Arkansas Water
Resources Center

RELATIONSHIP BETWEEN GROUND AND SURFACE WATER QUALITY IN KARST SYSTEMS

For

Arkansas Department of Pollution Control & Ecology

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By

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Acknowledgments

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INTRODUCTION

Springs in Northwest Arkansas may originate from relatively small fractures in rock strata or from cave systems. The water emerging from these springs is frequently used as water sources for plants, animals and humans. The quality of the ground water source and the emerging water are uncertain and frequently unknown. In addition, the opportunity to monitor changes in water quality during flow from origin (water entering the cave) to emergence is uncommon. Cave systems with definable drainage basins and accessible sampling points near the midpoint of the cave are also uncommon. Examining the interface between the quality of surface water source and the changes in ground water quality during its traverse to a spring provides valuable information concerning hydrogeological processes.

Logan Cave system is divided into three zones by a rubble pile from the collapsed roof of the cave. The collapsed roof produces an open sinkhole. Zone one is from water entering the cave to the rubble pile. The rubble pile constitutes the second zone. The third zone extends from the rubble pile to the cave mouth. Emphasis is given to the quality of water prior to the calcareous rubble (Zone 1), post rubble (Zone 2) and at the exit of the cave (Zone 3). A wetland or marsh area occurs over the fracture line of the cave. Water may perculate from the marsh into the cave as well as through subterranean movement. Marsh area samples can only be collected if and when water is in the marsh.

The purpose of this monitoring activity is to deteemine if changes in water quality occur during the movement of water through Logan Cave. Sample sites were selected to try to identify changes in water quality within each zone.

SITE DESCRIPTION

Logan Cave, in the karst region of Northwest Arkansas contains a delineated drainage basin, a collapsed roof that forms a sinkhole, and a perennial spring and stream. A detailed description of the geology and drainage basin characteristics are presented by Aley and Aley (1987). A further description of the site and its location is given by Hustead (1992).

A subsidence (open sinkhole) near midpoint of the cave forces a portion of the water to flow under and through a pile of limestone rubble before re-emerging. The sinkhole provides an opening for runoff from rains to enter the cave. Also it provides an opening for gases to escape and for air to be drawn into the cave. The sinkhole/rubble pile divides the underground system into three major zones: 1) inflow upstream of the pile (pre-rubble), 2) the calcareous rubble pile near the mid-point of the cave, and 3) post-rubble to exit. The cave contains a March to October seasonal bat population. These populations roost away from the stream along shelves and crevasses. These populations only contribute nutrients to the stream during their entrance to and egress from the cave. Guano deposits are near the roost areas and may contribute to nutrient loading only during extreme flooding.

Determination of the origin of the water entering the cave is to be determined by other researchers. Of interest was a potential recharge area-a nominally wet or marshy depression known to be over the cave.

METHODS

Four sampling sites were selected for collecting water quality parameters. These sites include: 1) a wet or marshy depression over the cave, 2) cave water upstream of the rubble (Zone 1), 3) cave water immediately downstream of the rubble pile (Zone 2), and 4) the exit stream (Zone 3). The data from Hustead (1992) clearly demonstrates that there is minimal change in water chemistry during its movement 1.2 km down stream. Therefore, water samples were collected a few meters downstream from the cave mouth to avoid disturbing ongoing research activities concerning endangered species studies of the U.S. Fish and Wildlife Service. The potential recharge area of the marsh was lacking free-standing water throughout the sampling period.

Field analysis included: temperature, dissolved oxygen, conductance, and when possible flow rate. Collected water samples were analyzed for turbidity, alkalinity, nitrate-nitrogen, nitrite-nitrogen, ammonia-nitrogen, total

Kjeldahl-nitrogen, soluble reactive phosphate-phosphorus and total phosphate-phosphorus at the Water Quality Laboratory of the Arkansas Water Resources Research Center. A detailed description of the methods are described by Hustead (1992). [Note: A copy of Hustead (1992) has been previously forwarded to the Arkansas Department of Pollution Control and Ecology.] The data are included in electronic format as a Microsoft Excel 4.0 spreadsheet.

Samples were collected prior to the contract period in order to establish a broader data base and to test methodologies. Therefore the data reported below extends beyond and is greater than the information base outlined in the contract. Certain data points are absent when collecting condition were hazardous for safe entry into the cave. Thus, in certain instances data points will be absent for Zone 1 and Zone 2 (pre- and post-rubble) sites.

RESULTS AND DISCUSSION

The results are discussed in association with the several parameters measured. An annual profile of the parameters, based upon data collected near the spring orifice, is presented. Secondly, data collected within the cave and at the cave exit are compared. The data from the marsh could not be included since the extended drought had lowered the water table and no free water was found standing at the marsh site. There was adequate ground water, however, to maintain wetland-type vegetation.

The annual temperature ranged between 13.0 to 15.0°C with a median and mean value of 14.0°C. The standard deviation was only 0.5°C. These data suggest a thermally stable system. Figure 1 for the exit stream (Zone 3) depicts a profile which has little change except for cold rain, high flow (April 14) or warm weather, low flow (July 31 and August 28) conditions. A comparison of temperature changes through the cave (Figure 2) suggests that under high flow conditions temperatures are isothermal and during lower flows that temperatures moderate towards 14°C.

Oxygen at the exit ranges from a low of 4.2 mg/l in March to a high of 10.0 mg/l in November (Figure 3). The annual mean and median values are 7.1 and 7.3 mg/l, respectively. The standard deviation is 1.7 mg/l. Lowest values are noted before the emigration of the bats in October. In general, the oxygen content of the water increases ca. 3.5 mg/l during its traverse downstream from the pre-rubble site to the exit during the summer months (Figure 4). During the winter the values are nearly equal.

