ANALYSIS OF DOWNHOLE DISSOLVED OXYGEN MEASUREMENTS IN SHALLOW AQUIFERS NEAR MOSCOW, IDAHO

A Thesis

Presented in Partial Fulfillment of the Requirements for the

Degree of Master of Science

with a

Major in Hydrology

in the

College of Graduate Studies

University of Idaho

by

Paul Lockwood Jr.

October 1996

Major Professor: Dale Ralston, Ph.D.

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AUTHORIZATION TO SUBMIT

THESIS

This thesis of Paul Lockwood, submitted for the degree of Master of Science with a major in Hydrology and titled "Analysis of Downhole Dissolved Oxygen Measurements in Shallow, Aquifers near Moscow, Idaho," has been reviewed in final form, as indicated by the signatures and dates given below. Permission is now granted to submit final copies to the College of Graduate Studies for approval.

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ABSTRACT

Downhole measurement of dissolved oxygen can be an important aspect of ground water studies. Dissolved oxygen concentrations in ground water can provide clues to the age, direction of flow and general quality of an aquifer. The objectives of this study; 1) are to establish field operation procedures for the YSI model 50B dissolved oxygen meter which was used in this study, 2) to collect dissolved oxygen and temperature data from the University of Idaho Ground Water Research Site (UIGRS), University of Idaho Plant Science Site 1 and 2 (UIPSS1, UIPSS2) and the University of Idaho Sweet Avenue Site (UISAS) all located near Moscow, Idaho, 3) evaluate the utility of downhole dissolved oxygen measurements, and 4) describe the factors that affect dissolved oxygen in shallow ground water in the Moscow area.

Data were collected from 75 wells at various depths and from different aquifer types at the four sites. Although most of the wells were logged completely, data from within the perforated portion of the wells constitute the only useful information for this study. Mean dissolved oxygen values in the perforated sections of wells range from <0.01 to 6.18 mg/L. Mean dissolved oxygen values of test sites ranged from 0.29 to 3.35 mg/L.

The data from the four research sites show that dissolved oxygen increases with depth within shallow sedimentary systems. Mean dissolved oxygen values are low near the ground surface in shallow alluvium (<1.0 mg/L), presumably due to the presence of organics in the root zone. Deeper alluvium show the highest mean dissolved oxygen values (>3.0 mg/L). Wells penetrating the upper portion of the underlying basalt at two sites have low mean

dissolved oxygen values (<1.0 mg/L) possibly because of chemical reactions with minerals in the basalt.

Depth below ground surface is the single most significant variable of influence on dissolved oxygen at the research sites. Aquifer material and the presence or absence of contamination are also important factors that influence dissolved oxygen at the sites.

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I would like to thank my major professor Dr. Dale Ralston who has been an inspirational role model and a great teacher. I would like to thank Dr. Roy Mink for giving me an interesting job through the Idaho Water Resources Research Institute. I would like to thank Dr. Scott Kellogg for his time and advice as a committee member. I would also like to thank my last committee member Dr. Roy Williams for his time and flexibility. I also wish to acknowledge Dr. John Bush who first introduced me to the graduate program at the University of Idaho.

I sincerely thank my parents and step-parents, without whose support and advice, I might never have finished this degree. I would especially like to thank my wife Jennifer, who has been incredibly helpful and patient throughout the duration of this study. Finally, I would like to thank my two best friends on four legs Max and Kato, who let me know when it was time to get away from the thesis for awhile.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Dissolved Oxygen Logging of the UISAS

Chapter 1

Introduction

Statement of the Problem

Measurement of dissolved oxygen can be an important aspect of ground water studies. The concentration of dissolved oxygen in ground water is dependent on the depth below ground surface, the depth below the water table, age of the ground water, type of aquifer in which the ground water is contained, temperature, pressure, solubility, and chemical and biological conditions (Mazor, 1991). The determination of dissolved oxygen is informative in several respects:

1. Defining aquifer environment in terms of degree of anaerobic conditions.
2. Detecting changes in an aquifer: a temporal or spatial decrease in dissolved oxygen could indicate an increase in biological activity, associated with the arrival of some subsurface contaminant.
3. Identifying position within a ground water flow system (postulated decrease in dissolved oxygen along a flow path).
4. Determining the recharge point of a ground water flow system by locating areas of highest dissolved oxygen values.
5. Identifying the mixing of different water types, by finding intermediate levels of dissolved oxygen.

Dissolved oxygen in ground water can be measured ex-situ from a sample, or directly by downhole measurement. Measurement of downhole dissolved oxygen has several advantages over ex-situ measurement (Rose and Long, 1988). Ex-situ or extraction methods that use bailers, submersible pumps, gas driven piston pumps, or nitrogen displacement have the potential of increasing concentrations of dissolved oxygen during extraction or pumping (Rose and Long, 1988). Measurement of downhole dissolved oxygen also can provide depth discrete data showing more detail in the aquifer.

This study is an examination of downhole dissolved oxygen measurements using a number of shallow wells at several different sites near Moscow, Idaho. The sites include contaminated and uncontaminated areas, unconsolidated sediments plus fractured basalt and a range of well completions. The existence of a new dissolved oxygen logger and the availability of the sites led to this study.

Purpose and Objectives

The purpose of this study is to evaluate the utility of downhole dissolved oxygen measurements in shallow ground water systems. The general objectives are to characterize downhole dissolved oxygen conditions in a variety of shallow ground water systems near Moscow, Idaho, and to evaluate the usefulness of downhole dissolved oxygen data collection.

There are six specific objectives in this study:

1. To review literature on downhole and ex-situ measurement of dissolved oxygen.
2. To establish field operation procedures for the YSI model 50B dissolved oxygen and temperature meter acquired by the University of Idaho.

3. To collect and present dissolved oxygen and temperature data from selected wells at the Ground Water Research Site, the Plant Sciences Farm Sites, and the Sweet Avenue Site, all on land owned by the University of Idaho.
4. To relate dissolved oxygen data to well construction, depth below ground surface, hydrologic and ground water contamination.
5. To evaluate the effectiveness of downhole dissolved oxygen data as an indicator of subsurface conditions.
6. To state conclusions and recommendations.

Method of Study

A review of the literature on dissolved oxygen measurement and interpretation was completed prior to data collection for two reasons: 1) to understand the variables that can effect dissolved oxygen, and 2) to gain insight on the collection and interpretation of downhole dissolved oxygen data. A methodology was developed for logging dissolved oxygen in wells since no complete methodology is available in the literature.

Four study sites were chosen based on the criteria of accessibility, amount of hydrogeological information available, level of contamination, and location of aquifer system. The four sites are the University of Idaho Ground Water Research Site (UIGRS), the two sites at the University of Science Plant Science Farm (UIPSS1 and UIPSS2), and the University of Idaho Sweet Avenue Site (UISAS). The wells at the UIGRS were logged first because the site is well characterized and free of contamination. The next sites logged were the contaminated site at the University of Idaho Plant Science Farm (UIPSS1), the uncontaminated site at the University of Idaho Plant Science Farm (UIPSS2) and the contaminated University of Idaho Sweet Avenue Site (UISAS).

Dissolved oxygen data were reviewed as logs of the entire well, logs of screened intervals only, plots of dissolved oxygen values versus depth below ground surface, and localized vertical dissolved oxygen trends. The utility of the downhole dissolved oxygen data collection effort was evaluated based on the results from the four sites.

Review of Previous Investigations of Dissolved Oxygen Conditions in Ground Water

Rain and surface water equilibrate with air, thereby becoming saturated with dissolved oxygen. This water enters the unsaturated zone during recharge events (Mazor, 1991). The three main variables that affect the concentration of dissolved oxygen in water in the unsaturated zone are pressure, salinity and temperature. Pressure is dependent simply upon altitude; the dissolved oxygen meter can be corrected for pressure changes (YSI, 1995). Salinity causes a decrease in the dissolved oxygen in water; however salinity is usually negligible in shallow continental ground water systems (Mazor, 1991). Temperature generally has the greatest effect on dissolved oxygen; this relationship is shown in table 1-1. Dissolved oxygen levels decrease with increasing temperatures due to reduced solubility and out gasing (Kellogg, personal communication, 1996).

Many factors effect dissolved oxygen once water reaches the saturated zone. They include age and depth of water, rate of chemical and biological reactions and temperature.

Table 1-1 : Solubility of Oxygen in Water (Eriksson, 1985).

Temperature (°C)	mg/L	Temperature (°C)	mg/L	Temperature (°C)	mg/L
0	14.55	9	11.52	18	9.45
1	14.16	10	11.25	19	9.26
2	13.77	11	10.99	20	9.08
3	13.41	12	10.74	21	8.91
4	13.06	13	10.50	22	8.73
5	12.73	14	10.28	23	8.57
6	12.40	15	10.06	24	8.41
7	12.10	16	9.84	25	8.25
8	11.80	17	9.64		

Concentrations of dissolved oxygen in uncontaminated ground water range from near air saturation to anoxic (White et al., 1990). Specific concentrations of dissolved oxygen depend on the age of the water, rate of oxygen consumption, depth below ground surface and access to recharge. Typically, older, deeper water is anoxic, although some very old water (>10,000 YBP) has been measured at concentrations approaching air saturation levels (Winograd and Robertson, 1982); Rose (1987) also measured appreciable concentrations of dissolved oxygen (>1.0 mg/L) in relatively deep ground water systems. Concentrations of dissolved oxygen in recharge areas are typically much higher than discharge areas. Pionke and Urban (1987) found dissolved oxygen concentrations to be almost 92% higher in recharge areas than discharge areas.

Concentrations of dissolved oxygen in highly contaminated ground water usually are very low. This finding was documented by Somasundaram et al. (1993), Godsy et al. (1992), and White et al. (1990).

Effective and reliable methods of measuring dissolved oxygen are discussed by Barcelona et al. (1994), Tank and Musson (1993), Spanjers and Olsson (1992), Pionke and Urban (1987), and Garner (1987). Garner (1988), and Rose and Long (1988), describe the complexities and benefits of measuring dissolved oxygen in the field.

Dissolved oxygen can be measured effectively in the field by the modified Winkler titration method or by electrode methods (Rose and Long, 1988). The Winkler titration or iodometric test is the more reliable method with a precision of ± 5 μg/L dissolved oxygen (APHA, 1992). The test is based on the addition of divalent maganese solution, followed by a strong alkali, to the sample in a glass-stoppered bottle. Dissolved oxygen rapidly oxidizes an equivalent amount of the dispersed divalent manganous hydroxide precipitate to hydroxides of higher valence states. In the presence of iodide ions in an acidic solution, the oxidized manganese reverts to the divalent state, with the liberation of iodine equivalent to the original dissolved oxygen content. The iodine is then titrated with a standard solution of thiosulfate. The titration end point can be detected visually, with a starch indicator, or electometrically, with potentiometric or dead-stop techniques (APHA, 1992). Although the iodometric method is more precise, this titration process is difficult to perform in the field. For this reason, electrode methods are used more commonly in the field.

The electrode method involves a membrane that is stretched over a sensor. The sensor isolates the sensor elements from the environment, but allows oxygen and other gases to enter. When a polarizing voltage is applied across the sensor, oxygen that has passed through the membrane reacts at the cathode causing current to flow (YSI, 1995). The membrane passes oxygen at a rate proportional to the pressure difference across it. Since oxygen is consumed rapidly at the probe's cathode, it can be assumed that the oxygen pressure inside the membrane is zero. Therefore, the amount of oxygen diffusing through the membrane is proportional to the absolute pressure of oxygen outside the membrane. If the oxygen pressure increases, more oxygen diffuses through the sensor and thus, more current flows through the sensor. Logically, a lower pressure results in less current (YSI, 1995). Some dissolved oxygen meters calculate values of dissolved oxygen by using a formula. The dissolved oxygen meter used in this study determines first the temperature and then converts the current to dissolved oxygen in mg/L using a table similar to Table 1-1 (Uffindell, personal communication 1996).

Dissolved oxygen often is one of the parameters tested in ground water quality studies, i.e., Landon et al. (1993), Lawlor and Mack (1992), Flanagan and Stekl (1991), Duwelius and Silcox (1991), Bobo and Eikenberry (1982). This trend has evolved because dissolved oxygen concentrations have significant effects on ground water quality by regulating the valence state of trace metals and by constraining the bacterial metabolism of dissolved organic contaminants (Rose and Long, 1988). Ground water often is anoxic when it is contaminated, even in shallow systems. Bacteria use dissolved oxygen as part of their metabolism (Rose and Long, 1988). This activity becomes accelerated in the presence of some contaminants and the biological oxygen demand (BOD) increases. BOD can be increased by other processes such as decomposition of organic matter and degradation of dissolved organic carbon. These processes are most apparent in shallow flow systems where ground water is closest to the surface where the presence of organics are greater (Chapelle, 1993). If the BOD increases sufficiently, the microorganisms can render a system anoxic.

In many cases BOD will increase with contamination; thus the concentration of dissolved oxygen can be used as an indicator of ground water contamination. This procedure was done in: 1) Somasundaram et al. (1993) where a shallow alluvial aquifer was contaminated with municipal sewage and heavy metals, 2) Godsy et al. (1992) where a shallow sand and gravel aquifer was contaminated with creosote-derived compounds and pentachlorophenol, 3) White et al. (1990) where a shallow alluvium aquifer was contaminated with selenium and 4) Wang et al. (1985) where the contaminant was a leachate from a waste disposal site that consisted mainly of polynuclear aromatic hydrocarbons, phenolics, nitrogen and sulfur. Chaffe and Weimar (1983) used dissolved oxygen to detect and monitor a gasoline plume. This method proved reliable and far less expensive than conventional lab analysis.

Chapter 2

Field Equipment and Operation Procedures

Equipment Description

The dissolved oxygen meter used for this study is the YSI model 50B. The meter is a microprocessor-based instrument designed for field or laboratory measurement of dissolved oxygen and temperature in water and wastewater applications. Specifications for the YSI 50B meter are given in Table 2-1. Dissolved oxygen may be read in either mg/L or in % air saturation. The display provides a reading to two decimal places in the mg/L mode and to one decimal place in the % air saturation and the temperature modes. The last digit may be suppressed if desired when reading dissolved oxygen. This mode is exceedingly useful when quick estimates are required. Otherwise, the meter may take upwards of 15 minutes before equilibrium is reached so that a single measurement can be recorded. Temperature is indicated in degrees Celsius.

Table 2-1 : YSI 50B instrument specification

Specifications	Dissolved Oxygen mg/L	Dissolved Oxygen % Air Saturation	Temperature °C
Range	0 - 19.99 mg/L	0 - 199.9%	-5.0 - 45°C
Accuracy	±0.1% of calibrated value	±0.1% of calibrated value	±0.1°C
Temperature Compensation	±1% between 0 - 5°C ±0.6% between 5 - 45°C	±0.5% between 0 - 5°C ±0.3% between 5 - 45°C	NA
Resolution	0.01 mg/L	0.1%	±0.1°C

The meter owned by the University of Idaho is connected to 150 feet of cable. The cable was unmarked when received from YSI; the cable subsequently was measured and marked appropriately. The lengths of the cable are marked in 2 ft. increments, with a red piece of tape. Every 10 ft. interval is marked with a yellow piece of tape and every 50 ft. interval is marked with two pieces of yellow tape. A model number 5739 dissolved oxygen probe specifically designed for field use is attached to the end of the cable. The probe uses Clark-type membranes. The "standard" thickness of the membrane suggested for general use in the probe is 1 millimeter (0.039 inches). A thicker membrane is more durable but also requires greater time for the meter to reach equilibrium for a measurement.

Calibration

Many different variables affect dissolved oxygen in a liquid. Therefore, there are many different methods in which the dissolved oxygen meter can be calibrated depending on the research requirements. The main calibration methods are calibration by air, calibration by fresh water, calibration by salt water and the traditional Winkler Titration method (YSI, 1995). The calibration method used for the dissolved oxygen meter in this study was air calibration. Air calibration is one of the easiest and most reliable methods when examining water and/or wastewater (Kellogg, personal communication, 1995). This method is accurate because oxygen is constant at 20.946 volume percent air in the Earth's atmosphere (Pertrucci, 1989).

The calibration method for the YSI model 50B dissolved oxygen meter used for this project is a modification of the procedures described in the operating manual for the YSI model 50B dissolved oxygen meter. The calibration is a two step process: initial setup and calibration to 100% air saturation.

Intial Setup:

1. The probe is prepared according to the 5700 probe instructions. This procedure includes : a) filling the probe with probe solution; b) placing a membrane over the head of the probe; c) placing a rubber O-ring around the head of the probe to keep the membrane in place. (Wrinkles in the membrane are removed by pulling on the part of the membrane which is outside of the O-ring); d) cutting off the excess membrane, around the outside of the O-ring.

2. The probe cable is connected to the meter.

3. A wet cloth or sponge is placed in the plastic adjoining cap that houses the probe. The probe is placed into the cap in a location where the temperature is not changing. Care must be taken to insure that the wet cloth or sponge is not touching the probe membrane. The objective is to create an environment where the probe exists in air that is fully saturated with water vapor at a given temperature. About 10 minutes is allowed for temperature equilibration. The operating instructions suggest 3 to 5 minutes for temperature equilibration, but after trial and error, 10 minutes was found to be better because it increased stability during calibration which follows the initial setup procedure.

4. The instrument is turned on by setting the function switch to °C position. The meter then runs a self diagnostic. A message flashes on the display if there are any problems with the unit. Otherwise the meter is ready to be calibrated.

Calibration to 100% Air Saturation:

1. Follow initial setup procedure.

2. Set the function switch to %. Let the number on the display stabilize. This stabilization may take as long as 5 minutes.

3. Turn the function switch to % CAL.

4. Press CAL key once. 100.0 will appear on the display.

5. Turn the function switch back to %. 100.0 will appear on the display. If the number on the display does not drift ±0.02 from 100.0 for 1 minute, the meter is calibrated. The calibration procedure is repeated if drift occurs.

Procedure Development Tests

Downhole dissolved oxygen logging requires repetitive measurements at different depths. Procedural development tests were completed to determine the minimum time for the instrument to come to equilibrium with the subsurface conditions. Results of preliminary downhole testing of the YSI model 50B dissolved oxygen meter indicate that the data values on the meter's display become essentially constant after a period of time. Criteria were developed to determine when this "constant" level was reached. Based on data from the preliminary tests, it was decided that a measurement would be considered equilibrated when the display value did not stray more than ±0.02 mg/L dissolved oxygen in 30 seconds. Logging times to reach these criteria ranged from 0.3 to 15 minutes, but typical times were about 3 minutes.

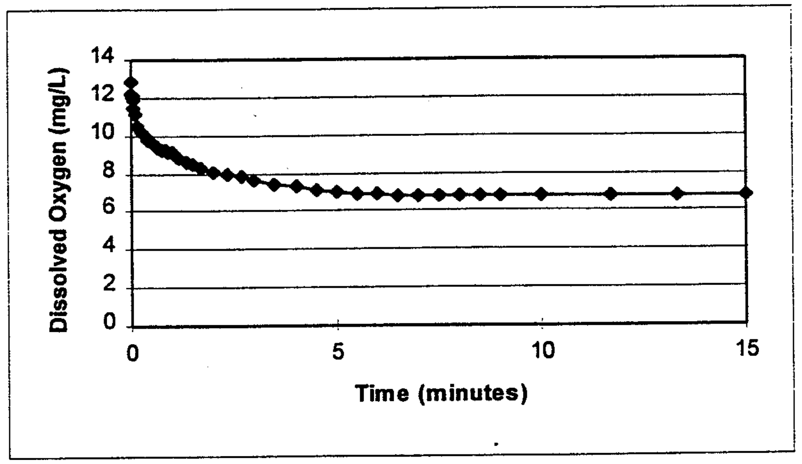

Figure 2.1 : Procedural development test using well MW-4 at the UIPSS2.

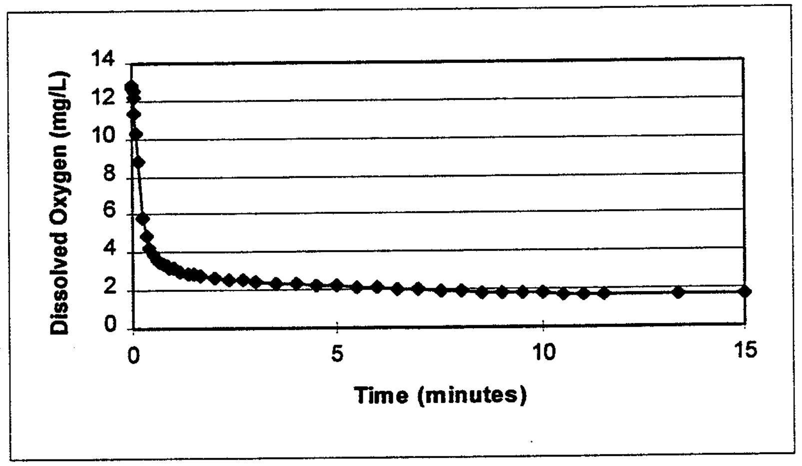

Figure 2.2 Procedural development test using well MW-2 at the UIPSS2.

The probe was lowered to a specific depth in two wells and maintained at the same level for 15 minutes to test the stability of the equilibrium reading. The time and the dissolved oxygen were recorded. Figures 2.1 and 2.2 present the temporal dissolved oxygen data. In both tests the curves eventually reach a constant value. For test 1, an approximate equilibrium was reached in 7 minutes, with a dissolved oxygen value of 6.82 mg/L. The dissolved oxygen value at the end (after 15 minutes) of test 1 was 6.79, a difference of 0.03

mg/L. For test 2, an approximate equilibrium was reached at 9 minutes, with a value of 1.74 mg/L. The value at the end of test 2 (after 15 minutes) was 1.72, a difference of 0.02 mg/L. The average difference for the two tests between the accepted value and the final value after 15 minutes was 0.8%.

Description of Procedures and General Field Use

The meter was run through the initial setup and calibration procedures at the start of each day. The membrane was changed on a daily basis even though the manual recommended the membrane be changed only once every three weeks. The measurements came to equilibrium much faster with fresh membranes.

Field procedures were developed to collect the downhole dissolved oxygen data systematically. All wells were logged for both dissolved oxygen and temperature. The logging was done only on the way down into the well to avoid mixing within the borehole. The probe was moved slowly between measurements. This practice was done for three reasons: 1) less chance of the probe being damaged; 2) less chance for mixing to occur within the borehole; and 3) the probe reached equilibrium more quickly. Care was taken to keep the cable in a fixed position when measuring; any movement disrupted the equilibrium process of the probe. A pulley system consisting of a short piece of PVC pipe was fixed on top of the well casing so that the cable and probe did not rub against the sides of the casing. The depth frequency of intervals of logged wells varied from one to five feet depending on the site: details are provided in the following sections.

Chapter 3

Selection of Wells for Survey

Hydrogeologic Overview of Moscow

The Pullman-Moscow Basin is located on the eastern edge of the Columbia River Plateau (see Figure3.1). The four general types of rock that exist in the Pullman-Moscow Basin are: (1) alluvium of the Quarternary Age, (2) eolian (wind-blown) silts of the Palouse formation of the Pleistocene Age, (3) basalt flows and intercalated sedimentary rocks of the Columbia River group of the Miocene Age, and (4) granitic and other crystalline basement rocks of pre-Tertiary Age (Ross, 1965) (see Figure 3.2).

Ground water in the Pullman-Moscow Basin occurs in three distinct aquifer units. These are: (1) the loess and shallow alluvial sediments, (2) the basalt and associated interbeds, and (3) the crystalline basement rocks (Kopp, 1994). The loess and shallow alluvium which range in thickness from zero to several hundreds of feet can yield up to 30 gallons per minute to wells (Baines, 1992). The crystalline basement rocks seldom yield more than 5 gallons per minute (Kopp, 1994). The basalts and the associated interbeds form the dominant aquifers in the area.

The basalt and associated interbeds can be further subdivided into the Wanapum and Grande Ronde formations. The Wanapum formation immediately underlies the loess in most areas and ranges in thickness from 0 to 250 feet (Li, 1991). Wells completed in the Wanapum yield up to 1500 gallons per minute (Baines, 1992). The Grande Ronde formation

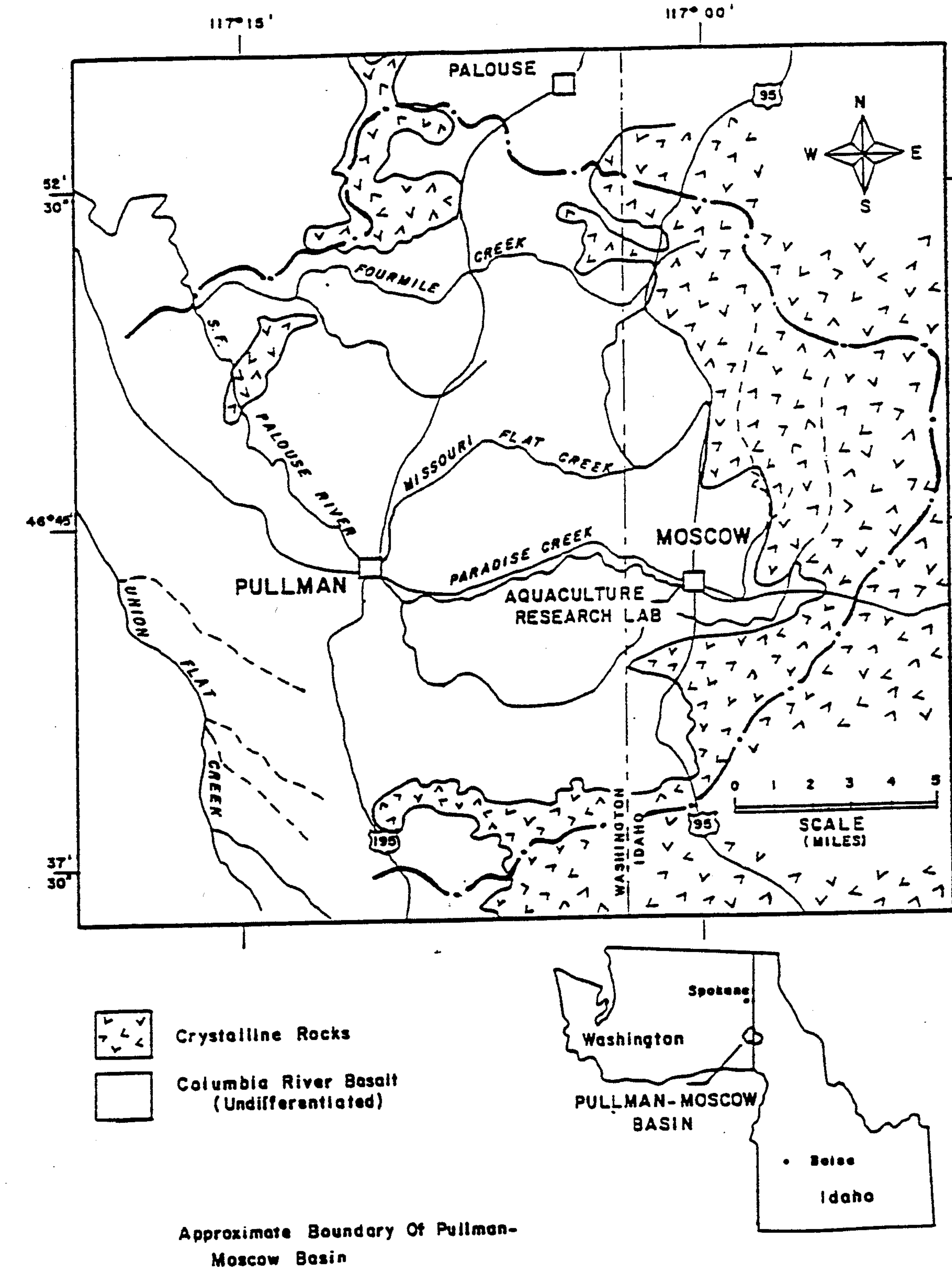

Figure3.1 : Generalized geology of the Pullman-Mosow Basin (Barker, 1979).

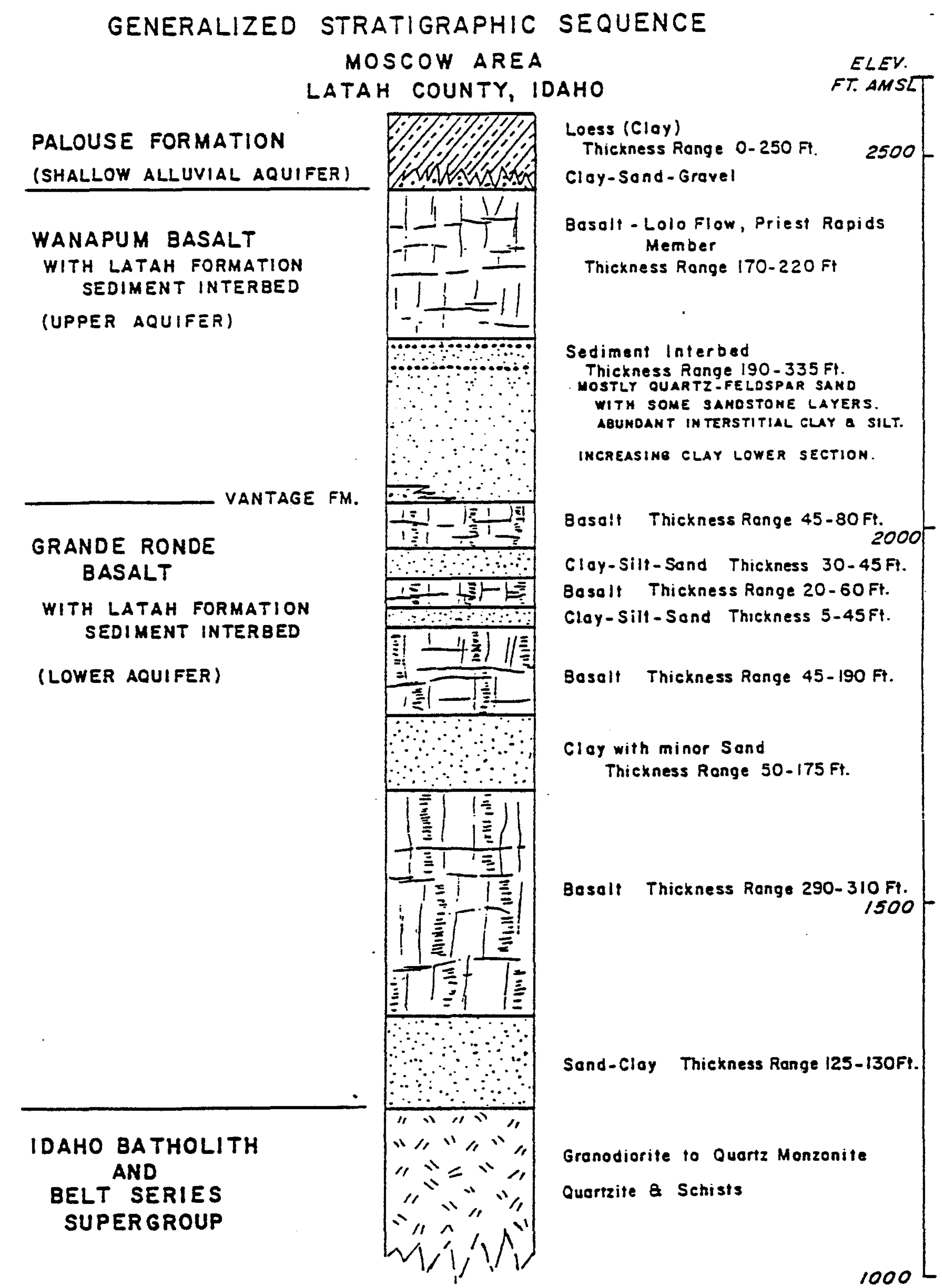

Figure 3.2 : Generalized stratigraphic sequence of the Pullman-Moscow Basin (Kopp, 1994).

underlies the Wanapum and ranges in thickness from 0 to 3500 feet (Li, 1991). Wells completed in this unit yield up to 3000 gallons per minute (Baines, 1992). The static water levels in the Moscow area generally are in the ranges of 5-20 feet below ground surface for the shallow sediments, 60-100 feet for the Wanapum formation and greater than 250 feet for the Grande Ronde formation (Ralston, personal communication, 1996).

Site Selection Criteria

The length of the cable (150 feet) attached to the dissolved oxygen probe limited analysis to wells completed in the sedimentary and Wanapum aquifers. The selection criteria for study sites within these aquifers were well availability, well construction, chemical and physical site conditions, proximity to Moscow and available site information. Six sites were considered for research with this project: the University of Idaho Ground Water Research Site (UIGRS), the two University of Idaho Plant Science Sites (UIPSS1 and UIPSS2), the University of Idaho Sweet Avenue Site (UISAS), the Zip Trip gas station on the Pullman Highway in Moscow and the Conoco gas station on North Main street in Moscow. All of these sites have multiple, shallow wells in close proximity. The two gas station sites were eliminated from consideration because of access considerations. The field research was done at the four University sites.

