)$$

Deep wells:

$$\text{Zinc (mg/l)} = \text{EXP}(0.072((0.998*Pa_{d-1})+0.13(T_a-25^\circ\text{F}))+1.53) \quad (6.5)$$

These equations for calculating the theoretical average zinc concentrations were determined using the average slope and intercept of the API versus zinc concentration correlations. This approximation is valid only for API values ranging from 4 to 16 inches (those used as input to the model) because other factors may limit the maximum and minimum concentrations in the aquifer. Therefore zinc concentration values calculated from equations 6.4 and 6.5 using API values outside the range of 4 to 16 inches should be viewed as rough approximations only.

In addition, for any of the relationships established by correlation analysis three restrictions apply (Johnson, 1988):

1) Regression never proves causation, it only measures the movement between the two variables.

2) Regression equations are valid only in the domain of the x variable studied.

3) The results from one sample should be used only to make inferences about the population from which it is drawn.

The use of the API explains the early zinc concentration peak in 1990 compared to the later peak in water levels. The recharge occurred much earlier on the Flats in 1990, causing the zinc concentrations to rise. Snow melting in the surrounding mountains occurred later in the season causing, the rise in water levels. The similarity between water level and zinc concentration trends in 1989 is due to a thick accumulation of snow on the Flats and cold temperatures early that year which caused the snow melt on the Flats to occur roughly simultaneous with high river flow.

The simultaneous occurrence of infiltration and high zinc concentrations implies that natural leaching of heavy metals from the sediments is occurring. The use of lixiviants would tend to increase the concentration of metals in the ground water. Thus, in situ leaching may be feasible.

FIGURE 6.5, THE NATURAL LOG OF ZINC CONCENTRATION VERSUS API, SHALLOW WELLS , 1989

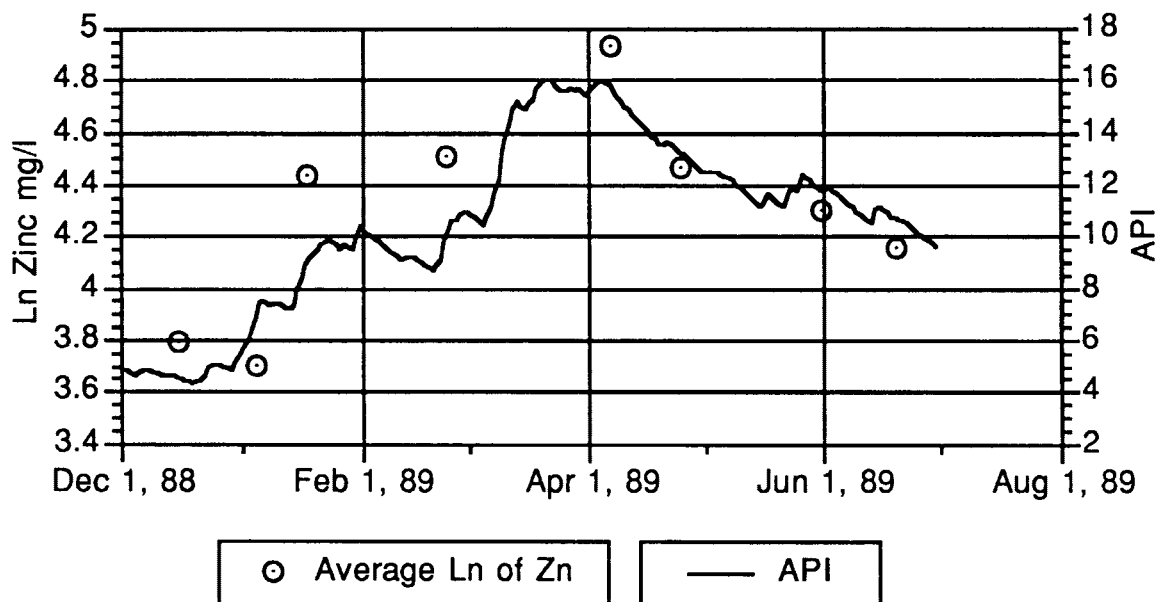


FIGURE 6.6, THE NATURAL LOG OF ZINC CONCENTRATION VERSUS API, DEEP WELLS , 1989

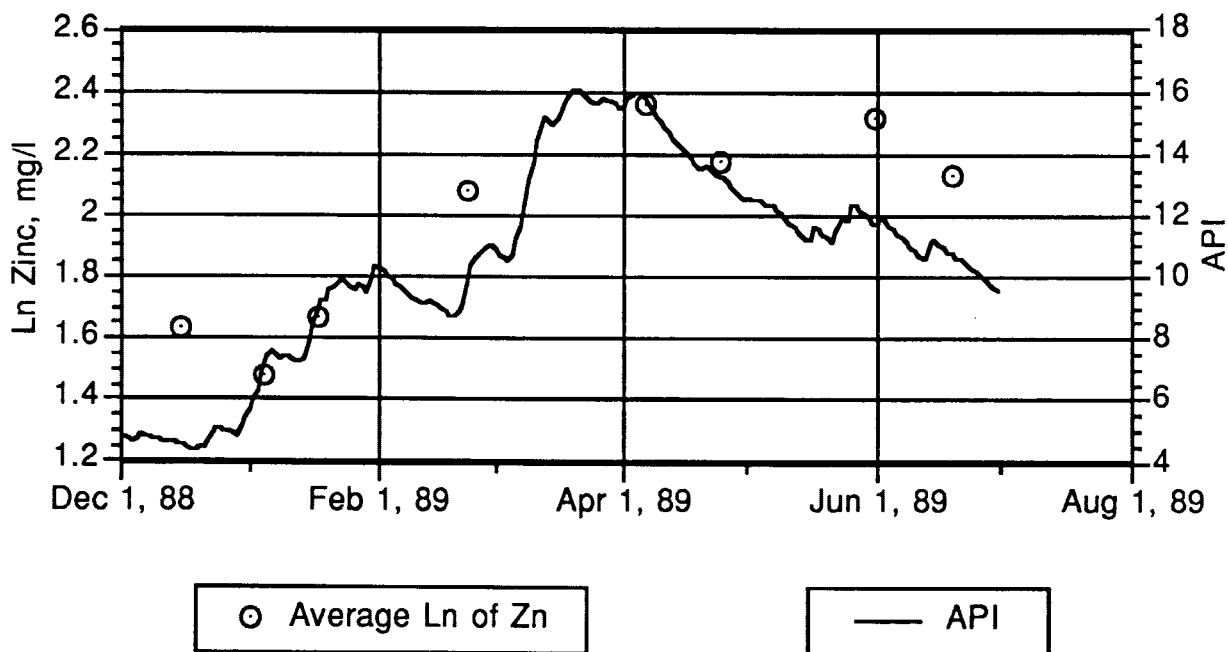


FIGURE 6.7, THE NATURAL LOG OF ZINC CONCENTRATION VERSUS API, SHALLOW WELLS , 1990

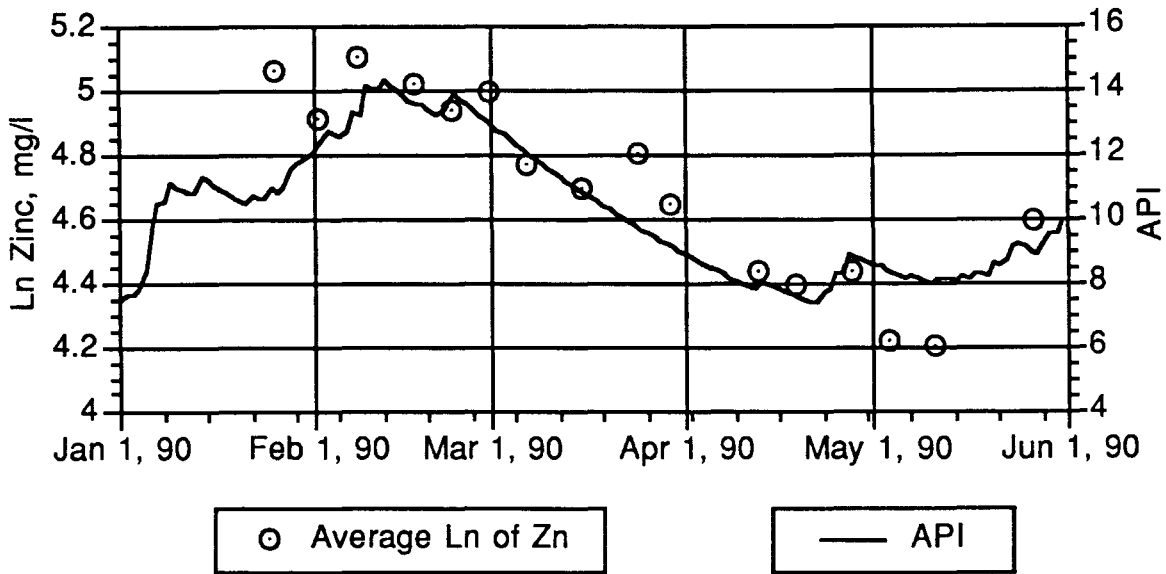


FIGURE 6.8, THE NATURAL LOG OF ZINC CONCENTRATION VERSUS API, DEEP WELLS , 1990

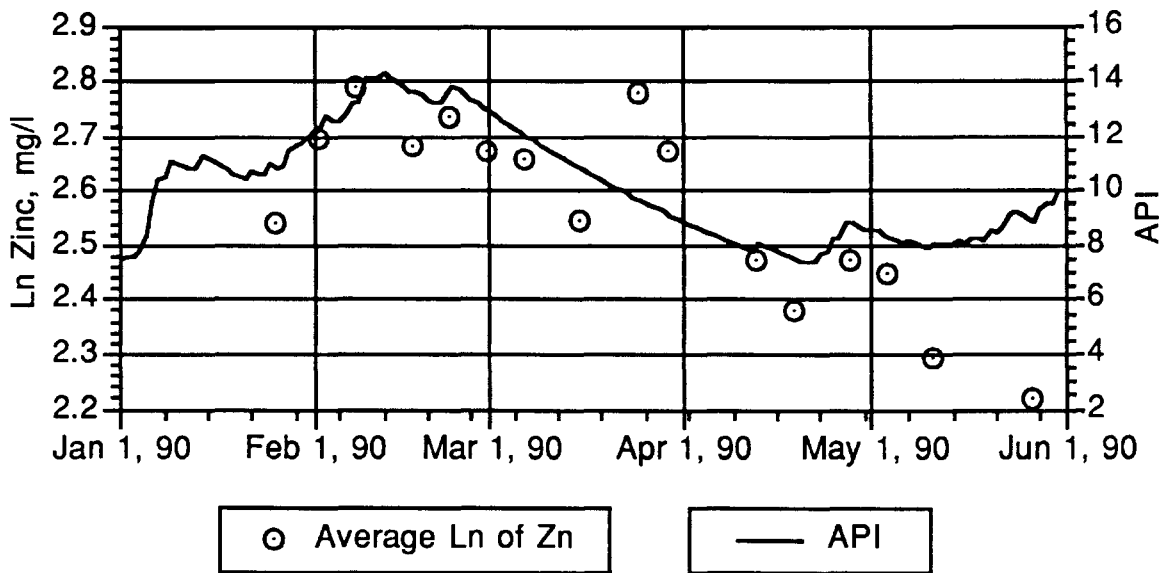


TABLE 6.4, COEFFICIENTS OF DETERMINATION FOR THE NATURAL LOG OF ZINC CONCENTRATION VS API

	R ²		Slope		Intercept	
	1989	1990	1989	1990	1989	1990
Shallow	0.742	0.763	0.102	0.117	3.23	3.46
Deep	0.729	0.549	0.086	0.058	1.09	1.96