Conductivity, a measure of the total dissolved ions, varied from 102 uS/cm to 265 uS/cm (Figure 5) at the cave exit. The mean and median values are nearly equal, 206 and 203 uS/cm, respectively. The standard deviation was 45 uS/cm. Conductivity was nearly equivalent at all sites (Figure 6). This suggests little solubilization of the substrate and/or of guano deposits in the rubble pile to orifice zone.

Annual flow has a maximum rate of 121 cm/sec in mid-April and a minimum of 26 cm/sec at the end of July (Figure 7). The mean and median rates were equivalent; 63 and 60 cm/sec, respectively. The standard deviation was only 23 cm/s. The maximum flow followed an extended period of precipitation followed by intense rains. Flow rate is not reported for the cave stream because of the difficulty in establishing a dependable sampling position. A slight change in depth or lateral position would result in erratically variable results.

The highest turbidity for the exit stream (Zone 3), 8.50 NTU's, was measured on April 14 during the maximum flow rate (Figure 8). The second highest value (3.95 NTU's) was measured during moderate flow rates in September. Most of the time the turbidity was less than 1 NTU. The mean turbidity was 1.56 NTU's while the median was only 0.75 NTU's. The standard deviation was 2.11 NTU's. The cave and exit turbidities were essentially equivalent except for September 18 and February 15 (Figure 9). These outliers may represent substrate disturbance during collection of the sample. The April 14 data suggest that the origin of the turbidity must be upstream from the pre-rubble collection site. This may represent transport of overburden material or resuspension of bottom sediments from the upper cave pools in association with a rain event.

Annual distribution of pH shows a two pH unit range (6.4-8.4) with a maximum in early March and a minimum in late July (Figure 10). In general the pH is stable with nearly equal mean and median, 7.0 and 7.2, respectively. The standard deviation was only 0.5 unit. The pH at all sites varied only within the limits (0.1 pH) of the instruments. Thus, there is no measurable change during the waters traverse through the cave.

Alkalinity values extended over a range of 32 to 112 mg/l (Figure 11). Both mean and median values were near 80; i.e., 85 and 79 mg/l, respectively. The standard deviation was 25 mg/l. Figure 12 depicts the similarity between the alkalinity concentrations at the rubble pile and exit. It is apparent that the rate of solution and/or erosion is not significant. It is possible that the flow rate is too great and/or the residence time too brief to result in a measurable change in concentration from this pile of limestone rubble.

Nitrate-N concentrations for the exit stream (Zone 3) remain relatively stable (approximately 3 mg/l) during the March to October period when active bat colonies are present in the cave (Figure 13). The highest values, 8.29 mg/l, are observed in the fall when the soil is saturated and flow rates are increasing. Background levels of ca. 3.00 mg/l are present throughout most of the year. A minimum of 2.63 mg/l was determined. Mean and median values of 2.89 and 3.92 mg/l, respectively, are near the minimum level. The outliers result in a standard deviation of 1.72 mg/l. In most collections there is no appreciable difference between pre-rubble, post-rubble and exit concentrations (Figure 14). The anomalous results on September 18 and November 3 correspond with increased turbidities. Repetition of analysis produced the same results. These outliers may be a result of erosion. This conclusion is based upon the observed elevated turbidity values on these dates (see Figure 8).

Nitrite-N data are not presented since all values were at or below reliable detection limits.

Soluble reactive phosphorus-P (SRP-P) or ortho-phosphate-P concentrations in the exit stream (Zone 3) are low (Figure 15). Mean and median values are 0.036 and 0.016 mg/l, respectively. The maximum value was 0.096 mg/l while the minimum level was below reliable detection limits (0.001 mg/l). The diverse values resulted in a standard deviation of 0.033 mg/l. The distribution of SRP-P is independent of flow rate, conductivity, nitrate-N, alkalinity and other measured parameters. Further study will be necessary to describe the dynamics of phosphorus in this ecosystem. A comparison of pre- and post-rubble sites indicates that there is no measurable change between these sampling points (Figure 16). Under certain conditions there is no measurable change between the rubble pile and the exit. In certain instances there is a marked increase in SRP-P at the exit. It is unclear what factors or features would result in the observed increase in phosphorus at the stream exit. Most of these anomalies occurred when the bats were present.

If the bats were an important contributor of phosphorus it would be expected that a parallel response would have been observed in nitrate-nitrogen concentration. However, there is no correlation between SRP-P and nitrate-nitrogen concentrations. The data suggests that the dynamics of phosphorus and nitrogen are independent of one another and not interconnected with the bat population. Activities outside of the cave may be a possible source of these nutrients.

Total Phosphate-P and total Kjeldahl nitrogen-N analyses are incomplete because of technical difficulties, field sampling problems, etc. were involved. Therefore sampling and analysis is continuing. When the new data becomes available it will be appended to this report.

CONCLUSIONS

Waters interfacing with the cave environment are not influenced by this interaction. This lack of effect is expressed in the following observations.

1) Temperatures are very stable at the cave orifice with values of ca.$14 \pm 0.5^{o}C$.
2) Temperatures upstream of the rubble pile may be $1^{o}C$ greater than the exit temperatures.
3) Oxygen concentrations extent over a range of 4.2 to 10 mg/l at the orifice with equal or slightly lower values upstream of the rubble pile.

4) Conductivity at the cave mouth have a mid-summer maximum of 265 uS/cm with winter minimums of ca. 150 uS/cm.

5) The conductivity values upstream of the rubble pile are equivalent to those at the orifice.

6) Flow at the orifice seem to be storm event and soil saturation dependent.

7) Turbidity spikes are associated with storm events and the source of turbidity is either from infiltration or the upper cave zone.

8) pH values varied over a narrow range around neutrality at all sites.