Description of Survey Sites

University of Idaho Ground Water Research Site

The University of Idaho Ground Water Research Site (UIGRS) consists of 21 wells completed in the surficial sediments and the upper basalt flow of the Wanapum formation (Table 3-1 has well information for UIGRS). UIGRS is located on the northwest corner of the University of Idaho Campus (see Figure 3.3). The site has been well characterized (Li, 1991).

The geology of the UIGRS includes three stratigraphic units of interest to this study. The uppermost layer is the Palouse formation, which ranges in thickness from 9 to 12 feet (Li, 1991). Underlying the Palouse formation is the Latah formation which include a layer of sand and gravel (labeled as alluvium in Table 3-1). This layer ranges in thickness from 2 to 10 feet and parts probably are fluvial deposits from Paradise Creek (Li, 1991). The lowest identified layer is basalt interpreted as the Priest Rapids Member of the Wanapum Formation. The thickness of the basalt is about 185 feet (Li, 1991). Two major fracture zones called the E and W have been identified within the basalt. The E fracture zone occurs at depths of 63 to 75 feet in the eastern portion of the site. The W fracture zone occurs at depths of 70 to 140 feet in the western portion of the site. There are also several minor fractures that occur at depths of 30 to 60 feet in the eastern and southern portions of the site (Li, 1991). Additional geologic units occur at depth but are not penetrated by wells at the UIGRS.

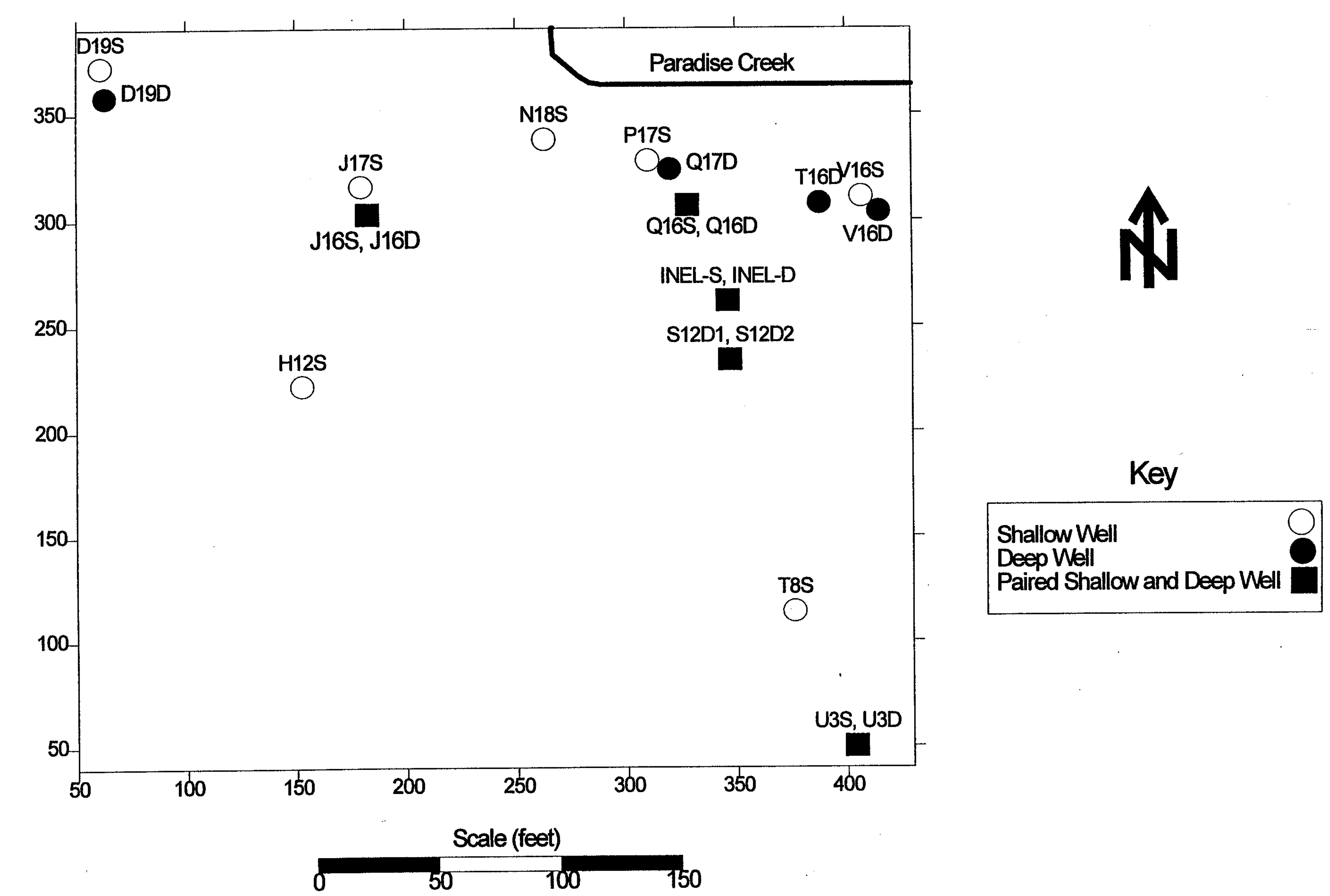

Figure 3.3 : Plan view map of well locations at the University of Idaho Ground Water Research Site.

Table 3-1 : Well Construction Information at UIGRS (from Li, 1991).

Well No.	Total Depth (ft. below GS)	Perforation Interval (ft. below GS)	Perf. Within :	Temporal Range in Depth to water (ft.)
D19S	10	9-10	Alluvium	NA
H12S	17	13-16	Alluvium	7.3-10.5
J17S	16	14-16	Alluvium	6.5-10.4
N18S	17	13-16	Alluvium	6.5-10.0
P17S	10	9-10	Alluvium	6.3-10.0
T8S	15	13-15	Alluvium	7.0-10.5
V16S	10	9-10	Alluvium	3.9-8.2
Inel-S	NA	NA	Basalt	NA
D19D	140	137-139	Basalt : W-fracture zone	24.0-24.9
Inel-D	205	203-205	Basalt	NA
J16S	20	19-20	Basalt	6.2-10.3
J16D	68	65-67.5	Basalt : W-fracture zone	25.7-27.4
Q16S	27	26-27	Basalt	6.5-10.4
Q16D	80	70-72.5	Basalt : E-fracture zone	6.4-10.2
Q17D	100	76-79	Basalt : E-fracture zone	5.7-9.4
S12D1	146	119-126	Basalt : W-fracture zone	6.5-11.5
S12D2	146	65-74	Basalt : W-fracture zone	26.6-27.6
T16D	80	65-69	Basalt : E-fracture zone	4.8-8.5
U3S	34	33-34	Basalt	4.5-7.4
U3D	83	81-83	Basalt : W-fracture zone	27.6-29.3
V16D	70	65-67.5	Basalt : E-fracture zone	3.7-7.4

University of Idaho Plant Science Sites

The University of Idaho Plant Science Sites (UIPSS) are located at the University of Idaho Plant Science Farm approximately 2 miles east of Moscow, Idaho. The sites lie near the South Fork of the Palouse River (Petrich, 1995). Both sites are basically flat with a gentle slope to the southeast towards the river (see Figures 3.4 and 3.5). The two sites are about 150 yards apart with the same basic geology and hydrogeology characteristics. UIPSS1 is located to the west and includes 25 wells all completed in sediments (Table 3-2 has well information for UIPSS1). The site is contaminated with agricultural chemicals. UIPSS2 is located to the east, has 20 wells all completed in sediments (Table 3-3 has well information for UIPSS2). Figure 3.5 only shows the locations of wells logged for this study. UIPSS2 is free of contamination.

The geology of both sites consists of two main stratigraphic layers of interest to this study. The uppermost layer is the Palouse Formation which is a silt loam, ranges in thickness from 0 to about 4 feet. The next layer is the Latah Formation which consists of clay, silt, sand and gravel. This layer has an average thickness of about 75 feet (Petrich 1995). Additional geologic units occur at depth but are not penetrated by wells at the UIPSS1 or UIPSS2. All of the wells are completed in the alluvial material within the upper portion of the Latah formation.

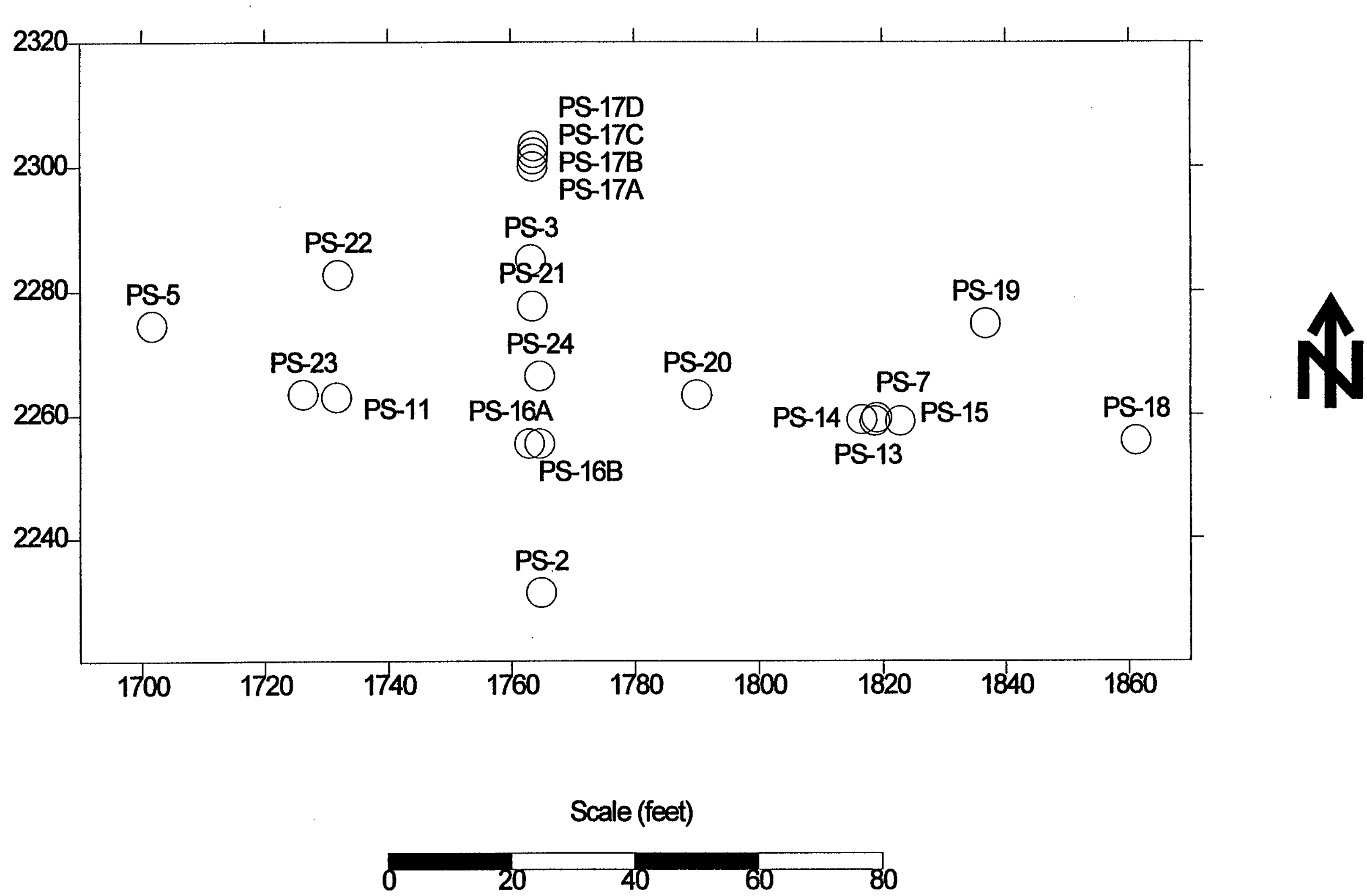

Figure 3.4 : Plan view map of well locations at the University of Idaho Plant Science Site #1.

Table 3-2 : Well Construction at UIPSS1 (information from well logs, water levels measured from 3/95 - 6/96).

Well No.	Total Depth (ft. below GS)	Perforation Interval (ft. below GS)	Perf. Within :	Temporal Range in Depth to water (ft.)
PS-2	17	12-17	Alluvium	1.96-7.63
PS-3	17	12-17	Alluvium	NA
PS-4	17	12-17	Alluvium	1.41-6.84
PS-5	17	12-17	Alluvium	5.03-10.83
PS-6	17	12-17.5	Alluvium	1.26-5.95
PS-7	17.7	12-17.7	Alluvium	3.15-8.82
PS-8	28	21.7-27.1	Alluvium	11.09-17.07
PS-9	18	15-17	Alluvium	2.23-6.85
PS-10	17	12-16.4	Alluvium	1.85-7.53
PS-11	16.2	15.4-16.03	Alluvium	NA
PS-12	11.8	11.2-11.73	Alluvium	NA
PS-13	11.1	10.4-11.1	Alluvium	3.57-9.35
PS-14	17	15.46-16.47	Alluvium	3.60-9.28
PS-15	31	27.6-30	Alluvium	3.82-9.48
PS-16A	32	16.5-24	Alluvium	NA
PS-16B	14.5	11.5-14	Alluvium	NA
PS-17	35	28.3-33.3	Alluvium	3.11-8.84
PS-17B	24	21-23.5	Alluvium	3.15-8.90
PS-17C	19	16-18.5	Alluvium	3.16-8.94
PS-17D	15.3	12.5-15	Alluvium	3.15-8.93
PS-18	29.2	18.7-28.7	Alluvium	1.66-7.32
PS-19	32	17.8-30.3	Alluvium	2.22-7.89
PS-20	32	18.5-31	Alluvium	2.20-7.89
PS-21	24	15-22.5	Alluvium	NA
PS-22	24	13.5-23.5	Alluvium	NA

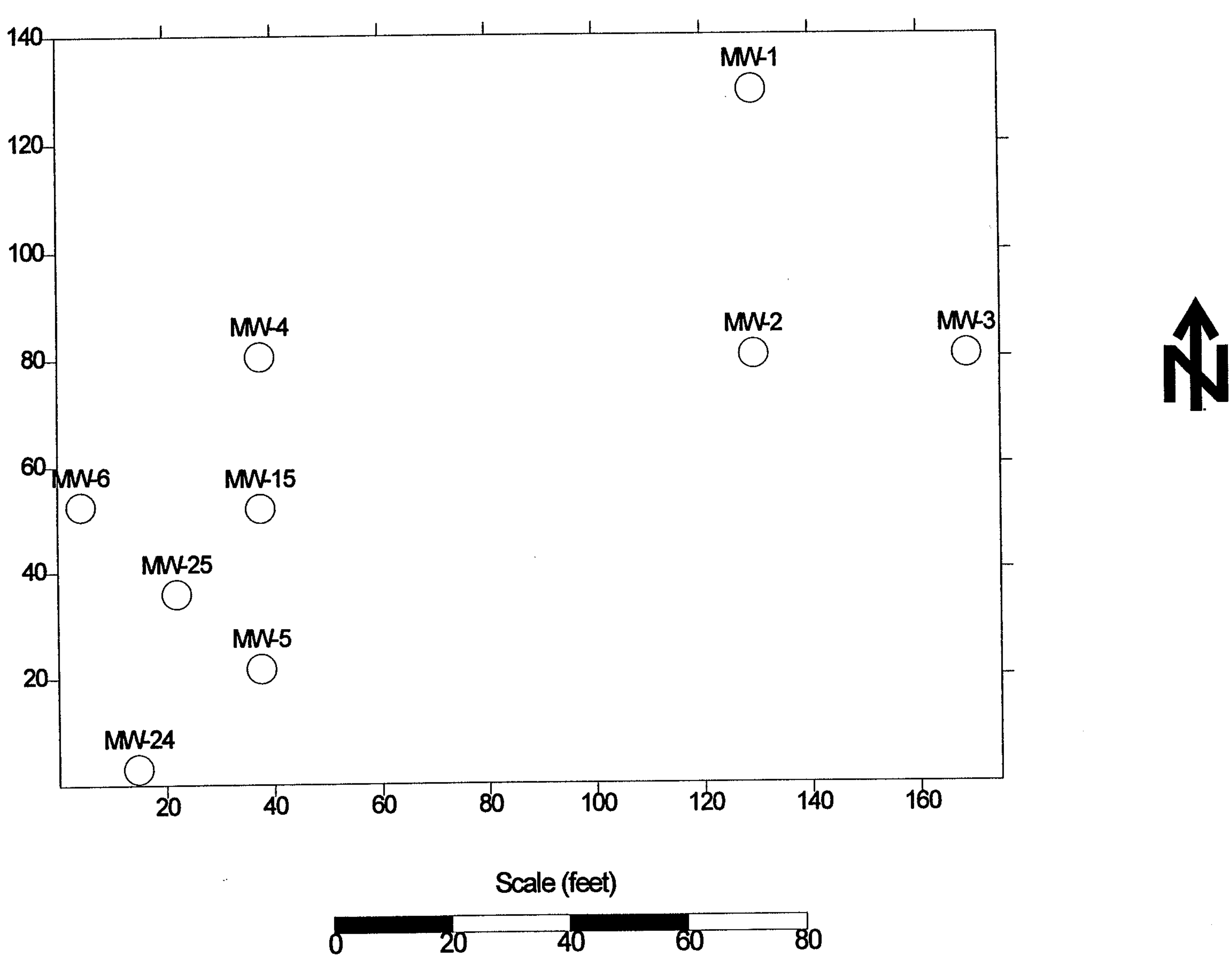

Figure 3.5 : Plan view map of well locations at the University of Idaho Plant Science Site #2.

Table 3-3 : Well Construction at UIPSS2 (information from well logs from Petrich, 1995, water levels measured from 3/95 - 6/96).

Well No.	Total Depth (ft. below GS)	Perforation Interval (ft. below GS)	Perf. Within :	Temporal Range in Depth to water (ft.)
MW-1	13	8.5-13	Alluvium	0.00-5.75
MW-2	12.5	7.5-12	Alluvium	0.00-5.15
MW-3	13	8.5-12.5	Alluvium	0.00-5.32
MW-4	14	9.4-13.5	Alluvium	0.00-4.30
MW-5	13.5	8-13	Alluvium	0.00-3.47
MW-6	14	9.5-13.5	Alluvium	0.53-3.80
MW-12	13.4	12.2-13.4	Alluvium	NA
MW-13	11.4	10-11.4	Alluvium	NA
MW-14	13.5	9-13.1	Alluvium	NA
MW-15	13.5	8.8-13	Alluvium	0.82-3.70
MW-16	13.6	9-13.5	Alluvium	NA
MW-17	10.3	8.6-9.8	Alluvium	NA
MW-18	12.7	11.5-12.5	Alluvium	NA
MW-19	13	9-13	Alluvium	NA
MW-20	11	10-11	Alluvium	NA
MW-21	12.5	11.5-12.5	Alluvium	NA
MW-22	11.5	9.9-11.5	Alluvium	NA
MW-23	12.6	11.5-12.5	Alluvium	NA
MW-24	13.5	9-13	Alluvium	0.69-3.19
MW-25	13.3	9-13.3	Alluvium	0.58-3.10

University of Idaho Sweet Avenue Site

The University of Idaho Sweet Avenue Site (UISAS) is an 11 acre tract located in the southeastern corner of the University of Idaho campus. The UISAS has documented soil and ground water contamination. Remediation efforts to date have included removal of sediments contaminated by either petroleum products or agricultural chemicals. Thirty-two wells have been completed in alluvium or shallow basalt at the site (Table 3-4 has well information for UISAS).

The geology of the UISAS consists of three basic stratigraphic layers of interest to this study. The uppermost layer is the Palouse formation accompanied with some man-made debris termed "fill." This layer consists of unconsolidated gravel, silty sand, brick, cinders and organic debris. This layer ranges in thickness from 1 to 6 feet. Underlying the Palouse formation is the Latah formation which includes unconsolidated alluvium. This layer ranges in thickness from 9 to 27 feet. Parts of the Latah formation probably are fluvial deposits from Paradise Creek (Terragraphics, 1992). The alluvium consists of layered clastics ranging from sand to clayey silts, with a few clay layers. The lowest identified stratigraphic layer is basalt and associated interbeds basalt (Terragraphics, 1992). The basalt is interpreted as the Priest Rapids Member of the Wanapum formation. Additional geologic units occur at depth but are not penetrated by wells at the UISAS.

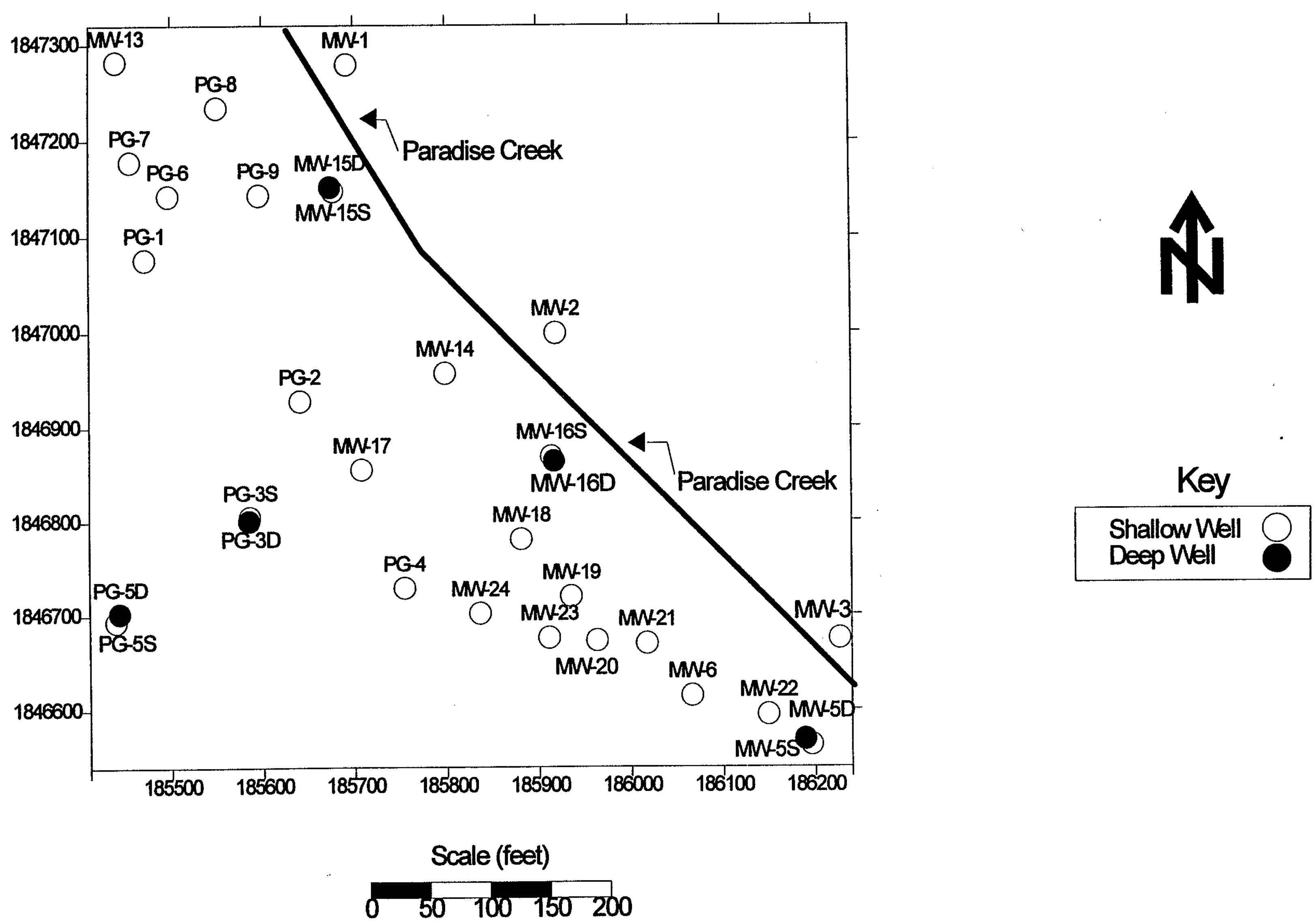

Figure 3.6 : Plan view map of well locations at the University of Idaho Sweet Avenue Site.

Table 3-4 : Well Construction Information at UISAS, (information from well logs in Terragraphics, 1992, water levels measured from 4/6/95-5/2/96).

Well No.	Total Depth (ft. below GS)	Perforation Interval (ft. below GS)	Perf. Within:	Temporal Range in Depth to water (ft.)
PG-1	18	8-18	Alluvium	2.73-8.73
PG-2	14	5-14	Alluvium	2.08-7.84
PG-3S	18	9-17	Alluvium	2.51-7.81
PG-3D	30.5	29.5-30.5	Weathered Basalt	14.55-19.68
PG-4	15	5.5-14	Alluvium	1.46-1.91
PG-5S	15	6-14.5	Alluvium	8.74-14.66
PG-5D	36	33.5-35.5	Basalt	24.05-26.41
PG-6	18	8-18	Alluvium	2.59-7.21
PG-7	15	5-15	Alluvium	2.31-7.48
PG-8	15	5-15	Alluvium	0.78-6.12
PG-9	15	5-15	Alluvium	1.11-6.96
MW-1	14.8	9.4-14.4	Alluvium	2.22-8.05
MW-2	12	6.6-11.6	Alluvium	1.77-7.26
MW-3	16.3	5.9-15.9	Alluvium	3.63-11.08
MW-5S	8.4	5.5-8	Alluvium	0.12-6.92
MW-5D	26.5	21.3-26.3	Basalt	0.00-5.55
MW-6	12	9.1-11.6	Alluvium	0.14-6.33
MW-13	16.9	6.7-16.9	Alluvium	1.23-6.17
MW-14	16	5.6-15.6	Alluvium	2.16-8.10
MW-15S	16.4	6-16	Alluvium	1.94-9.49
MW-15D	38	32.6-37.6	Basalt	28.38-30.53
MW-16S	15	12.1-14.6	Alluvium	2.25-7.81
MW-16D	27.3	22.1-27.1	Basalt	1.54-7.19
MW-17	16	14-16	Alluvium	1.54-7.29
MW-18	16	11-16	Alluvium	1.09-6.43
MW-19	16.5	10.5-16	Alluvium	2.23-7.36
MW-20	15	9-15	Alluvium	2.02-7.18
MW-21	13.5	9.5-12	Alluvium	1.89-6.80
MW-22	12	8.5-12	Alluvium	0.30-6.22
MW-23	16	9.5-16	Alluvium	2.33-7.42
MW-24	16.5	13.5-15.5	Alluvium	1.87-7.08

Chapter 4

Observations and Results of the UIGRS

All twenty-one of the wells at the UIGRS were logged for dissolved oxygen and temperature. Each well was logged entirely from the water level to the bottom of the perforated interval which is almost always at the bottom of the well. Logging intervals were 5 feet within the casing and 1 foot within the perforated sections. Wells were logged going down the well only. Results of these tests can be viewed in Figures A.1-A.19 in Appendix A and Table 4-1.

After the wells at the UIGRS were logged, data between the non-perforated and the perforated sections of wells were compared. Ranges and means of dissolved oxygen values within the non-perforated and perforated sections are presented in Table 4-1. Mean dissolved oxygen values for the non-perforated sections were all higher than the perforated sections, with the exception of well S12D1. The range of dissolved oxygen values for the non-perforated usually had a larger range than the perforated sections. Some wells showed this trend more than others; T16D had a dissolved oxygen range of 2.17 to 7.02 mg/L within the non-perforated section while the perforated section had a range of 1.97-2.05 mg/L.

The dissolved oxygen data within the non-perforated sections may have been affected by the air-water interface, since the wells were not purged prior to data collection. The validity of this hypothesis was strengthened due to the large difference between data values (both temperature and dissolved oxygen) in the perforated and non-perforated sections.

Thus, it was concluded that measurements taken within the non-perforated sections are not valid representations of ground water conditions, when the well is not purged.

Table 4.1 : Ranges and means of dissolved oxygen within the perforated and non-perforated intervals of wells at the UIGRS.

Well No.	D.O. Range within Perforated Interval (mg/L)	Mean D.O. within Perforated Interval (mg/L)	D.O. Range within Non-Perforated Interval (mg/L)	Mean D.O. within Non-Perforated Interval (mg/L)
D19S	0.60-0.85	0.75	1.72	1.72
H12S	0.03-0.33	0.24	0.41-5.18	2.18
J17S	0.01	0.01	0.55-2.65	1.48
N18S	0.03-0.39	0.21	<0.01-3.22	1.15
P17S	0.17-0.65	0.45	2.29	2.29
T8S	0.13-0.27	0.22	0.29-2.50	1.15
V16S	0.15-0.20	0.18	0.37	0.37
J16S	0.26	0.26	0.71-1.85	1.05
Q16S	<0.01-0.12	0.06	0.20-4.42	1.44
U3S	0.37	0.37	1.34-5.92	3.86
Q16D	0.27-0.63	0.41	1.14-4.11	3.26
Q17D	1.05-1.71	1.30	1.67-5.88	4.42
T16D	1.97-2.05	2.01	2.17-7.02	4.39
V16D	1.20-1.22	1.21	1.86-3.80	2.93
D19D	0.14-1.50	0.66	2.52-2.70	2.62
J16D	0.27-1.10	0.67	1.01-1.85	1.32
S12D1	0.40-1.94	1.73	0.48-2.58	1.17
S12D2	0.06-0.24	0.15	0.20-4.23	1.34
U3D	1.21-2.70	2.09	2.35-2.85	2.70

Dissolved oxygen data from the perforated sections of all but five of the wells at the UIGRS are included in Figures 4.1, 4.2 and 4.3. J16S, J17S and U3S are shallow wells, and only had one data point in the perforated section because ground water levels were low at the time of data collection. Inel-S and Inel-D are deeper wells in which the cable is not long enough to allow the probe to reach the perforated sections.

The dissolved oxygen data at the UIGRS may be correlated to the three identified shallow aquifers: the alluvial aquifer, the E-fracture basalt aquifer and the W-fracture basalt aquifer (Li, 1991). Wells completed in the alluvial aquifer all had low dissolved oxygen values in the perforated sections. The dissolved oxygen range was from 0.01 to 0.85 mg/L, with an average value of 0.29 mg/L. Wells in the E-fracture aquifer varied over a greater range than wells in the alluvium. The E-fracture aquifer had dissolved oxygen values in the perforated sections of the wells ranging from 0.27 to 2.05 mg/L, with an average value of 1.23 mg/L. Well T16D had the highest value at near 2 mg/L; Q16D had the lowest values. The W-fracture wells showed the greatest dissolved oxygen variability. Well U3D had the highest dissolved oxygen value (2.09 mg/L) at the UIGRS, but showed a decrease in dissolved oxygen with depth in the perforated interval. The dissolved oxygen values in S12D1 are slightly lower (1.73 mg/L). The other W-fracture wells have dissolved oxygen values more in line with the alluvial wells. The W-fracture aquifer had dissolved oxygen values in the perforated sections of the wells ranging from 0.06 to 2.70 mg/L, with an average value of 1.06 mg/L.

Dissolved oxygen in the perforated sections of the UIGRS wells either decreased with depth or remained the same within the perforations. These values are summarized in Figures 4.1-4.3 and Table 4.2.

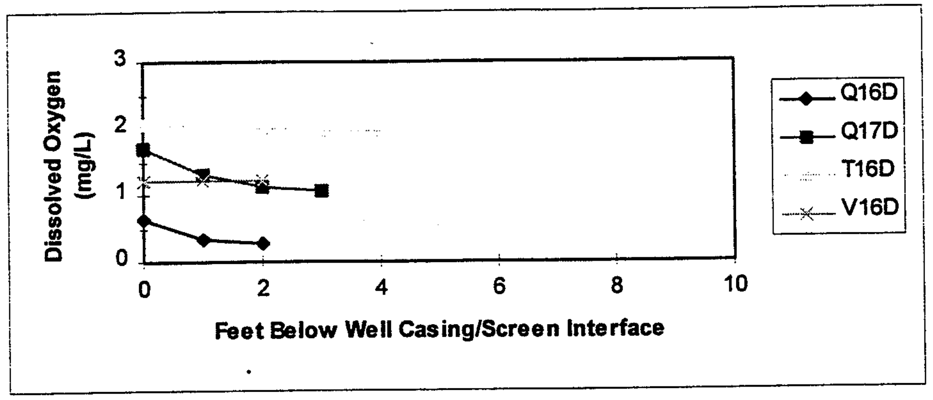

Figure 4.1 : Dissolved oxygen trends within the perforated section of the E-fracture wells at the UIGRS.

