Use of GIS to Determine Effectiveness of Natural Attenuation

by

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Abstract

Louisiana Army Ammunition Plant (LAAP), located near Shreveport, Louisiana, is a government-owned contractor-operated plant. Its purpose is to manufacture, load and assemble ammunition items. Area P has been used over the past 40 years to dump explosive-laden wastewater into 16 unlined lagoons. In 1989 LAAP was placed on the National Priorities List because of the contamination caused by the wastewater and its contribution to groundwater pollution. Natural attenuation, a remediation technique based on in-situ chemical degradation, has been tested as a potential cleanup technique at LAAP. Quarterly sampling of groundwater, referred to as sampling rounds, from 30 wells were conducted over a period of 3 years. This information has been assembled in QuattroPro spreadsheets. Because of the overwhelming amount of data, however, the data are no longer easily manipulated and displayed. A GIS (geographic information system) was needed to provide the interactive framework required to visualize the large amounts of data and to identify areas where natural attenuation has been effective. Each well location with its accompanying chemical data was entered into the GIS. Individual themes were created on the chemicals so that they could be overlain or viewed as separate layers. The GIS allowed the visualization of chemical concentration in the area. GIS was used to show that in the area around Area P, the concentrations were increasing in a few wells in the northwest part of the site and decreasing elsewhere.
Acknowledgements

I would like to thank Dr. Charles L. Rosenfeld, my major professor, for his guidance and support throughout this project and my stay at OSU. I also wish to thank my minor professor Dr. Gordon Matzke for his support in this project. Additionally I would like to say thank you to Dr. Jon A. Kimerling who provided support through classroom instructions. I am also very grateful to Maureen Corcoran and Danny Harrelson of U.S. Army Engineer Waterways Experiment Station for providing the opportunity to work on this project as well as providing technical assistance when I needed it. I am very grateful to them for all their help and encouragement.

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# Table Of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>BACKGROUND</td>
<td>1</td>
</tr>
<tr>
<td>PURPOSE</td>
<td>2</td>
</tr>
<tr>
<td>STUDY AREA</td>
<td>3</td>
</tr>
<tr>
<td>CLIMATE</td>
<td>5</td>
</tr>
<tr>
<td>GEOLOGY</td>
<td>6</td>
</tr>
<tr>
<td>HYDROLOGY</td>
<td>8</td>
</tr>
<tr>
<td>NATURAL ATTENUATION</td>
<td>9</td>
</tr>
<tr>
<td>METHODS</td>
<td>10</td>
</tr>
<tr>
<td>ANALYSIS</td>
<td>13</td>
</tr>
<tr>
<td>CONCLUSIONS/RECOMMENDATIONS</td>
<td>20</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>23</td>
</tr>
<tr>
<td>APPENDEX A</td>
<td>25</td>
</tr>
</tbody>
</table>
# List Of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Louisiana Army Ammunition Plant</td>
<td>4</td>
</tr>
<tr>
<td>2. Area P and well locations</td>
<td>5</td>
</tr>
<tr>
<td>3a. RDX concentrations for February and June 1996</td>
<td>15</td>
</tr>
<tr>
<td>3b. RDX concentrations for February 1997 and 1998</td>
<td>16</td>
</tr>
<tr>
<td>4a. TNT concentrations for February and June 1996</td>
<td>17</td>
</tr>
<tr>
<td>4b. TNT concentrations for February 1997 and 1998</td>
<td>18</td>
</tr>
<tr>
<td>5. Wells with increase concentrations of TNT and RDX</td>
<td>20</td>
</tr>
</tbody>
</table>
## List of Tables

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Intrinsic permeabilities for unconsolidated sediments</td>
<td>7</td>
</tr>
<tr>
<td>2. Concentration change in wells for RDX and TNT</td>
<td>19</td>
</tr>
</tbody>
</table>
Use Of GIS to Determine Effectiveness
Of Natural Attenuation