9) Although alkalinity values varied during the year, with a broad range from 32 to 112 mg/l, all sites were equal. Therefore alkalinity was not influenced by the water's interface with the cave substrate.

10) Nitrate-N concentrations remained low (ca. 3 mg/l) throughout most of the year. In the winter however values greater than 5 mg/l were measured. The in-cave and orifice value were equivalent throughout the year.

11) SRP was always less than 0.1 mg/l within the cave and at its orifice.

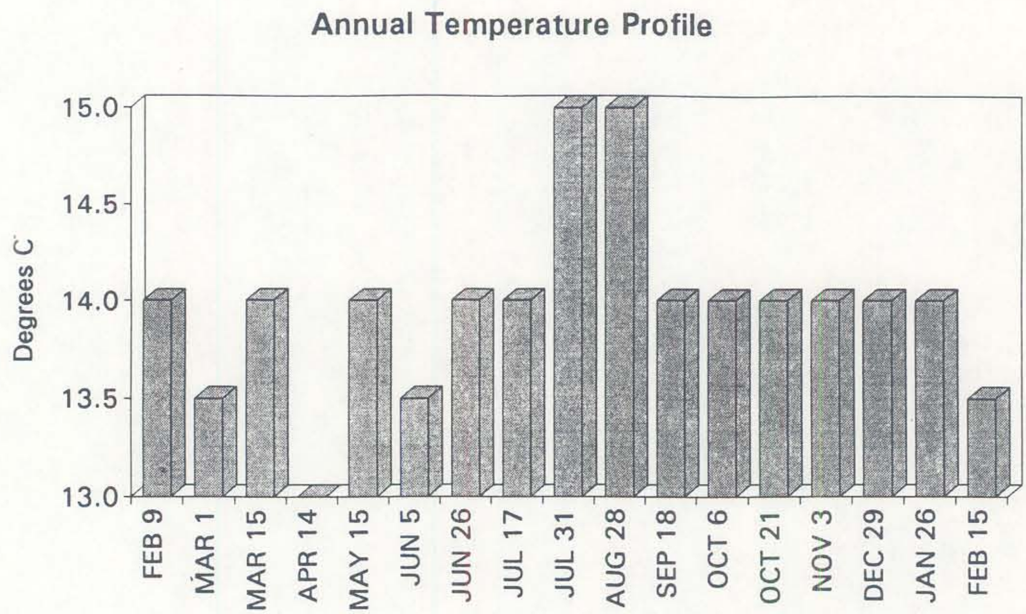
12) Nitrate-N and SRP variations did not correlate.

LITERATURE CITED

Aley, T. and C. Aley, 1987. Water quality protection studies. Logan Cave, Arkansas. Underground Laboratory. Report to Arkansas Game and Fish Commission. Protem, MO. 59pp +app, +maps.

Hustead, Lynda E., 1992. Selection and Monitoring of Steno thermal Algae Assemblages in Logan Cave Springs and its Associated Stream. University of Arkansas Master's in Botany Thesis. 74pp + app.

Figure 1



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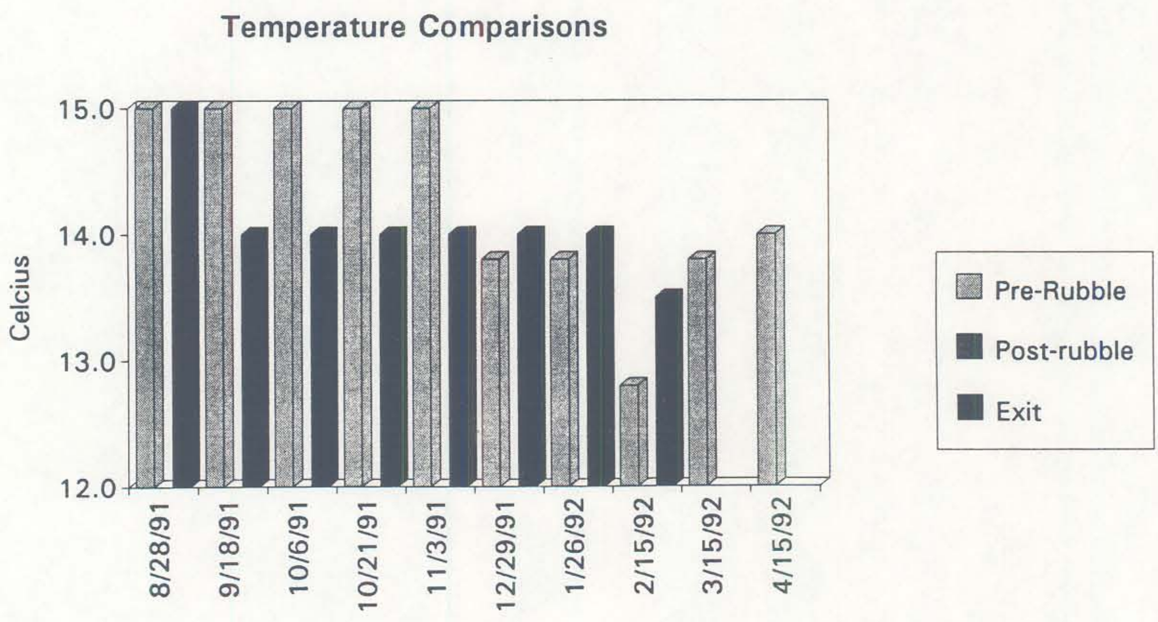