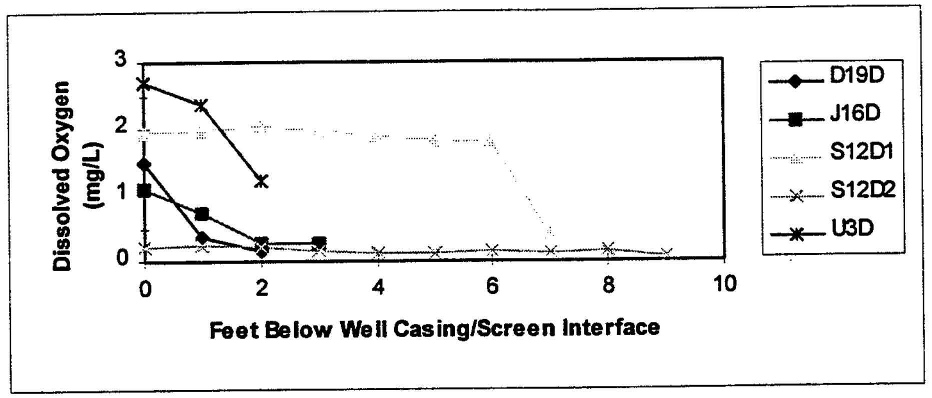

Figure 4.2 : Dissolved oxygen trends within the perforated section of the W-fracture wells at the UIGRS.

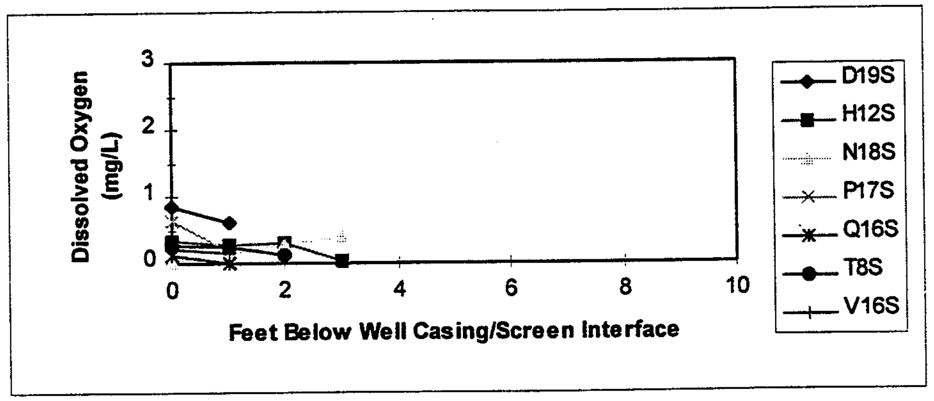

Figure 4.3 : Dissolved oxygen trends within the perforated section of the shallow wells at the UIGRS.

Table 4.2 : Ranges and means of dissolved oxygen within the perforated intervals of wells at the UIGRS.

Well No.	D.O. Range within Perforated Interval (mg/L)	Mean D.O. within Perforated Interval (mg/L)	Perf. Within:
D19S	0.60-0.85	0.75	Alluvium
H12S	0.03-0.33	0.24	Alluvium
J17S	0.01	0.01	Alluvium
N18S	0.03-0.39	0.21	Alluvium
P17S	0.17-0.65	0.45	Alluvium
T8S	0.13-0.27	0.22	Alluvium
V16S	0.15-0.20	0.18	Alluvium
J16S	0.26	0.26	Basalt
Q16S	<0.01-0.12	0.06	Basalt
U3S	0.37	0.37	Basalt
Q16D	0.27-0.63	0.41	Basalt : E-Fracture zone
Q17D	1.05-1.71	1.30	Basalt : E-Fracture zone
T16D	1.97-2.05	2.01	Basalt : E-Fracture zone
V16D	1.20-1.22	1.21	Basalt : E-Fracture zone
D19D	0.14-1.50	0.66	Basalt : W-Fracture zone
J16D	0.27-1.10	0.67	Basalt : W-Fracture zone
S12D1	0.40-1.94	1.73	Basalt : W-Fracture zone
S12D2	0.06-0.24	0.15	Basalt : W-Fracture zone
U3D	1.21-2.70	2.09	Basalt : W-Fracture zone

Means and ranges of dissolved oxygen values presented in Table 4-2, show that dissolved oxygen levels in the alluvial aquifer are significantly lower than in both the E-fracture and the W-fracture. Figure 4.4 and Table 4-3 show the relationship of dissolved oxygen and depth of the perforated interval. In five out of six paired wells (except for D19S and D19D), dissolved oxygen levels are higher for the deeper basalt wells. The deeper basalt wells averaged 0.73 mg/L dissolved oxygen higher than in the corresponding shallow well.

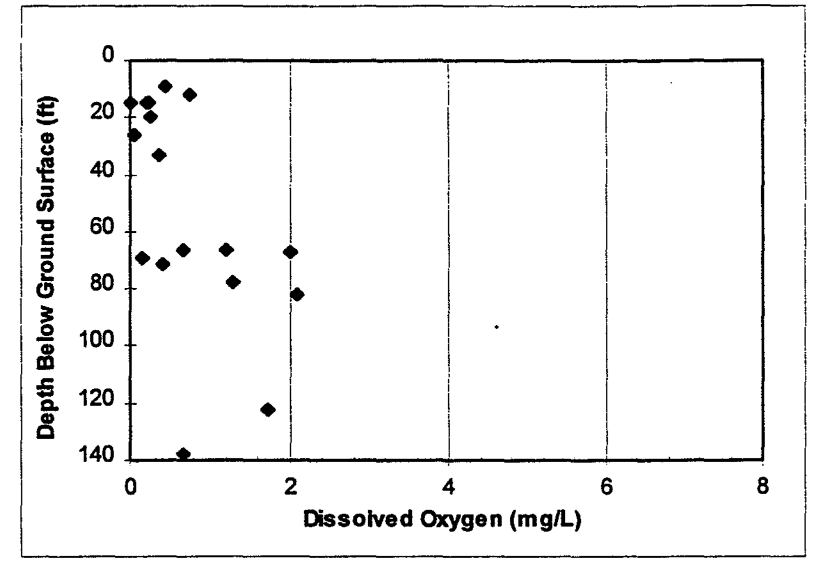

Figure 4.4 : Scatter plot of mean depth of the perforated interval below ground surface versus mean dissolved oxygen of the perforated interval.

Table 4-3 : Comparison of mean values of dissolved oxygen of shallow and deep wells; Values taken from within the perforated interval.

Well Number	Mean Dissolved Oxygen Value in Perforated Intervals (mg/L)	Perforation Depth (ft. below GS)
J16S	0.26	19-20
J16D	0.67	65-67.5
V16S	0.18	9-10
V16D	1.21	65-67.5
P17S	0.17	9-10
Q17D	1.11	76-79
Q16S	0.06	26-27
Q16D	0.41	70-72.5
U3S	0.37	33-34
U3D	2.09	81-83
D19S	0.75	9-10
D19D	0.66	137-139

A clear horizontal trend of dissolved oxygen does not occur in the alluvial wells, although values tended to be greater near Paradise Creek. Ground water levels in shallow wells are affected by changes in stream stage, suggesting the alluvial aquifer and the stream are hydraulically connected (Li, 1991). However, ground water flow is toward the stream in the summer period when field measurements were taken. The stream recharges the alluvial aquifer only during high flow periods. Greater dissolved oxygen values in proximity to the stream support the hypothesis of hydraulic connection.

Chapter 5

Observations and Results of the UIPSS1

Fourteen wells at the UIPSS1 were logged; not all the wells at the UIPSS1 were logged because the probe could not fit into the smaller diameter casings. Each well was logged entirely from the water level to the bottom of the perforated interval which was almost always at the bottom of the well. Logging intervals were 1 foot within the casing and 1 foot within the perforated sections. Wells were logged going down the well only. Results of these tests can be viewed in Figures A.20 - A.31 in Appendix A. Data in non-perforated sections of the wells are not analyzed for reasons stated in Chapter 4. Table 5-1 and Figures 5.1-5.3 present a summary of data from the perforated intervals of the wells.

The wells completed in the alluvial aquifer at the UIPSS1 had mean dissolved oxygen values that ranged from <0.01 mg/L to 6.18 mg/L with an average of 3.35 mg/L in the perforated sections. Dissolved oxygen trends within the perforated sections of the wells at the UIPSS1 are shown in Figures 5.1 - 5.3. Little variation of dissolved oxygen values with depth within the perforated sections was observed in any of the wells.

Mean dissolved oxygen values in the perforated sections of wells at the UIPSS1 showed a general increase with depth (Figure 5.4 and Table 4-1). This is similar to the depth relationship that was found in the wells at the UIGRS.

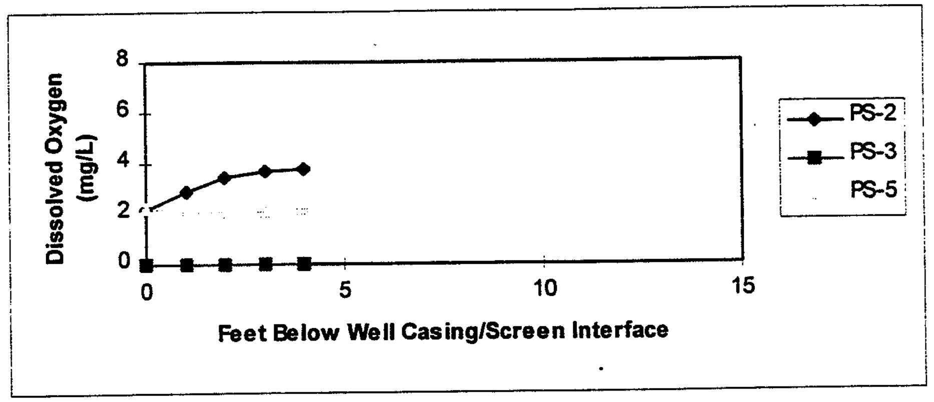

Figure 5.1 : Dissolved oxygen trends within the perforated section of the Alluvial wells at the UIPSS1.

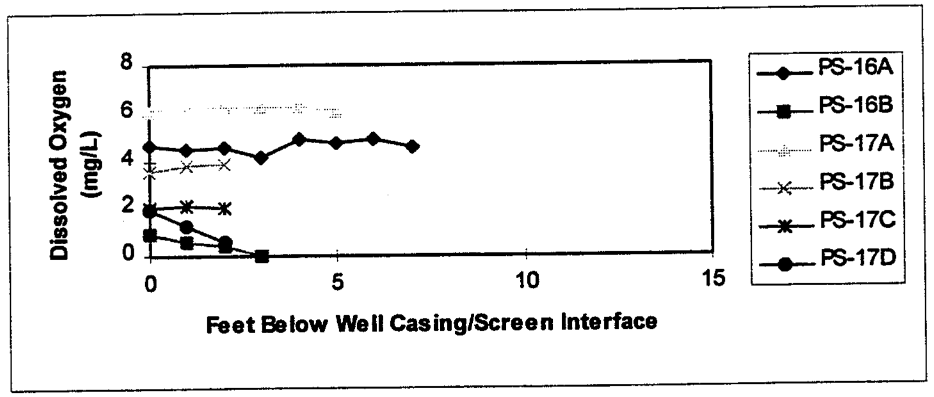

Figure 5.2 : Dissolved oxygen trends within the perforated section of the Alluvial wells at the UIPSS1.

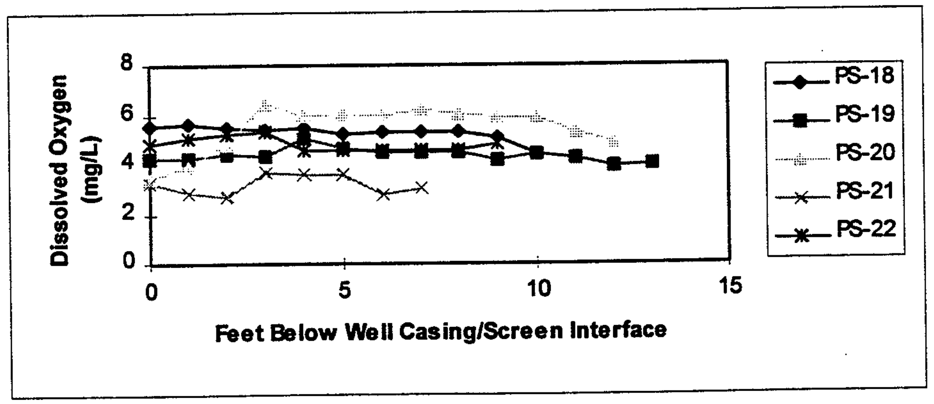

Figure 5.3 : Dissolved oxygen trends within the perforated section of the Alluvial wells at the UIPSS1.

Table 5-1 : Ranges and means of dissolved oxygen within the perforated intervals of wells at the UIPSS1.

Well No.	D.O. Range within Perforated Interval (mg/L)	Mean D.O. within Perforated Interval (mg/L)	Perf. Within:
PS-2	2.16-3.78	3.19	Alluvium
PS-3	<0.01-0.01	<0.01	Alluvium
PS-5	2.07-2.21	2.13	Alluvium
PS-16A	4.12-4.89	4.60	Alluvium
PS-16B	0.44-0.91	0.65	Alluvium
PS-17A	6.04-6.32	6.18	Alluvium
PS-17B	3.50-3.88	3.72	Alluvium
PS-17C	2.01-2.13	2.05	Alluvium
PS-17D	0.56-1.92	1.25	Alluvium
PS-18	4.42-5.53	5.27	Alluvium
PS-19	3.94-5.05	4.37	Alluvium
PS-20	3.43-6.18	5.45	Alluvium
PS-21	2.80-3.66	3.19	Alluvium
PS-22	4.55-5.29	4.82	Alluvium

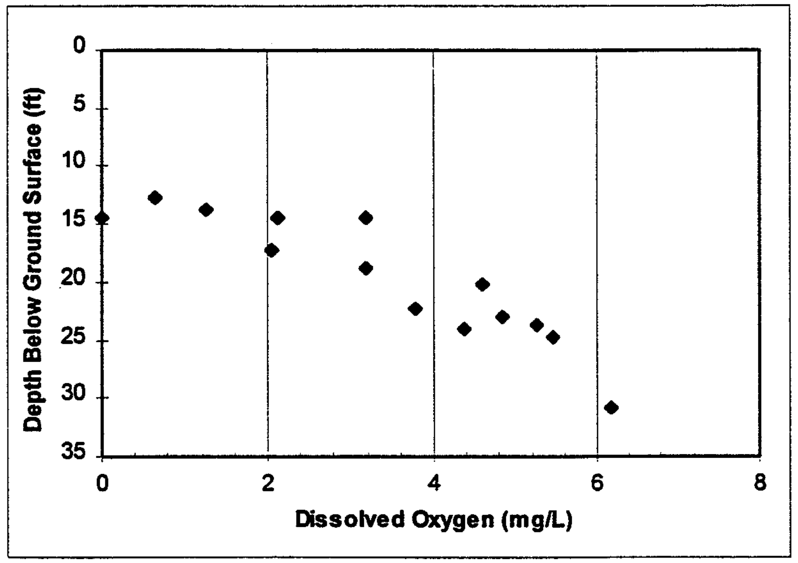

Figure 5.4 : Scatter plot of mean depth of the perforated interval below ground surface versus mean dissolved oxygen of the perforated interval.

The contamination at the UIPSS1 may be a factor in the observed dissolved oxygen data at several wells. The contaminant concentrations are higher in the shallower portion of the aquifer. The contaminant probably is accelerating the natural rate of oxygen depletion by increased microbial metabolism. Figure 5.5 shows the dissolved oxygen profiles of wells PS-2, PS-3 and PS-5. All three wells have identical construction specifics. PS-2 and PS-5 have no detectable amounts of dinoseb and dicamba (the primary contaminants at the site) at the time when the wells at the UIPSS1 were logged for dissolved oxygen. PS-3 was the second most contaminated well at the site (PS-11 was the most contaminated well at the site but it was not logged for dissolved oxygen because the casing was to narrow to insert the probe). At the time of logging the concentrations were 160 μg/L dinoseb and 210 μg/L dicamba. PS-3 had a mean dissolved oxygen value in the perforated interval of <0.01 mg/L while PS-2 and PS-5 had 3.19 mg/L and 2.13 mg/L respectively.

Data from other wells at the site suggest that the relationship of contaminant and dissolved oxygen is not simple. The contamination levels of dinoseb and dicamba and mean dissolved oxygen values are listed in table 5-2. Wells 16A, PS-20, and PS-18 had measurable dinoseb concentrations (24, 12 and 6 μg/L respectively) but had dissolved oxygen values above the mean for the site (3.35 mg/L dissolved oxygen). These results show that factors other than contamination also are important in controlling dissolved oxygen levels

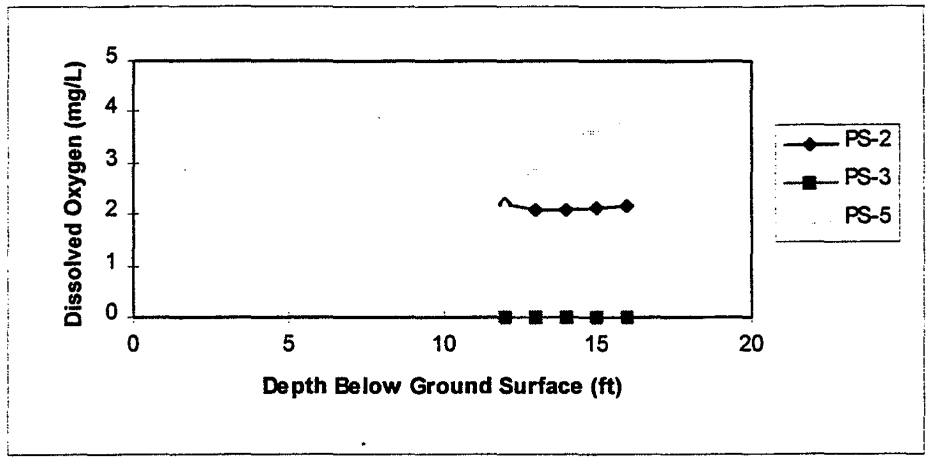

Figure 5.5 : Dissolved oxygen within the perforated intervals of the wells versus depth below ground surface.

Table 5-2 : Contamination levels and dissolved oxygen means of wells at the UIPSS1. Chemical data of the UIPSS1, supplied by D. Duncan.

Well No.	Mean D.O. within Perforated Interval (mg/L)	Dinoseb (μg/L)	Dicamba (μg/L)
PS-2	3.19	ND	ND
PS-3	<0.01	160.0	210
PS-5	2.13	ND	ND
PS-16A	4.60	24.0*	ND
PS-16B	0.65	3.6	ND
PS-17A	6.18	ND	2.7
PS-17B	3.72	ND	ND
PS-17C	2.05	ND	ND
PS-17D	1.25	ND	ND
PS-18	5.27	6.0*	ND
PS-19	4.37	ND	ND
PS-20	5.45	12.0*	ND
PS-21	3.19	ND	ND
PS-22	4.82	ND	1.25*

* Average concentration of sampling points at various depths within the well.

Chapter 6

Observations and Results of the UIPSS2

Nine wells were logged at the UIPSS2; the casing of most of the wells at this site are too narrow for the probe. UIPSS2 was the last of the four sites logged in this study. At the time of logging UIPSS2, it was considered unnecessary to log within the casing; thus, only the perforated sections were logged at 1 foot intervals. Wells were logged going down the well only. Results of the logging are summarized in table 6-1.

The wells completed in the alluvial aquifer at the UIPSS2 had mean dissolved oxygen values that ranged from <0.01 to 2.16 mg/L with an average of 0.41 mg/L within the perforated sections. Dissolved oxygen levels are relatively low at the UIPSS2; only one well (MW-4) had a mean dissolved oxygen value greater than 1.00 mg/L. Dissolved oxygen concentrations within the perforations were fairly constant, which is consistent with the other sites (see Figures 6.1 and 6.2).

Mean dissolved oxygen values of the perforated sections of wells at the UIPSS2 did not show a trend with depth (Figure 6.3 and Table 6-1). This is because mean depth below ground surface for the perforated sections of wells at the UIPSS2 varied less than 2 feet for the entire site. This allowed for little analysis of depth versus dissolved oxygen at the UIPSS2. However, the same relatively low dissolved oxygen values near the ground surface was a relationship apparent at the UIGRS and the UIPSS1.

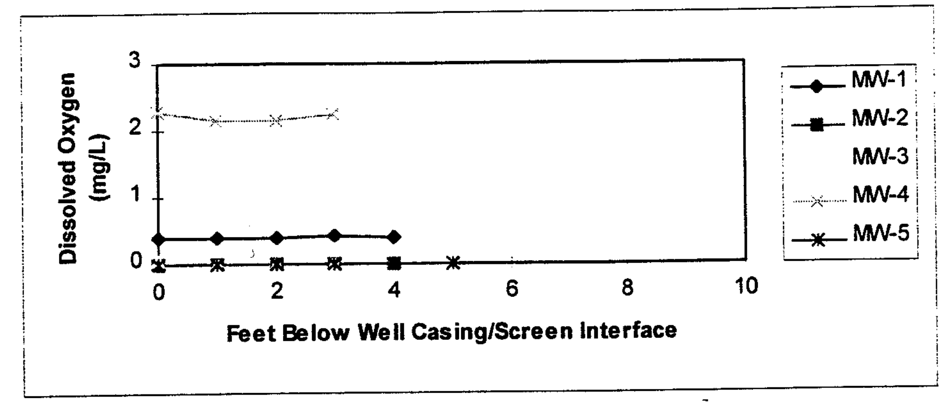

Figure 6.1 : Dissolved oxygen trends within the perforated section of the Alluvial wells at the UIPSS2.

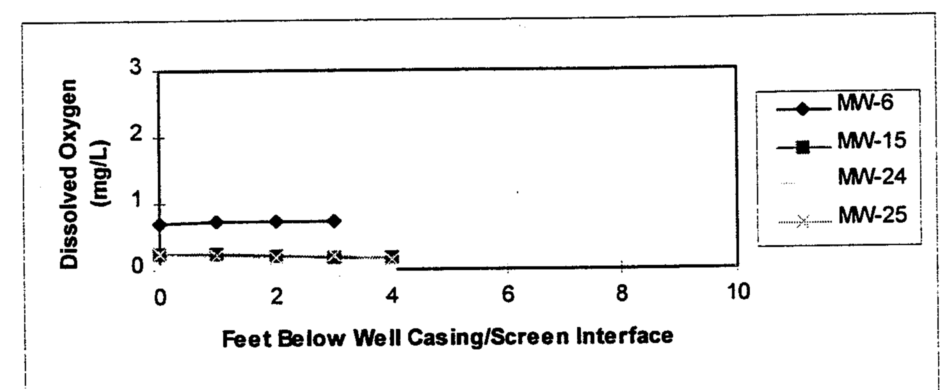

Figure 6.2 : Dissolved oxygen trends within the perforated section of the Alluvial wells at the UIPSS2.

Table 6.1 : Ranges and means of dissolved oxygen within the perforated intervals of wells at the UIPSS2.

Well No.	D.O. Range within Perforated Interval (mg/L)	Mean D.O. within Perforated Interval (mg/L)	Perf. Within:
MW-1	0.38-0.42	0.40	Alluvium
MW-2	<0.01-<0.01	<0.01	Alluvium
MW-3	<0.01-0.05	0.01	Alluvium
MW-4	2.00-2.25	2.16	Alluvium
MW-5	<0.01-<0.01	<0.01	Alluvium
MW-6	0.70-0.73	0.72	Alluvium
MW-15	0.18-0.25	0.21	Alluvium
MW-24	<0.01-<0.01	<0.01	Alluvium
MW-25	0.15-0.23	0.19	Alluvium

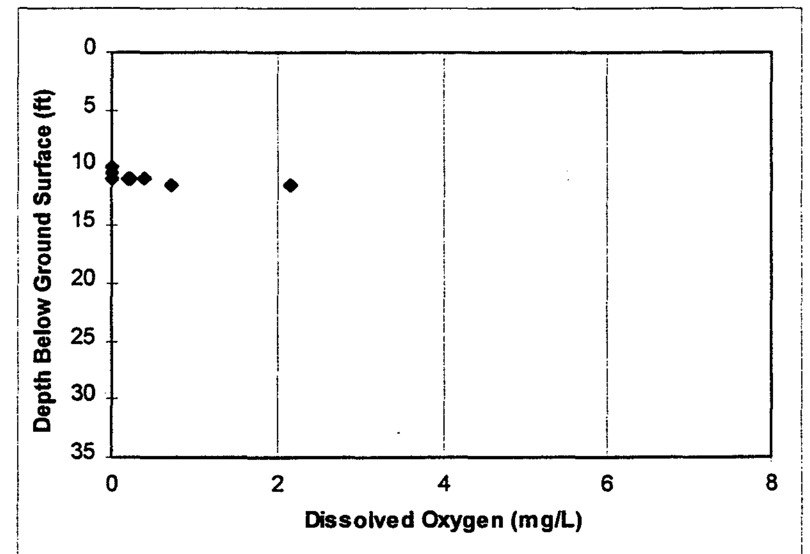

Figure 6.3 : Scatter plot of mean depth of the perforated interval below ground surface versus mean dissolved oxygen of the perforated interval.

Chapter 7

Observations and Results of the UISAS

Thirty-one of the wells at the UISAS were logged for dissolved oxygen and temperature. Each well was logged entirely from the water level to the bottom of the perforated interval which was almost always at the bottom of the well. Logging intervals were 1 foot within the casing and 1 foot within the perforated sections. Wells were logged going down the well only. Results of these tests can be viewed in Figures A.32-A.61 in Appendix A and in Table 7.1. Most wells are completed in the alluvial aquifer, while a few wells are completed in the upper portion of the underlying basalt.

Wells completed in the alluvial aquifer had mean dissolved oxygen values within the perforations that ranged from 0.17 to 3.19 mg/L with an average of 0.80 mg/L, with two exceptions. Well PG-8 had a mean dissolved oxygen value of 8.16 mg/L. This value was higher than any other well measurement at the sites. Faulty well construction may allow surface water that pooled in a depression surrounding the casing to leak into the well. The other well that had a relatively high dissolved oxygen value in the alluvial aquifer (4.83 mg/L) is MW-5S. This well has perforations opposite a gravelly, sand lens that may be directly connected to the nearby stream. The well is only 8 feet deep and is located only several tens of feet away from Paradise Creek. The water level in the well reflects changes in stream stage. For these reasons both PG-8 and MW-5S are discounted as being representative of the alluvial aquifer.

Table 7-1: Ranges and means of dissolved oxygen within perforated intervals of wells at the UISAS.

Well No.	D.O. Range within Perforated Interval (mg/L)	Mean D.O. within Perforated Interval (mg/L)	Perf. Within:
PG-1	0.44-0.70	0.55	Alluvium
PG-2	0.17-0.53	0.37	Alluvium
PG-3S	1.26-1.70	1.58	Alluvium
PG-3D	0.09-0.11	0.10	Weathered Basalt
PG-4	0.74-2.01	1.40	Alluvium
PG-5S	0.85-1.49	1.17	Alluvium
PG-5D	0.29-0.47	0.37	Basalt
PG-6	0.29-0.31	0.29	Alluvium
PG-7	0.38-0.74	0.45	Alluvium
PG-8	7.50-8.81	8.16	Alluvium
PG-9	2.83-3.49	3.19	Alluvium
MW-1	0.13-0.27	0.17	Alluvium
MW-2	1.67-1.90	1.74	Alluvium
MW-3	1.83-2.33	2.11	Alluvium
MW-5S	4.49-5.07	4.83	Alluvium
MW-5D	1.80-1.89	1.86	Basalt
MW-6	0.12-0.20	0.17	Alluvium
MW-13	0.24-0.42	0.33	Alluvium
MW-14	0.14-0.96	0.35	Alluvium
MW-15S	1.28-1.52	1.37	Alluvium
MW-15D	?	?	Basalt
MW-16S	0.32-0.36	0.33	Alluvium
MW-16D	0.20-0.22	0.21	Basalt
MW-17	0.67-0.81	0.73	Alluvium
MW-18	0.30-0.85	0.70	Alluvium
MW-19	0.03-0.09	0.05	Alluvium
MW-20	0.17-0.21	0.19	Alluvium
MW-21	0.17-0.23	0.20	Alluvium
MW-22	0.18-0.23	0.21	Alluvium
MW-23	0.47-0.70	0.62	Alluvium
MW-24	0.89-0.93	0.91	Alluvium

The four wells completed in the top of the underlying basalt had mean dissolved oxygen values of 0.10, 0.21, 0.37 and 1.86 mg/L. A dissolved oxygen value is not presented for one of the basalt wells, MW-15D, because the well is partially plugged. The probe could only be lowered to 31 feet when the perforated interval is in the depth range of 32.6-37.6 feet below ground surface. Since it is not conclusive that dissolved oxygen values were obtained from the perforated interval, the well is discounted as being representative of the basalt aquifer.

Each of the four wells in the basalt has a corresponding adjacent well that is completed in the alluvial aquifer. Each of the deeper wells has lower dissolved oxygen values than the associated shallower well. The deeper wells have an average dissolved oxygen value of 0.64 mg/L as compared to the average value of the corresponding alluvial wells of 1.98 mg/L.

Dissolved oxygen trends within the perforated intervals of the wells at the UISAS are presented in Figures 7.1-7.6. Values tended to be constant within the perforated sections of wells.

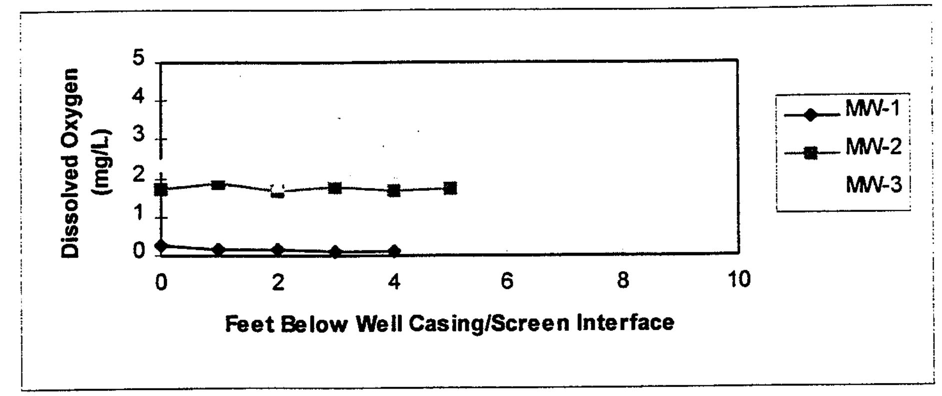

Figure 7.1 : Dissolved oxygen trends within the perforated section of wells at the UISAS.

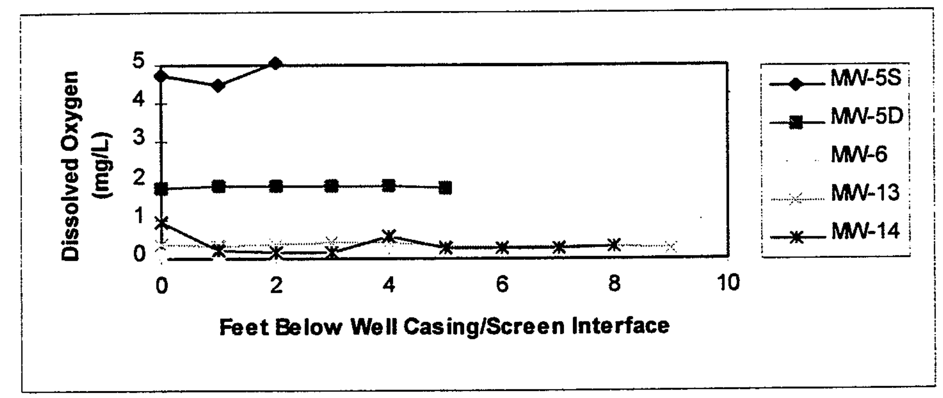

Figure 7.2 : Dissolved oxygen trends within the perforated section of wells at the UISAS.

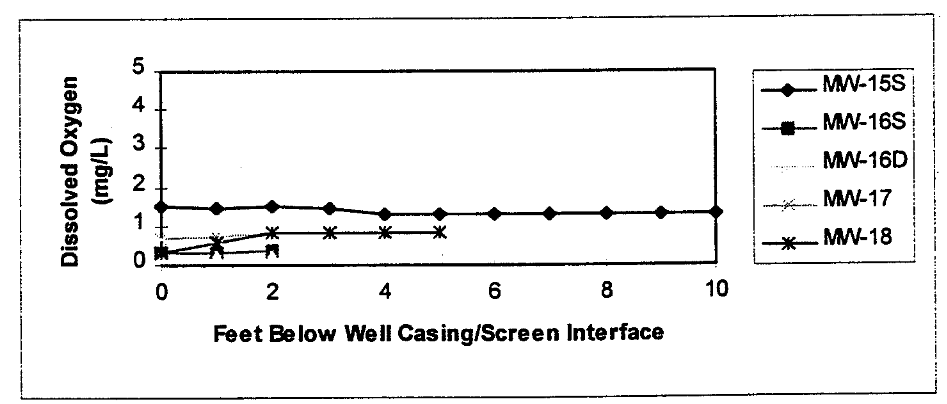

Figure 7.3 : Dissolved oxygen trends within the perforated section of wells at the UISAS.