Conceptual Model of Heavy Metals Influx

A conceptual model of heavy metals influx into the shallow aquifer has been established from observations described in this paper. This model consists of three stratigraphic layers within the upper aquifer (figure 6.9): 1) an unsaturated layer with high metals concentration and low hydraulic conductivity, 2) a saturated, medium conductivity zone, and 3) a saturated high conductivity zone. A description of the recharge flow path and corresponding zinc concentrations follows:

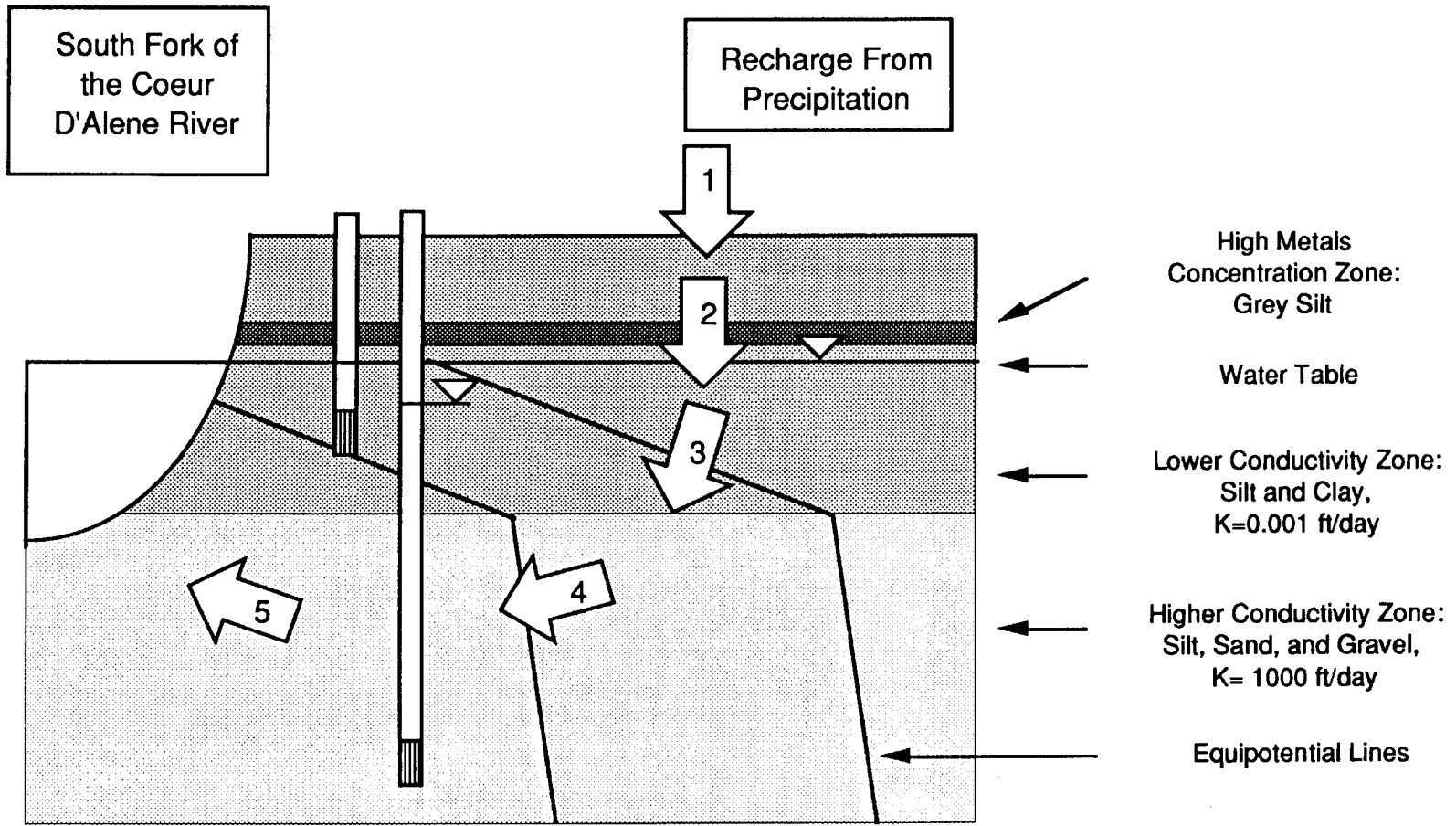
1. Infiltration occurs from precipitation and snow melt.
2. The metals concentration of the water is increased as it passes through the "metallic" layer within the unsaturated zone. The recharge water enters and mixes with the shallow ground water.
3. The upper portion of the shallow aquifer has lower hydraulic conductivity than the lower portion. This difference results in downward hydraulic gradient and downward flow to the lower portion of the shallow aquifer. Thus, water quality in the shallow piezometers represent local conditions. The vertical flow pattern results in shallow well, aqueous

zinc concentrations that reflect the concentration of zinc in the mine wastes proximal to the piezometer sand pack and therefore the widely varying distribution of zinc concentrations in the upper wells.

4. The high zinc concentration water enters the lower portion of the upper aquifer and mixes with horizontally migrating ground water of lower zinc concentration. Thus water quality in the deeper piezometers represent regional conditions. Metals concentrations in this zone are lower and more uniform. Metals continue to travel downward within this zone due to the downward hydraulic gradient and lateral dispersion from horizontal advection. This results in the vertical concentration gradient seen in the set of deep piezometers. The water migrates between the shallow and deep piezometers in less than a week because weekly sampling showed the changes in water in the sets of shallow and deep piezometers quality to occur simultaneously.

5. Some of this water is then discharged into the South Fork of the Coeur D'Alene River.

Figure 6.9, Conceptual model of Heavy Metal Influx into the Shallow Aquifer Beneath the Smelerville Flats



Not to Scale

BLM 4 C and D - Possible Influence by River

The wells at location 4 deviate from the other wells in a number of ways. First, the pH for both wells at location 4 measures consistently between 6 and 7. The pH of the river averages 7.6, and the other wells have pH levels between 4.5 and 6. This difference in pH in wells 4C and 4D versus the other wells is statistically significant at the 0.001 level of significance. The difference between the pH at location 4 and the rest of the wells is displayed in figures 4.9 and 4.10.

Second, the slope of the zinc-cadmium correlation line for well 4C is markedly different from those of the other wells (figure 4.2). The zinc/cadmium ratio cannot be determined for the river to see if it is similar because the concentrations are too low. The zinc/cadmium ratio for well 4D is not appreciably different from the other wells.

Third, the correlations of zinc concentrations and electrical conductivity in 4C and 4D are different from those of other wells. Figures 6.10 and 6.11 show the correlation of zinc concentration versus electrical conductivity in wells at location 4 compared to those at the other locations. In figures 6.10 and 6.11, zinc concentrations from well 4C are consistently low for the corresponding EC value. Data from 4D show significantly more scatter than data from the other wells.

For all of the zinc concentration vs depth correlations in chapter 3, data for well 4D was discarded as an outlier. Figure 6.12 shows the zinc concentration versus depth from water table correlation for January 26, 1990, which is representative of the other sample dates. Concentrations in 4D on January 26 and all other days were consistently low for the depth. All variations suggest dilution from the river to be the probable cause of

the anomaly. The wells at location 4 are the closest to being down gradient from the river and may be affected by the river (figure 3.3).