Background

Louisiana Army Ammunition Plant (LAPP) has a long history of producing ammunitions during periods of war. The plant (Figure 1) has eight ammunition lines and one ammonium nitrate graining plant, which were constructed by Silas Company between July 1941 and May 1942 (SAIC 1994). In August of 1945 production of ammunition ceased with the conclusion of World War II. The plant was placed on standby status in November 1945, and in February 1957 it was reactivated by Remington Rand Incorporated and stayed in operation during the Korean conflict. In October of 1957 the plant was again placed on standby status. Five years later in 1962 it was reactivated by Sperry Rand Corporation to produce ammunition for the Vietnam Conflict. During all these periods of operations, explosive-laden wastewater was disposed of in the local environment. The area of concern in this study, Area P, (Figure 2) consists of 16 unlined lagoons and is located in the south central part of LAAP. The Area P lagoons were in active use between 1940 and 1981 for storage of untreated explosive-laden wastewater from industrial operations within LAAP. In addition to the explosives, the unlined ponds were also used to dispose of wastewater from plating and fabrication operations. In March of 1989, due to contamination caused by the past disposal of explosive-laden wastewater into the unlined lagoons, LAAP was placed on the National Priorities List. As a result, some investigations have been conducted for the Area P lagoons to determine
the extent of soil and groundwater contamination (SAIC 1994, Harrilson 1996?). In 1988 an interim remedial action was initiated because it was determined that the contaminated wastewater was seeping down to the groundwater. As a result of this investigation, the lagoons were drained and the wastewater treated. Soil was excavated from the lagoons and adjacent land in Area P and incinerated. This process was continued until a total field-determined explosive concentration of less than 100 parts per million (PPM) was achieved in the area. By 1990 incineration of 101,929 tons of soil had been completed and 53,604,490 gallons of wastewater and rainwater had been treated. The area was backfilled with the incinerated soil and capped with a 2-foot clay layer, which was covered with 4 inches of topsoil and vegetated (Harrilson 1996). The wells in this area have been monitored monthly to determine concentration of the contaminants.

**Purpose**

The primary objective of this project was to develop a GIS database that could be used in monitoring the effectiveness of the natural remediation treatment. Monitoring the change in chemical concentration over time will be made easier with this database; thus the effectiveness of remediation can be determined. The overall goal for LAAP is the restoration of the groundwater to meet the water quality standards set by the EPA. This particular part of the study will enable the easy manipulation of the data by creating a GIS database that can be viewed spatially. A GIS database is much more useful for this kind of interpretation. By creating a GIS database the data becomes more meaningful, and is tied to actual locations in space and can be mapped much more efficiently. Once this database is created it will establish a base layer so that future monitored data can
easily be added to it. This will simplify future mapping of the chemical concentrations. Utilization of a GIS system for the data has played an important part in this evaluation. Once chemical concentration layers were created, an immense amount of data were easily displayed and analyzed. ArcView was the GIS program used to manipulate and analyze the data so trends could be seen. Through visualization of these data it was possible to locate areas of concentration change. This new database format will allow officials at LAAP to display their data for faster assessments of trends. With the previous format it was not possible to see trends as easily since each chemical had to be graphed in order to show the trend. Now it is possible to show change in 2-D and 3-D, as well as graphing.

**Study Area**

LAAP located in Northwest Louisiana (Figure 1) is a government-owned contractor-operated facility, which is located 22 miles east of Shreveport, Louisiana (SAIC 1994). The study site lies in the Atchafalaya Basin of the West Gulf Coastal Plain Physiographic Region of the United States (Hunt 1974). Regionally it lies within the North Louisiana Syncline. This syncline lies on the eastern part of the Sabine Uplift. LAAP is bounded by the Monroe Uplift to the east and the Sabine uplift to the west and north (Harrilson 1996?). Area P is located in the south central part of LAAP (Figure 1). The wells that were tested are located throughout the area in and around Area P (Figure 2).
Figure 1. Louisiana Army Ammunition Plant.
Climate

The climate in this part of Louisiana is continental with cool winters and hot summers. Mean temperature in winter is $45^\circ F$ and the monthly minimum is $35^\circ F$. Mean summer temperature is $81^\circ F$ with the average monthly maximum of $92^\circ F$. The coldest month is January with average temperature of $40^\circ F$, and the hottest month is July with temperatures averaging $83^\circ F$ (U.S Department of Commerce). Relative humidity is 60 percent for three-quarters of the year and less than 40 percent around 7 percent of the year. Annual rainfall is estimated at 53 inches per year, with monthly rainfall averaging 5 inches in spring and winter, and around 3 inches in summer and autumn. The wettest
months in the area are October and November: the driest months are generally August and September (SAIC 1994). Pan evaporation in Northwest Louisiana is about 55 inches annually. From the months of May through October, potential evaporation exceeds precipitation. From November to March precipitation exceeds potential evaporation. This is when most of the infiltration and recharge occur in the area (Williamson Grubb and Weiss 1990).