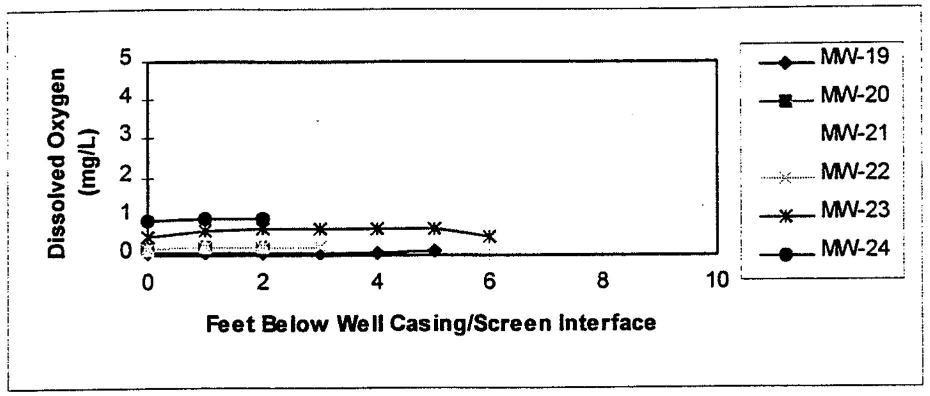

Figure 7.4: Dissolved oxygen trends within the perforated section of wells at the UISAS.

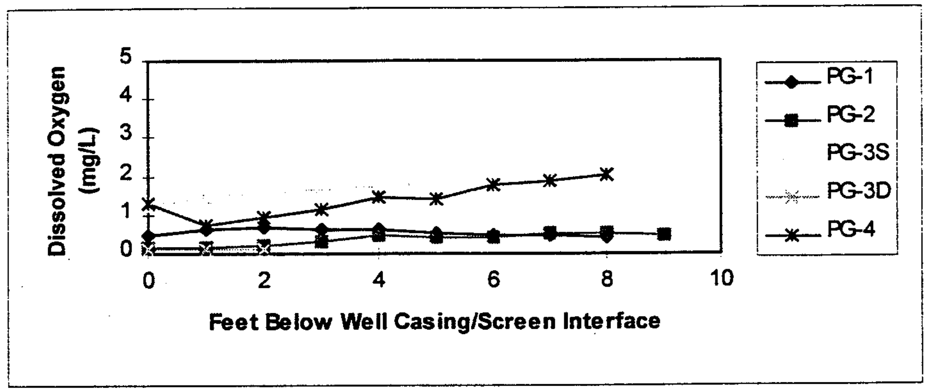

Figure 7.5: Dissolved oxygen trends within the perforated section of wells at the UISAS.

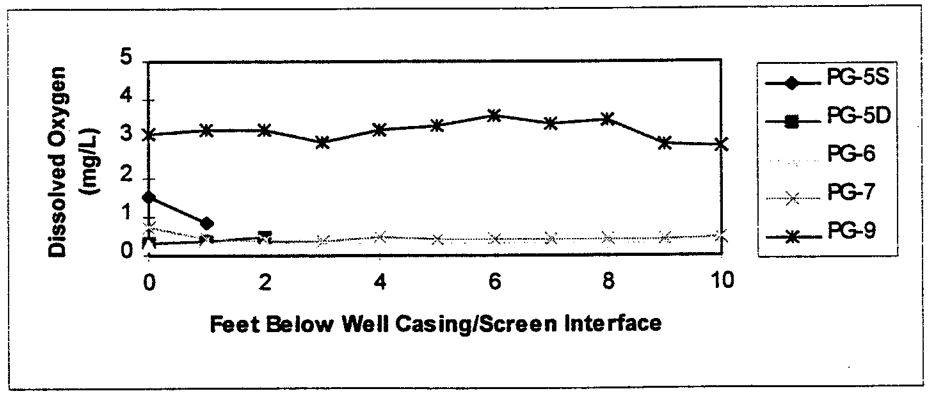

Figure 7.6: Dissolved oxygen trends within the perforated section of wells at the UISAS.

A plot of mean dissolved oxygen versus the mean depth of the perforated interval below ground surface for wells at the UIGRS does not show a clear relationship (Figure 7.7). Most shallow wells at the UISAS are completed in the sediments and showed relatively low dissolved oxygen values. The deeper wells are all completed in basalt and show relatively low dissolved oxygen values.

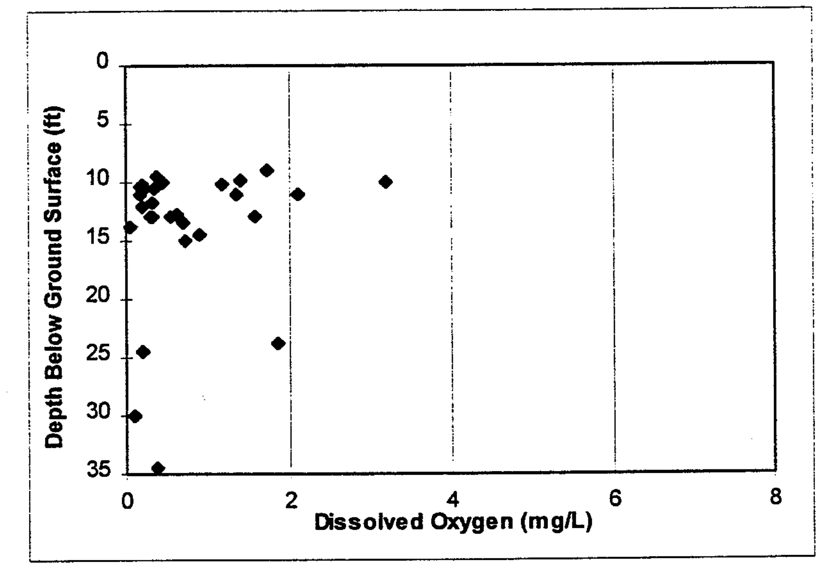

Figure 7.7 : Scatter plot of mean depth of the perforated interval below ground surface versus mean dissolved oxygen of the perforated interval.

Chapter 8

Comparison of the Research Sites

Wells at the four research sites in this study have a range of mean dissolved oxygen values from <0.01 to 6.18 mg/L. Table 8-1 summarizes the range and mean dissolved oxygen values for each site and/or aquifer. Factors influencing the data could be either error or numerous variables affecting dissolved oxygen at each site. These variables are aquifer material, depth of the perforated interval below ground surface, degree and type of contamination and proximity to a recharge source. These variables are discussed in the following sections.

Table 8-1 : Ranges and means of dissolved oxygen concentrations of the research sites.

Research Site	Aquifer Type	Mean D.O. Range of Wells within Perforated Interval (mg/L)	Mean D.O. of the Site/Aquifer (mg/L)
UIGRS	Alluvial	<0.01-0.85	0.29
UIGRS	Basalt : E-Fracture	0.27-2.05	1.23
UIGRS	Basalt : W-Fracture	0.06-2.70	1.06
UIPSS1	Alluvial	<0.01-6.18	3.35
UIPSS2	Alluvial	<0.01-2.16	0.41
UISAS	Alluvial	0.17-3.19	0.80
UISAS	Basalt	0.10-1.86	0.64

Error

Some of the variability in the dissolved oxygen data could have been caused by instrument problems, field procedure problems or field data collection or recording error. Potential instrument problems include instrument malfunction and error introduced because the probe does not have a built in stirrer. The instrument has an internal diagnostics system that identifies any instrument malfunctions. No malfunctions of this type occurred during the data collection for this study. Laboratory dissolved oxygen instruments often include a stirrer to insure that the probe does not deplete the oxygen at the membrane and result in a low reading. The field probe used in this study does not include a stirrer. As noted previously the field dissolved oxygen logger was very sensitive to small movements of the wire and probe. This suggests that the lack of a stirrer could be a problem. The field probe was checked against a stirred lab instrument early in the study. The two readings were within 0.1 mg/L of each other. These data suggest that the field instrument readings are accurate.

Variations in the field procedures probably did not cause dissolved oxygen variations. The meter was calibrated systematically every day according to the calibration procedures stated in Chapter 2. The calibration routine was the same at all sites. The probe membranes were changed daily even though the YSI manual suggested they be changed every three weeks. The logging procedures were the same at all sites. Field data collection and recording error was minimized as each site was researched in the same systematic fashion. Thus error is not believed to be a major factor in the observed variability in dissolved oxygen values at the research sites.

Dissolved Oxygen Variables

Each research site of this study had wells completed in alluvial aquifers. The UIGRS and the UISAS also had wells completed in the underlying basalt. The mean dissolved oxygen for the alluvium at the sites range from of 0.29 mg/L for the UIGRS to 3.35 mg/L for the UIPSS1. The basalt sites had more intermediate dissolved oxygen values of 0.64 mg/L at the UISAS and 1.06 and 1.23 mg/L for the W and E-fractures respectively at the UIGRS. All of these results suggest that aquifer material is not the only or primary controlling factor.

A consistent relationship of an increase in dissolved oxygen concentrations and depth of perforation interval exists for wells completed in the sediments at the sites. Figure 8.1 shows a plot of mean dissolved oxygen versus the mean depth of the perforated interval below ground surface for all of the alluvial wells from the research sites. Dissolved oxygen values in the most shallow alluvial wells are probably depressed because of the presence of organics near the ground surface (Kellogg, personal communication, 1996). The UIGRS, the UIPSS1 and the UIPSS2 all have ample surface vegetation and clearly show a trend of low dissolved oxygen close to the ground surface. The UISAS does not show this trend as well, possibly because of less ground cover due to recent remediation efforts. All of these results suggest that depth below ground surface is a primary factor in controlling dissolved oxygen in ground water within sedimentary aquifers at the sites.

Wells completed in the underlying basalt show a less distinct trend of increasing dissolved oxygen with depth (Figure 8.2). The shallow basalt wells (depths of less than 40 feet) at the UIGRS and the UISAS have lower dissolved oxygen values than the wells of the

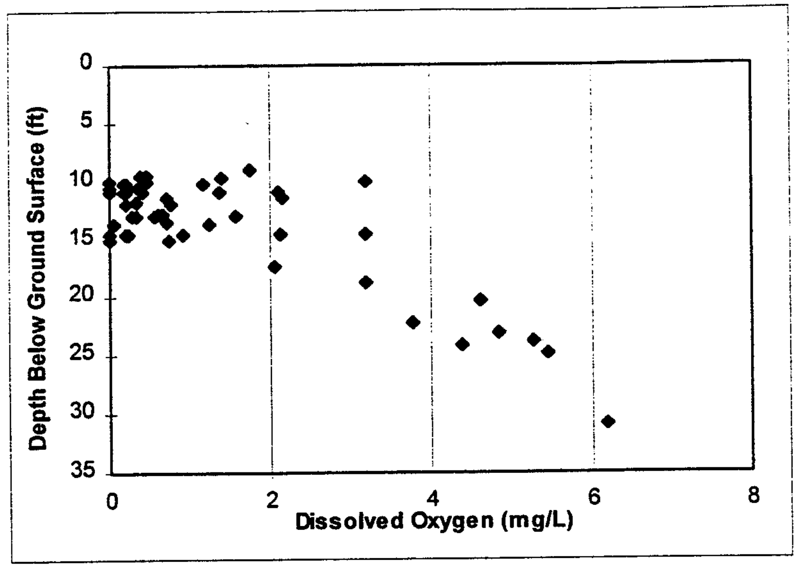

Figure 8.1 : Scatter plot of mean depth of the perforated interval below ground surface versus mean dissolved oxygen of the perforated interval for all of the alluvial wells at all the research sites.

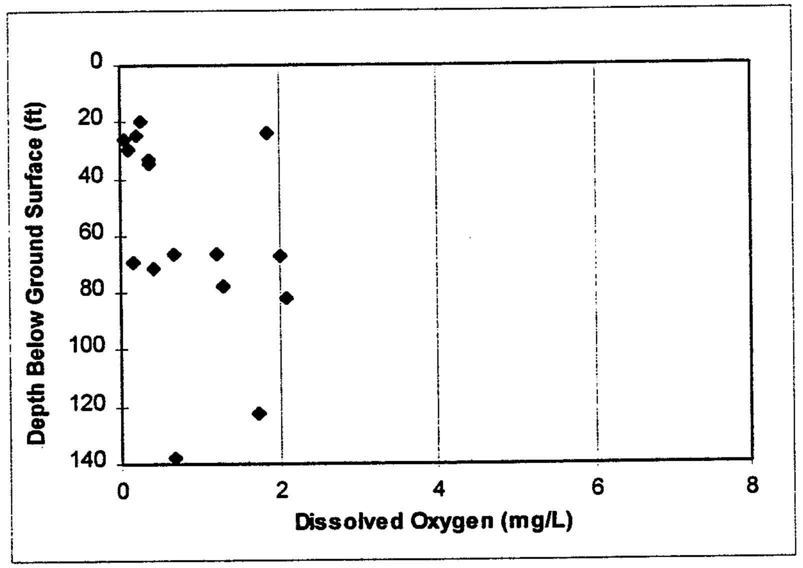

Figure 8.2 : Scatter plot of mean depth of the perforated interval below ground surface versus mean dissolved oxygen of the perforated interval for all of the basalt wells at the UIGRS and the UISAS.

E and W- fracture completed in the deeper basalt (depth range of approximately 65 to 125 feet) at the UIGRS. However, wells completed in the basalt have dissolved oxygen values much lower than wells in the deeper portion of the alluvium. This suggests that dissolved oxygen values are suppressed in the basalt. Chemical reactions involving iron or sulfur rich phases in the basalt may be consuming dissolved oxygen. These phases occur 10 to 100 times more frequently in the basalt than in the alluvium in Moscow area (Geist, personal communication, 1996).

Contamination also is a factor that influences dissolved oxygen values for at least one of the sites. PS-3 at the UIPSS1 has the lowest mean dissolved concentration of the wells measured (<0.01 mg/L), and the highest concentrations of dinoseb (160 µg/L) and dicamba (210 µg/L). Yet the UIPSS1 had the highest mean dissolved oxygen value (3.35 mg/L) of any site. Other wells at this site or others did not display this relationship, suggesting that contaminant concentrations may have been too low. This suggests that except possibly for this well, contamination is not the only or primary controlling factor at the four research sites.

Other factors that may have affected dissolved oxygen concentrations at the sites are testing time or seasonal differences. The time of year for testing may affect dissolved oxygen concentrations mainly due to fluctuations in ground water temperature. Differences in temperature would effect the solubility of water and the behavior of microorganisms. Proximity to a recharge area may have a significant effect on dissolved oxygen concentration in ground water. Pionke and Urban (1987) noticed that recharge areas had almost 92% higher dissolved oxygen concentrations than discharge areas in a shallow sand and shale aquifer. No clear delineation of recharge effects was possible at any of the sites.

Chapter 9

Conclusions and Recommendations

Conclusions

The general conclusion of this study is that dissolved oxygen data in ground water are highly variable and are influenced by many factors. The dominant factor appears to be depth to the perforated interval. The downhole measurement of dissolved oxygen is a good tool to use in site characterization, particularly in deeper (>20 feet) sedimentary aquifers.

Specific conclusions are :

1. A clear pattern of increasing dissolved oxygen with depth exists at the sites for wells completed in the alluvium. The wells completed in the basalt also show this trend although not as clearly. The basalt dissolved oxygen values are lower probably because of chemical reactions involving iron and sulfur phases in the basalt that consume dissolved oxygen.

2. In general, dissolved oxygen is higher in the non-perforated sections of wells than in the perforated sections. This observation is probably because the non-perforated sections in wells are more shallow and closer to the air-water interface where oxygen saturation is greater. This trend is clearly present at the UIGRS and the UIPSS2 but not as clear at the UIPSS1 and UISAS where other factors may be important.

3. In general, dissolved oxygen concentrations in the perforated sections of wells are constant. This suggests that two or three measurements in the perforated sections are adequate to estimate dissolved oxygen for an aquifer system in a well.

4. Contamination may decrease dissolved oxygen concentrations at the UIPSS1, particularly in the more contaminated wells such as PS-3. Other, less contaminated wells at the UIPSS1 and the other contaminated sites do not clearly show this trend.

5. The primary window for downhole dissolved oxygen characterization is in the sedimentary aquifers below a depth of about 20 feet.

Recommendations

1) Using this study as a baseline, explore in greater detail the effects that contaminants have on the dissolved oxygen concentrations of an aquifer; particular attention should be paid to different types of contaminants and varying concentrations of those contaminants.

2) Temporal, downhole dissolved oxygen data should be obtained to investigate seasonal and yearly trends in shallow aquifers, particularly those sites near streams.

3) The effect of purging wells prior to dissolved oxygen logging should be investigated.

Appendix A

Dissolved Oxygen Logging of UIGRS

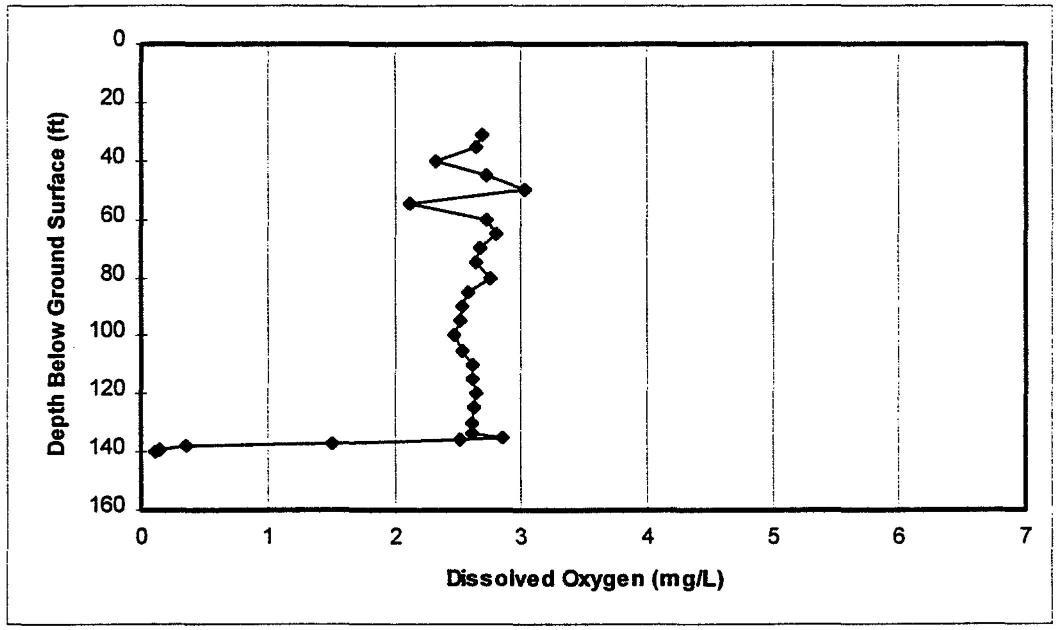

Figure A.1 : Dissolved oxygen profile of well D19D, screened interval 137-139 ft.

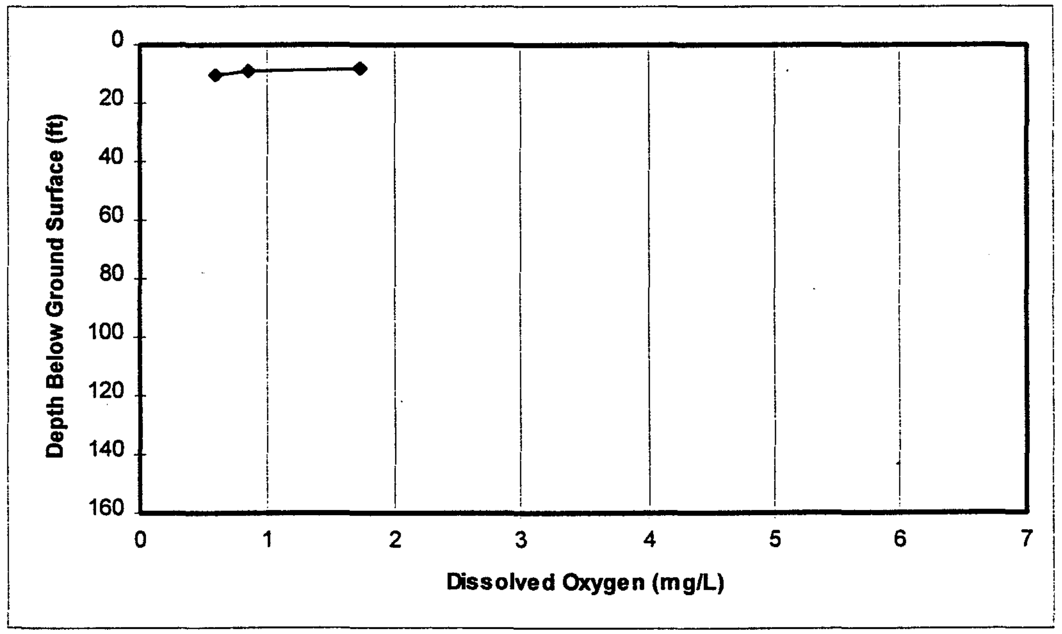

Figure A.2 : Dissolved oxygen profile of well D19S, screened interval 9-10 ft.

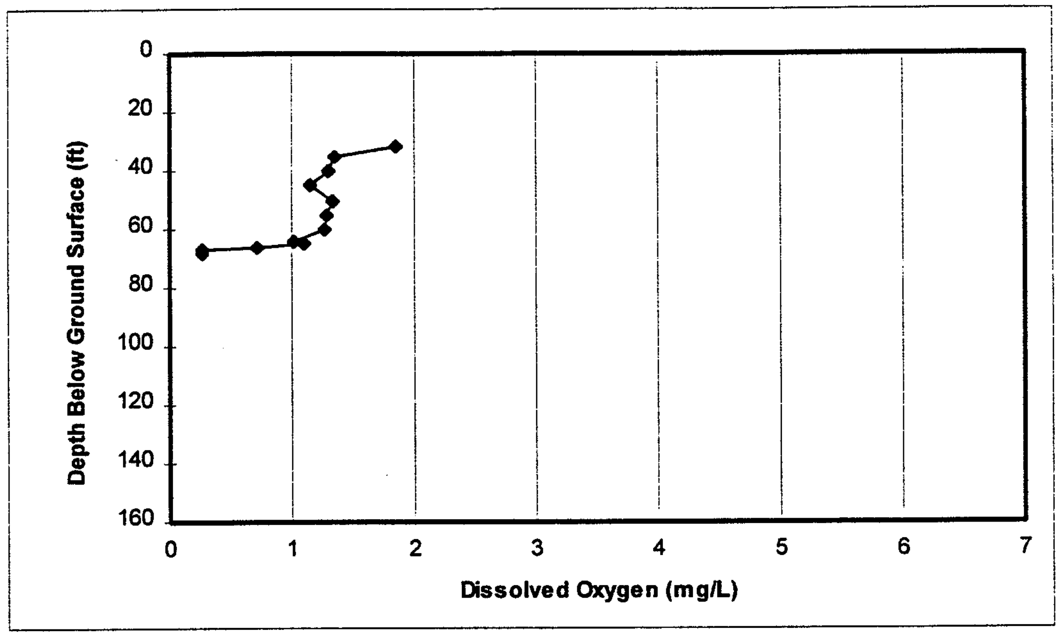

Figure A.3 : Dissolved oxygen profile of well J16D, screened interval 65-67.5 ft.

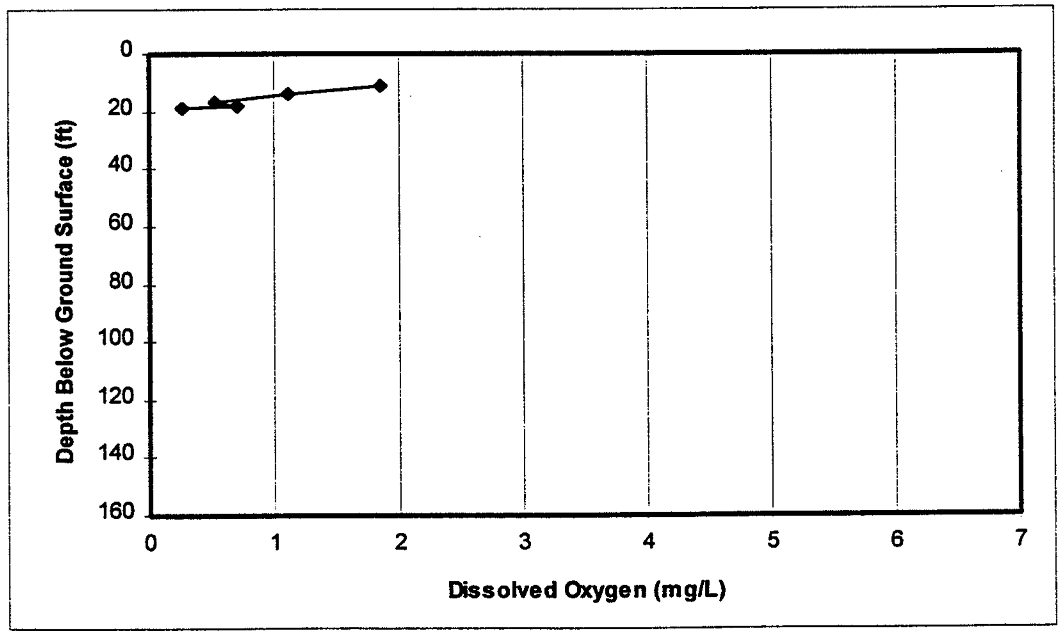

Figure A.4 : Dissolved oxygen profile of well J16S, screened interval 19-20 ft.

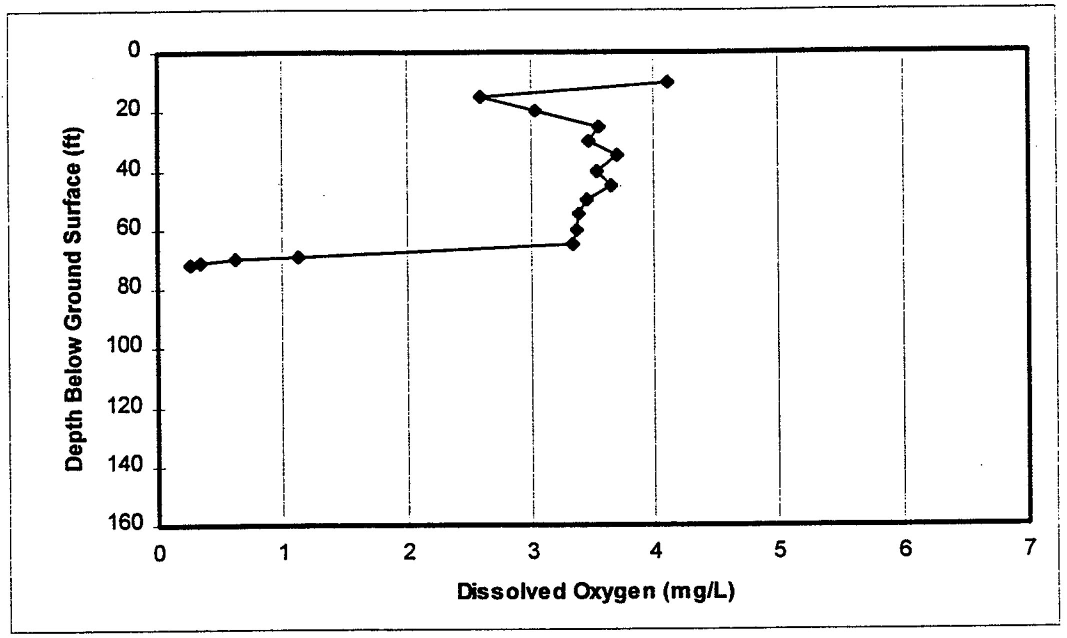

Figure A.5 : Dissolved oxygen profile of well Q16D, screened interval 70-72.5 ft.

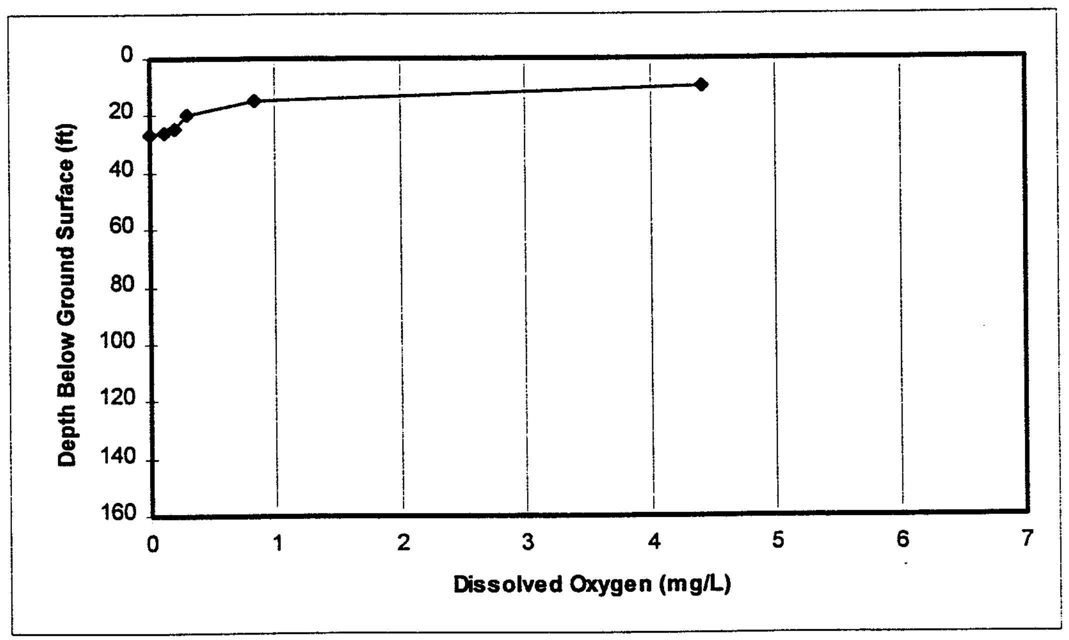

Figure A.6 : Dissolved oxygen profile of well Q16S, screened interval 26-27 ft.

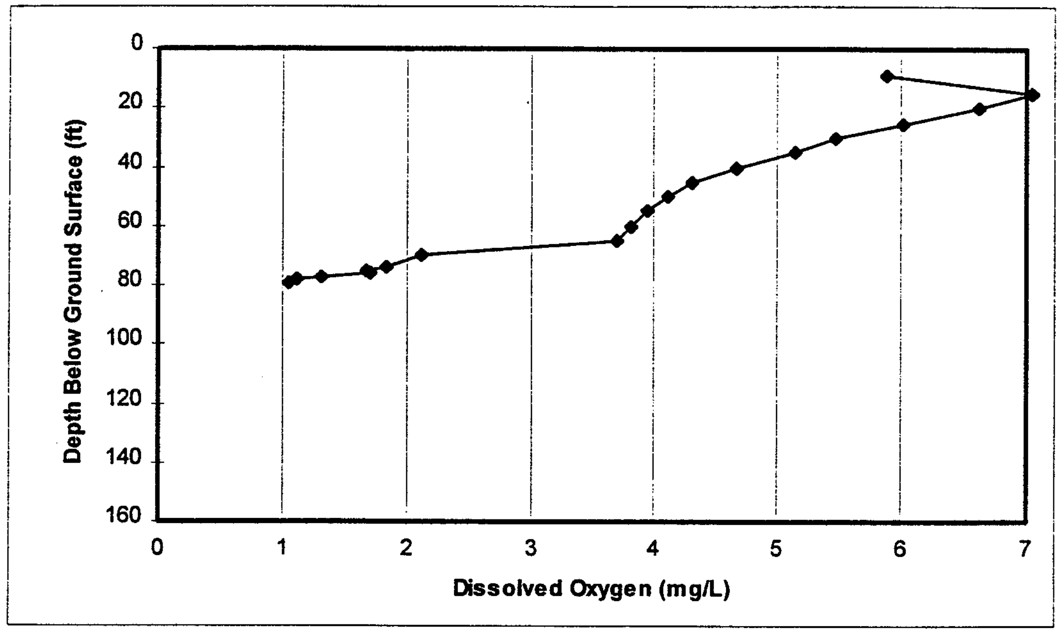

Figure A.7 : Dissolved oxygen profile of well Q17D, screened interval 76-79 ft.