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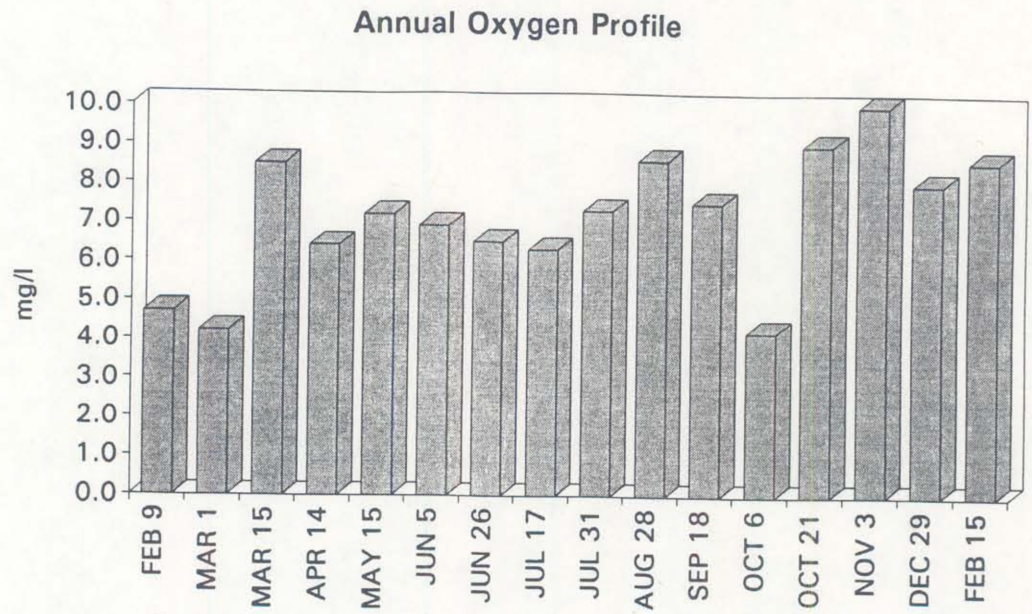

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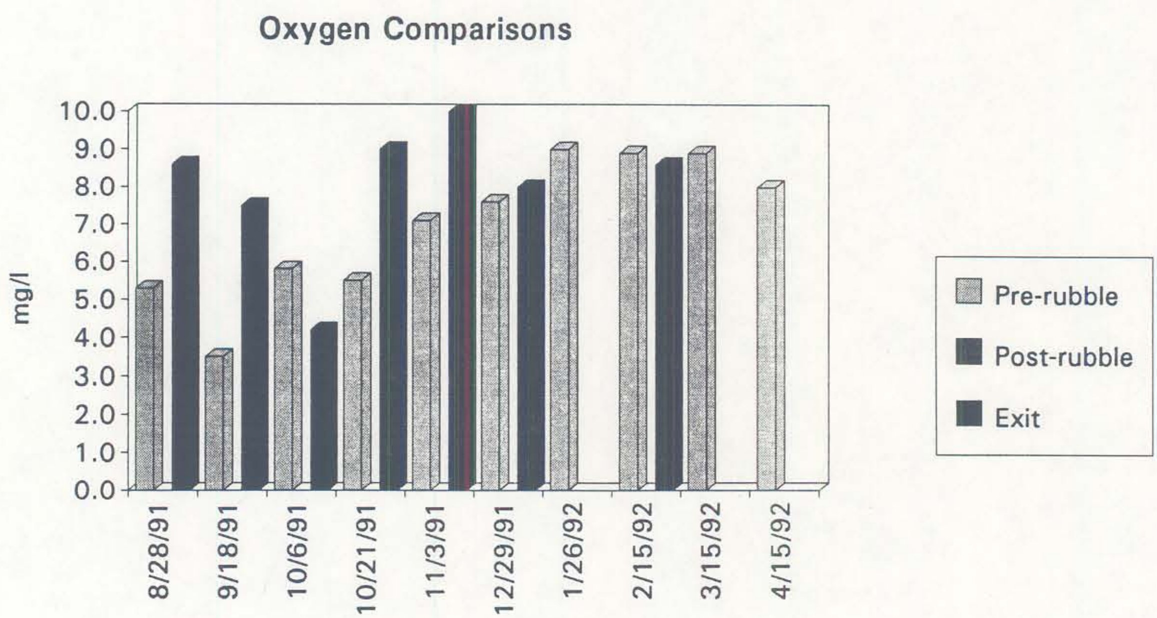

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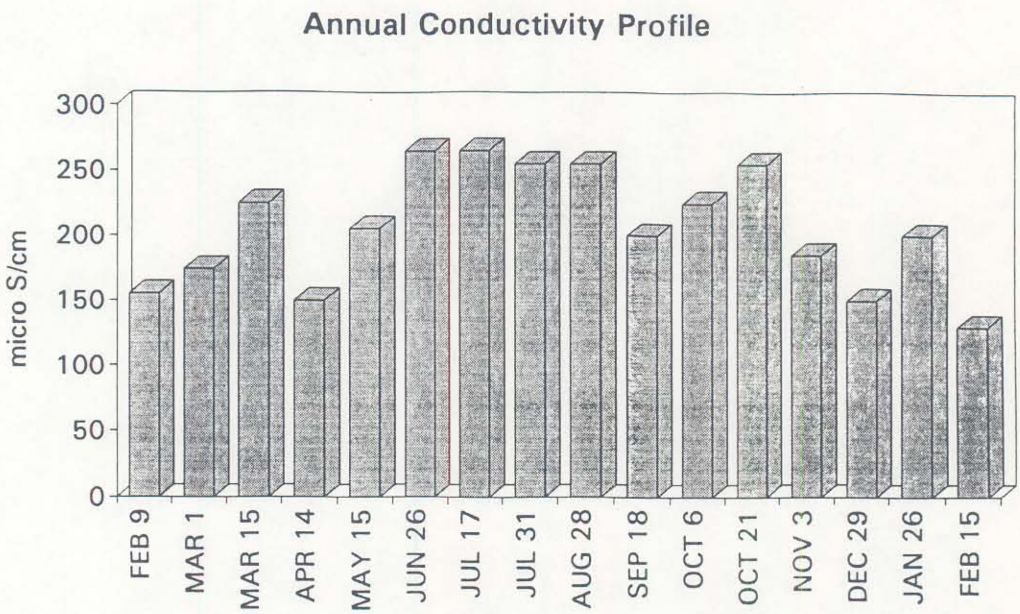