FIGURE 6.10, ZINC CONCENTRATION VERSUS ELECTRICAL CONDUCTIVITY FOR WELL 4C VERSUS ALL OTHER SHALLOW WELLS

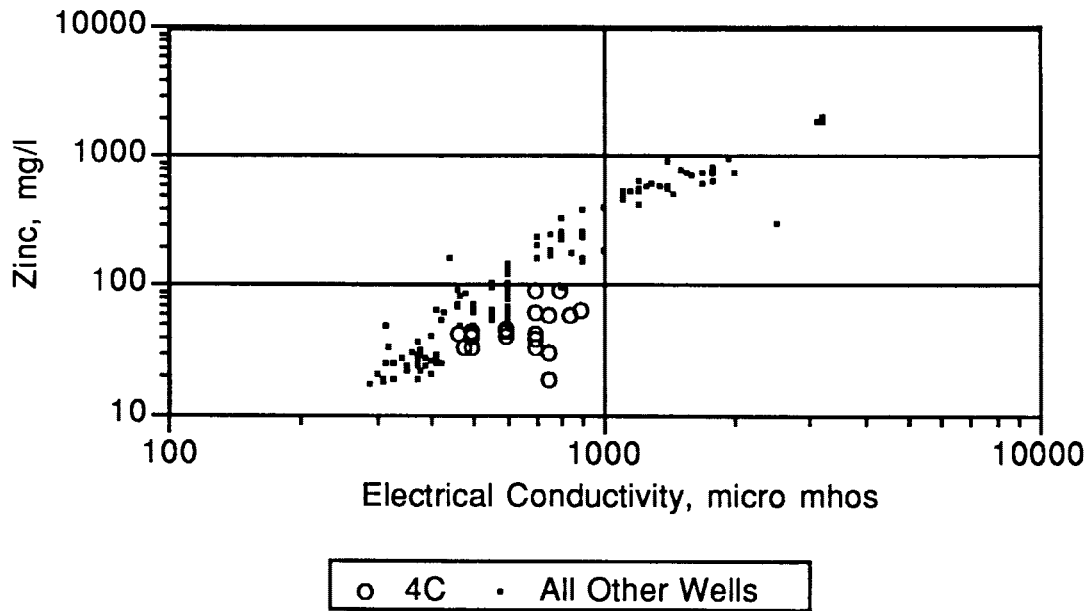


FIGURE 6.11, ZINC CONCENTRATION VERSUS ELECTRICAL CONDUCTIVITY FOR WELL 4D VERSUS ALL OTHER DEEP WELLS

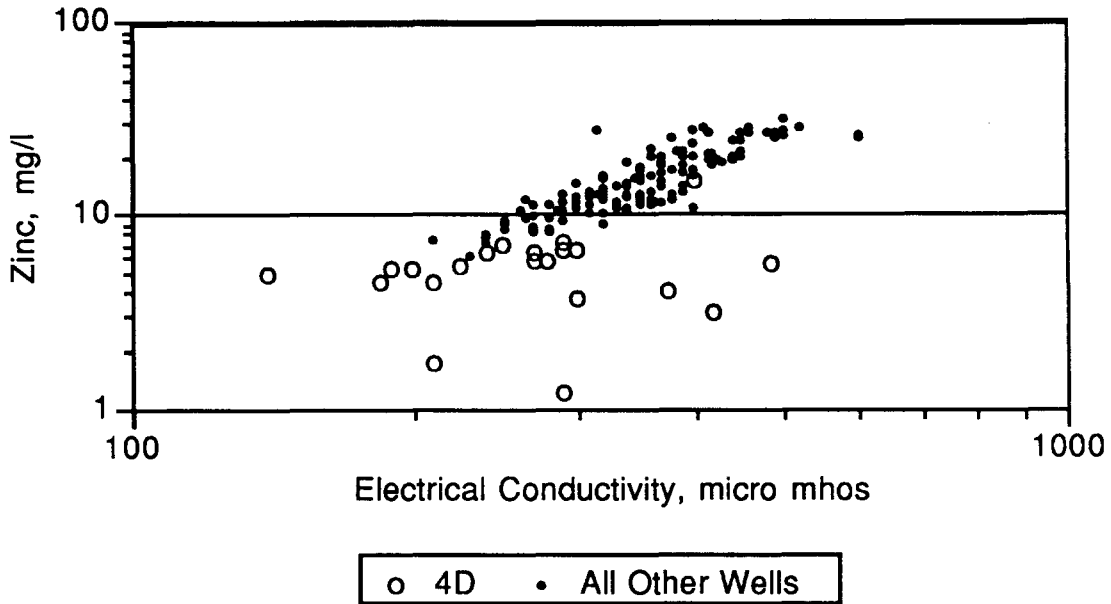
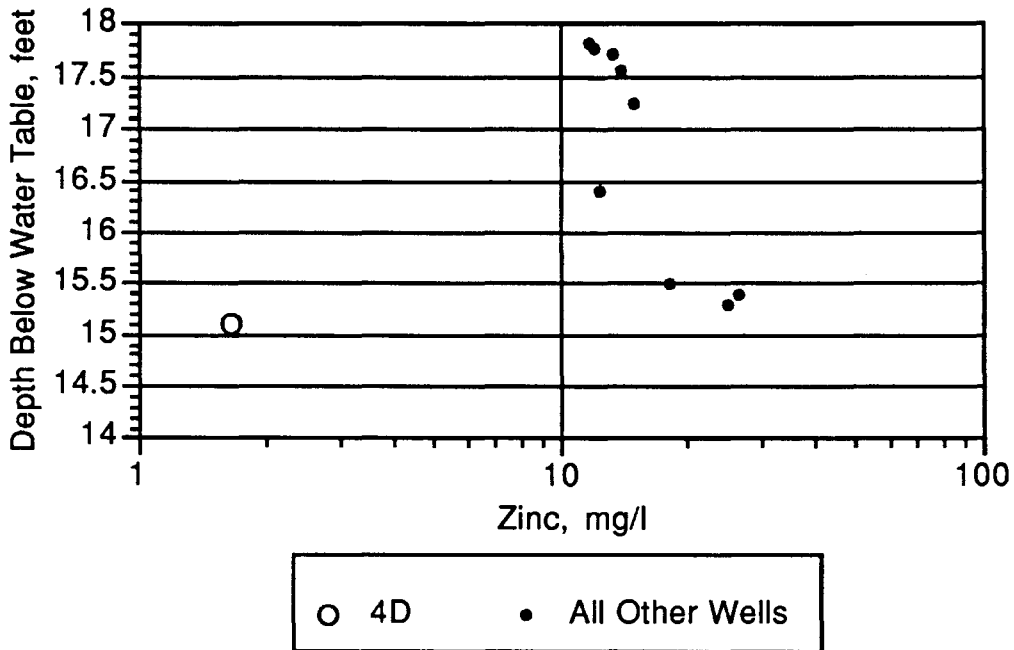


FIGURE 6.12, ZINC CONCENTRATION IN THE DEEP WELLS VERSUS DEPTH FROM WATER TABLE ON JANUARY 26 1990



CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The following conclusions regarding the water quality of the upper aquifer beneath Smeltonville Flats can be drawn from this study:

1. Good correlation between zinc concentration and antecedent precipitation index (API) implies that precipitation and subsequent infiltration controls zinc concentration in the upper aquifer. Consequently, remediation efforts to mitigate shallow ground water contamination should focus on reducing downward recharge over metal rich areas. Remediation efforts which increase recharge such as irrigation will have a negative impact.

2. The conceptual model of heavy metal influx into the upper aquifer of the Smeltonville Flats is based on the existence of three stratigraphic layers: 1) an unsaturated layer with high metals concentration and low hydraulic conductivity, 2) a saturated, medium conductivity zone, and 3) a saturated high conductivity zone. Infiltrating ground water passes through the first layer and dissolves heavy metal ions. The direction of ground water movement in the second layer is downward due to the low hydraulic conductivity of the second layer. The heavy metal bearing water enters the lower portion of the upper aquifer and mixes with horizontally migrating ground water of lower heavy metals concentration. Some of this water eventually enters the South Fork of the Coeur D'Alene River.

3. Downward flow in the upper portion of the upper aquifer results in shallow well, aqueous zinc concentrations that reflect the concentration of zinc in the mine wastes proximal to the piezometer sand pack. The downward flow, combined with the heterogeneously distributed

heavy metal concentrations in the tailings, accounts for the widely varying distribution of zinc concentrations in the upper wells.

4. The dominantly horizontal flow pattern in the lower portion of the shallow aquifer results in the dilute and more uniform concentrations in the deep piezometers. Lateral dispersion of the heavy metals combined with the downward hydraulic gradient results in the vertical concentration gradient seen in the deep piezometers.

5. Zinc is the best indicator for ground water contamination by heavy metals on the Smeltonville Flats. A linear relation between zinc concentration and cadmium concentration and to a lesser extent between zinc and lead supports the use of zinc as an indicator for studying contamination of ground water by mine wastes. Whereas zinc concentration correlates well with electrical conductivity when all wells are correlated together, well by well correlation is not consistent. Thus electrical conductivity is not a useful indicator. Zinc concentration correlates negatively with pH in the deep wells but it does not do so conclusively in the shallow wells and is therefore not useful as an indicator.

5. The relationship between metal concentrations and the timing of infiltration and recharge events and the high concentrations of metals in the ground water implies that natural leaching of the wastes on Smeltonville Flats is occurring. This information suggests that in situ leaching of the wastes using appropriate lixivants may be feasible.

Recommendations

The following recommendations are suggested for further study of the upper aquifer beneath the Smeltonville Flats:

1. Install additional monitoring wells at depths intermediate to the shallow and deep wells previously discussed to verify further the existence of the concentration gradient observed herein.

2. Verify the proposed antecedent precipitation model by monitoring the zinc concentrations in the upper aquifer during a known application of irrigation water.

3. Measure the exact thickness and metals concentration of the mine wastes located immediately adjacent to the shallow wells to determine the effect of those variables on the concentrations measured in the piezometers.

4. Continue monitoring the zinc concentration/electrical conductivity ratio in wells 1C, 5C, 7C, 9C, 10C, and 10D to determine their suitability for long term high frequency sampling by electrical conductivity transducer.

5. Correlate zinc concentration, vertical water temperature gradient and vertical hydraulic gradient with measured recharge.

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APPENDICES

APPENDIX 1: NORMALITY OF DATA

Two samples must be normally distributed to be correlated. If the samples are not normally distributed a transformation must be applied. The natural log transformation has been found to work with most earth science data (Symader and Thomas, 1982). Figures A1.1-A1.8 show the distributions of the water quality data with and without the log transformation. In all cases the natural log transformation exhibits better normality than the untransformed data. The natural log transform has therefore been applied before averaging and correlation through out the study. The only exception is pH data which is already a log function. Second log transforms are not often performed.