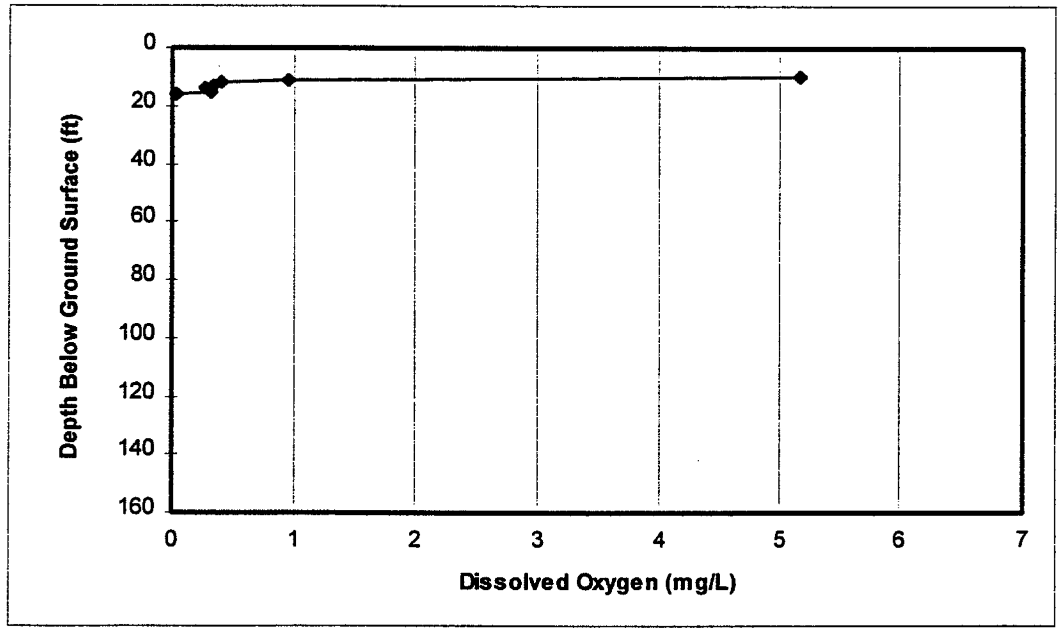

Figure A.8 : Dissolved oxygen profile of well H12S, screened interval 13-16 ft.

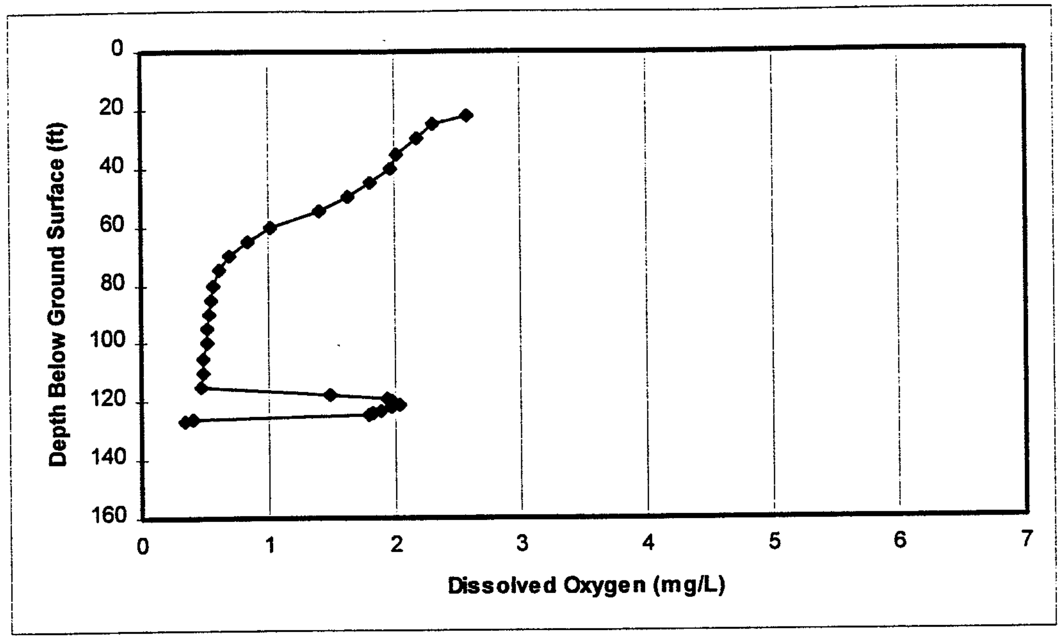

Figure A.9 : Dissolved oxygen profile of well S12D1, screened interval 119-126 ft.

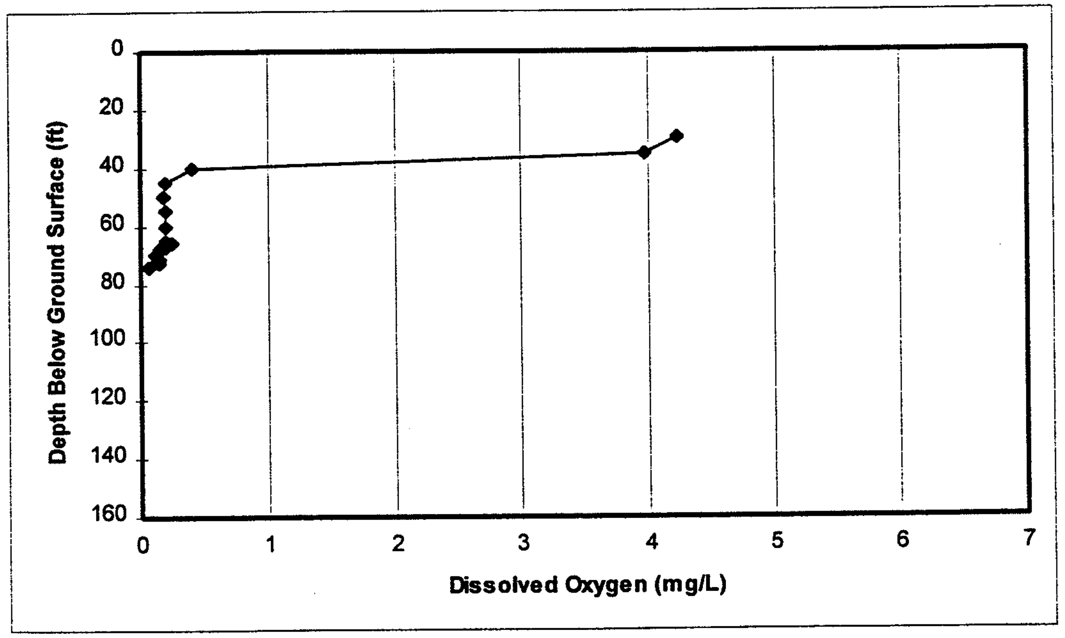

Figure A.10 : Dissolved oxygen profile of well S12D2, screened interval 65-74 ft.

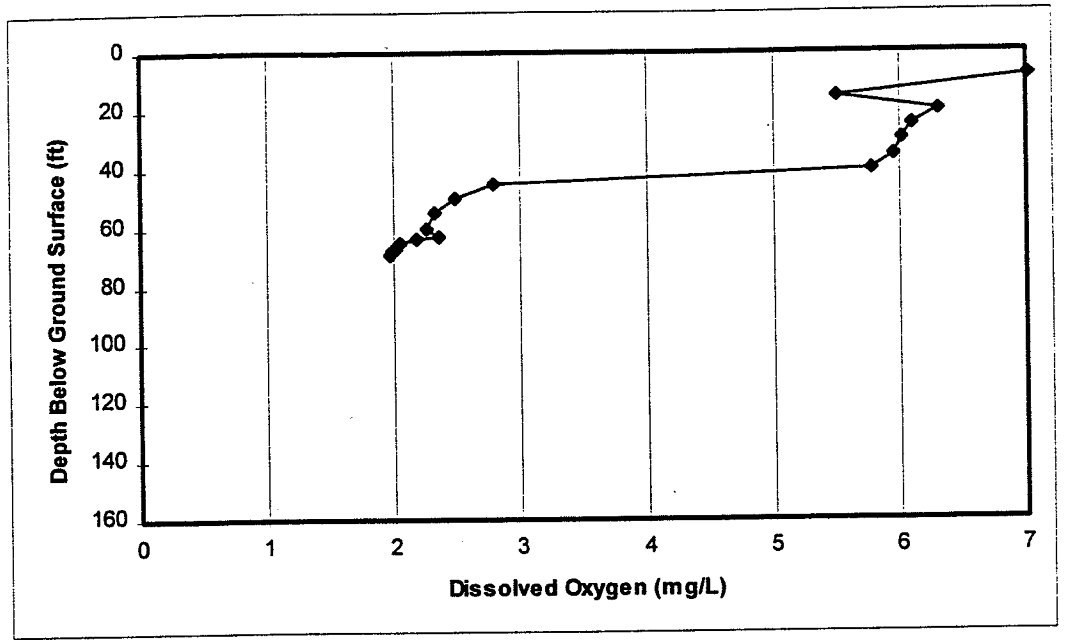

Figure A.11 : Dissolved oxygen profile of well T16D, screened interval 65-69 ft.

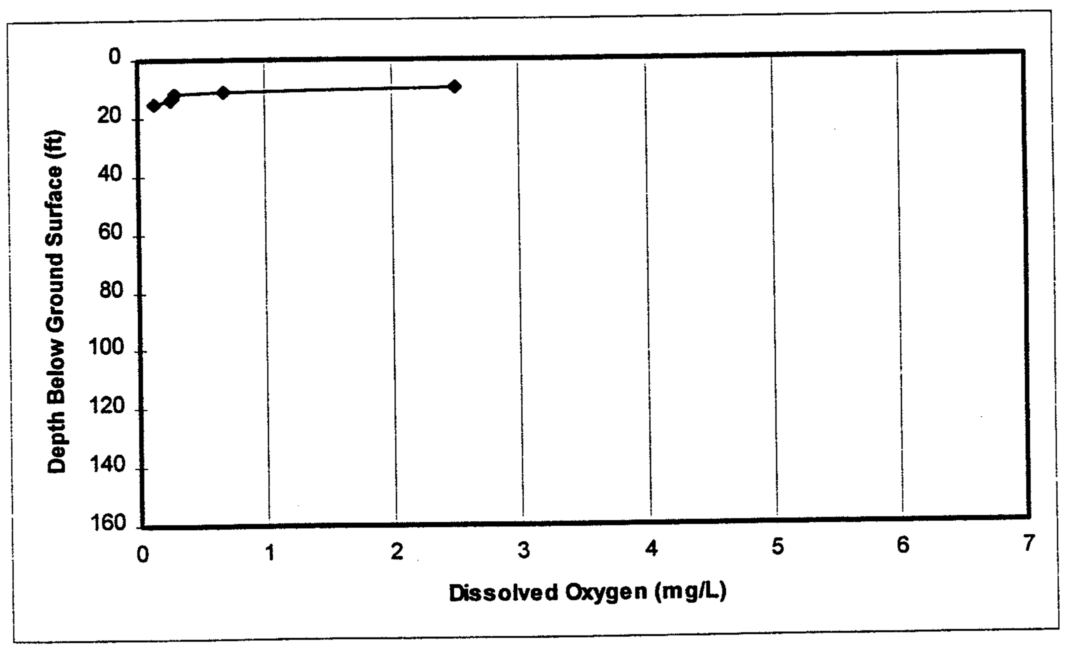

Figure A.12 : Dissolved oxygen profile of well T8S, screened interval 13-15 ft.

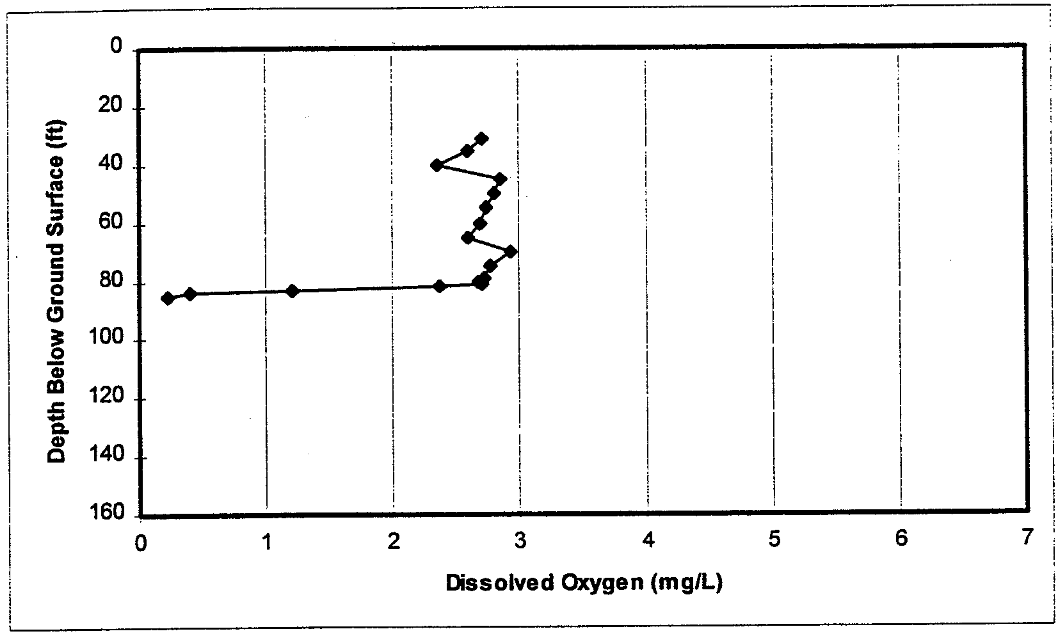

Figure A.13 : Dissolved oxygen profile of well U3D, screened interval 81-83 ft.

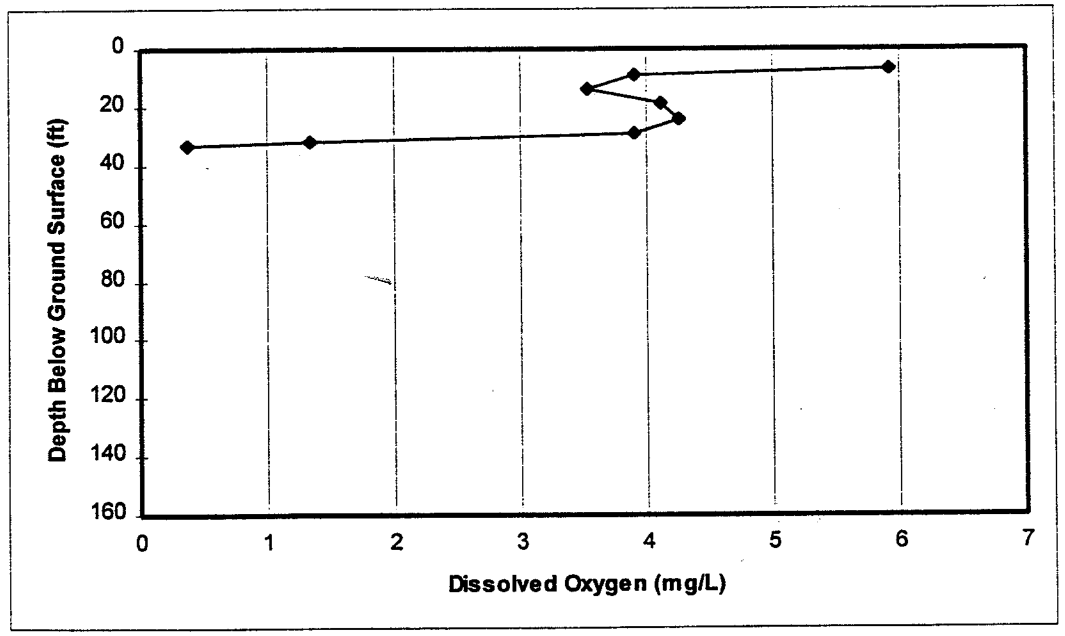

Figure A.14 : Dissolved oxygen profile of well U3S, screened interval 33-34 ft.

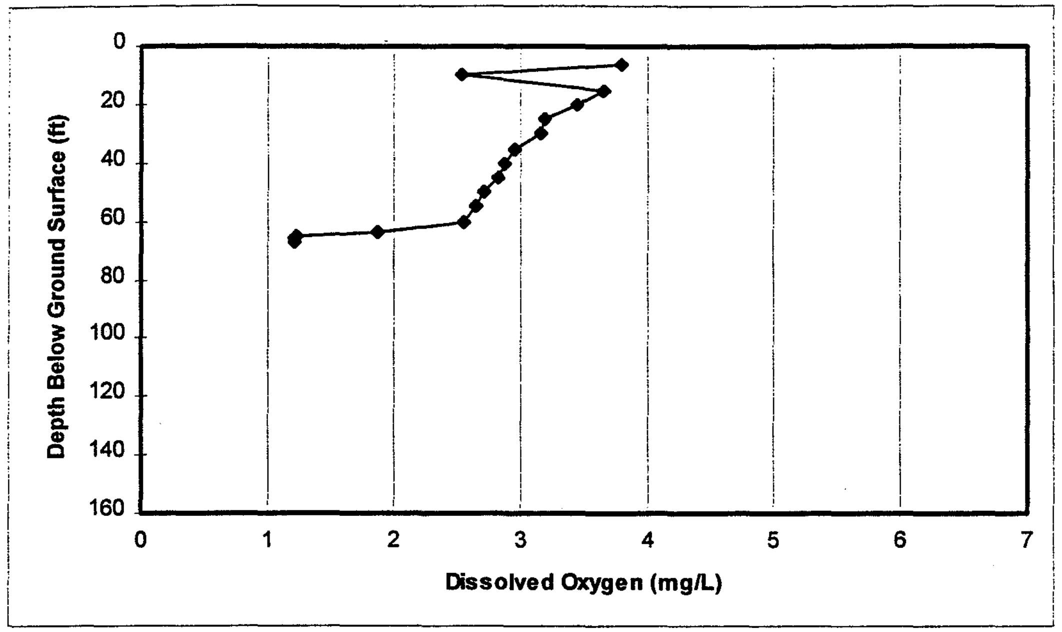

Figure A.15 : Dissolved oxygen profile of well V16D, screened interval 65-67.5 ft.

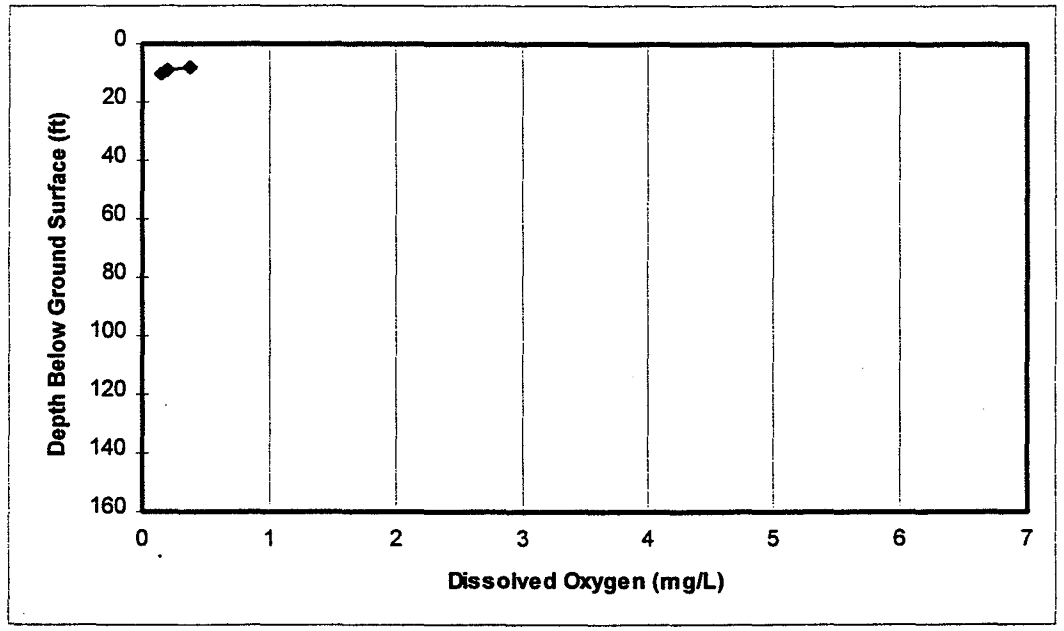

Figure A.16 : Dissolved oxygen profile of well V16S, screened interval 9-10 ft.

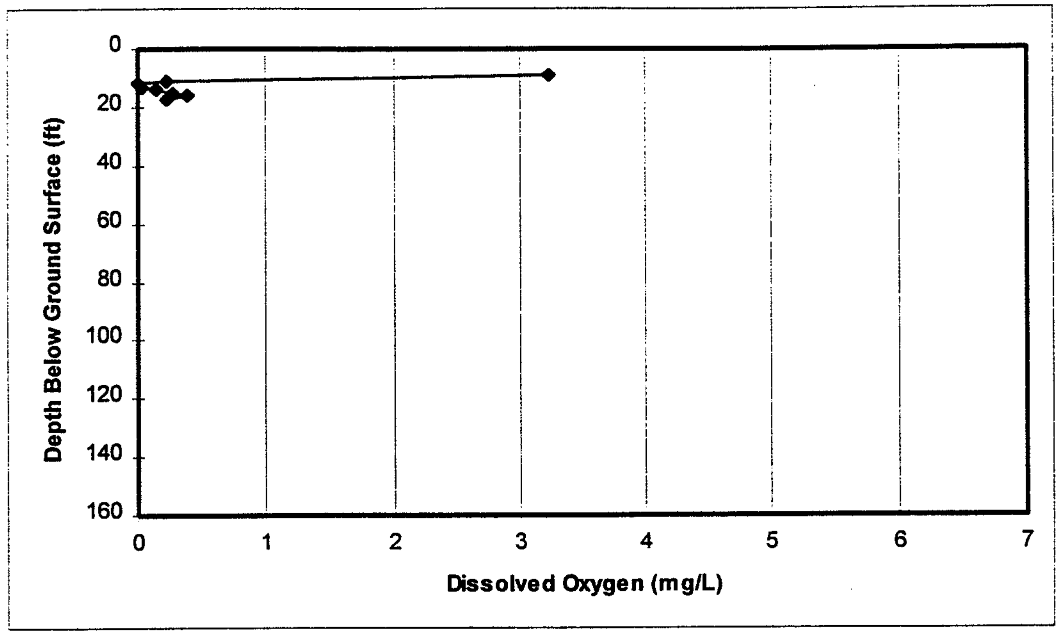

Figure A.17 : Dissolved oxygen profile of well N18S, screened interval 13-16 ft.

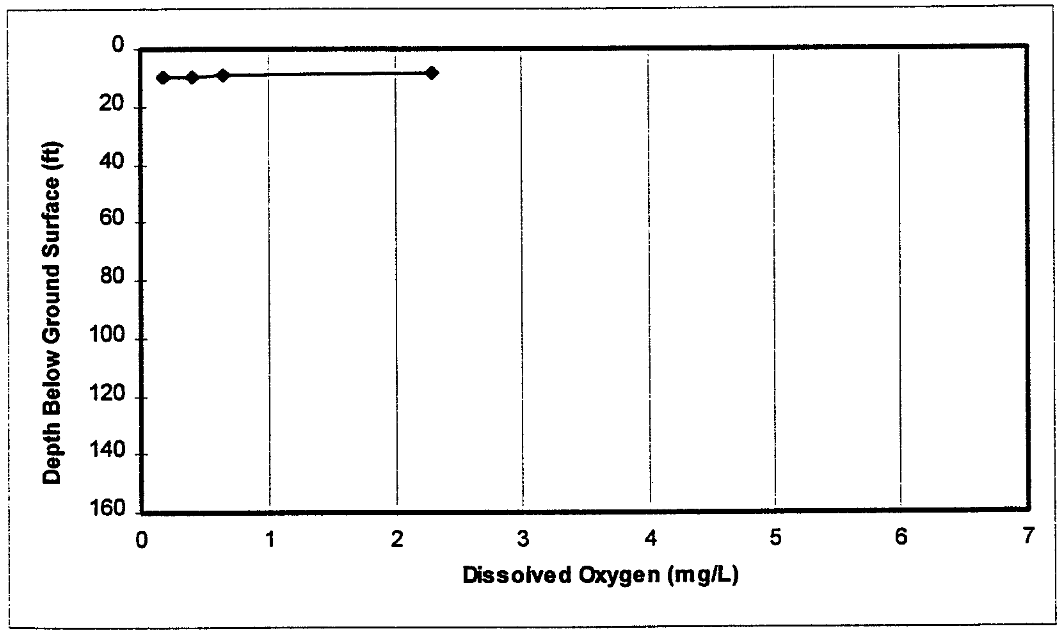

Figure A.18 : Dissolved oxygen profile of well P17S, screened interval 9-10 ft.

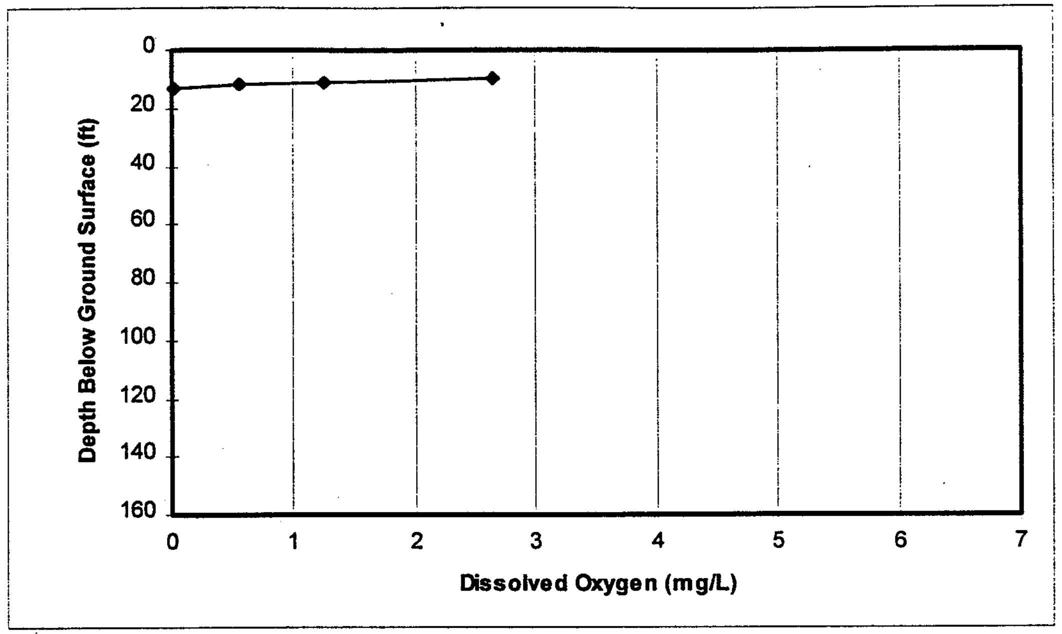

Figure A.19 : Dissolved oxygen profile of well J17S, screened interval 14-16 ft.

Dissolved Oxygen Logging of UIPSS1

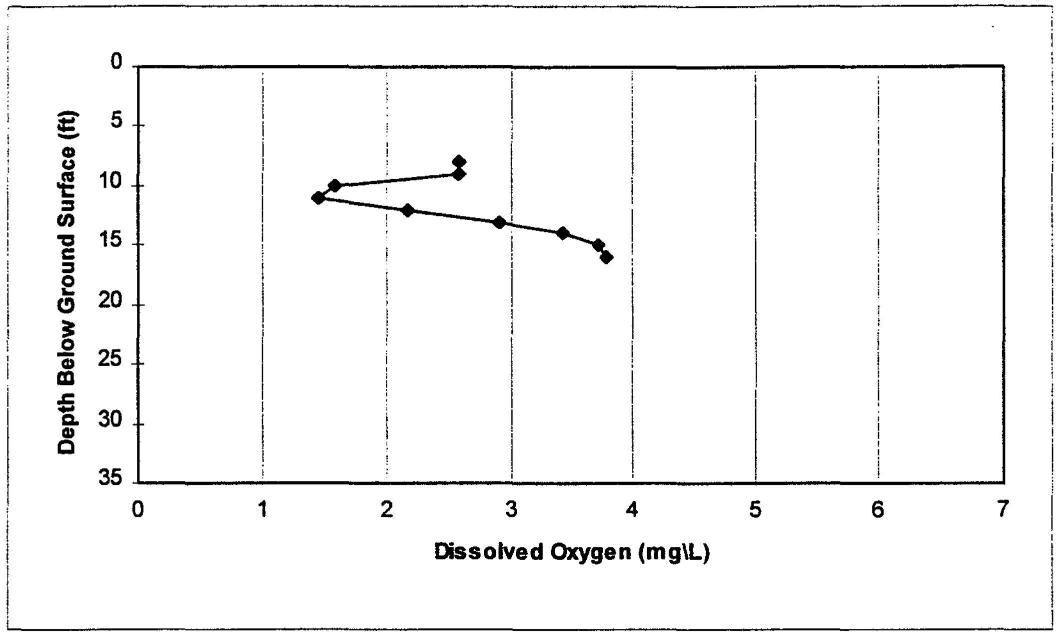

Figure A.20 : Dissolved oxygen profile of well PS-2, screened interval 12-17 ft.

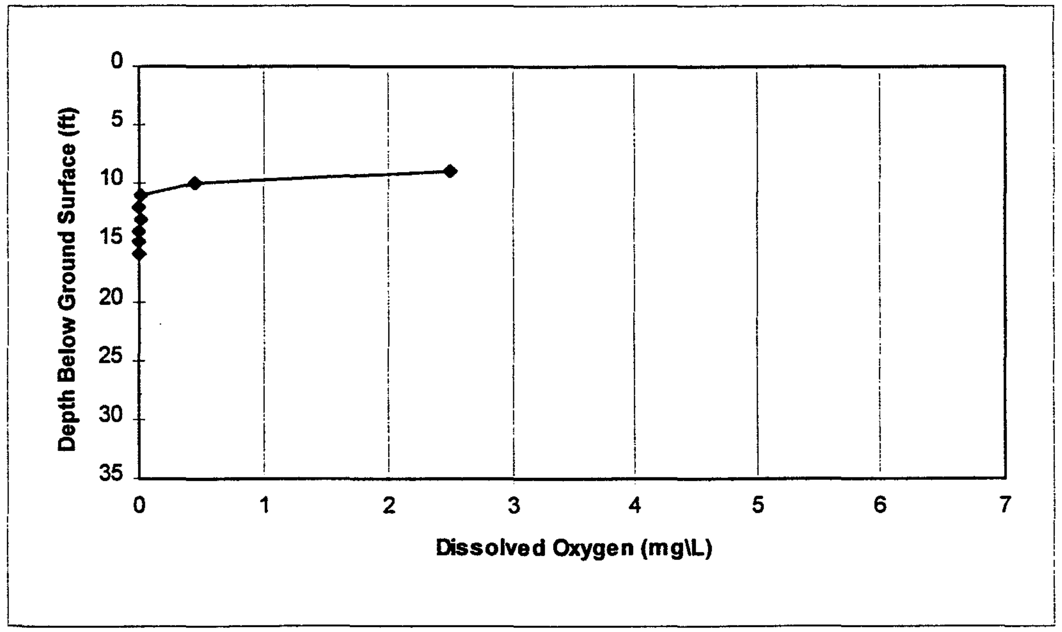

Figure A.21 : Dissolved oxygen profile of well PS-3, screened interval 12-17 ft.

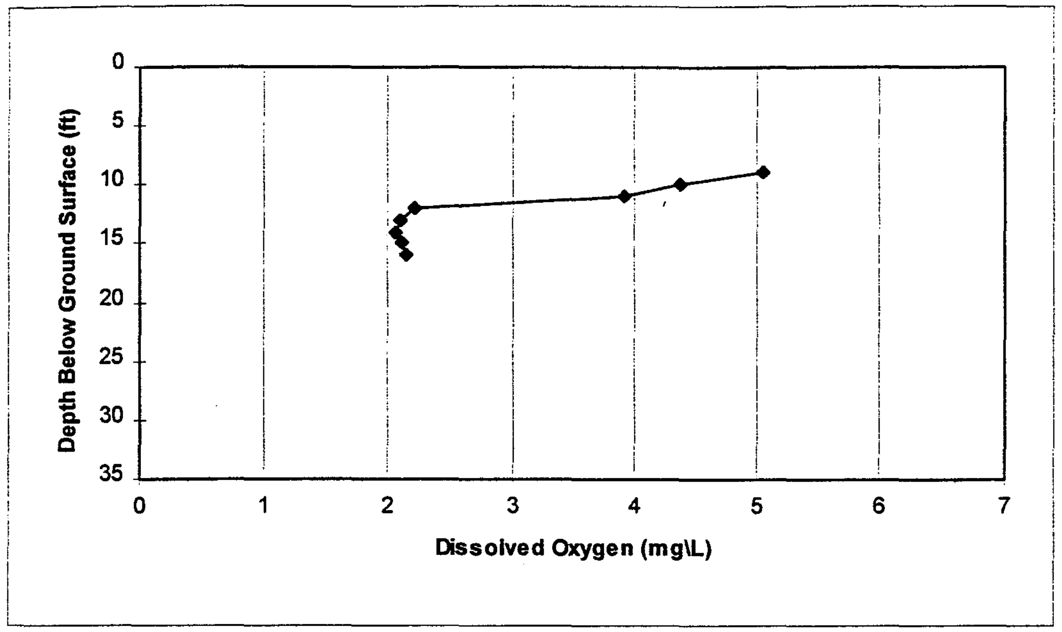

Figure A.22 : Dissolved oxygen profile of well PS-5, screened interval 12-17 ft.