Geology

The regional geology around LAAP consists of unconsolidated sediments from the Eocene to the Pleistocene age. The entire surface of LAAP is covered with Pleistocene terrace deposits; this alluvial strata consist of interlayered discontinuous sand seams, silt and clay. These are deposits left by the ancient Red River and have been classified into four separate terraces; LAAP is located on the Montgomery terrace. At LAAP the Pleistocene section ranges from 30 to 150 feet and lies unconformably on top of the Claiborne Group, which consists of sandstone, siltstone and silty shale (Payne 1975). Regional dips of two degrees (170 feet/mile) have been reported to the northeast from the Sparta Sand, a member of the Claiborne group. The Eocene Cane River formation lies directly below the Sparta Sand and has the same northeasterly dip (SAIC 1994). This formation consists of foraminifera and marine clay; it also has some silt and shale. The oldest member of the Claiborne Group, the Eocene Carrizo Sand, lies under the Cane River Formation and contains fine to coarse-grained sand deposits. Carrizo is reported to be absent over most of LAAP. Where Carrizo does exist, it is composed primarily of well-sorted sand deposited as fill (SAIC 1994). Under Area P the geologic
units consist of unconsolidated Pleistocene-aged upper terrace deposits, Lower Terrace Sparta Sand, and the Cane River Formation. In the area of the lagoons the alluvium is predominantly sand and silty sand with smaller amounts of interbedded silt and clay. The same conditions exist to the east and north of the lagoons (SAIC 1994). Intrinsic permeability of silty sand ranges from $10^{-2}$ to 1 Darcys, while that of well-sorted sand ranges from 1 to $10^2$ Darcys. These permeabilities are relatively higher than that of clay, which ranges from $10^{-6}$ to $10^{-3}$ (Table 1). The higher permeability of these deposits will allow the contaminants to move farther in the groundwater under Area P. To the south of the lagoons the alluvium ranges from clay to sand; these deposits extend from 40 to 50 feet below the surface under Area P (SAIC 1994). Sparta Sand ranges from 8 to 30 feet below the surface. The upper part of the sand consists of fine quartz, whereas coarser-grained sand and gravel are found deeper in the layer (SAIC 1994). Here the intrinsic permeability would range from 1 to $10^3$ Darcys. More detail on this sites geology can be found in Payne (1968) and SAIC (1994).

<table>
<thead>
<tr>
<th>Material</th>
<th>Intrinsic Permeability (Darcys)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay</td>
<td>$10^{-6} - 10^{-3}$</td>
</tr>
<tr>
<td>Silt, Sandy silts, Clayey sands, till</td>
<td>$10^{-3} - 10^{-1}$</td>
</tr>
<tr>
<td>Silty sands, Fine sands</td>
<td>$10^{-2} - 10^{-1}$</td>
</tr>
<tr>
<td>Well-sorted sands, glacial outwash</td>
<td>$1 - 10^2$</td>
</tr>
<tr>
<td>Well-sorted gravel</td>
<td>$10 - 10^3$</td>
</tr>
</tbody>
</table>

Table 1. Intrinsic permeabilities for unconsolidated sediments (from Fetter 1994).
Hydrology

Surface drainage around the study site flows into Lake Bistineau, which is just South of the instillation, through Clark Bayou, Cany Creek and Brooke Creek (Figure 1). These main streams are mostly intermittent, shallow streams. Primary drainage pathways for Area P are Clark Bayou and Coney Creek (SAIC 1994). There are three aquifers from the Gulf Coast Regional Aquifer system underlying LAAP: the Upper Terrace Aquifer, Lower Terrace Aquifer and Wilcox Group/Carrizo sand Aquifer (SAIC 1994, Hotchkiss and Johnson 1991). The Upper Terrace Aquifer consists of Pleistocene Terrace deposits, which form the surface of the facility. Terrace aquifer wells are not located at LAAP. Domestic wells, however, are located in the surrounding towns of Haughton, Princeton, Dixie Inn, Minden, Sibley and Doyling (SAIC 1994). This aquifer's hydraulic conductivity was approximated at 160 feet per day, with transmissivity ranging between 16,200 and 22,700 gallons per day per foot. The linear velocity of the groundwater for this aquifer was calculated to be 29.47 ft/year. With this velocity over an estimated 48 years, the contaminants might have traveled around 1,400 feet from the original source in Area P (SAIC 1994). The regional groundwater flow in the Upper Terrace aquifer is toward the southwest. Simulations conducted by Engineering Technologies Associates (ETA) in 1991, however, show that the contaminants move downward with small horizontal movement. The Lower Terrace/Sparta Sand Aquifer is located directly beneath the Upper Terrace Aquifer, which is mostly located in the north-central portion of the state and thins westward towards LAAP. Under Area P the thickness of the Lower Terrace/Sparta Sand is 6 to 8
feet. The third aquifer in the area, the Wilcox Group/Carrizo Sand aquifer, supplies LAAP with groundwater. Water from this aquifer has been used for all operations in the plant. The aquifer depth ranges from 100 feet below the surface in the southwest part of the facility to 500 feet in the northeast (SAIC 1994). The Cane River formation, which has low permeability, lies over the Wilcox aquifer, confining it. Recharge of this aquifer occurs from precipitation and the streams that cross the Quaternary deposit (SAIC 1994).