FIGURE A1.1, NORMALITY DISTRIBUTION OF ZINC CONCENTRATIONS, SMELTERVILLE FLATS, 1990 STUDY PERIOD

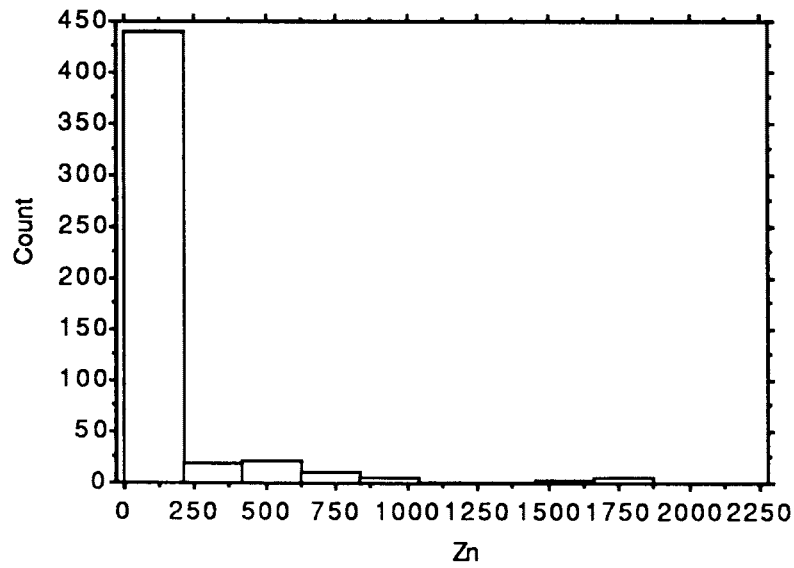


FIGURE A1.2, NORMALITY DISTRIBUTION OF THE NATURAL LOG OF ZINC CONCENTRATIONS, SMELTERVILLE FLATS, 1990 STUDY PERIOD

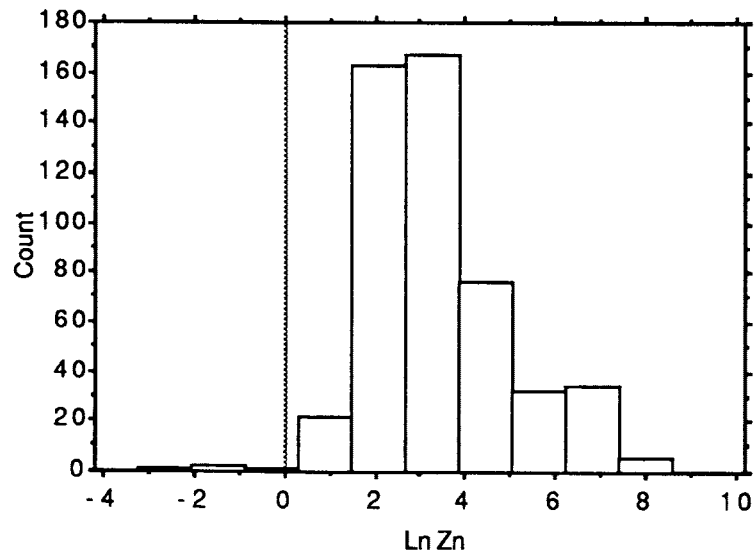


FIGURE A1.3, NORMALITY DISTRIBUTION OF ELECTRICAL CONDUCTIVITY DATA, SMELTERVILLE FLATS, 1990 STUDY PERIOD

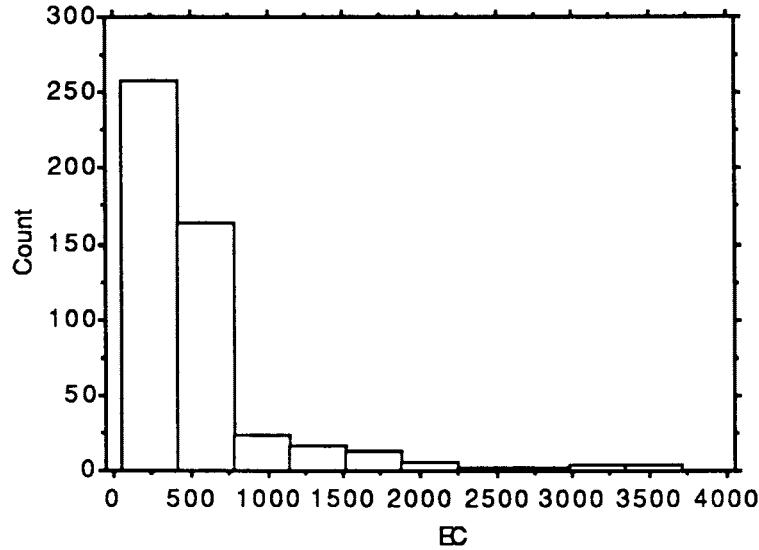


FIGURE A1.4, NORMALITY DISTRIBUTION OF THE NATURAL LOG OF ELECTRICAL CONDUCTIVITY DATA, SMELTERVILLE FLATS, 1990 STUDY PERIOD

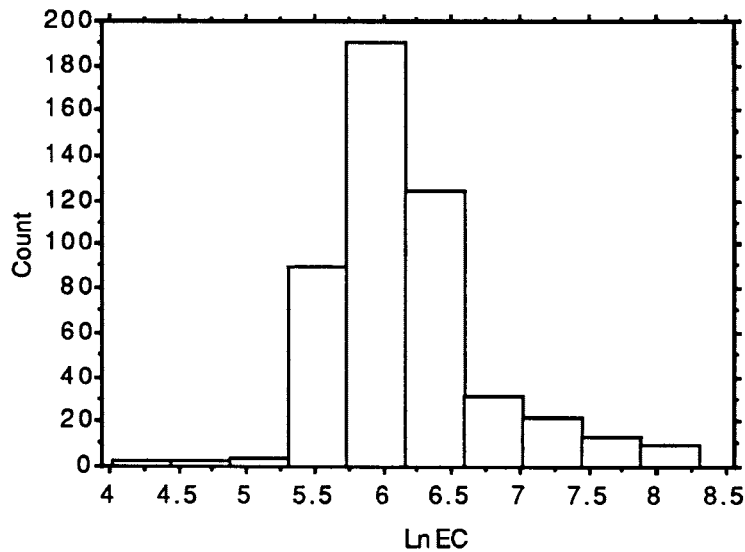


FIGURE A1.5, NORMALITY DISTRIBUTION OF PH DATA, SMELTERVILLE FLATS, 1990 STUDY PERIOD

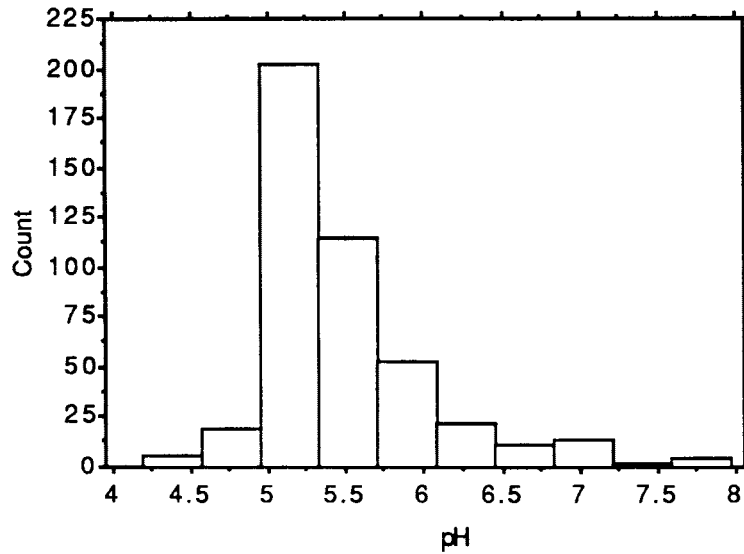


FIGURE A1.6, NORMALITY DISTRIBUTION OF THE NATURAL LOG OF PH DATA, SMELTERVILLE FLATS, 1990 STUDY PERIOD

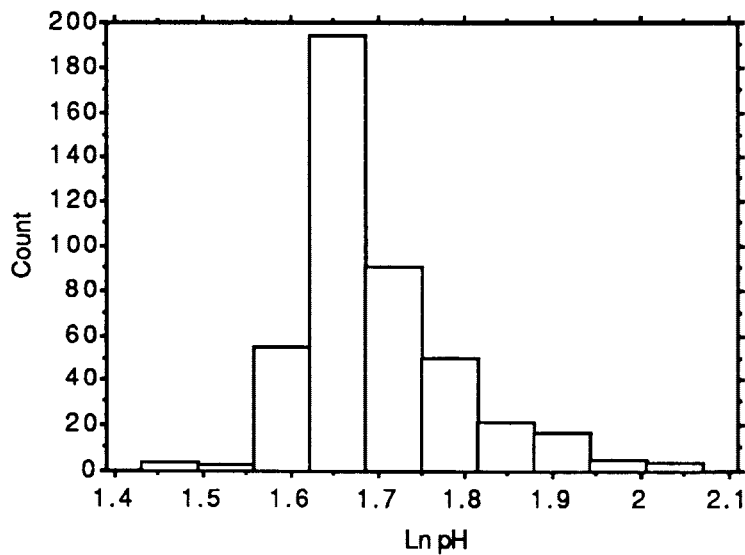


FIGURE A1.7, NORMALITY DISTRIBUTION FOR WATER TEMPERATURE,
SMELTERVILLE FLATS, 1990 STUDY PERIOD

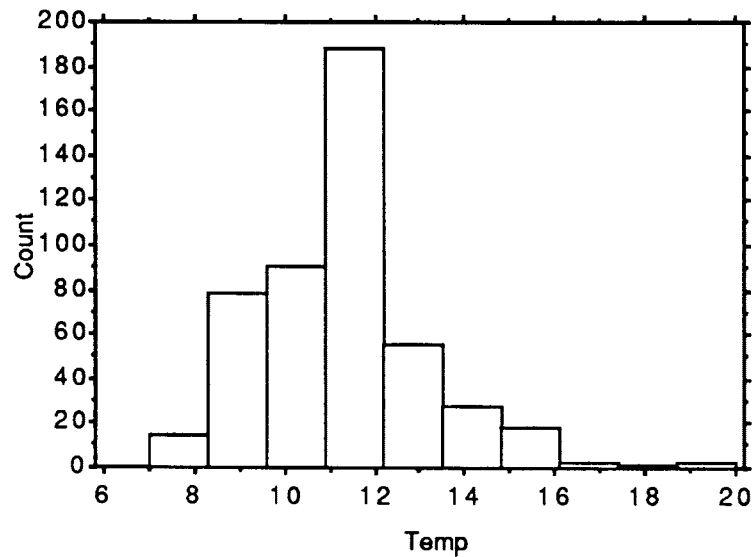
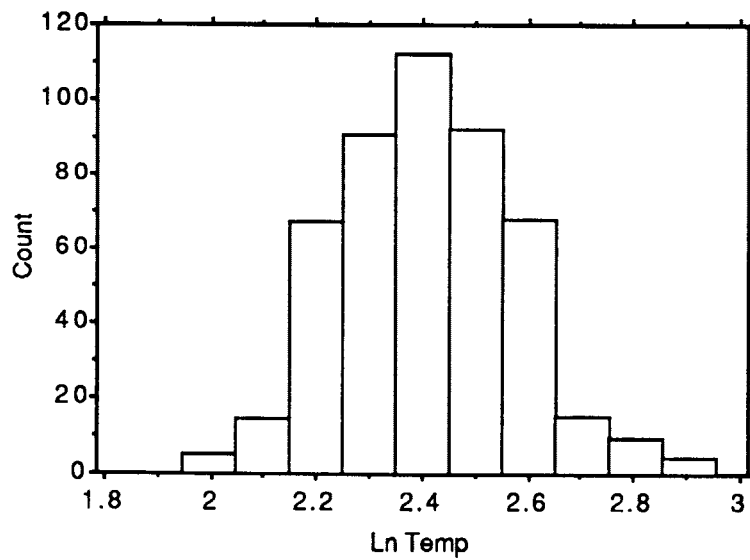


FIGURE A1.8, NORMALITY DISTRIBUTION OF THE NATURAL LOG OF WATER
TEMPERATURE, SMELTERVILLE FLATS, 1990 STUDY PERIOD



APPENDIX 2, ELEMENTAL CONCENTRATION DATA

TABLE A2.1, ALUMINUM CONCENTRATIONS IN MG/L , SHALLOW WELLS

Shallow Wells	BLM 1C	BLM 2C	BLM 3C	BLM 4C	BLM 5C	BLM 6C	BLM 7C	BLM 8C	BLM 9C	BLM 10C
26-Jan	1.7		0.6	<0.2	<0.2	1.4	1.3	2.3	1.8	<0.2
2-Feb	2.4		0.6	<0.2		1	1.3	2.3	1.7	<0.2
8-Feb	2.1		0.6		<0.2	0.8	1.2	2	1.6	<0.2
17-Feb	1.7		0.5		<0.2	1	1.2	2.4	1.5	<0.2
23-Feb	2		0.5		<0.2	0.9	1.3	2.2	1.6	<0.2
1-Mar	2				0.2	0.8	1.1	1.9	1.5	<0.2
7-Mar	1.9		0.4		<0.2	0.8	1.2	1.9	1.5	<0.2
16-Mar	1.5		0.3		0.2	0.6	1	1.9	1.3	<0.2
25-Mar	1.5		0.5	0.1	0.5	0.8	1.1	1.8	1.3	0.1
30-Mar	1.5		0.5	0.1	0.4	0.8	1.2	2	1.3	0.1
13-Apr	1.3	1.3	0.4	0.1	0.3	0.7	1	1.6	1.1	0.1
19-Apr	1.3	1.3	0.4	0.1	0.3	0.7	1.1	1.6	1.1	0.2
28-Apr	1.5	0.6	0.6	0.1	0.3	0.7	1.2	2.1	1.5	0.4
4-May	0.6		0.6	0.1		0.8	1	1.7	1.2	0.1
11-May	1.2		0.7	0.1	0.5	0.8	1	1.8	1.1	0.1
27-May	1.1	1.3	0.4	0.1	0.3	0.7	0.9		1	0.1