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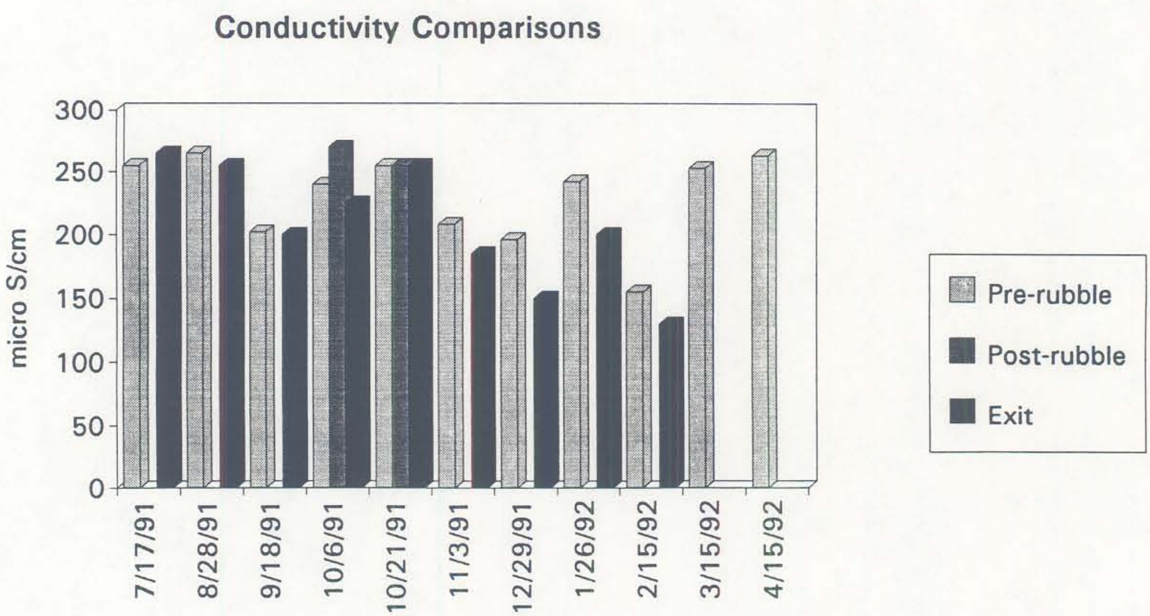

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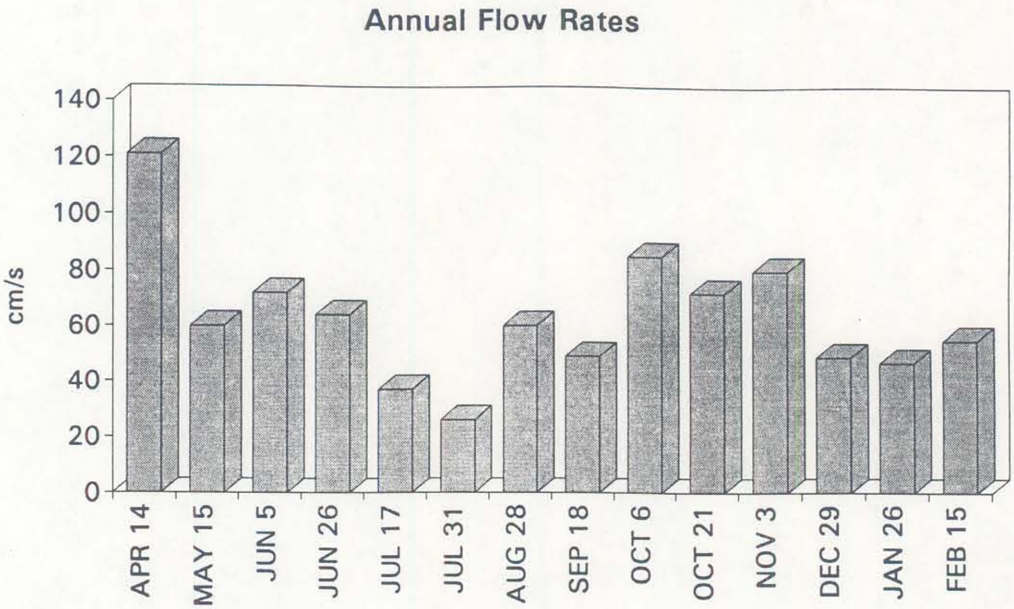
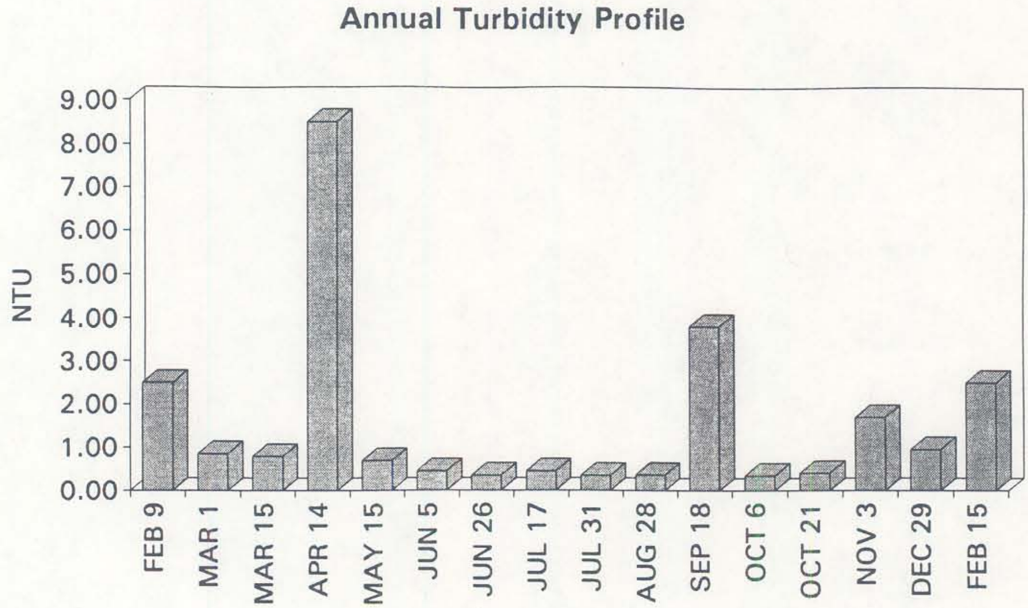