Natural Attenuation

Traditionally the method of cleaning groundwater in North America was to extract the polluted ground water, treat it, and then discharge the treated water (Barker 1998). The high cost and limitations of this approach have resulted in newer methods for treating contaminated groundwater. A new treatment method has resulted from scientific evidence showing that many contaminants undergo significant attenuation in at least some groundwater environments. The basic concept in natural attenuation is to let naturally occurring biological or chemical processes degrade contaminants (Rugge 1998). Many advantages have been found for using natural attenuation as a remediation technique: 1.) Contaminants are not just transferred to another location in the environment or phase, but they are transformed into innocuous by-products. 2.) In some remediation techniques contaminants are transferred into the atmosphere; this is not the case with natural attenuation. 3.) It is nonintrusive since it allows continued use of existing infrastructure during remediation. 4.) Most mobile toxic compounds are usually the most susceptible to biodegradation. 5.) It is a much less expensive method than the current remediation technologies available (Wiedemeir 1997).
Evidence for natural attenuation with fuel hydrocarbons and chlorinated solvents has been reported (Baker 1998, Rugge 1998, Wiedemeir 1997). There are some limitations to using this method, the main being the long time period required to complete this process. It can also be effected by changes in the hydrogeologic conditions, both natural and manmade (Wiedemeir 1997). The reported success of natural attenuation and its low cost were the main motivations to use this method. This process may occur one of the following ways: 1) Microbial transformation to similar or more complex, but innocuous compounds, 2) microbial mineralization to very simple, nonhazardous compounds, 3) immobilization due to the restrictive geology and/or hydrology of the site, 4) immobilization caused by the interactions with the soil or aquifer (Harrilson 1996).

Natural attenuation is being used as a potential cleanup technique in reducing the contamination levels at LAAP. The first step was to restrict further contamination of the groundwater, this was accomplished by treating the soil and adding the cap. The purpose of the cap was to minimize rainwater infiltration through the treated soil under the cap. For three years the groundwater has been monitored for explosive concentrations to test the effectiveness of natural attenuation. Since the data collected to monitor this process are so overwhelming in size, a GIS is needed to manipulate these large amount of data in order to visualize it. The interactive framework provided by the GIS will enable the identification of the areas where natural attenuation is effective and also help locate problem areas.

Methods

Geographic Information System technology has proven to be a powerful tool in data analysis since its first appearance in Canada in 1964 (Aronoff 1991). In the early years
GIS use emphasized mapping and spatial database management. A new wave of applications in GIS concentrated on spatial modeling by using advanced analytical operations (Berry 1995). The importance of GIS comes from its ability to manage and manipulate large amounts of data. Traditionally the use of this technology was limited to manipulating geographic databases and producing maps. More recently, however, GIS has been used extensively for planning water quality programs and in studying environmental processes (Hsiu-Hua 1998). Hydrologic applications of GIS have ranged from prediction of response to hydrologic events to characterization of hydrologic tendencies (DeVantier et al. 1993). In this case GIS will be used to analyze contaminants contained in an aquifer system by creating a manageable database.

ArcView 3.1 was the primary GIS program used for the data analysis. One of the biggest problems encountered while trying to utilize this GIS was in determining the data structure needed to best manipulate the information. All the data were contained in spreadsheets and stored by well number for the 30 wells. There were 14 rounds of data taken over a period of three years. The data began in February 1996 with round 1 and ended in August 1998 with round 14. There are many gaps in the data where testing was abandoned because there was too little water in the wells or the water was too silty. Some wells were also missing readings in the later rounds because a consistent reading of 0.2 PPM or less was obtained. For those data points an assumption was made that the readings were still the same for the purpose of creating the grids.