TABLE A2.2, ALUMINUM CONCENTRATIONS IN MG/L , DEEP WELLS

Deep Wells	BLM 1D	BLM 2D	BLM 3D	BLM 4D	BLM 5D	BLM 6D	BLM 7D	BLM 8D	BLM 9D	BLM 10D
26-Jan	1.9	1.9	0.3	<0.2	0.5	0.3	0.5	1	0.6	0.2
2 Feb	2	2.2	0.3		0.5	0.3	0.4	1	0.6	0.2
8-Feb	1.8	1.9	0.2		0.4	0.2	0.4	1	0.6	0.2
17-Feb	1.8	1.9	<0.2		0.4	0.2	0.3	1.1	0.5	<0.2
23-Feb	1.9	2.1	0.2		0.4	0.2	0.3	1	0.5	<0.2
1-Mar	1.8	1.8			0.4	<0.2	0.3	0.9	0.5	<0.2
7-Mar	1.8	1.9			0.3	<0.2	0.2	0.8	0.3	<0.2
16-Mar		1.8			0.3	<0.2	0.2	0.9	0.4	<0.2
25-Mar	1.6	1.7	0.3	0.1	0.4	0.3	0.4	1	0.6	0.2
30-Mar	1.7	1.8	0.2	0.1	0.4	0.2	0.4	0.9	0.5	0.2
13-Apr	1.5	1.5	0.2	0.1	0.4	0.2	0.4	0.9	0.5	0.2
19-Apr	1.5	1.4	0.2	0.1	0.4	0.2	0.4	0.8	0.4	0.2
28-Apr	1.6	1.6	0.3	0.1	0.4	0.4	0.4	0.9	0.5	0.2
4-May	1.8	1.8	0.3	0.1	0.3	0.1	0.3	0.9	0.4	0.1
11-May	1.5	1.5	0.2	0.1	0.4	0.2	0.4	1	0.5	0.2
27-May	1.4	1.4	0.2	0.1	0.4	0.3	0.4		0.5	0.3

TABLE A2.3, ARSENIC CONCENTRATIONS IN MG/L , SHALLOW WELLS

Shallow Wells	BLM 1C	BLM 2C	BLM 3C	BLM 4C	BLM 5C	BLM 6C	BLM 7C	BLM 8C	BLM 9C	BLM 10C
26-Jan	<.05	Dry	0.05	0.08	<.05	<.05	0.1	0.1	0.06	<.05
2-Feb	<.05	Dry	0.05	0.08	Dry	0.08	<.05	<.05	<.05	0.15
8-Feb	0.1	Dry	0.06	Dry	0.14	0.17	0.05	0.07	0.09	0.11
17-Feb	0.06	Dry	<.05	0.05	<.05	<.05	0.05	0.19	<.05	0.12
23-Feb	0.24	Dry	0.07	0.09	<.05	<.05	0.09	0.05	<.05	0.07
1-Mar	0.12	Dry	Dry	<.05	0.09	0.1	<.05	<.05	0.12	0.2
7-Mar	0.07	Dry	0.15	0.12	0.05	<.05	0.17	<.05	0.07	0.08
16-Mar	0.1	Dry	0.09	0.17	0.05	0.09	<.05	0.13	0.09	0.06
25-Mar	0.05	Dry	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
30-Mar	0.05	Dry	0.05	0.05	0.05	0.05	0.05	<.005	0.05	0.05
13-Apr	0.05	0.05	0.05	0.1	0.05	0.05	0.05	<.005	0.05	0.12
19-Apr	0.08	0.19	0.05	0.11	0.08	0.06	0.05	<.05	0.06	0.11
28-Apr	0.24	0.29	0.29	0.22	0.24	0.11	0.25	<.05	0.23	0.23
4-May	0.19	Dry	0.19	0.09	0.11	0.05	0.08	0.05	0.05	0.19
11-May	0.07	Dry	0.05	0.11	0.21	0.05	0.07	0.05	0.24	0.05
27-May	0.05	0.05	0.05	0.05	0.22	0.05	0.05		0.05	0.05

TABLE A2.4, ARSENIC CONCENTRATIONS IN MG/L , DEEP WELLS

Deep Wells	BLM 1D	BLM 2D	BLM 3D	BLM 4D	BLM 5D	BLM 6D	BLM 7D	BLM 8D	BLM 9D	BLM 10D
26-Jan	<.05	<.05	0.05	<.05	<.02	0.11	0.14	<.04	0.05	<.05
2 Feb	<.05	<.05	<.05	<.05	<.02	<.05	<.05	<.04	0.07	0.17
8-Feb	0.15	0.21	0.11	0.05	0.08	0.08		0.11	0.12	0.16
17-Feb	<.05	<.05	0.14	0.12	0.18	0.14	0.21	0.06	0.15	<.05
23-Feb	0.22	0.13	<.05	<.05	<.02	0.09	<.05	0.12	<.05	0.12
1-Mar	0.05	0.07	<.05	<.05	<.002	0.14	0.14	0.08	<.05	0.13
7-Mar	<.05	0.06	0.08	<.05	0.11	0.07	<.05	0.12	0.11	0.18
16-Mar	<.05	0.05	<.05	<.05	0.14	<.05	<.05	<.04	<.05	<.05
25-Mar	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
30-Mar	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.07	0.05	0.05
13-Apr	0.05	0.05	0.07	0.05	0.08	0.06	0.05	0.09	0.09	0.05
19-Apr	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.07	0.05	0.05
28-Apr	0.23	0.2	0.14	0.19	0.21	0.12	0.15	0.05	0.23	0.15
4-May	0.05	0.05	0.05	0.16	0.1	0.21	0.09	0.09	0.08	0.05
11-May	0.11	0.05	0.13	0.12	0.05	0.05	0.08	0.16	0.16	0.07
27-May	0.05	0.08	0.12	0.19	0.05	0.05	0.05		0.05	0.07

TABLE A2.5, CALCIUM CONCENTRATIONS IN MG/L , SHALLOW WELLS

Shallow Wells	BLM 1C	BLM 2C	BLM 3C	BLM 4C	BLM 5C	BLM 6C	BLM 7C	BLM 8C	BLM 9C	BLM 10C
26-Jan	105		74.1	73.2	100	73.8	79.5	120	116	182
2-Feb	130		71.2	69.4		67.4	72.9	108	88.2	186
8-Feb	129		64.4		102	63.5	73.7	105	93.3	173
17-Feb	117		61.6	64	88.4	67	78.8	95.4	100	166
23-Feb	112		61.1	55.2	89.3	68.2	74.6	99.7	85.8	142
1-Mar	119			61.6	89.1	60.7	66.9	92.7	81.9	123
7-Mar	114		57.3	54.9	82.5	65	77.3	100	89.3	144
16-Mar	105		57.5	53.5	89.5	63.9	66.1	97	78.9	132
25-Mar	94		53.1	52.3	78.6	56.6	68.7	91.8	76.1	0.2
30-Mar	81.5		42.1	18.9	61.2	50.4	59	81.4	56.5	0.1
13-Apr	73.5	66.5	40.3	51.5	49.7	49.6	54.9	57.9	59.9	107
19-Apr	76.4	65.7	40.1	49.5	45.7	46.8	55.1	72	56.7	100
28-Apr	70.9	61.2	30.4	43.3	36.7	44.4	44.3	62.4	41.4	85.3
4-May	59.6		32.3	44.7	36.2	42.2	45.2	62.9	39.3	106
11-May	43.9		25.8	40.9	36	32	37.1	55.4	36.7	80.8
27-May	37.2	40.2	25.1	36.3	42	28.3	32.9		35.3	89

TABLE A2.6, CALCIUM CONCENTRATIONS IN MG/L, DEEP WELLS

Deep Wells	BLM 1D	BLM 2D	BLM 3D	BLM 4D	BLM 5D	BLM 6D	BLM 7D	BLM 8D	BLM 9D	BLM 10D
26-Jan	100	92	59.3	41.6	63.6	57.6	62.5	74.4	65.8	57.8
2-Feb	93.9	93.3	56.2	48.2	61	57.1	58.1	73.6	63.6	58.4
8-Feb	96	99.4	56.5	48.6	62.9	57.2	62.1	77.6	64.1	59.6
17-Feb	98.7	99.6	55.4	45.8	55.7	50.3	51.7	68.5	55.5	48.4
23-Feb	96.3	90.4	48.7	45.6	58.9	53.4	0.05	71.9	61.2	55.7
1-Mar	86.8	84.8	47.2	41.9	54	56.4	61.2	77.5	63.4	54.3
7-Mar	86.2	93.3	48	42.6	55.2	53.3	54.8	79.9	59.6	53.1
16-Mar		95.8	46.4	40.2	54.9	46.9	53.4	68	52.8	49.3
25-Mar	80.4	81.3	42.6	36.5	51.3	43.4	51.5	63.3	50.4	43.4
30-Mar	72.3	72.4	46.1	36.3	49.5	43.2	47.5	65	50.6	43.9
13-Apr	67.4	64.6	27.4	28.7	41	35.7	41	54.9	41.3	33.4
19-Apr	66.2	62.8	35	26.8	37.8	33.4	39.9	52.5	40.3	32.4
28-Apr	58.5	50.4	23.9	22.9	28.7	24.9	30.9	41.3	28.3	23.6
4-May	57.9	48.2	32.1	24.4	34.4	30.8	34.4	45.7	34.9	29.3
11-May	44.6	43.9	23.6	18.5	26.9	23.7	26.6	35.9	26.8	23.1
27-May	40.9	39.8	20.5	17	25.4	22.4	25.6		26.4	22

TABLE A2.7, CHROMIUM CONCENTRATIONS IN MG/L , SHALLOW WELLS

Shallow Wells	BLM 1C	BLM 2C	BLM 3C	BLM 4C	BLM 5C	BLM 6C	BLM 7C	BLM 8C	BLM 9C	BLM 10C
26-Jan	0.13		0.12	0.09	0.11	0.09	0.03	0.11	0.07	0.19
2-Feb	0.06		0.1	0.04		0.06	0.13	0.11	0.09	0.18
8-Feb	0.17		0.14		0.05	0.11	0.07	0.09	0.11	0.2
17-Feb	0.15		0.11	0.04	0.14	0.07	0.09	0.07	0.07	0.24
23-Feb	0.14		0.12	0.02	0.18	0.14	0.03	0.09	0.08	0.17
1-Mar	0.12			0.1	0.07	0.05	0.06	0.12	0.05	0.11
7-Mar	0.1		0.07	0.06	0.1	0.06	0.08	0.08	0.06	0.15
16-Mar	0.13		0.1	0.03	0.08	0.09	0.08	0.11	0.05	0.12
25-Mar	0.02		0.01	0.02	0.03	0.03	0.03	0.01	0.01	0.1
30-Mar	0.01		0.02	0.03	0.06	0.01	0.05	0.01	0.04	0.07
13-Apr	0.05	0.01	0.02	0.08	0.06	0.04	0.07	0.05	0.08	0.05
19-Apr	0.02	0.04	0.02	0.11	0.01	0.06	0.05	0.04	0.06	0.02
28-Apr	0.06	0.04	0.03	0.12	0.04	0.01	0.05	0.03	0.04	0.02
4-May	0.04		0.02	0.08	0.01	0.04	0.03	0.02	0.01	0.08
11-May	0.04		0.01	0.04	0.05	0.07	0.05	0.07	0.05	0.04
27-May	0.01	0.06	0.02	0.07	0.08	0.04	0.05		0.08	0.12