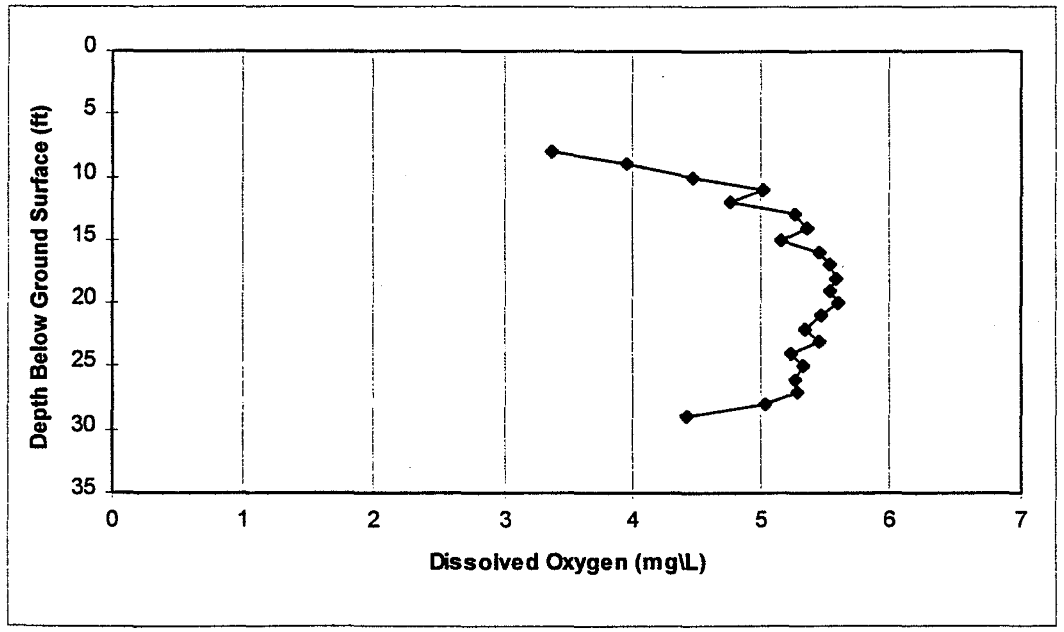

Figure A.23 : Dissolved oxygen profile of well PS-18, screened interval 18.7-28.7 ft.

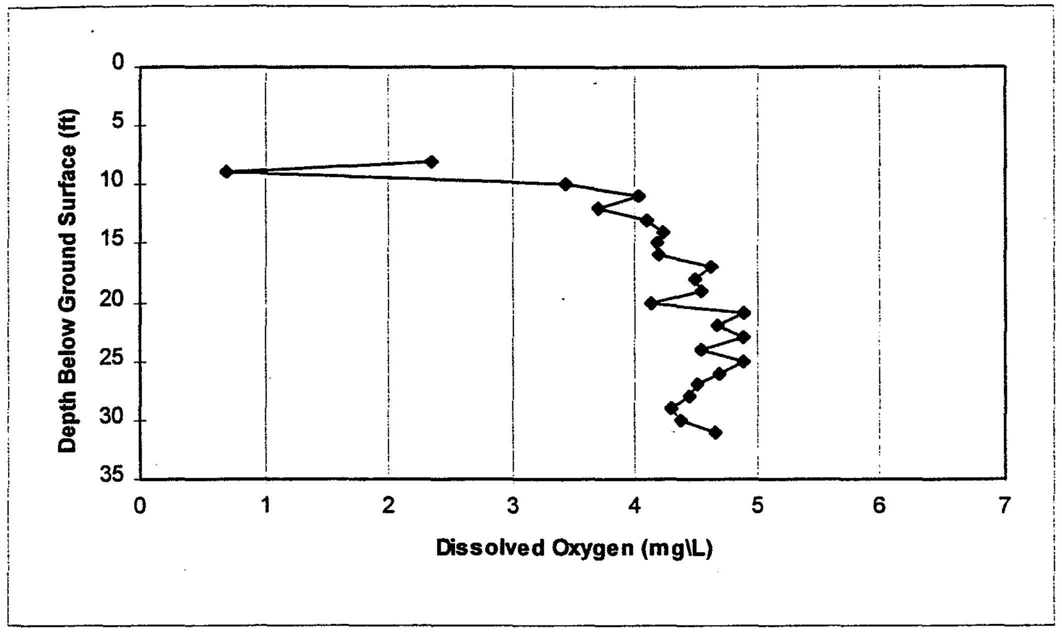

Figure A.24 : Dissolved oxygen profile of well PS-16A, screened interval 16.5-24 ft.

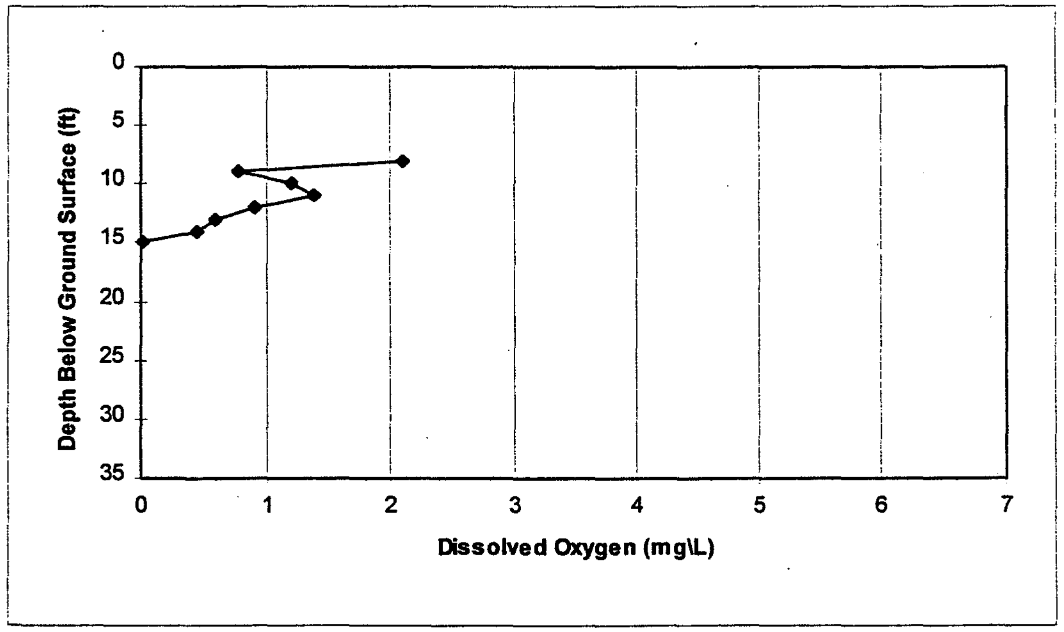

Figure A.25 : Dissolved oxygen profile of well PS-16B, screened interval 11.5-14 ft.

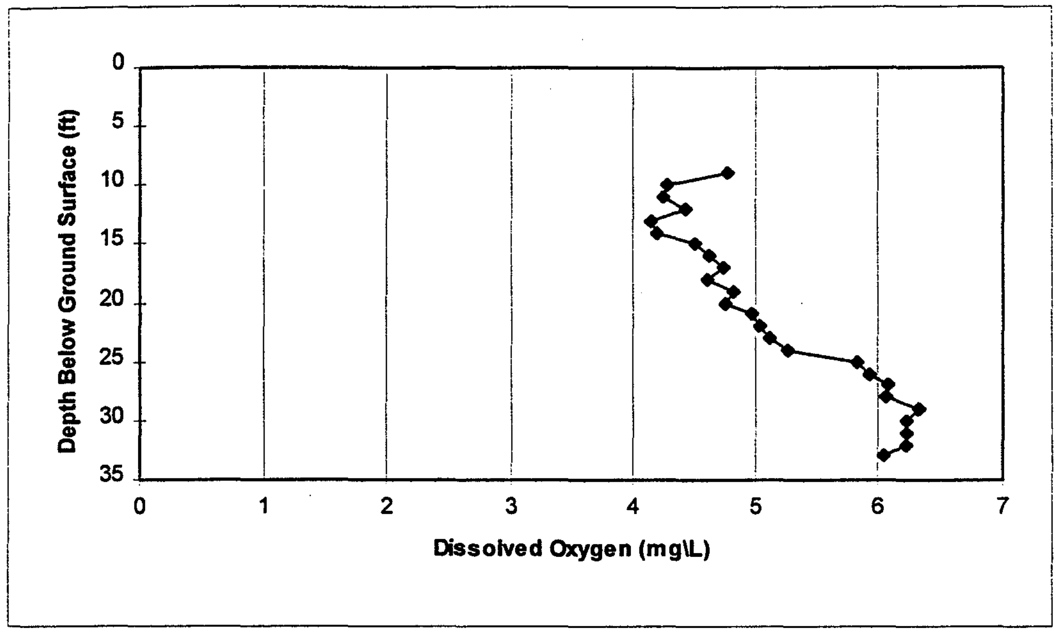

Figure A.26 : Dissolved oxygen profile of well PS-17A, screened interval 28.3-33.3 ft.

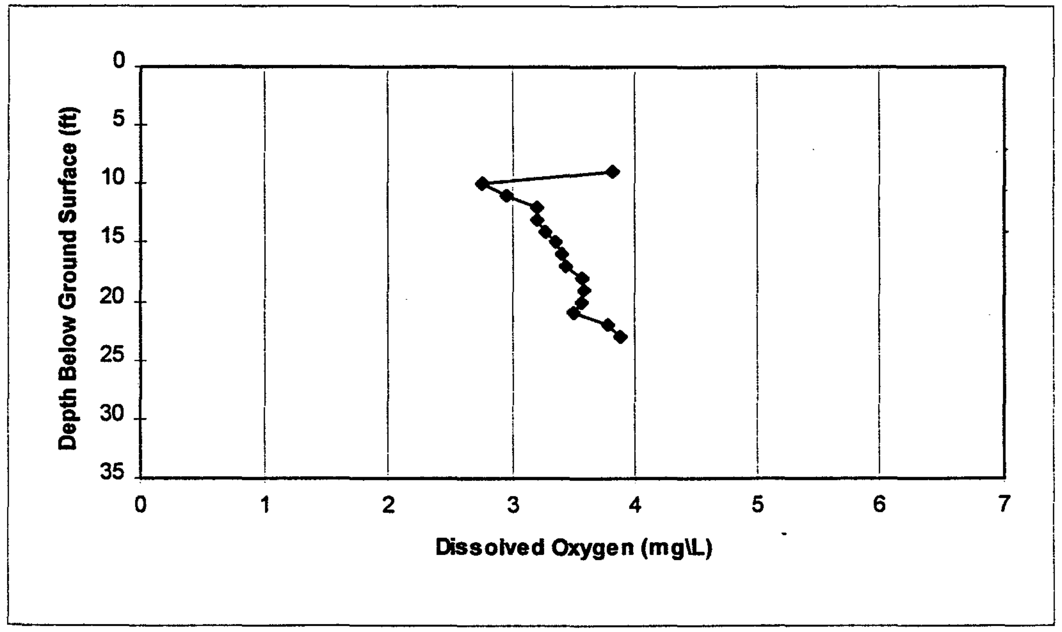

Figure A.27 : Dissolved oxygen profile of well PS-17B, screened interval 21-23.5 ft.

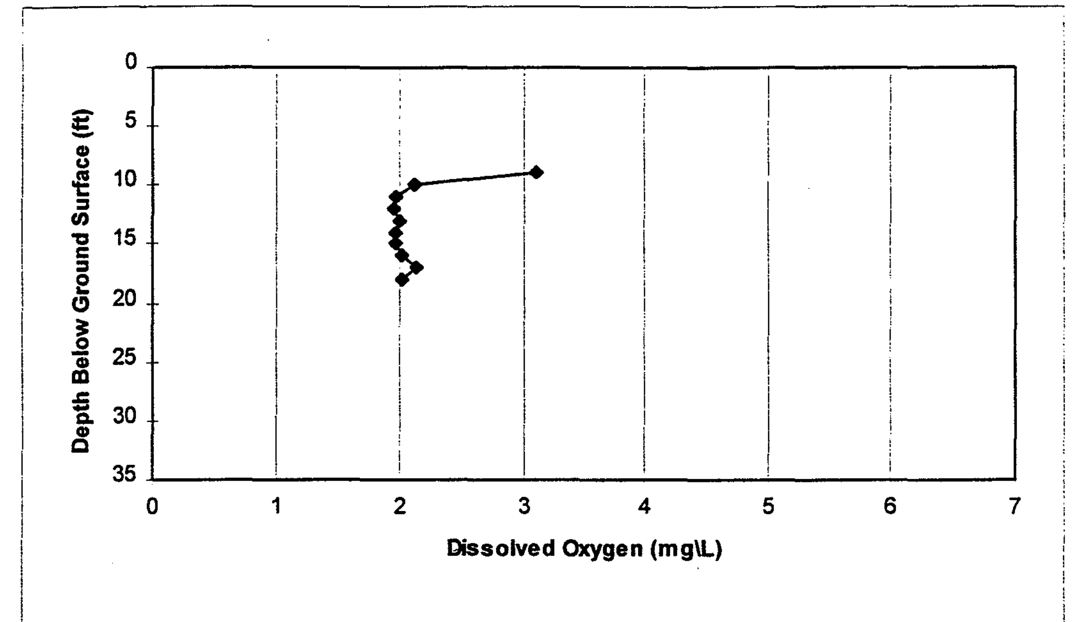

Figure A.28 : Dissolved oxygen profile of well PS-17C, screened interval 16-18.5 ft.

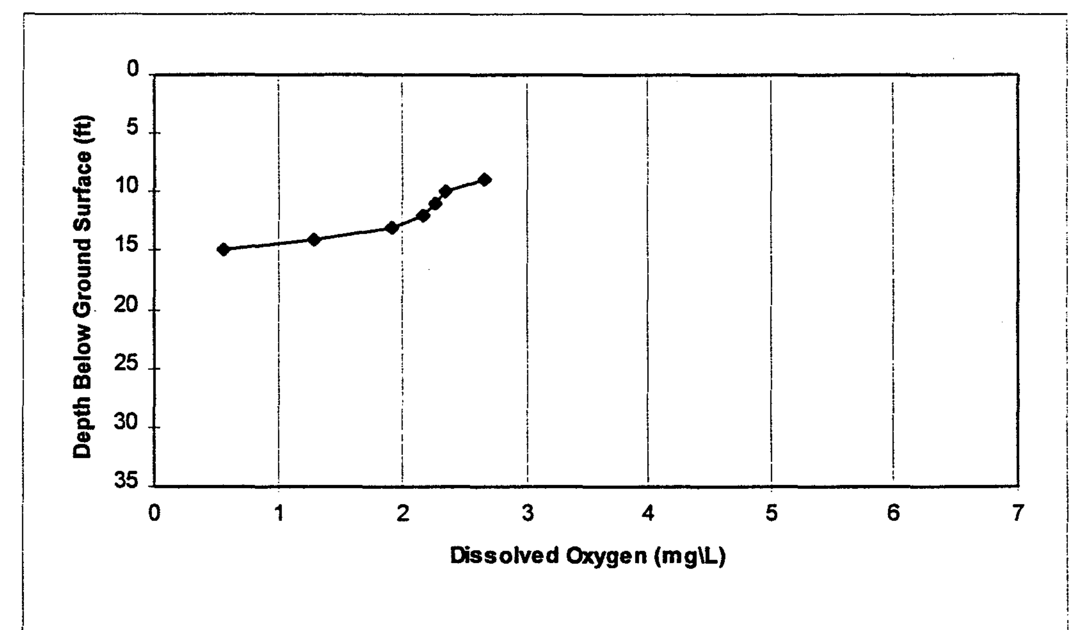

Figure A.29 : Dissolved oxygen profile of well PS-17D, screened interval 12.5-15 ft.

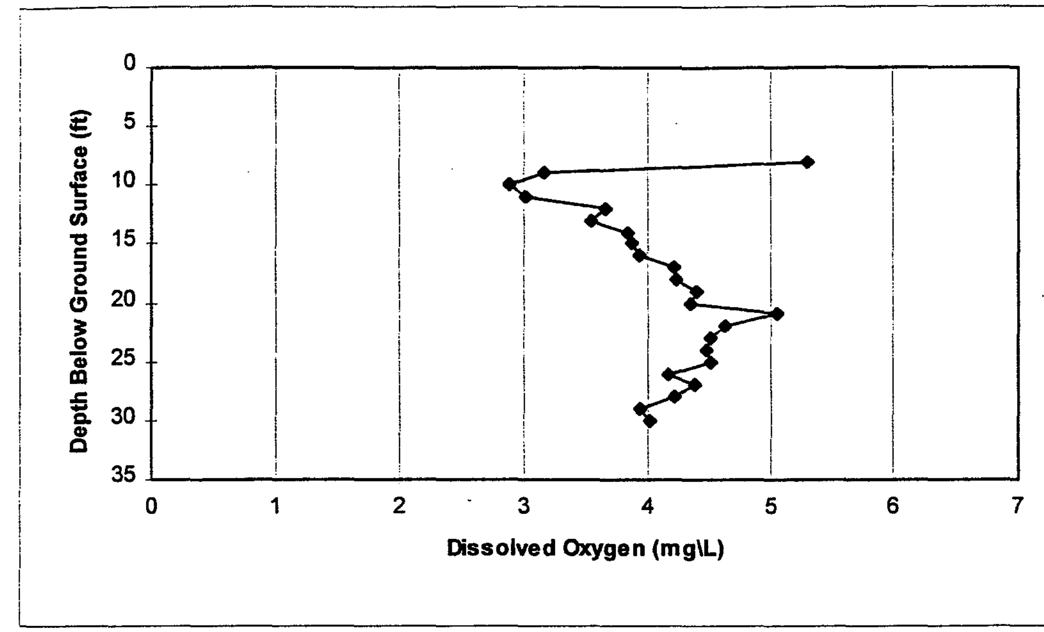

Figure A.30 : Dissolved oxygen profile of well PS-19, screened interval 17.8-30.3 ft.

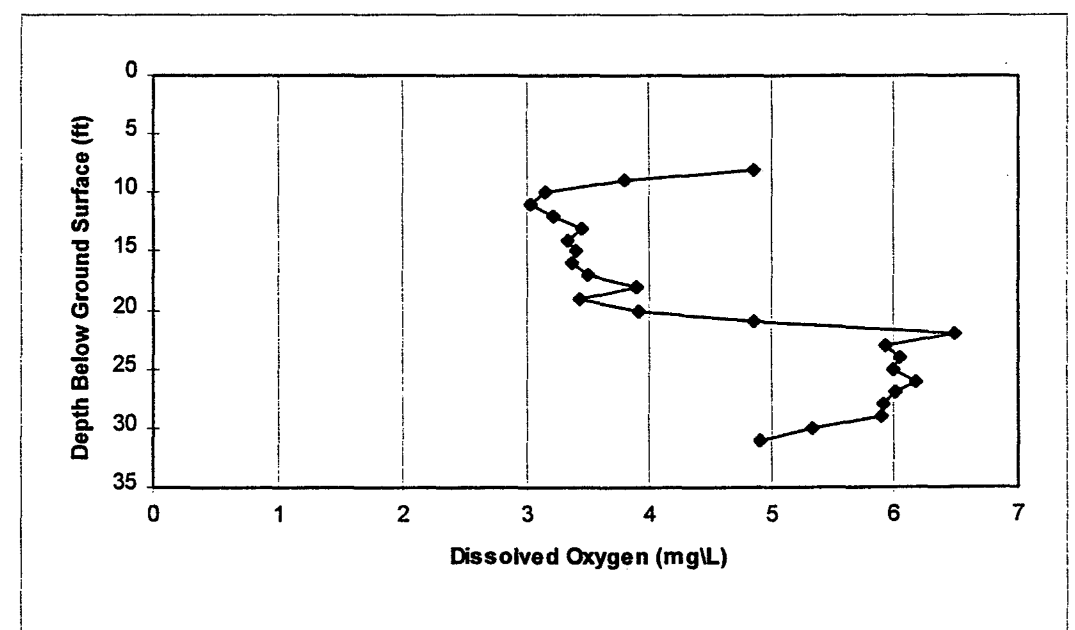

Figure A.31 : Dissolved oxygen profile of well PS-20, screened interval 18.5-31 ft.

Dissolved Oxygen Logging of the UISAS

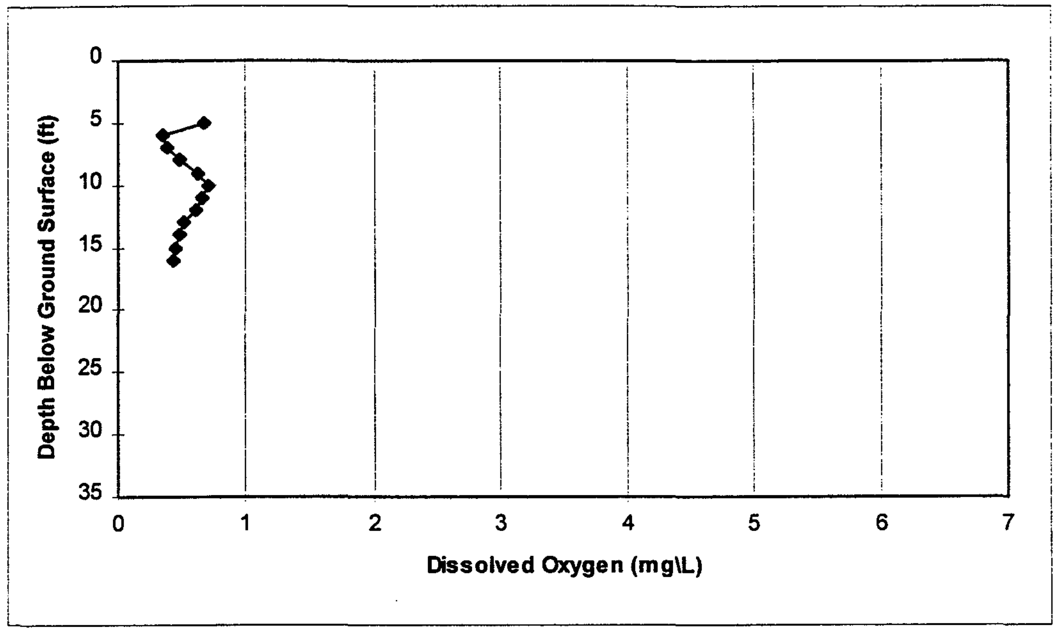

Figure A.32 : Dissolved oxygen profile of well PG-1, screened interval 5-14 ft.

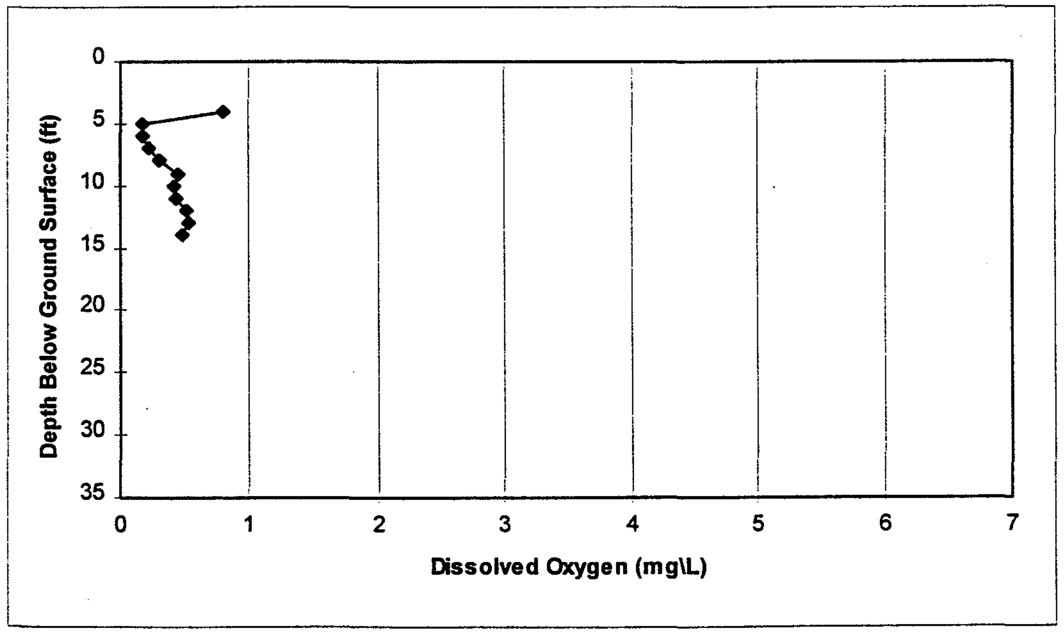

Figure A.33 : Dissolved oxygen profile of well PG-2, screened interval 5-14 ft.

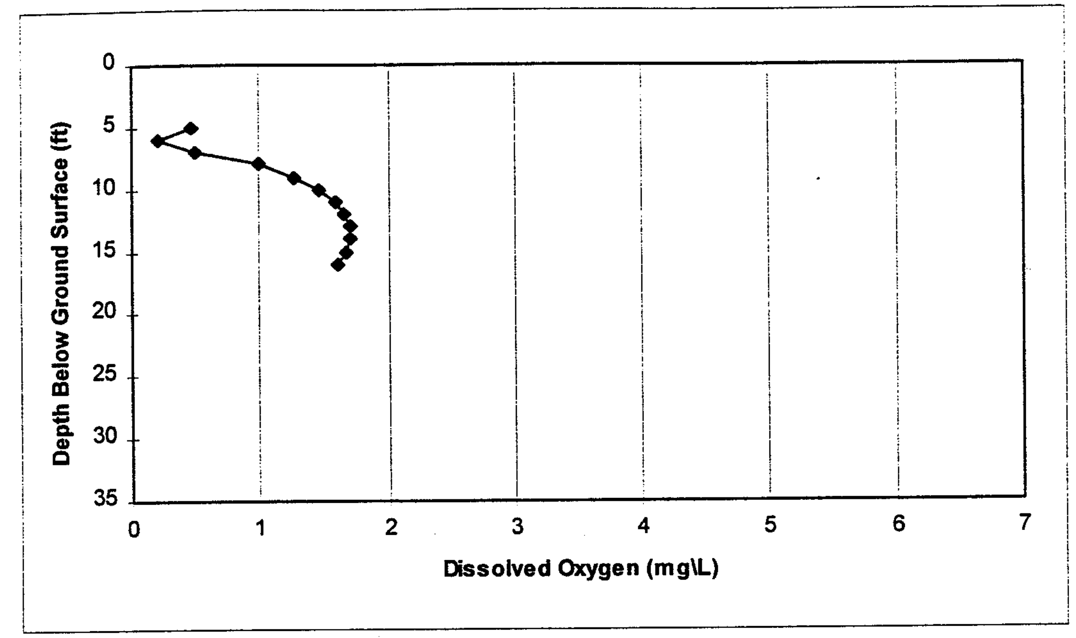

Figure A.34 : Dissolved oxygen profile of well PG-3S, screened interval 9-17 ft.

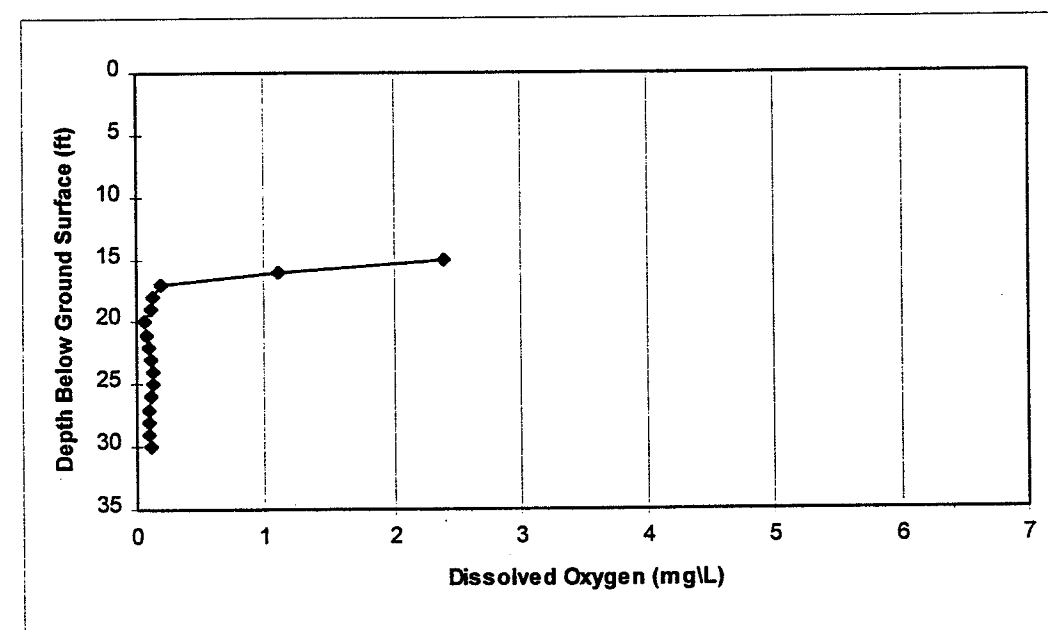

Figure A.35 : Dissolved oxygen profile of well PG-3D, screened interval 29.5-30.5 ft.

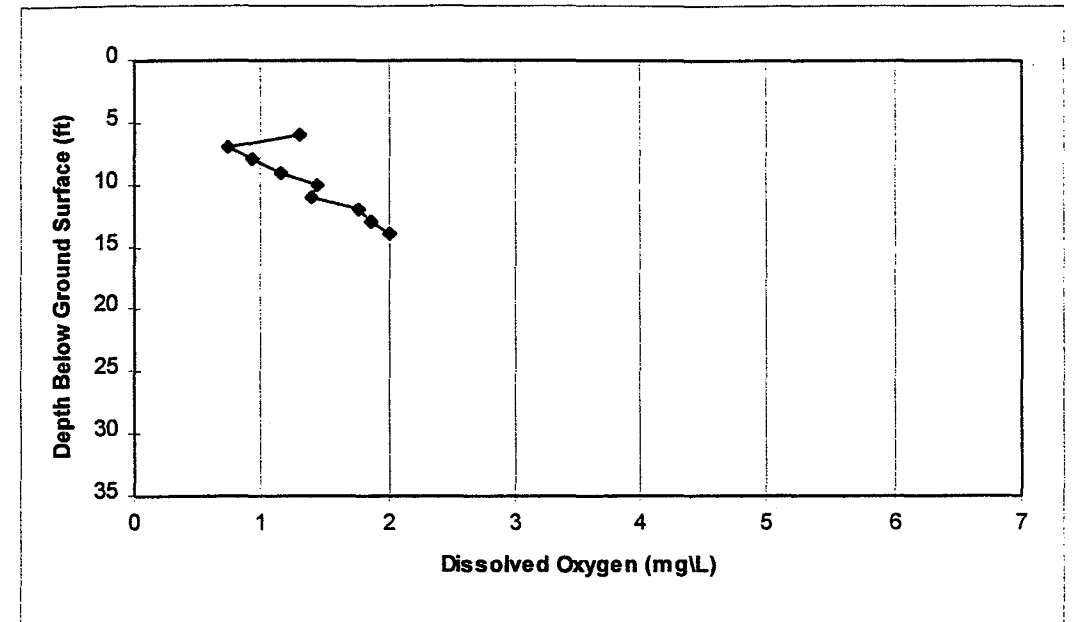

Figure A.36 : Dissolved oxygen profile of well PG-4, screened interval 5.5-14 ft.

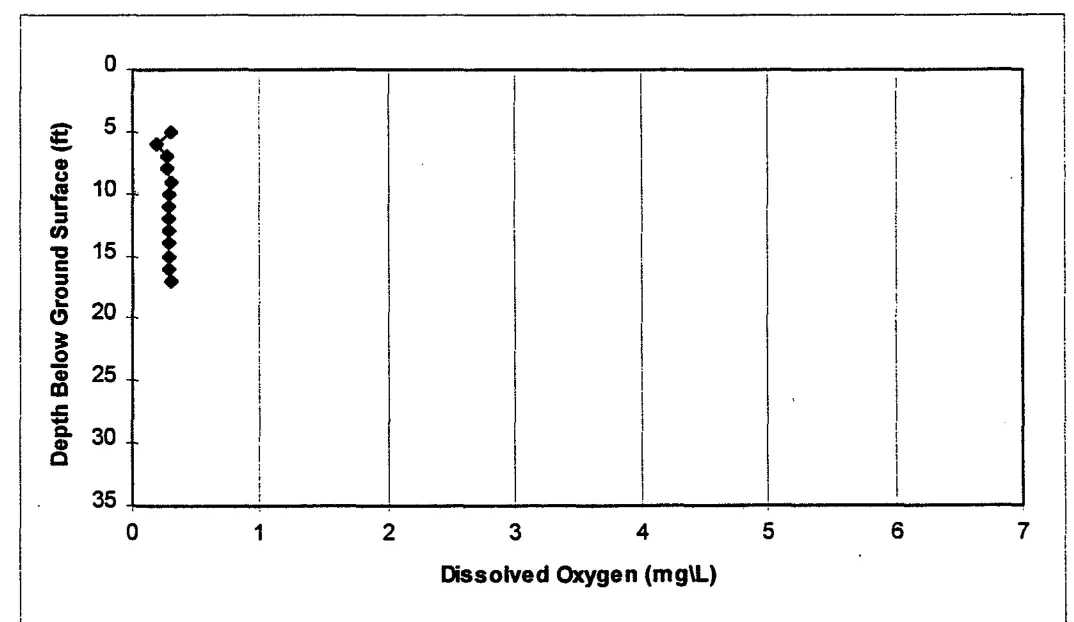

Figure A.37 : Dissolved oxygen profile of well PG-6, screened interval 8-18 ft.