Annual Flow Rates
cm/s
0
20
40
60
80
100
120
140
APR 14
MAY 15
JUN 5
JUN 26
JUL 17
JUL 31
AUG 28
SEP 18
OCT 6
OCT 21
NOV 3
DEC 29
JAN 26
FEB 15

Figure 8



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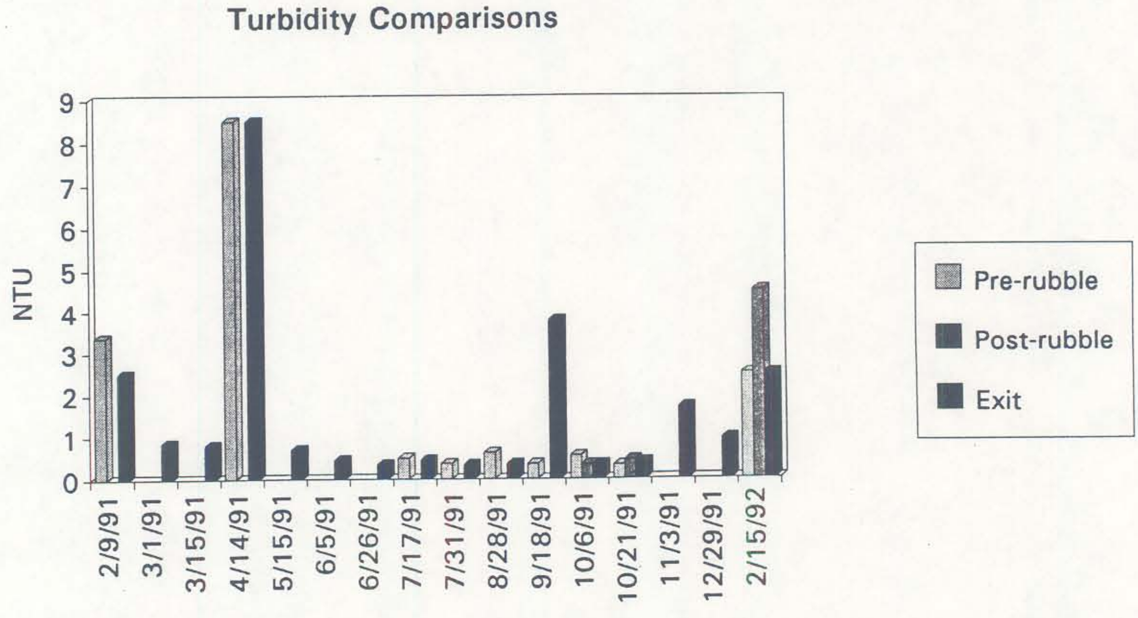

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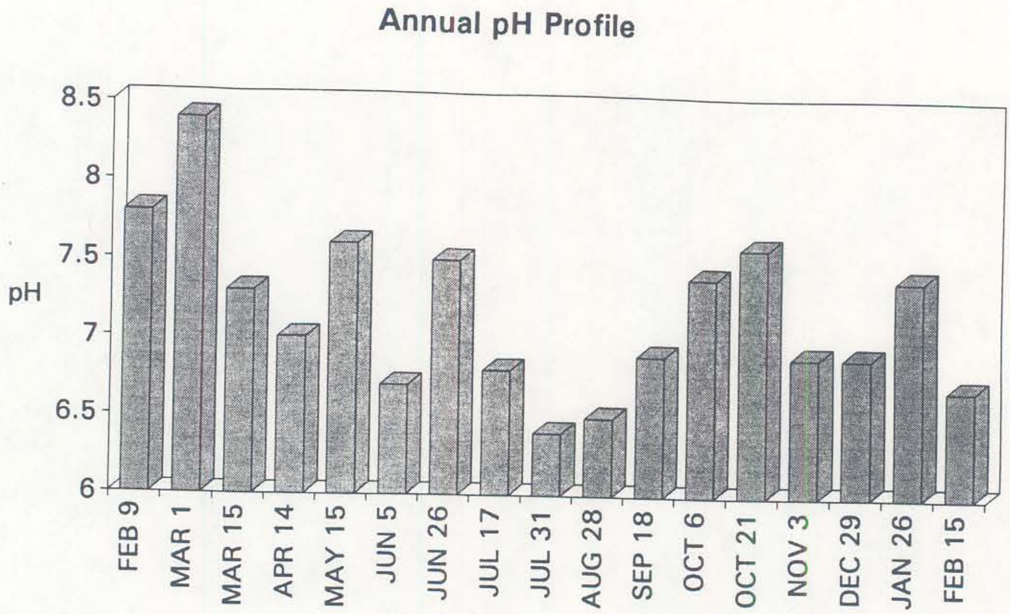
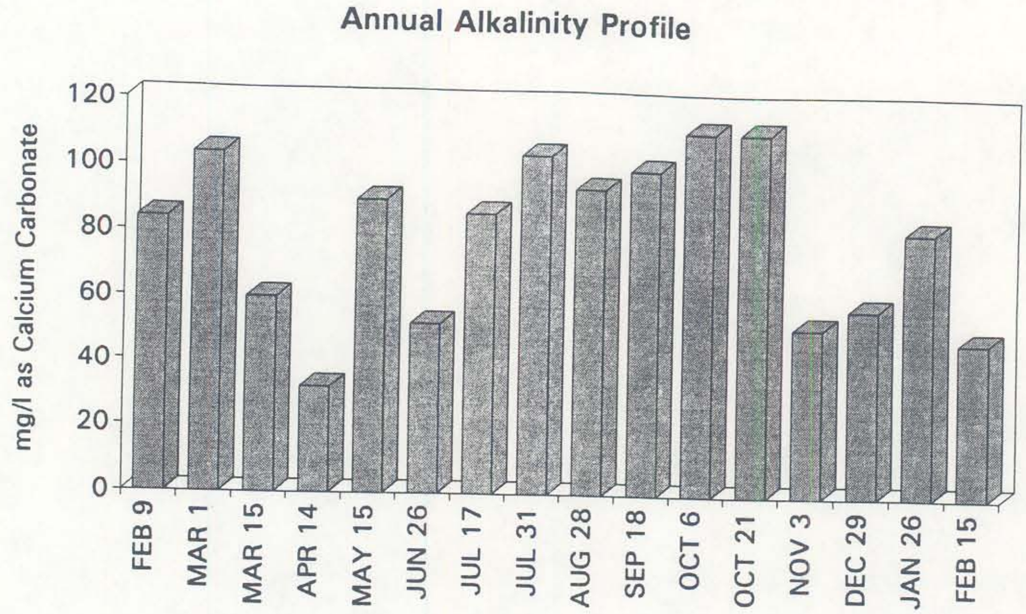