TABLE A2.8, CHROMIUM CONCENTRATIONS IN MG/L , DEEP WELLS

Deep Wells	BLM 1D	BLM 2D	BLM 3D	BLM 4D	BLM 5D	BLM 6D	BLM 7D	BLM 8D	BLM 9D	BLM 10D
26-Jan	0.08	0.09	0.1	0.04	0.08	0.08	0.1	0.07	0.11	0.07
2 Feb	0.08	0.06	0.09	0.02	0.05	0.08	0.07	0.08	0.09	0.07
8-Feb	0.12	0.12	0.06	0.06	0.02	0.09	0.09	0.07	0.07	0.09
17-Feb	0.12	0.1	0.1	0.07	0.08	0.1	0.1	0.1	0.07	0.06
23-Feb	0.07	0.07	0.07	0.11	0.11	0.05	0.05	0.09	0.1	0.12
1-Mar	0.08	0.05	0.04	<.02	0.05	0.09	0.08	0.02	0.05	0.09
7-Mar	0.1	0.06	0.08	0.04	0.09	0.09	<.02	0.1	0.1	0.09
16-Mar		0.1	0.06	0.06	0.04	0.06	0.1	0.06	0.03	0.06
25-Mar	0.02	0.04	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.01
30-Mar	0.07	0.05	0.02	0.06	0.02	0.03	0.03	0.03	0.03	0.03
13-Apr	0.05	0.03	0.03	0.01	0.03	0.03	0.04	0.06	0.03	0.01
19-Apr	0.04	0.03	0.01	0.02	0.03	0.01	0.01	0.02	0.03	0.01
28-Apr	0.03	0.02	0.03	0.01	0.01	0.03	0.01	0.01	0.01	0.01
4-May	0.01	0.03	0.03	0.01	0.02	0.01	0.01	0.04	0.02	0.01
11-May	0.01	0.06	0.04	0.04	0.02	0.03	0.05	0.03	0.04	0.05
27-May	0.04	0.04	0.03	0.03	0.01	0.03	0.05		0.01	0.01

TABLE A2.9, COPPER CONCENTRATIONS IN MG/L , SHALLOW WELLS

Shallow Wells	BLM 1C	BLM 2C	BLM 3C	BLM 4C	BLM 5C	BLM 6C	BLM 7C	BLM 8C	BLM 9C	BLM 10C
26-Jan	<.02		<.02	<.02	<.02	<.02	<.02	0.03	0.03	<.02
2-Feb	<.02		<.02			<.02	<.02	<.02	<.02	<.02
8-Feb	<.02		<.02		0.03	<.02	<.02			<.02
17-Feb	<.02		<.02		<.02	<.02	<.02	0.03		<.02
23-Feb	0.06		<.02		0.09	0.02	<.02	0.03		<.02
1-Mar	<.02				<.02	<.02	<.02	<.02		<.02
7-Mar	<.02		<.02		<.02	<.02	<.02	<.02		<.02
16-Mar	0.06		0.07	0.03	0.05	0.04	0.03	<.02	0.03	0.03
25-Mar	0.04		0.01	0.01	0.05	0.01	0.03	0.01	0.01	0.01
30-Mar	0.01		0.02	0.01	.01	0.01	0.02	0.01	0.03	0.01
13-Apr	0.03	0.03	0.01	0.01	0.04	0.02	0.01	0.01	0.02	0.01
19-Apr	0.08	0.09	0.08	0.08	0.09	0.05	0.06	0.08	0.06	0.06
28-Apr	0.07	0.07	0.07	0.08	0.08	0.05	0.06	0.06	0.06	0.06
4-May	0.01		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
11-May	0.05		0.07	0.04	0.08	0.04	0.04	0.04	0.05	0.02
27-May	0.07	0.03	0.02	0.03	0.04	0.03	0.04		0.03	0.03

TABLE A2.10, COPPER CONCENTRATIONS IN MG/L , DEEP WELLS

Deep Wells	BLM 1D	BLM 2D	BLM 3D	BLM 4D	BLM 5D	BLM 6D	BLM 7D	BLM 8D	BLM 9D	BLM 10D
26-Jan	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02
2 Feb	<.02	<.02			<.02	<.02		<.02	<.02	<.02
8-Feb	<.02	<.02			<.02	<.02		<.02	<.02	<.02
17-Feb	<.02	<.02	0.03	0.04	0.05	0.04	0.05	0.06	0.02	0.03
23-Feb	<.02	<.02			<.02	<.02	0.4	<.02	<.02	<0.0 2
1-Mar	<.02	<.02			<.02	<.02		<.02	<.02	<.02
7-Mar	<.02	<0.0 2			<.02	<.02		0.09	0.07	0.04
16-Mar		<.02			<.02	<.02		<.02	<.02	
25-Mar	0.01	0.01	0.01	0.03	0.01	0.01	0.01	0.01	0.03	0.01
30-Mar	0.01	0.01	0.02	0.01	0.01	0.01	0.03	0.01	0.02	0.02
13-Apr	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.01
19-Apr	0.05	0.03	0.04	0.04	0.02	0.05	0.03	0.02	0.04	0.03
28-Apr	0.07	0.06	0.05	0.01	0.04	0.01	0.01	0.01	0.01	0.01
4-May	0.01	0.01	0.05	0.05	0.05	0.06	0.03	0.04	0.01	0.02
11-May	1.1	0.05	0.03	0.04	0.03	0.05	0.05	0.04	0.05	0.03
27-May	0.03	0.03	0.01	0.03	0.06	0.03	0.04		0.03	0.04

TABLE A2.11, POTASSIUM CONCENTRATIONS IN MG/L , SHALLOW WELLS

Shallow Wells	BLM 1C	BLM 2C	BLM 3C	BLM 4C	BLM 5C	BLM 6C	BLM 7C	BLM 8C	BLM 9C	BLM 10C
26-Jan	3.1		1.5	1.2	8.5	1.8	1.7	4.2	2.9	3.3
2-Feb	3.4		1.6	0.7		1.8	2.5	3.8	1.9	3
8-Feb	3.6		1.6		9.6	1.9	2.1	4.6	2.2	3.7
17-Feb	4		2.1	0.7	7.5	1.8	2.3	3.2	2.9	3
23-Feb	7.7		6.4	3	10.7	2.5	3.8	3.7	3	5.7
1-Mar	4.9			1.7	6.7	4.5	3.9	4.8	3.9	4.8
7-Mar	5.1		4.6	2.8	8.7	3.4	4	5.9	5.1	5
16-Mar	3.5		4	2.9	6.5	2.7	2.9	2.9	2.6	3.5
25-Mar	6.9		4.7	4.3	8.7	5.3	4.8	7.6	5.5	7.1
30-Mar	6.3		4.6	3.3	7.5	5.3	5.3	7	6	9.3
13-Apr	6.6	5	4	3.5	7.6	4.5	4.3	5.8	5.4	6
19-Apr	6.7	5.6	4.3	3.5	6.1	4.7	4.3	6.5	4.6	4.9
28-Apr	6.8	7.7	3.8	4.4	6.3	4.7	5	6.6	4.6	5.3
4-May	7.8		4.4	4.1	6	5.5	3.3	4.3	2.4	4.1
11-May	4.5		3.2	2.3	5.1	3	3.4	5.2	3.4	3.7
27-May	7.3	5.7	4.3	3.8	7.3	3.9	3		3.1	4.8

TABLE A2.12, POTASSIUM CONCENTRATIONS IN MG/L , DEEP WELLS

Deep Wells	BLM 1D	BLM 2D	BLM 3D	BLM 4D	BLM 5D	BLM 6D	BLM 7D	BLM 8D	BLM 9D	BLM 10D
26-Jan	2.9	3.6	0.9	0.9	1.6	1.3	1.9	2.4	1.9	1.1
2 Feb	3	3.2	0.7	0.6	1.6	1.5	0.8	2.3	1.8	1
8-Feb	4.2	3.5	0.9	1.1	1.5	1.5	1	2.8	2.1	0.4
17-Feb	4.6	3.6	1.7	0.6	1.2	0.6	1	2.4	1.8	1.3
23-Feb	4.5	4.8	0.5	4.4	6.9	1.2	3.3	2.4	3.9	3.8
1-Mar	6.5	9.9	4	2.9	2.7	22.7	2.7	3.2	2.9	2.6
7-Mar	5.3	9.2	3	1.9	2.3	2.5	3.3	3.1	1.3	2.8
16-Mar		10.6	2.4	1	2.7	3.2	3.2	3.4	3.5	1.7
25-Mar	6.9	5.5	3.8	3.1	5.3	3.7	4	4.1	3.9	3.6
30-Mar	7.2	6.4	4.1	3.8	4	3.6	4.5	5.3	4.8	3.2
13-Apr	5.7	5.1	3.6	3.4	3.6	3.3	3.3	4.4	4.3	2.1
19-Apr	5.8	6.3	1.9	1.8	3.9	3.7	2.5	3.9	3.5	1.9
28-Apr	5.3	4.9	3.1	2.5	3.8	3	3.4	3.9	3.3	3.2
4-May	5.7	7.7	4	4.1	4.6	1.5	2.1	2.9	2.4	1.3
11-May	4.3	3.7	2.1	1.3	2.1	2	2.4	3.4	3	1.6
27-May	6	6	3.8	2.7	4.5	3.2	1.7		2.4	2.3

TABLE A2.13, MAGNESIUM CONCENTRATIONS IN MG/L , SHALLOW WELLS

Shallow Wells	BLM 1C	BLM 2C	BLM 3C	BLM 4C	BLM 5C	BLM 6C	BLM 7C	BLM 8C	BLM 9C	BLM 10C
26-Jan	69.4		39.7	71.1	83.9	39.6	65.9	48.7	66.2	180
2-Feb	87.0		37.9	69.5		36.1	63.7	44.5	46.3	180
8-Feb	91.0		36		81.4	38.5	56.1	48.5	53.1	174
17-Feb	84.3		34.8	67.2	99.4	40.6	63.6	44.4	64.5	162
23-Feb	76.3		34.9	59.8	86.7	37	56.4	41.9	52.3	140
1-Mar	74.5			61	52.9	38.8	56.8	45.8	54.6	136
7-Mar	71.0		29.9	52.9	50.7	34.3	49.7	43.3	51	129
16-Mar	68.8		31.9	57.9	48.9	38	52.3	43.2	50.5	145
25-Mar	72.6		34.9	69.6	53.3	42	58.3	52.8	52.1	151
30-Mar	62.2		32.8	68.2	41.5	38.8	53.4	52.8	47.4	109
13-Apr	57.0	42	28.8	95.8	33.5	34.4	45.7	47.4	43.6	69.9
19-Apr	59.8	43.3	29.4	114.	22.6	34.2	42	41.2	36.8	58.7
28-Apr	48.7	15.9	28.4	100	27	29.5	37.7	39.3	34.4	52.8
4-May	25.7		24.9	78.6	28	29.1	38.4	38.4	33.6	72.5
11-May	44.4		23.1	87.2	30.7	27.5	37.7	39.7	31.3	57.9
27-May	35.2	30.6	23.1	95.7	35.5	25.6	33.2		31.3	90.2