Displaying the data in the original format proved to be a difficult task. Graphs were used to show the concentration of each chemical (Appendix. A) The spreadsheets containing this data were immense because they showed concentration by well number
for each chemical, along with environmental conditions. The problem with this data set was that in this form it was impossible to visualize aside from graphing each individual concentration. The first step in producing this database was to find the best way to reorganize the data. The original data were stored by well number, so this format was used first to import the data into ArcView. In this format the wells were tied to their GPS readings and imported into ArcView. By assigning the wells to their GPS readings they obtained real world locations. This tied them to their exact field location. The files created in ArcView are known as a shape files; these are the files that result when data is imported into this program. Each well's shape file had concentration information for all the chemicals attached to it. This form of data organization proved ineffective, it did not allow grids to be created for the concentration of one given chemical. The shape files could only show the concentration of every chemical for one round of data at a given well, not for the three-year period. After the first attempt at data organization it became evident that the data had to be reorganized. The second attempt involved organization of the data by the individual chemicals. As a result, the old data set had to be completely restructured. New tables were created for every chemical. This process was one of the most time-consuming in this project. These new tables contained the location for all the wells and attached to them was the concentration for one chemical throughout the three-year period. This information was then imported into ArcView by using the GPS information as the x, y fields. With this new structure it was possible to create grids for individual chemicals showing concentration. The grids could be created for a particular time period and these grids could then be shown in sequence to show change.
Shape files were created for each chemical pollutant with its concentrations for each round of data and well. Visualization of the data was also possible using 3-D Analyst; this showed the data using concentration as the z-value. It was not possible, however, to print these 3-D images; they could only be displayed in ArcView. Spatial Analyst was used to create grids, using the nearest neighbor interpolation method, of the individual chemicals. This made it possible to spatially visualize the changes in chemical concentrations. Queries were performed on the shape files to identify areas where the concentrations were increasing or decreasing. It was found that the wells located in Area P and to the north of it had increasing concentrations of most pollutants. This information was used to determine problem areas where there needs to be further inspection to determine what is occurring.

Grids created of the concentrations by spatial analyst can be used to make a temporal animation, using GIF animation, for the location and concentration of the chemicals. This animation will allow one to see what is happening with the natural attenuation and where it is effective.

**Analysis**

After the individual chemical information was inputted into a GIS, two were chosen for closer examination: Hexahydro-1, 3,5-trinitro1, 3,5-triazine (RDX), and 2,4,6-Trinitrotoluene (2,4,6-TNT). These are the two compounds that were the most important to LAAP officials. RDX is much more mobile than TNT and serves as an indicator for contaminant movement. The main concern is to manipulate the data so they can be easily evaluated. This was determined using ArcView to create and analyze shape files for these chemicals. Rounds 1, 5, 8 and 12 were used for the comparison. These data were
collected in February 1996, June 1996, February 1997, and February 1998, respectively. Round 14 is the latest round of data; however, it is not complete for all chemicals, so round 12 was used instead. Grids were interpolated for the two chemicals during those rounds and are shown in the following figures (3a, 3b, 4a, and 4b). Point A is marked in the RDX grids to show the decrease in concentrations. This visualization is the final goal of this project. In the TNT grids area A and B are marked to show the decrease in the concentration of TNT in the ground water. With this format the data can be shown as both grids and graphs, which previously was the best method to show change. These images can be compared to the prior method of showing change in the data (Appendix A). Before this GIS database was created graphs were used for each well to show increase or decrease in the chemical concentrations (see fold out). With a GIS it is possible to use temporal maps to show the change in concentration for all the wells during a given time period.
Figure 3a. RDX concentrations for February and June 1996.
Figure 3b. RDX concentrations for February 1997 and 1998.
Figure 4a. TNT concentrations for February and June 1996.
Figure 4b. TNT concentrations for February 1997 and 1998.
Table 2 shows which wells had a concentration change for RDX and TNT through this three year period. For RDX six wells showed an increase in concentration from round 1 to round 12; four wells showed no change in concentration and the other 19 wells experienced decreasing concentration. With TNT there were 7 wells showing increasing concentration, five wells had no change and the other 17 had decreasing concentrations. The locations of the wells with increasing concentrations are shown in figure 5.