Annual pH Profile
8.5
8
7.5
7
6.5
6
pH
FEB 9
MAR 1
MAR 15
APR 14
MAY 15
JUN 5
JUN 26
JUL 17
JUL 31
AUG 28
SEP 18
OCT 6
OCT 21
NOV 3
DEC 29
JAN 26
FEB 15

Figure 11



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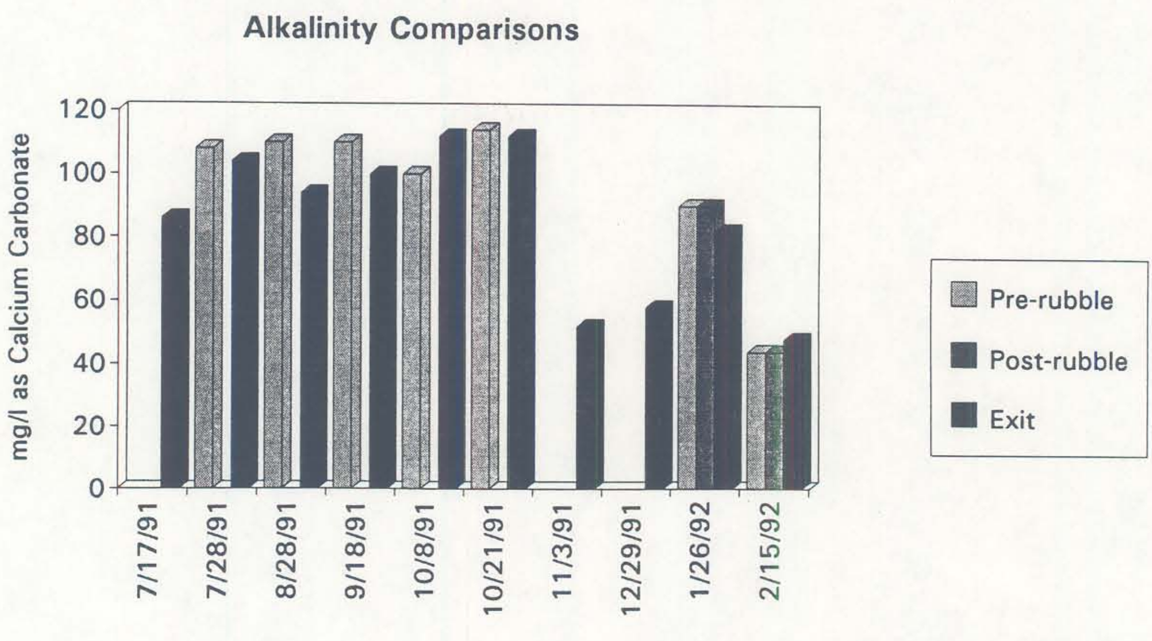