TABLE A2.14, MAGNESIUM CONCENTRATIONS IN MG/L , DEEP WELLS

Deep Wells	BLM 1D	BLM 2D	BLM 3D	BLM 4D	BLM 5D	BLM 6D	BLM 7D	BLM 8D	BLM 9D	BLM 10D
26-Jan	38.4	35.4	31.5	18.1	31.7	30	32.1	35.8	31.8	29.2
2 Feb	36.9	35.5	30.1	21.5	31.2	30.1	30	36.7	33.4	31.6
8-Feb	39.3	39.4	32.2	22.5	33.8	30.8	32.5	36	34.8	31.4
17-Feb	38.6	37	32.1	21.8	31.4	27.2	27.9	33.1	29.1	26.8
23-Feb	37.2	34.6	28.7	20.3	31	28.1	29.3	33.9	31.8	29.2
1-Mar	38.3	36.4	29.4	22.1	32.1	28.5	30.5	34.7	30.9	28
7-Mar	36.8	34.2	25.3	20.6	29	26.5	28.3	34	29.2	26.9
16-Mar		40.6	29.3	20.3	32.8	26.6	32.1	35.6	30.4	28.6
25-Mar	41.9	40.3	30.8	21.1	32.7	29.3	31.6	35.9	32.6	29
30-Mar	40.7	39.3	31.9	21.8	32	28.8	31.6	36.1	31	27.6
13-Apr	35.7	34.2	26.6	17.9	28.2	24.5	27.6	33.5	27.6	23.9
19-Apr	34.7	28.7	21.5	14.4	24.2	20.8	24.1	28.4	23	19.8
28-Apr	27.9	27.7	21.4	15.5	23.4	21	23.7	28.2	23	19.9
4-May	29	28	24	15.8	24.3	22	23.9	28.1	23.9	21
11-May	28.5	27.4	20.4	13.7	22	19.3	21.7	26.4	21.9	18.8
27-May	26.9	25.6	19.1	14.6	22.2	16.6	18.8		18.8	15.6

TABLE A2.15, MANGANESE CONCENTRATIONS IN MG/L , SHALLOW WELLS

Shallow Wells	BLM 1C	BLM 2C	BLM 3C	BLM 4C	BLM 5C	BLM 6C	BLM 7C	BLM 8C	BLM 9C	BLM 10C
26-Jan	24.7		2.57	18.8	56.6	0.3	2.02	6.38	22.6	99.0
2-Feb	25.7		0.86	18.7		0.34	2.12	7.18	8.53	105
8-Feb	29.5		0.67		52.6	0.22	2.07	8.08	10.8	96.2
17-Feb	25.4		0.87	16.0	43.4	0.25	2.14	6.54	18.5	86.6
23-Feb	29.9		0.76	15.5	46.0	2.5	2.18	6.94	14.3	81.7
1-Mar	27.9			15.1	27.7	0.27	2.33	7.16	15.1	82.8
7-Mar	28.7		0.84	14.9	29.3	0.25	2.19	6.42	12.3	57.5
16-Mar	24.1		0.66	14.5	23.5	0.2	2.22	6.73	14.1	77.8
25-Mar	16.2		0.35	10.0	15.8	0.15	1.6	4.43	7.26	55.2
30-Mar	13.9		0.28	0.46	12.7	0.16	1.62	4.91	7.07	42
13-Apr	18.6	4.36	0.55	9.29	9.91	0.23	2.02	5.12	8.25	27.0
19-Apr	18.5	4.27	0.55	3.58	9.41	0.24	2	5.23	7.86	23.6
28-Apr	13.1	4.21	0.92	2.32	6.79	0.18	1.59	4.07	5.39	18.9
4-May	4.09		0.3	9.35	8.8	0.16	1.45	4.42	5.09	29.3
11-May	11.4		0.28	10.6	9.31	0.13	1.46	4.36	4.2	18.8
27-May	9.22	3.17	0.47	2.44	13.0	0.13	1.27		5.2	20.7

TABLE A2.16, MANGANESE CONCENTRATIONS IN MG/L , DEEP WELLS

Deep Wells	BLM 1D	BLM 2D	BLM 3D	BLM 4D	BLM 5D	BLM 6D	BLM 7D	BLM 8D	BLM 9D	BLM 10D
26-Jan	4.38	4.89	0.17	0.31	0.16	0.11	0.11	1.06	0.24	0.29
2 Feb	4.35	4.88	0.17	0.8	0.15	0.09	0.09	1.38	0.25	0.02
8-Feb	4.13	4.77	0.11	0.8	0.11	0.07	0.2	1.38	0.26	0.03
17-Feb	4.25	4.75	0.09	0.53	0.21	0.08	0.06	1.57	0.27	0.15
23-Feb	4.05	4.73	0.17	0.31	0.29	0.09	0.07	1.37	0.19	0.42
1-Mar	4.28	5.05	0.12	0.35	0.18	0.11	0.11	1.56	0.27	0.21
7-Mar	4.08	4.93	0.07	0.17	0.29	0.08	0.07	1.63	0.18	0.55
16-Mar		4.73	0.22	0.2	0.21	0.1	0.08	1.35	0.21	0.36
25-Mar	2.9	3.22	0.05	0.07	0.13	0.05	0.06	1.07	0.14	0.33
30-Mar	3.08	3.43	0.08	0.13	0.18	0.06	0.1	1.48	0.19	0.29
13-Apr	3.57	3.72	0.07	0.04	0.08	0.04	0.09	1.34	0.16	0.01
19-Apr	3.45	3.44	0.05	0.03	0.16	0.05	0.11	1.29	0.18	0.15
28-Apr	2.73	2.73	0.11	0.03	0.09	0.05	0.06	0.99	0.13	0.11
4-May	2.48	2.62	0.07	0.06	0.07	0.04	0.04	0.99	0.09	0.04
11-May	2.52	2.63	0.08	0.02	0.03	0.01	0.02	0.89	0.1	0.01
27-May	2.41	2.43	0.08	0.07	0.19	0.04	0.09		0.23	0.66

TABLE A2.17, SODIUM CONCENTRATIONS IN MG/L , SHALLOW WELLS

Shallow Wells	BLM 1C	BLM 2C	BLM 3C	BLM 4C	BLM 5C	BLM 6C	BLM 7C	BLM 8C	BLM 9C	BLM 10C
26-Jan	26.5		8.3	9.6	513.	8.1	21.8	8.4	10	52.6
2-Feb	22.9		7.8	6.5		7	20.4	8.2	7	16.1
8-Feb	30.3		8		503	8	18.4	9.4	8.7	18.3
17-Feb	23		7.5	5.5	424	1.8	17.3	7.7	8.6	21.5
23-Feb	21.		7.4	4.5	376	7.3	13.3	7.4	7.7	35.5
1-Mar	21.5			4.1	181	7.6	16.4	8.4	8.1	20.2
7-Mar	21.2		6.5	4.8	170.	6.7	9.8	7.7	8.4	21.4
16-Mar	14.3		6	3.5	103.	6.4	12.7	6.7	6.6	27.1
25-Mar	21.1		7.7	4.9	136	8.7	10.2	9.7	9.3	37.4
30-Mar	13.9		8.4	4.8	90.8	8	9.3	2	8.9	14.2
13-Apr	21.0	9.4	6.9	3.2	66.6	7.6	8.7	9.7	8.6	11
19-Apr	20.4	8.6	6.9	3.7	58.4	7.4	7	8.8	7.4	9.4
28-Apr	20.4	9.2	5.9	5	50.3	7.6	6.7	9	6.7	11.8
4-May	20.5		6.6	3.5	65.9	7	8.1	8.5	6.2	16.9
11-May	8.20		3.4	2.6	31.4	3.5	3.7	4.9	3.7	6.4
27-May	7.80	4	2.9	2.2	51.7	3.3	3.8		3.7	17.2

TABLE A2.18, SODIUM CONCENTRATIONS IN MG/L , DEEP WELLS

Deep Wells	BLM 1D	BLM 2D	BLM 3D	BLM 4D	BLM 5D	BLM 6D	BLM 7D	BLM 8D	BLM 9D	BLM 10D
26-Jan	9.1	9.4	7	26	6.7	7.2	7.8	8.1	7.4	7.4
2-Feb	9	8.4	7.1	7.4	7.1	7.1	7.2	9.3	7.9	7.9
8-Feb	10.2	9.9	7.2	10.4	7.8	7.3	7.9	8.3	7.9	7.4
17-Feb	9.3	8.7	7.6	6.8	7.1	6.1	6.3	7.1	6.9	6.5
23-Feb	9.2	8.9	6.3	6.3	8	6.6	7	7.8	7.8	7.3
1-Mar	9.3	8.9	6.6	6.2	7.3	6.5	7	8.2	6.9	6.2
7-Mar	9.7	8.3	5.5	5.4	7.3	6	6.6	7	6	5.5
16-Mar		8.8	6	5	6.5	5.7	6.2	6.7	6	5.8
25-Mar	10	10.1	7.1	7.2	8.6	6.9	7.8	8.3	8.5	7
30-Mar	10.2	9.8	6.8	6.8	8	6.4	7.1	8.2	7.6	7.4
13-Apr	9	9.1	6.5	5.7	6.9	6.5	6.9	8	7.4	6.2
19-Apr	9.1	8	5.4	5.9	6.4	5.8	5.7	7	6.2	5.8
28-Apr	8.6	7.3	4.9	5.5	6.4	5.5	5.8	6.9	5.6	5.5
4-May	9	7.6	6.6	4.9	6.2	5.4	6.1	7	5.8	5.3
11-May	4.2	4.3	2.8	3	3.3	2.8	3.3	4	3.4	2.9
27-May	4.1	4.2	2.9	2.5	3.1	2.3	2.5		2.6	2.7