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Increasing</th>
<th>Decreasing</th>
<th>No Change</th>
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<tr>
<td>RDX</td>
<td>100,107,109,110,141,140</td>
<td>14,36,37,38,83,85,99,104,111,140,142,171,189,97,105,112,136,145,146</td>
<td>32,34,137,138</td>
</tr>
<tr>
<td>TNT</td>
<td>36,37,100,107,110,141,168</td>
<td>38,83,85,99,104,109,111,140,142,171,189,97,105,112,136,145,146</td>
<td>14,32,34,137,138</td>
</tr>
</tbody>
</table>

Table 2. Concentration change in wells for RDX and TNT.
Figure 5. Wells showing an increase of concentration for TNT and RDX.

Conclusions/Recommendations

It is evident from the maps that the concentrations in and around the study site are mostly decreasing, with some wells showing a slight increase. This increase in concentration could be caused by the infiltration of water through the formerly contaminated soil. Since most of the soil was incinerated and capped with uncontaminated clay soil, the clay cap should be inspected. It might prove necessary to
thicken the capped layer. The site should also be checked for ponded water and visible cracks in the clay caps.

This increase in the concentration of the contaminants in certain areas could also be a result of the movements of the chemicals from one area to the next. This could also be explained by the breakdown of the chemicals, thus showing an increase in those chemicals and decrease in others.

In order for this new GIS database to be most affective new data must be added to the shape files. Once more contaminant concentrations are added to these files, it will become easier to see trends. The shape files were created in a format so that new data could be added without much difficulty. This database will now make it possible to manage the new data coming in without overwhelming the analyzer with massive spreadsheets. Since natural attenuation of this kind does take a very long time, it is too early to say how effective this treatment method is. However, as seen with the few years of data available, it does seem to be effective. These layers will enable those who work with these data in the future to easily visualize them and see where the concentration is decreasing and where the chemicals are moving. With a few more years of data these shape files will become effective tools in analyzing the success of natural attenuation at this site.

By using GIS as an analysis tool the data will be much more easily manipulated. This new data format is more compatible and portable in comparison with the large graphs that were previously used to show change in the data. Now it can be shown on one sheet, and the GIS will still allow the data to be graphed if so desired. These data can also be seen in 3-D, making it easier for anyone to see trends. In the future when more
concentration readings are added, LAAP officials will have many more options in ways to display this data. The new grids and the related GIS allow for easier data manipulation in comparison with the old spreadsheet format.
References


Harrelson, Danny, Zakikhani, Mansour, Pennington, Judith C., and Gunnison, Douglas. 1997. Evaluation of Monitored Natural Attenuation of Explosives at Selected Department of Defense Sites. U.S. Army Engineer Waterways Experiment Station. Vicksburg, Mississippi


## Appendix A

### Former means of displaying data

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<tr>
<th>WELL</th>
<th>FEB 92</th>
<th>MAR 92</th>
<th>APR 92</th>
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<tr>
<td>1/4L</td>
<td>RND 1</td>
<td>RND 2</td>
<td>RND 3</td>
<td>RND 4</td>
<td>RND 5</td>
<td>RND 6</td>
<td>RND 7</td>
<td>RND 8</td>
<td>RND 9</td>
<td>RND 10</td>
<td>RND 11</td>
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<td>SO4 (mg/l)</td>
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<td>NOT TAKEN</td>
<td>0.046</td>
<td>NOT TAKEN</td>
<td>NOT TAKEN</td>
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<td>D4 (mg/l)</td>
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<td>2.4</td>
<td>1.4</td>
<td>22.3</td>
<td>19.4</td>
<td>16.3</td>
<td>32.5</td>
<td>28.1</td>
</tr>
<tr>
<td>D (mg/l)</td>
<td>1.92</td>
<td>0.21</td>
<td>0.12</td>
<td>1.82</td>
<td>1.82</td>
<td>1.82</td>
<td>2.81</td>
<td>2.54</td>
</tr>
<tr>
<td>F-NO3</td>
<td>3.58</td>
<td>3.58</td>
<td>3.58</td>
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<td>3.58</td>
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</tr>
<tr>
<td>pH</td>
<td>6.80</td>
<td>6.80</td>
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<td>6.80</td>
</tr>
</tbody>
</table>

*Note: Data in shaded cells indicate concentrations that were not measured or were below the detection limit.*