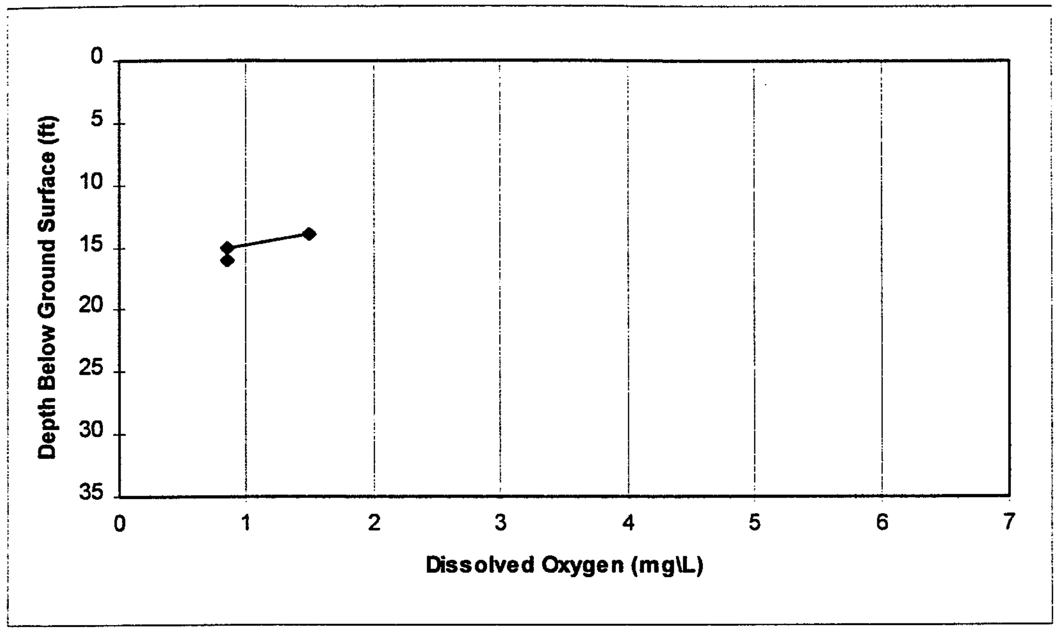

Figure A.38 : Dissolved oxygen profile of well PG-5S, screened interval 6-14.5 ft.

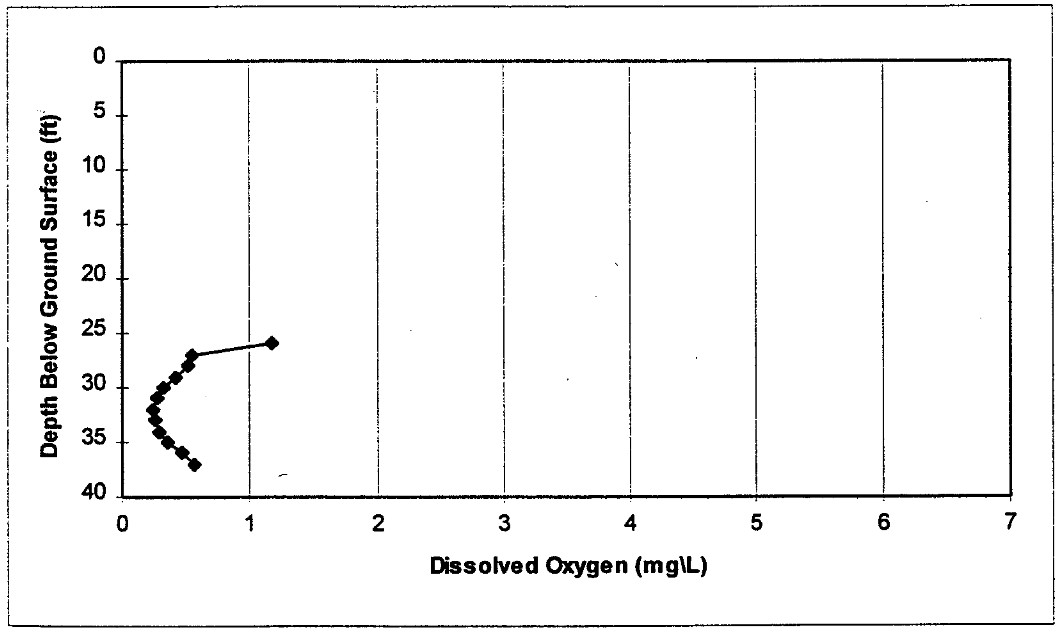

Figure A.39 : Dissolved oxygen profile of well PG-5D, screened interval 33.5-35.5 ft.

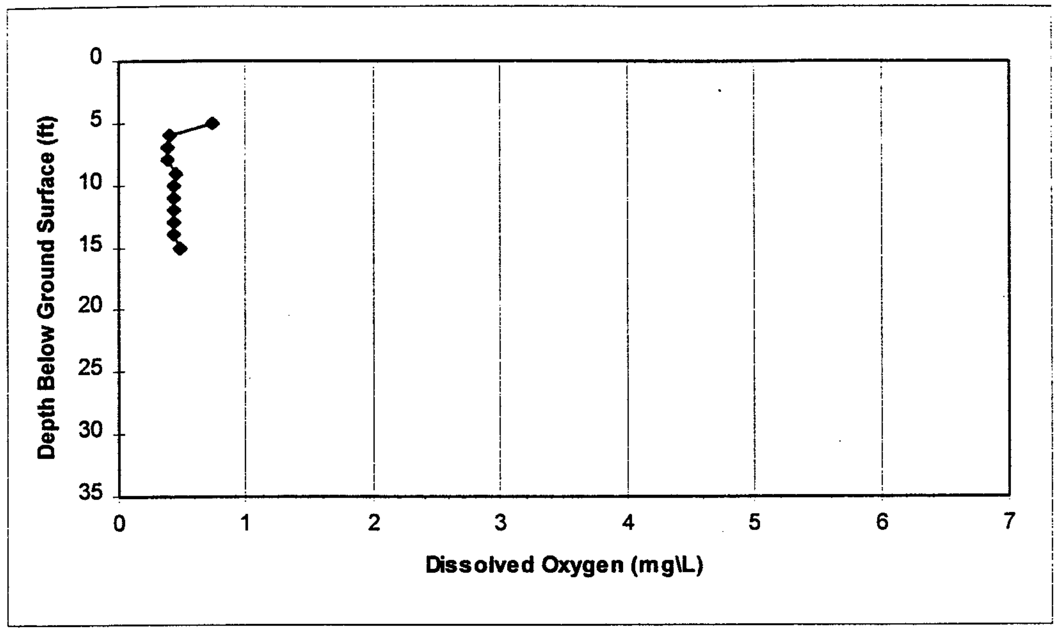

Figure A.40 : Dissolved oxygen profile of well PG-7, screened interval 5-15 ft.

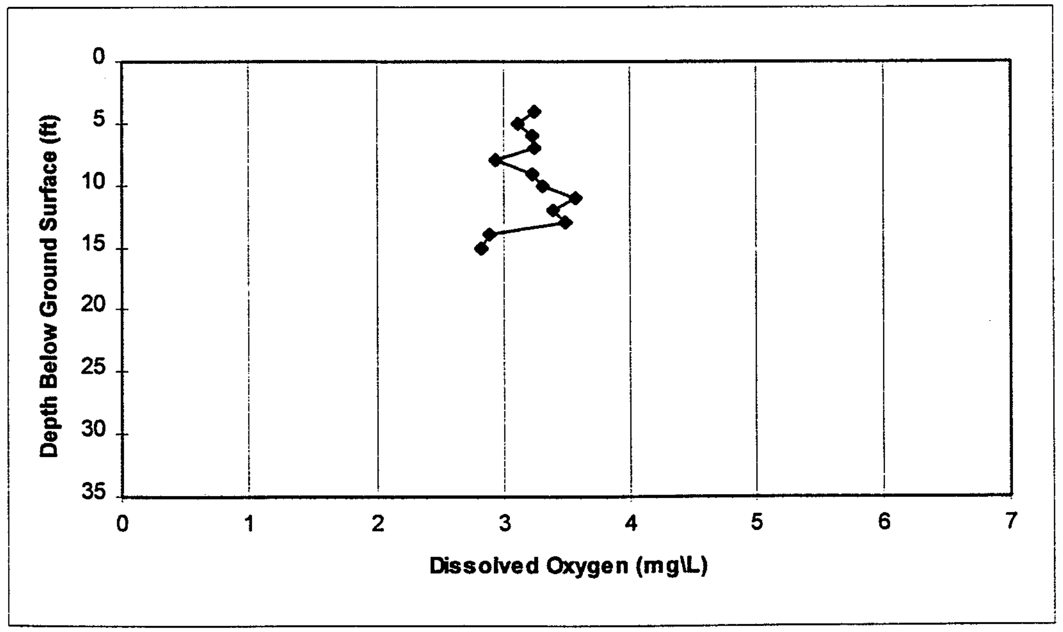

Figure A.41 : Dissolved oxygen profile of well PG-9, screened interval 5-15 ft.

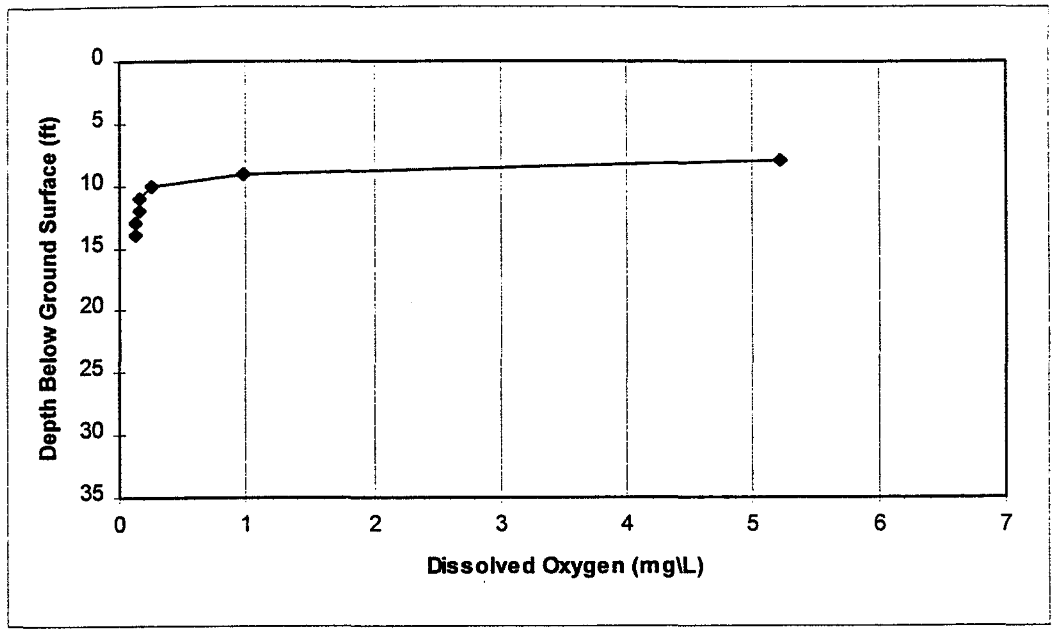

Figure A.42 : Dissolved oxygen profile of well MW-1, screened interval 9.4-14.4 ft.

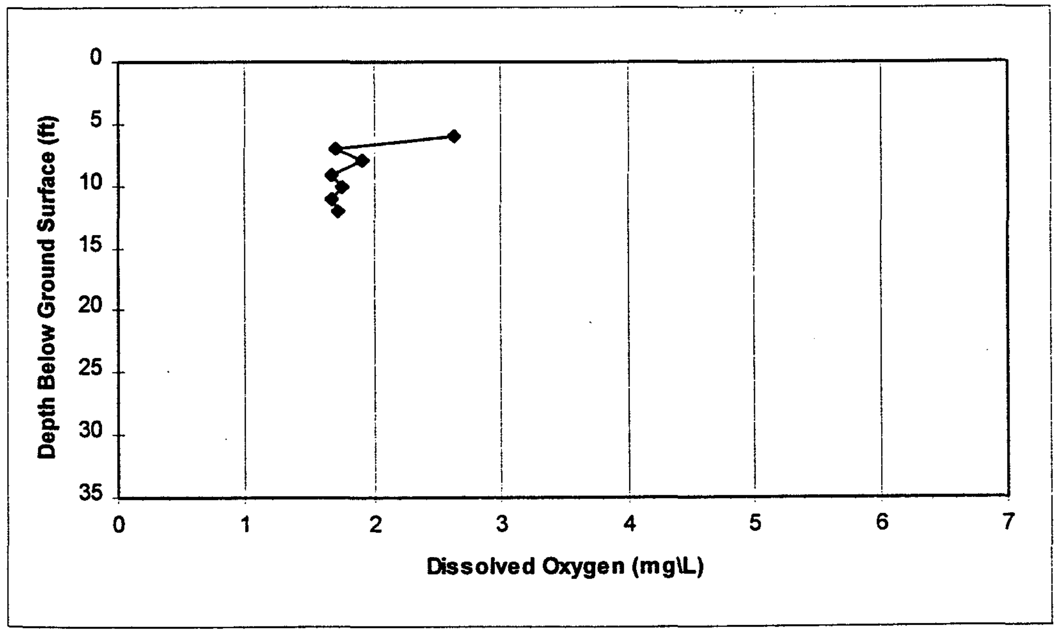

Figure A.43 : Dissolved oxygen profile of well MW-2, screened interval 6.6-11.6 ft.

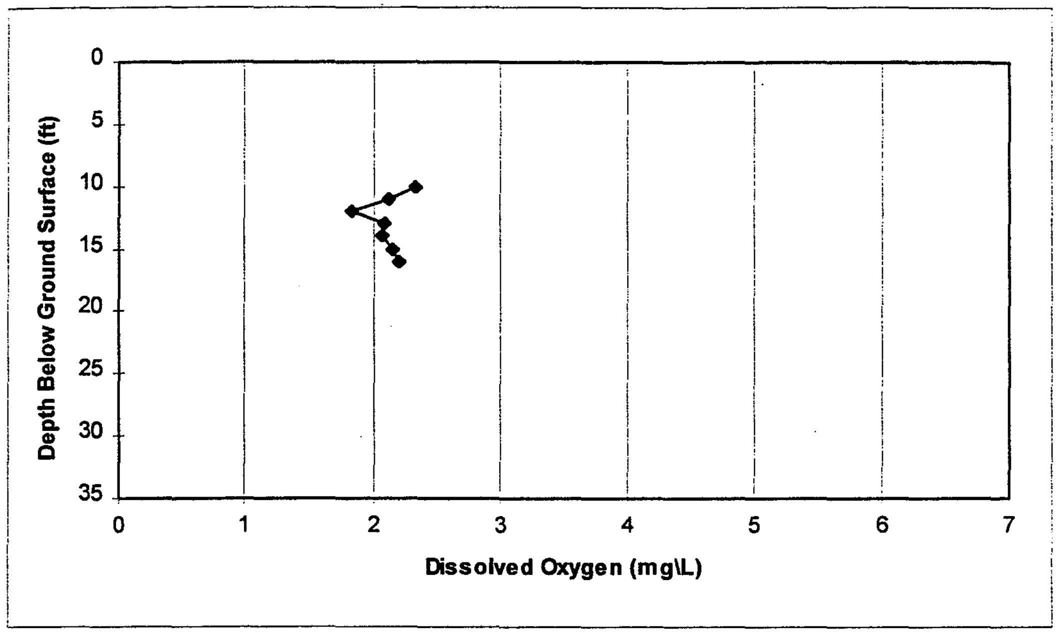

Figure A.44 : Dissolved oxygen profile of well MW-3, screened interval 5.9-15.9 ft.

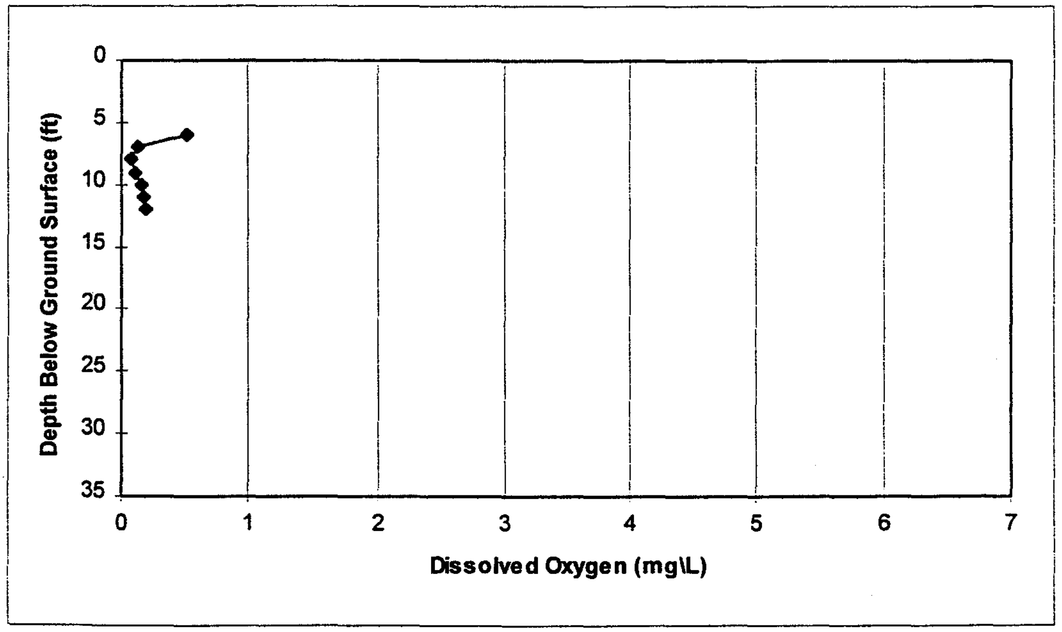

Figure A.45 : Dissolved oxygen profile of well MW-6, screened interval 9.1-11.6 ft.

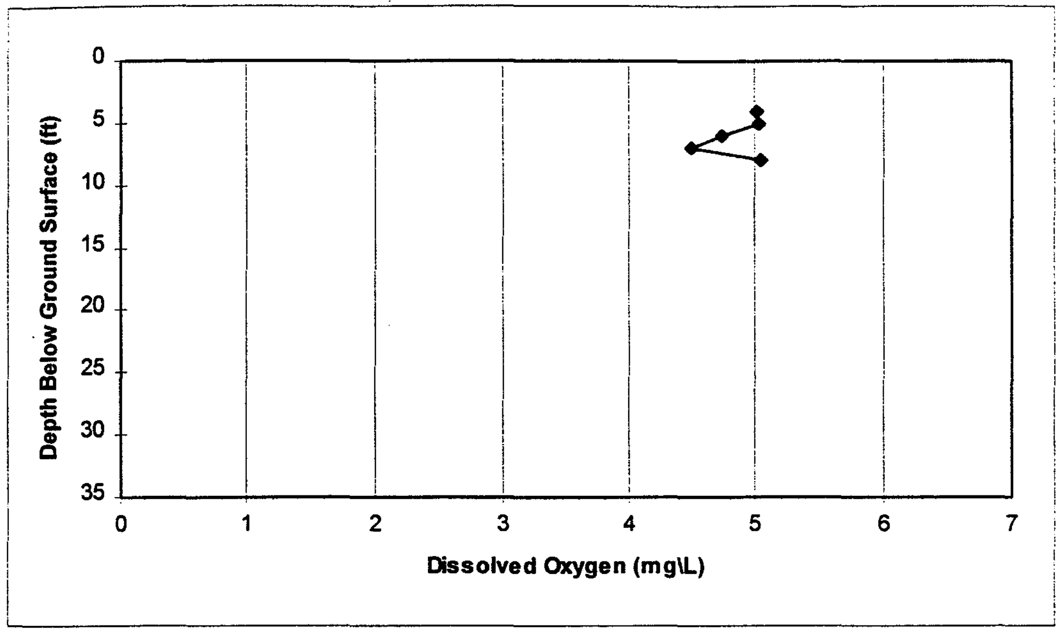

Figure A.46 : Dissolved oxygen profile of well MW-5S, screened interval 5.5-8 ft.

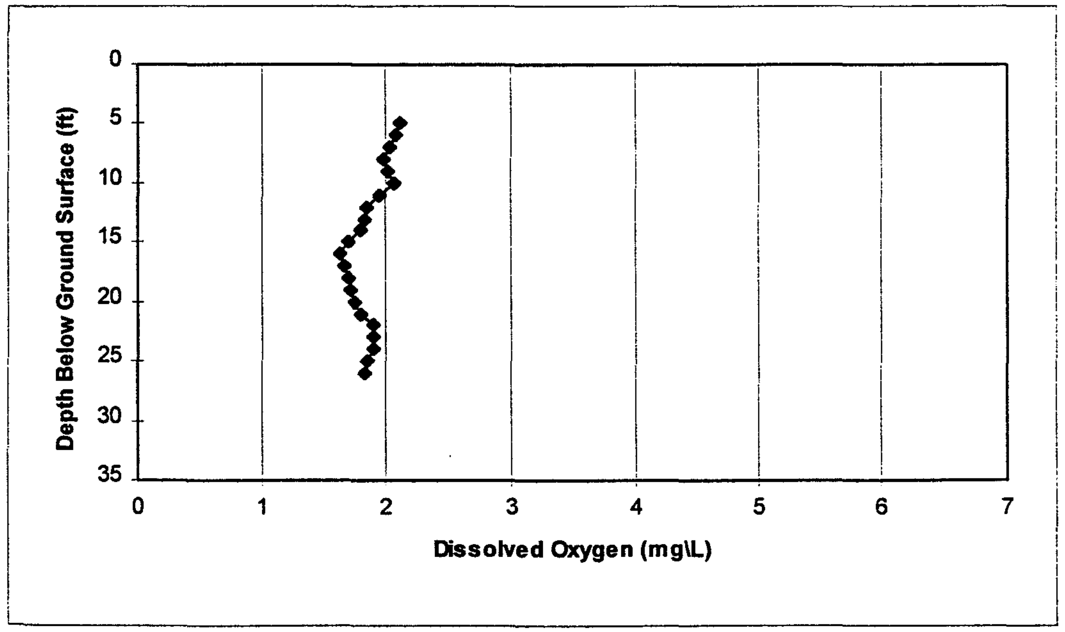

Figure A.47 : Dissolved oxygen profile of well MW-5D, screened interval 21.3-26.3 ft.

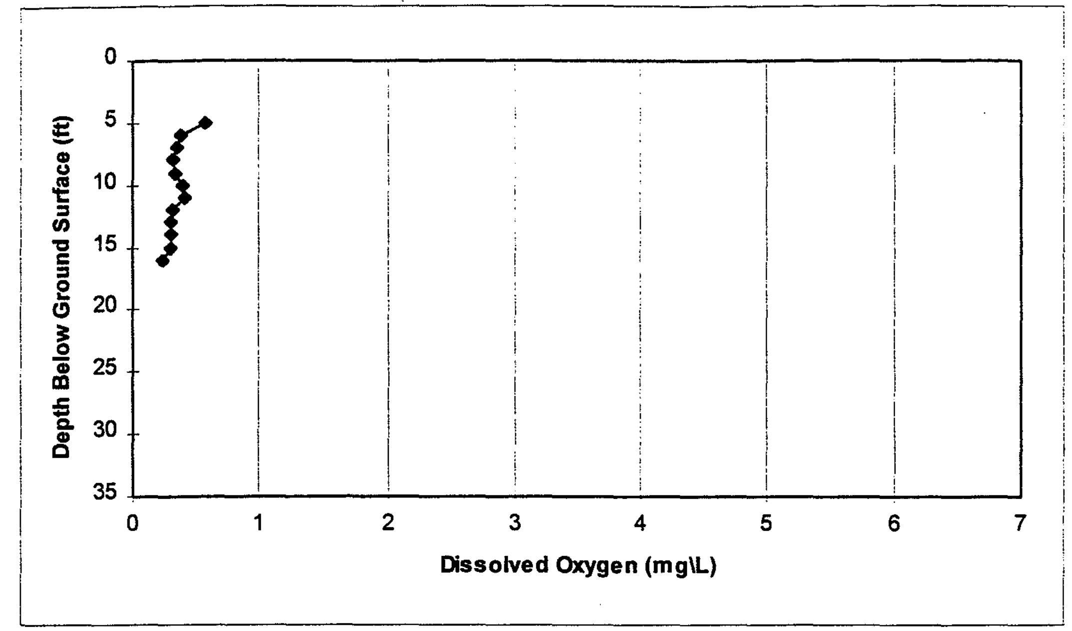

Figure A.48 : Dissolved oxygen profile of well MW-13, screened interval 6.7-16.9 ft.

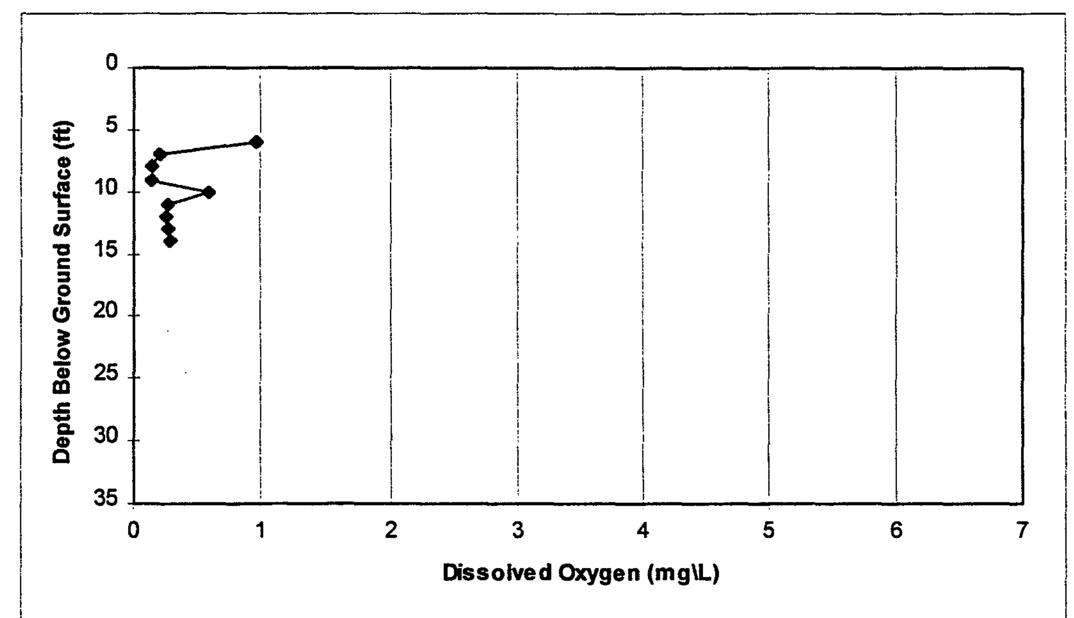

Figure A.49 : Dissolved oxygen profile of well MW-14, screened interval 5.6-15.6 ft.

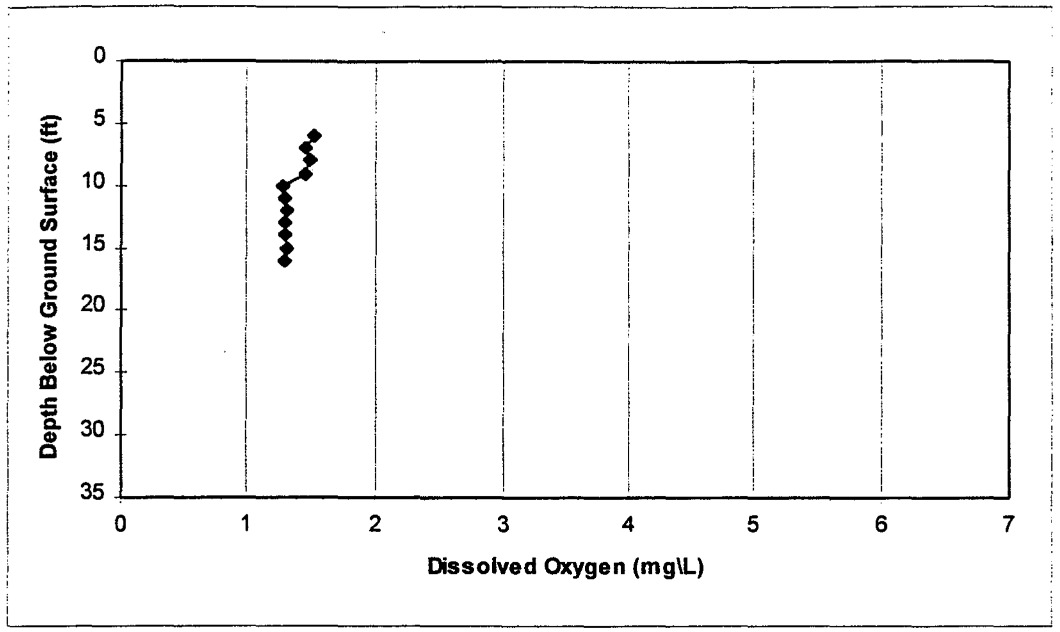

Figure A.50 : Dissolved oxygen profile of well MW-15S, screened interval 6-16 ft.

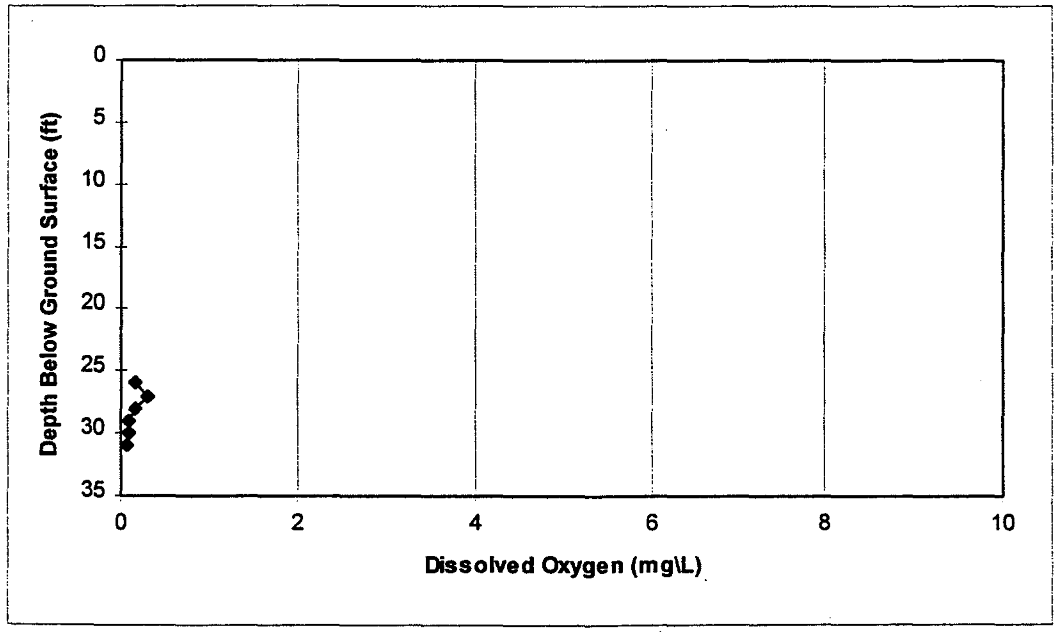

Figure A.51 : Dissolved oxygen profile of well MW-15D, screened int. 32.6-37.6 ft.