TABLE A2.19, NICKEL CONCENTRATIONS IN MG/L, SHALLOW WELLS

Shallow Wells	BLM 1C	BLM 2C	BLM 3C	BLM 4C	BLM 5C	BLM 6C	BLM 7C	BLM 8C	BLM 9C	BLM 10C
26-Jan	0.12		0.05	0.05	0.23	0.05	0.04	0.05	0.13	0.21
2-Feb	0.16		0.07	<.02		0.04	0.08	0.15	0.03	0.24
8-Feb	0.17		<.02		0.22	0.04	<.02	0.02	0.02	0.04
17-Feb	0.21		<.02		0.13	<.02	<.02	0.03	0.08	0.13
23-Feb	0.15		<.02		0.18	<.02	<.02	0.03	0.06	0.14
1-Mar	0.15				0.09	0.05	<.02	0.07	0.02	0.15
7-Mar	0.27		<.02		0.16	0.06	0.05	0.04	0.12	0.15
16-Mar	0.12		0.06		0.02		0.03	0.09	0.09	0.14
25-Mar	0.03		0.01	0.01	0.05	0.01	0.05	0.01	0.01	0.11
30-Mar	0.05		0.01	0.01	0.01	0.03	0.06	0.01	0.03	0.01
13-Apr	0.15	0.01	0.01	0.02	0.02	0.02	0.02	0.04	0.02	0.07
19-Apr	0.1	0.02	0.01	0.01	0.01	0.01	0.04	0.11	0.08	0.01
28-Apr	0.14	0.05	0.01	0.05	0.06	0.01	0.01	0.02	0.07	0.06
4-May	0.08		0.02	0.01	0.04	0.01	0.01	0.04	0.02	0.04
11-May	0.08		0.03	0.01	0.07	0.03	0.01	0.06	0.05	0.03
27-May	0.06	0.06	0.02	0.01	0.07	0.03	0.05		0.03	0.09

TABLE A2.20, NICKEL CONCENTRATIONS IN MG/L , DEEP WELLS

Deep Wells	BLM 1D	BLM 2D	BLM 3D	BLM 4D	BLM 5D	BLM 6D	BLM 7D	BLM 8D	BLM 9D	BLM 10D
26-Jan	0.03	<.02	0.08	0.1	0.04	0.1	0.09	0.04	<.02	0.07
2 Feb	0.06	0.09	0.08	0.09	<.02	0.04	<.02	<.02	0.06	0.15
8-Feb	0.03	0.03			<.02	<.02		0.1	0.04	0.05
17-Feb	0.05	0.06			<.02	<.02		<.02	<.02	<.02
23-Feb	0.07	<.02			<.02	<.02		<.02	<.02	<.02
1-Mar	<.02	0.02			<.02	<.02	0.03	<.02	<.02	0.03
7-Mar	0.07	0.13	0.1	0.07	0.1	<.02	0.15	0.03	<.02	<.02
16-Mar		<.02		0.04	<.02	<.02	0.02	<.02	0.03	0.02
25-Mar	0.01	0.08	0.01	0.01	0.01	0.01	0.01	0.03	0.01	0.03
30-Mar	0.03	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.02
13-Apr	0.06	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.01
19-Apr	0.08	0.05	0.06	0.01	0.01	0.07	0.01	0.07	0.05	0.01
28-Apr	0.03	0.01	0.01	0.03	0.01	0.01	0.01	0.01	0.01	0.03
4-May	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
11-May	0.02	0.03	0.01	0.01	0.02	0.01	0.04	0.02	0.02	0.02
27-May	0.01	0.02	0.01	0.02	0.01	0.01	0.02		0.01	0.01

TABLE A2.21, ANTIMONY CONCENTRATIONS IN MG/L , SHALLOW WELLS

Shallow Wells	BLM 1C	BLM 2C	BLM 3C	BLM 4C	BLM 5C	BLM 6C	BLM 7C	BLM 8C	BLM 9C	BLM 10C
26-Jan	0.07		0.04	0.12	<.04	0.06	0.07	0.13	0.06	0.21
2-Feb	0.08		0.1	0.04		0.06	<.04	0.12	0.13	0.07
8-Feb	<.04		0.05		0.06	0.07	0.1	<.04	<.04	0.09
17-Feb	0.04		0.07	<.04	0.14	0.08	0.04	0.11	0.04	0.06
23-Feb	0.07		0.09	0.06	0.17	0.13	0.05	0.16		0.13
1-Mar	0.04			0.05	0.1		<.04	<0.4		0.05
7-Mar	<.04		0.07		0.12		0.07	0.08		0.1
16-Mar	0.04		0.15	0.12	0.05	0.05	0.06	0.12	0.06	0.07
25-Mar	0.08		0.08	0.1	0.05	0.06	0.1	0.05	0.05	0.12
30-Mar	0.09		0.05	0.05	0.1	0.05	0.05	0.05	0.09	0.13
13-Apr	0.08	0.05	0.05	0.08	0.07	0.05	0.06	0.05	0.07	0.08
19-Apr	0.09	0.14	0.05	0.15	0.05	0.06	0.05	0.06	0.1	0.09
28-Apr	0.08	0.18	0.06	0.05	0.08	0.05	0.1	0.1	0.07	0.07
4-May	0.07		0.13	0.1	0.07	0.07	0.13	0.15	0.1	0.14
11-May	0.12		0.07	0.15	0.14	0.2	0.06	0.05	0.14	0.01
27-May	0.12	0.07	0.07	0.1	0.07	0.11	0.05		0.05	0.05

TABLE A2.22, ANTIMONY CONCENTRATIONS IN MG/L , DEEP WELLS

Deep Wells	BLM 1D	BLM 2D	BLM 3D	BLM 4D	BLM 5D	BLM 6D	BLM 7D	BLM 8D	BLM 9D	BLM 10D
26-Jan	0.05	<.04	0.09	0.04	0.1	0.04	0.11	0.17	<.04	<.04
2 Feb	0.12	0.06	0.04	0.07		0.16	0.09	0.12	0.08	<.04
8-Feb	0.07	0.1	0.12	0.08	0.08	<.04		0.11	0.06	<.04
17-Feb	<.04	0.11	0.12	0.07	0.12	0.09	0.2	0.21	0.17	0.15
23-Feb	0.06	0.14	0.1	<.04	0.07	0.09		0.13	0.03	0.05
1-Mar	0.1	<.04		0.05	0.08	<.04	0.11	<.04	0.08	0.04
7-Mar	0.09	<.04	0.07	0.07	0.07	<.04		0.08	0.05	0.1
16-Mar		0.07	0.1		0.09	0.08	0.08	0.07	<.04	0.04
25-Mar	0.09	0.09	0.05	0.08	0.1	0.05	0.05	0.05	0.06	0.05
30-Mar	0.05	0.06	0.05	0.05	0.05	0.06	0.05	0.05	0.05	0.05
13-Apr	0.06	0.05	0.05	0.05	0.06	0.05	0.05	0.06	0.05	0.06
19-Apr	0.05	0.07	0.05	0.05	0.07	0.05	0.05	0.05	0.05	0.05
28-Apr	0.09	0.11	0.05	0.05	0.08	0.07	0.06	0.11	0.1	0.07
4-May	0.07	0.14	0.12	0.05	0.06	0.05	0.05	0.09	0.09	0.05
11-May	0.18	0.05	0.07	0.09	0.08	0.05	0.06	0.05	0.06	0.05
27-May	0.06	0.05	0.05	0.05	0.05	0.05	0.07		0.05	0.05

TABLE A2.23, STRONTIUM CONCENTRATIONS IN MG/L , SHALLOW WELLS

Shallow Wells	BLM 1C	BLM 2C	BLM 3C	BLM 4C	BLM 5C	BLM 6C	BLM 7C	BLM 8C	BLM 9C	BLM 10C
26-Jan	0.37		0.26	0.19	0.63	0.25	0.29	0.36	0.34	0.3
2-Feb	1.7		0.26	0.19		0.25	0.29	0.36	0.29	0.28
8-Feb	0.39		0.26		0.6	0.26	0.29	0.38	0.32	0.28
17-Feb	0.34		0.24	0.18	0.59	0.26	0.31	0.35	0.31	0.27
23-Feb	0.34		0.25	0.16	0.53	0.26	0.3	0.35	0.29	0.25
1-Mar	0.33			0.17	0.37	0.24	0.27	0.34	0.28	0.23
7-Mar	0.33		0.23	0.16	0.35	0.25	0.29	0.36	0.31	0.26
16-Mar	0.28		0.2	0.14	0.31	0.24	0.25	0.32	0.25	0.23
25-Mar	0.31		0.22	0.16	0.32	0.26	0.3	0.36	0.29	0.28
30-Mar	0.29		0.21	0.17	0.28	0.25	0.28	0.36	0.27	0.26
13-Apr	0.27	0.29	0.19	0.14	0.23	0.22	0.25	0.33	0.25	0.25
19-Apr	0.28	0.3	0.19	0.12	0.22	0.22	0.23	0.29	0.21	0.22
28-Apr	0.27	0.28	0.16	0.1	0.21	0.21	0.21	0.27	0.19	0.21
4-May	0.25		0.16	0.14	0.2	0.2	0.22	0.28	0.17	0.27
11-May	0.23		0.16	0.17	0.23	0.19	0.22	0.3	0.2	0.25
27-May	0.19	0.23	0.16	0.11	0.28	0.18	0.2		0.2	0.32

TABLE A2.24, STRONTIUM CONCENTRATIONS IN MG/L , DEEP WELLS

Deep Wells	BLM 1D	BLM 2D	BLM 3D	BLM 4D	BLM 5D	BLM 6D	BLM 7D	BLM 8D	BLM 9D	BLM 10D
26-Jan	0.33	0.32	0.21	0.17	0.23	0.22	0.23	0.27	0.24	0.22
2-Feb	0.32	0.33	0.21	0.19	0.23	0.22	0.23	0.29	0.25	0.25
8-Feb	0.36	0.37	0.23	0.21	0.24	0.23	0.24	0.28	0.25	0.24
17-Feb	0.34	0.33	0.23	0.2	0.23	0.21	0.21	0.26	0.23	0.21
23-Feb	0.35	0.34	0.21	0.19	0.23	0.22	0.22	0.27	0.24	0.23
1-Mar	0.33	0.32	0.2	0.18	0.22	0.22	0.23	0.29	0.24	0.22
7-Mar	0.34	0.34	0.19	0.18	0.22	0.2	0.22	0.26	0.2	0.19
16-Mar		0.34	0.18	0.17	0.21	0.19	0.21	0.25	0.21	0.19
25-Mar	0.34	0.34	0.2	0.17	0.22	0.2	0.21	0.27	0.22	0.2
30-Mar	0.34	0.33	0.21	0.17	0.22	0.2	0.21	0.26	0.21	0.19
13-Apr	0.3	0.29	0.17	0.14	0.19	0.17	0.19	0.24	0.19	0.17
19-Apr	0.29	0.25	0.14	0.12	0.16	0.15	0.16	0.21	0.16	0.14
28-Apr	0.27	0.23	0.13	0.13	0.15	0.13	0.15	0.2	0.15	0.13
4-May	0.26	0.23	0.17	0.12	0.16	0.15	0.16	0.21	0.16	0.14
11-May	0.26	0.26	0.15	0.12	0.16	0.15	0.16	0.21	0.16	0.15
27-May	0.25	0.24	0.14	0.13	0.16	0.12	0.14		0.14	0.12