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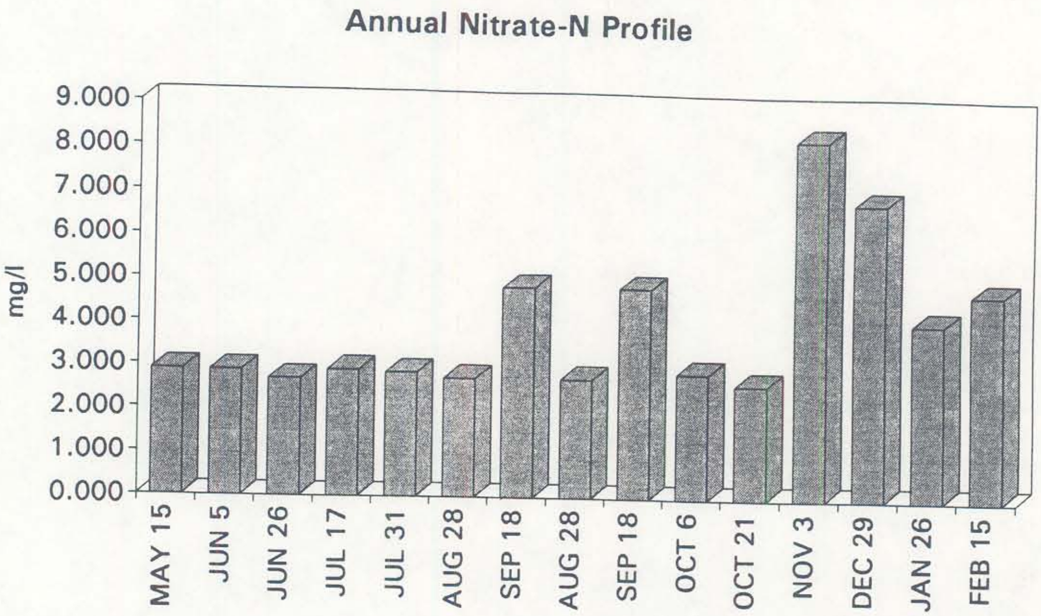

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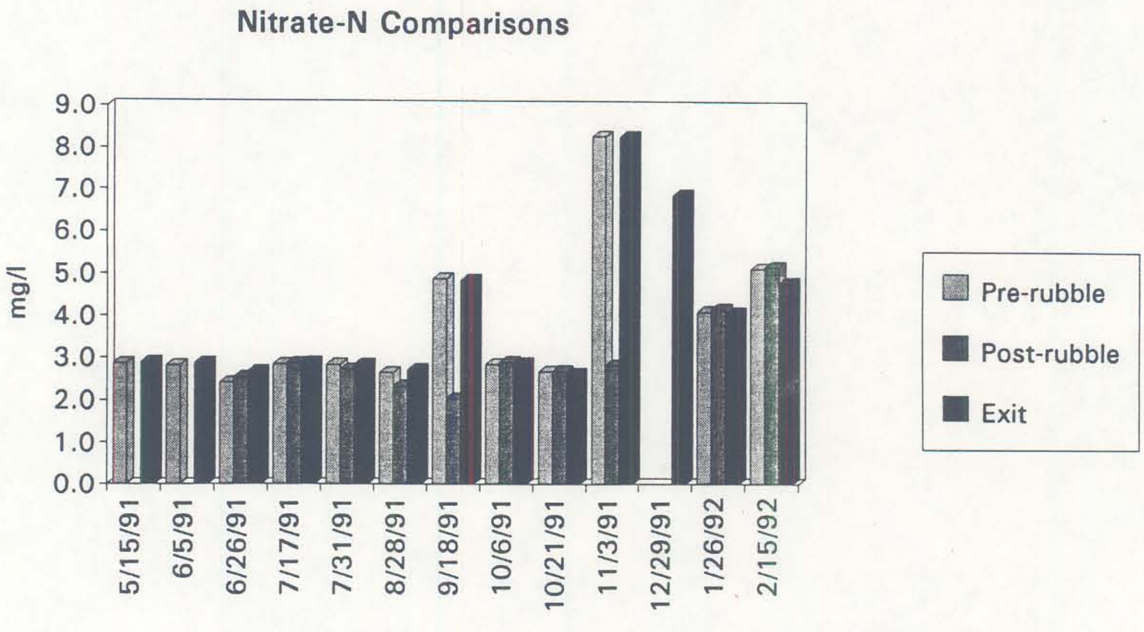

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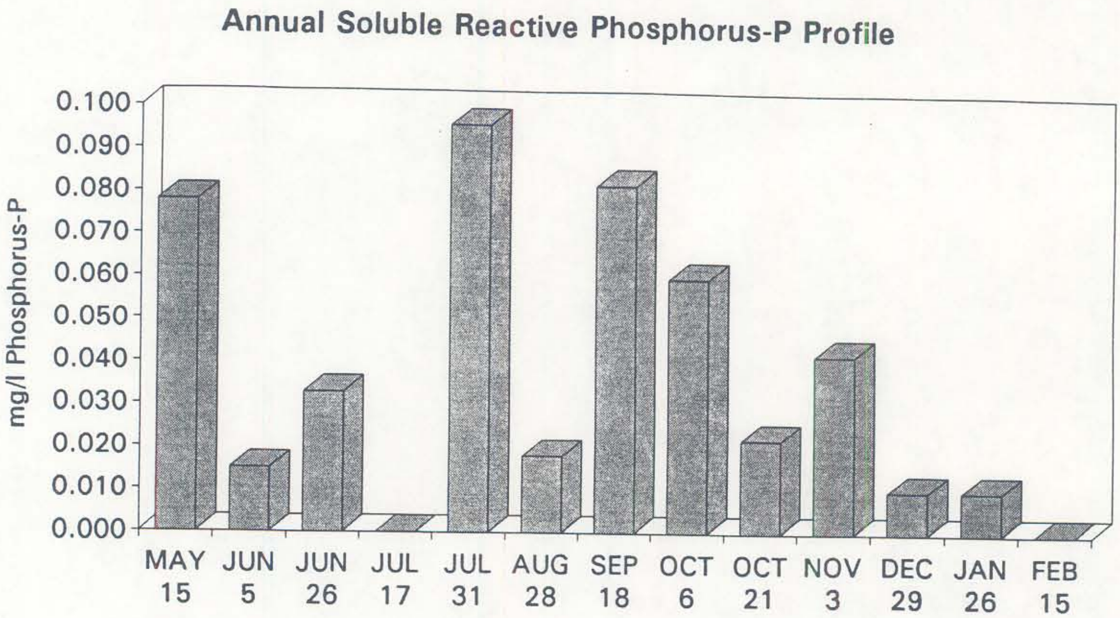

Figure 16