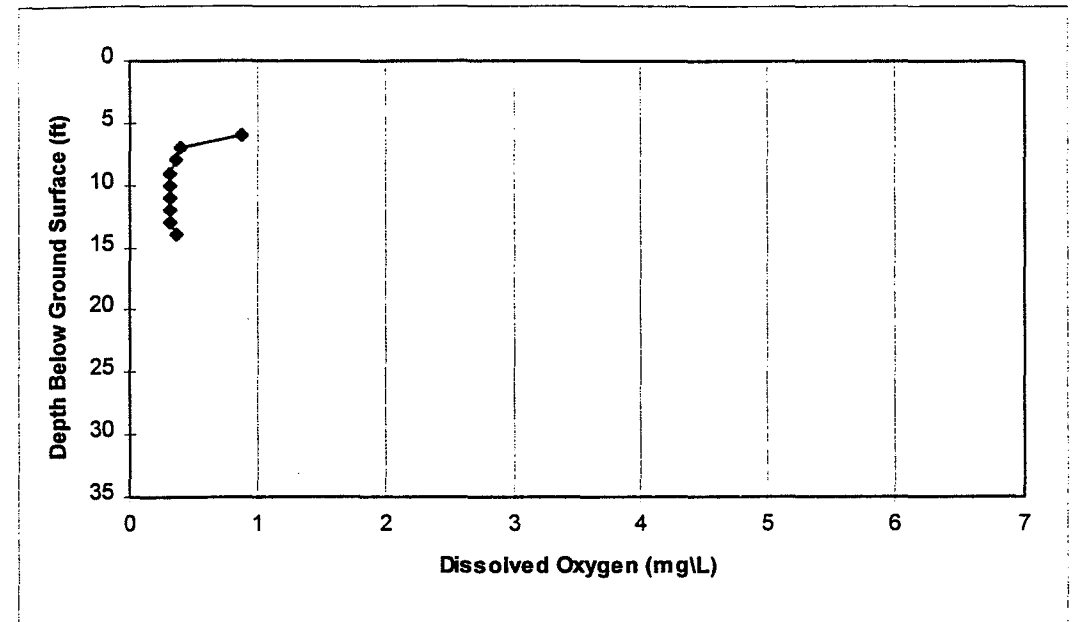

Figure A.52 : Dissolved oxygen profile of well MW-16S, screened int. 12.1-14.6 ft.

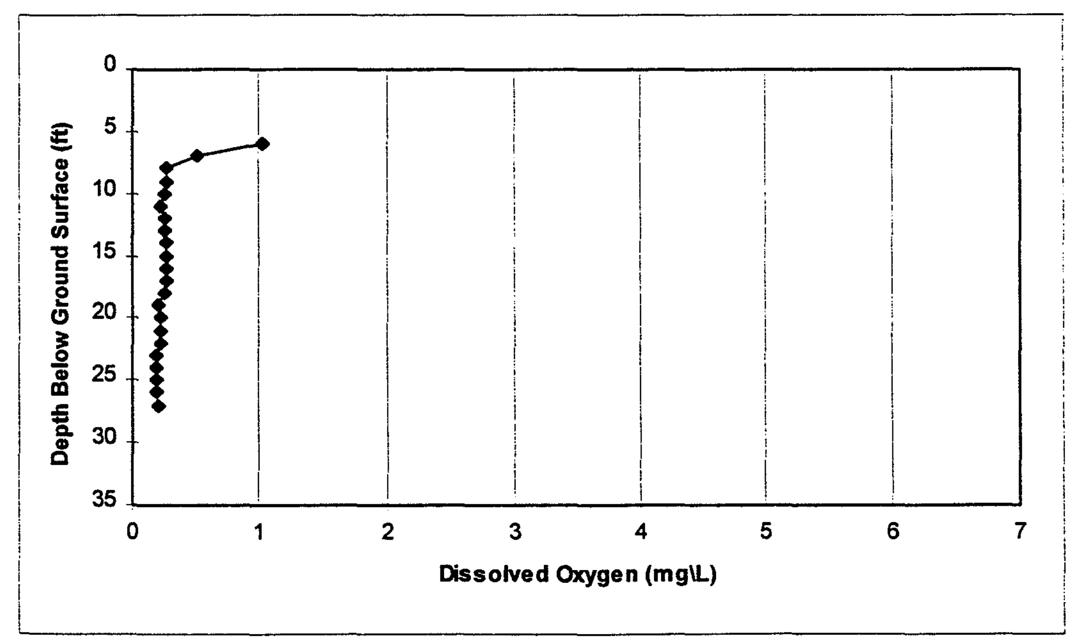

Figure A.53 : Dissolved oxygen profile of well MW-16D, screened int. 22.1-27.1 ft.

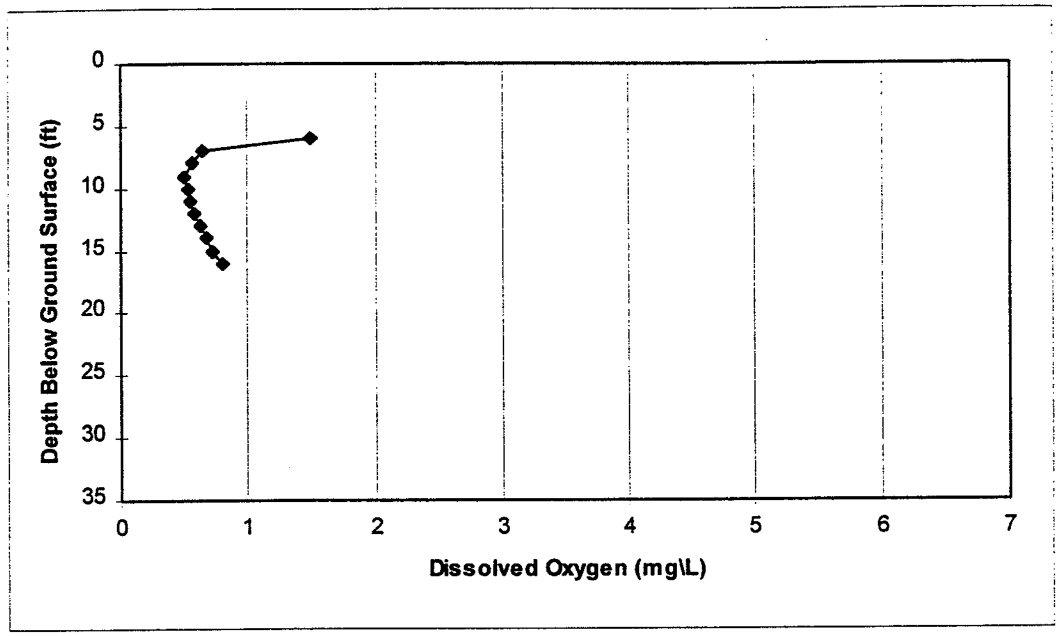

Figure A.54 : Dissolved oxygen profile of well MW-17, screened interval 14-16 ft.

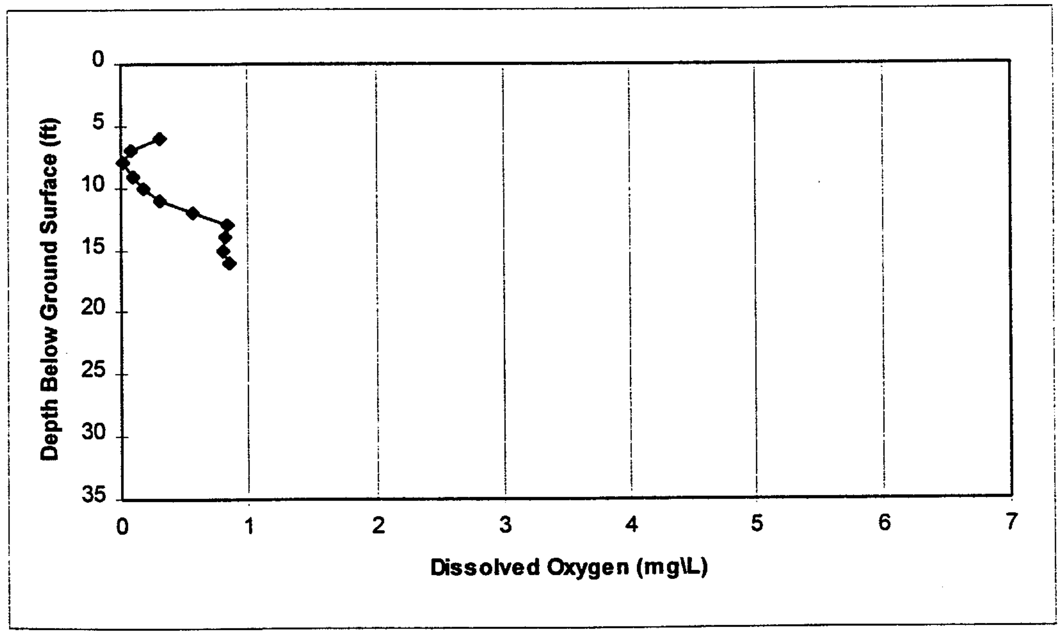

Figure A.55 : Dissolved oxygen profile of well MW-18, screened interval 11-16 ft.

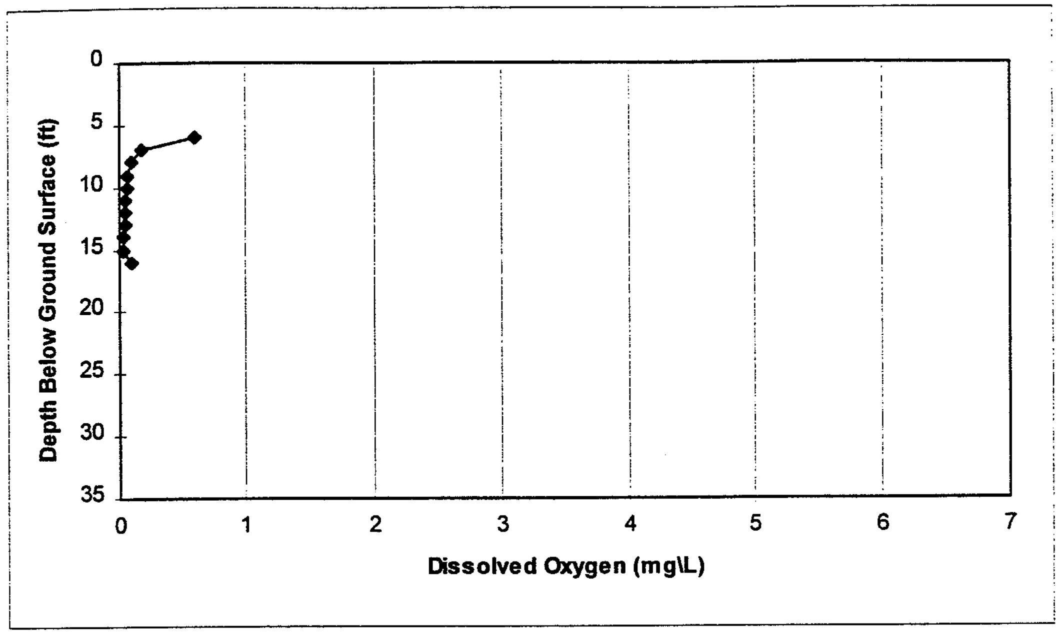

Figure A.56 : Dissolved oxygen profile of well MW-19, screened interval 10.5-16 ft.

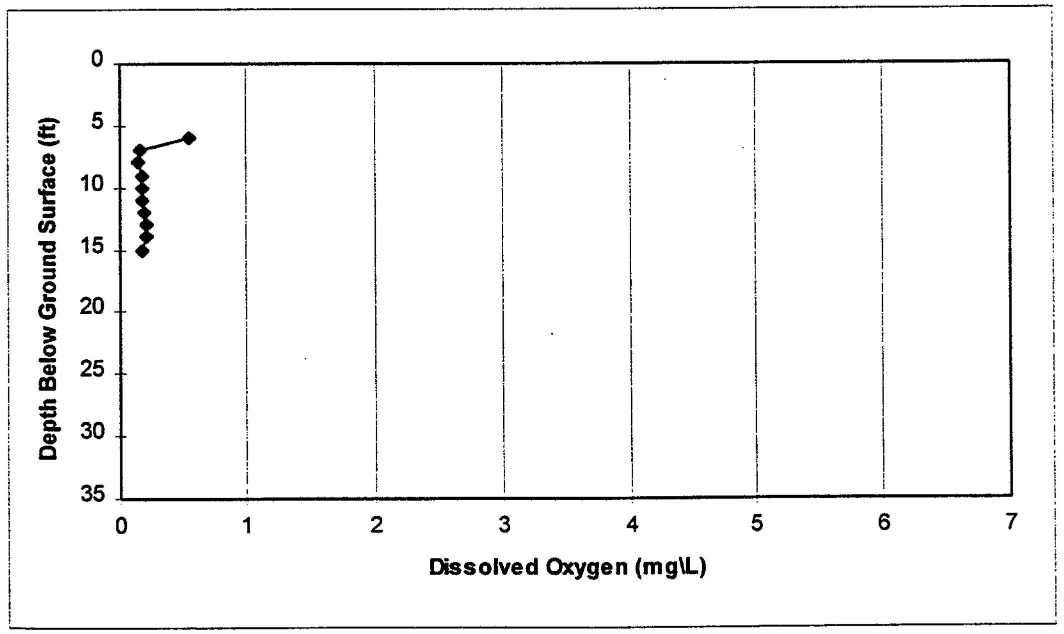

Figure A.57 : Dissolved oxygen profile of well MW-20, screened interval 9-15 ft.

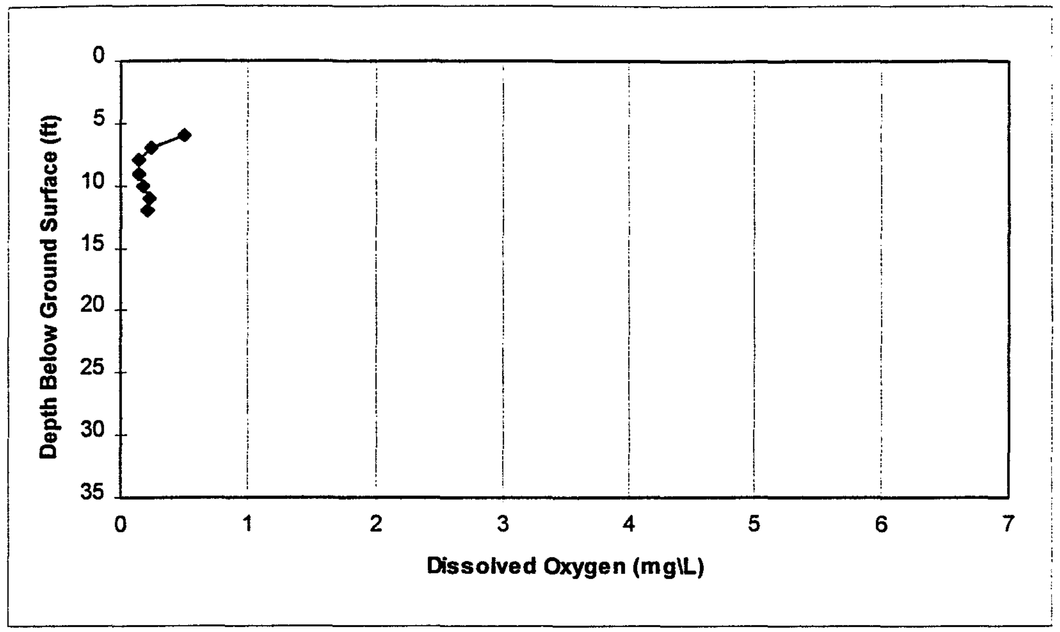

Figure A.58 : Dissolved oxygen profile of well MW-21, screened interval 9.5-12 ft.

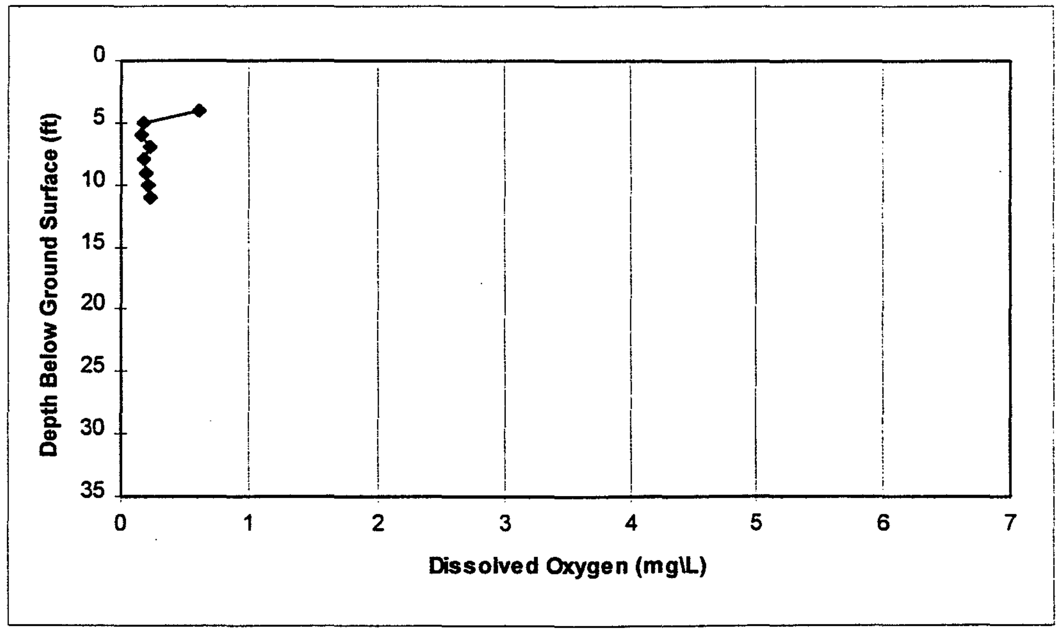

Figure A.59 : Dissolved oxygen profile of well MW-22, screened interval 8.5-12 ft.

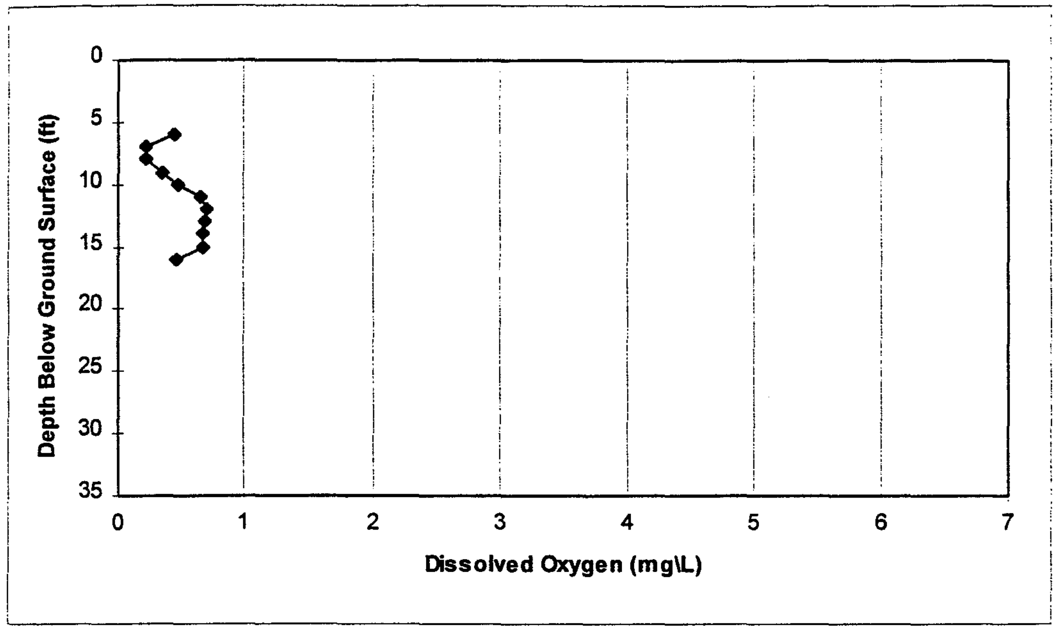

Figure A.60 : Dissolved oxygen profile of well MW-23, screened interval 9.5-16 ft.

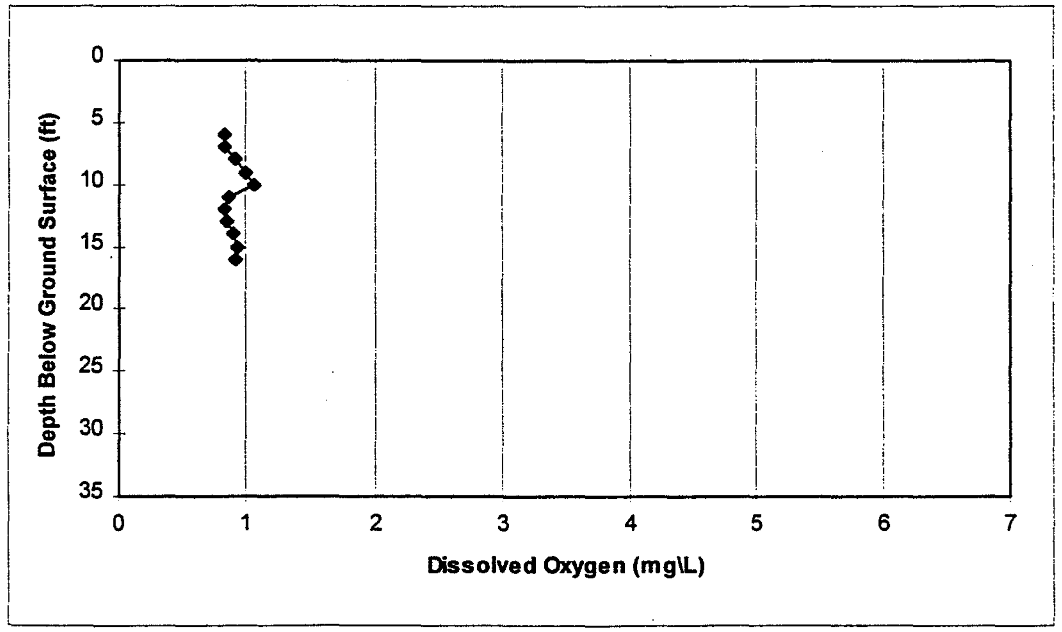

Figure A.61 : Dissolved oxygen profile of well MW-24, screened interval 13.5-15.5 ft.

Appendix B

Dissolved Oxygen and Temperature Data from UIGRS

D19D

DO (mg/L)	Feet	Temp (C)	Feet
2.7	31	10	31
2.65	35	10	35
2.33	40	10	40
2.73	45	10.1	45
3.04	50	10.1	50
2.11	55	10.1	55
2.72	60	10.2	60
2.8	65	10.2	65
2.68	70	10.2	70
2.64	75	10.3	75
2.76	80	10.3	80
2.58	85	10.3	85
2.53	90	10.4	90
2.51	95	10.4	95
2.46	100	10.4	100
2.54	105	10.5	105
2.61	110	10.5	110
2.62	115	10.5	115
2.64	120	10.6	120
2.63	125	10.6	125
2.61	130	10.6	130
2.61	134	10.7	134
2.85	135	10.7	135
2.52	136	10.7	136
1.5	137	10.7	137
0.35	138	10.7	138
0.14	139	10.7	139
0.11	140	10.7	140

D19S

DO (mg/L)	Feet	Temp (C)	Feet
1.72	8	12.5	8
0.85	9	12.3	9
0.6	10	12.2	10

INEL-D

DO (mg/L)	Feet	Temp (C)	Feet
1.72	55	11.1	55
1.03	60	11	60
0.72	65	10.9	65
0.99	70	10.9	70
1.02	75	10.9	75
1.02	80	10.9	80
1.07	85	10.9	85
1.04	90	10.9	90
1.08	95	10.8	95
1.11	100	10.8	100
1.12	105	10.9	105
1.14	110	10.9	110
1.1	115	10.9	115
1.07	120	10.9	120
1.02	125	10.9	125
0.95	130	10.9	130
0.94	135	11	135
0.92	140	11	140

INEL-S

DO (mg/L)	Feet	Temp (C)	Feet
2.95	26	11.2	26
2.59	30	10.8	30
2.79	35	10.9	35
3.01	40	11	40
3.13	45	11	45
2.84	50	11	50
2.57	55	11	55
2.25	60	11	60
1.79	65	10.9	65
1.69	66	10.9	66
1.59	67	10.9	67
1.41	68	10.9	68
1.21	69	10.9	69
1.11	70	10.9	70
1.05	71	10.9	71
0.94	72	10.9	72
0.83	75	10.9	75
0.75	80	10.9	80
0.49	85	10.9	85
0.46	90	10.9	90
0.43	95	10.8	95
0.34	98	10.8	98
0.08	100	10.9	100

J16D

DO (mg/L)	Feet	Temp (C)	Feet
1.85	32	10.2	32
1.35	35	10	35
1.3	40	10	40
1.15	45	10	45
1.33	50	10	50
1.28	55	10.1	55
1.27	60	10.1	60
1.01	64	10.1	64
1.1	65	10.1	65
0.72	66	10.1	66
0.27	67	10.2	67
0.27	68	10.2	68

J16S

DO (mg/L)	Feet	Temp (C)	Feet
1.85	11	12.3	11
1.12	14	11.2	14
0.52	17	10.5	17
0.71	18	10.3	18
0.26	19	10.2	19

J17S

DO (mg/L)	Feet	Temp (C)	Feet
2.65	10	12.1	10
1.24	11	11.9	11
0.55	12	11.7	12
0.01	13	11.4	13

Q16D

DO (mg/L)	Feet	Temp (C)	Feet
4.11	10	11.7	10
2.6	15	11	15
3.04	20	10.4	20
3.55	25	10.4	25
3.46	30	10.5	30
3.7	35	10.5	35
3.54	40	10.6	40
3.64	45	10.6	45
3.45	50	10.7	50
3.38	55	10.7	55
3.37	60	10.7	60
3.34	65	10.7	65
1.14	69	10.7	69
0.63	70	10.7	70
0.34	71	10.7	71
0.27	72	10.7	72

Q16S

DO (mg/L)	Feet	Temp (C)	Feet
4.42	10	12.3	10
0.83	15	11.2	15
0.3	20	10.5	20
0.2	25	10.4	25
0.12	26	10.4	26
0	27	10.4	27

H12S

DO (mg/L)	Feet	Temp (C)	Feet
5.18	10	11.4	10
0.95	11	11.1	11
0.41	12	10.9	12
0.33	13	10.7	13
0.27	14	10.5	14
0.31	15	10.4	15
0.03	16	10.3	16

Q17D DO (mg/L)	Feet	Temp (C)	Feet
5.88	9	12.3	9
7.05	15	11	15
6.62	20	10.4	20
6.02	25	10.3	25
5.47	30	10.4	30
5.15	35	10.5	35
4.67	40	10.6	40
4.3	45	10.6	45
4.11	50	10.7	50
3.95	55	10.7	55
3.81	60	10.7	60
3.7	65	10.7	65
2.12	70	10.7	70
1.84	74	10.7	74
1.67	75	10.7	75
1.71	76	10.7	76
1.31	77	10.7	77
1.11	78	10.7	78
1.05	79	10.7	79

N18S DO (mg/L)	Feet	Temp (C)	Feet
3.22	9	11.9	9
0.22	11	11.5	11
0	12	11	12
0.03	13	10.7	13
0.14	14	10.5	14
0.28	15	10.3	15
0.39	16	10.1	16
0.23	17	10	17

P17S DO (mg/L)	Feet	Temp (C)	Feet
2.29	8	12	8
0.65	9	11.7	9
0.4	9.5	11.6	9.5
0.17	10	11.4	10

S12D1 DO (mg/L)	Feet	Temp (C)	Feet
2.58	22	11.2	22
2.3	25	10.6	25
2.18	30	10.4	30
2.02	35	10.5	35
1.96	40	10.6	40
1.8	45	10.6	45
1.63	50	10.6	50
1.4	55	10.6	55
1.02	60	10.6	60
0.84	65	10.6	65
0.7	70	10.6	70
0.62	75	10.6	75
0.57	80	10.7	80
0.55	85	10.7	85
0.54	90	10.7	90
0.52	95	10.7	95
0.51	100	10.7	100
0.49	105	10.8	105
0.48	110	10.8	110
0.46	115	10.8	115
1.49	118	10.8	118
1.94	119	10.8	119
1.97	120	10.8	120
2.03	121	10.8	121
1.97	122	10.8	122
1.88	123	10.8	123
1.82	124	10.8	124
1.79	125	10.8	125
0.4	126	10.8	126
0.34	127	10.8	127

S12D2

DO (mg/L)	Feet	Temp (C)	Feet
4.23	30	10.5	30
3.98	35	10.5	35
0.41	40	10.5	40
0.19	45	10.6	45
0.18	50	10.6	50
0.19	55	10.6	55
0.2	60	10.6	60
0.2	65	10.6	65
0.24	66	10.6	66
0.2	67	10.6	67
0.15	68	10.6	68
0.13	69	10.6	69
0.12	70	10.6	70
0.14	71	10.6	71
0.13	72	10.6	72
0.14	73	10.6	73
0.06	74	10.6	74

T16D

DO (mg/L)	Feet	Temp (C)	Feet
7.02	8	13.1	8
5.51	15	12.8	15
6.3	20	11.2	20
6.1	25	11	25
6.02	30	11	30
5.95	35	11	35
5.77	40	11	40
2.79	45	11	45
2.48	50	10.9	50
2.31	55	10.9	55
2.25	60	10.8	60
2.35	63	10.8	63
2.17	64	10.8	64
2.05	65	10.8	65
2.02	66	10.8	66
2.01	67	10.8	67
1.98	68	10.8	68
1.97	69	10.8	69

T8S

DO (mg/L)	Feet	Temp (C)	Feet
2.5	10	12.3	10
0.67	11	12	11
0.29	12	11.7	12
0.27	13	11.5	13
0.25	14	11.3	14
0.13	15	11.2	15

U3D

DO (mg/L)	Feet	Temp (C)	Feet
2.71	31	11.9	31
2.59	35	11	35
2.35	40	10.8	40
2.85	45	10.8	45
2.8	50	10.8	50
2.74	55	10.8	55
2.68	60	10.8	60
2.59	65	10.8	65
2.93	70	10.9	70
2.76	75	10.9	75
2.72	79	10.9	79
2.67	80	10.9	80
2.7	81	10.9	81
2.36	82	10.9	82
1.21	83	10.9	83
0.4	84	10.9	84
0.23	85	10.9	85

U3S

DO (mg/L)	Feet	Temp (C)	Feet
5.92	7	13.9	7
3.91	9	13	9
3.54	14	11.2	14
4.12	19	10.4	19
4.25	24	10.3	24
3.91	29	10.5	29
1.34	32	10.6	32
0.37	33	10.7	33

V16D

DO (mg/L)	Feet	Temp (C)	Feet
3.8	6	15.1	6
2.52	10	13.6	10
3.65	15	12.4	15
3.44	20	11.7	20
3.19	25	11.4	25
3.15	30	11.4	30
2.94	35	11.3	35
2.86	40	11.3	40
2.82	45	11.2	45
2.71	50	11.1	50
2.64	55	11.1	55
2.54	60	11	60
1.86	64	10.9	64
1.22	65	10.9	65
1.2	66	10.9	66
1.2	67	10.9	67

V16S

DO (mg/L)	Feet	Temp (C)	Feet
0.37	8	14.1	8
0.2	9	14.2	9
0.15	10	14.2	10

Dissolved Oxygen and Temperature Data from UIPSS1

PS-2

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
2.57	8	12.5	8
2.57	9	12.7	9
1.59	10	12.9	10
1.45	11	12.9	11
2.16	12	12.9	12
2.91	13	12.9	13
3.41	14	12.8	14
3.71	15	12.7	15
3.78	16	12.5	16

PS-3

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
2.5	9	13.9	9
0.45	10	14	10
0.02	11	13.9	11
0	12	13.6	12
0.01	13	13.4	13
0	14	13.2	14
0	15	12.8	15
0	16	12.7	16

PS-5

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
5.05	9	11.6	9
4.38	10	11.8	10
3.91	11	11.8	11
2.21	12	11.8	12
2.1	13	11.7	13
2.07	14	11.6	14
2.11	15	11.4	15
2.15	16	11.3	16

PS-16

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
2.34	8	13.9	8
0.69	9	14	9
3.44	10	13.9	10
4.03	11	13.8	11
3.7	12	13.4	12
4.1	13	13.2	13
4.23	14	13	14
4.17	15	12.8	15
4.2	16	12.5	16
4.63	17	12.3	17
4.49	18	12.2	18
4.54	19	12.1	19
4.12	20	12	20
4.89	21	11.9	21
4.68	22	11.8	22
4.89	23	11.8	23
4.54	24	11.8	24
4.88	25	11.7	25
4.69	26	11.6	26
4.5	27	11.4	27
4.44	28	11.4	28
4.29	29	11.3	29
4.38	30	11.2	30
4.65	31	11.1	31

PS-16B

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
2.1	8	13.4	8
0.77	9	13.8	9
1.2	10	13.8	10
1.39	11	13.6	11
0.91	12	13.4	12
0.6	13	13.2	13
0.44	14	12.9	14
0.02	15	12.8	15

PS-17

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
4.77	9	12.9	9
4.27	10	13.2	10
4.24	11	13.2	11
4.43	12	13.2	12
4.14	13	13.1	13
4.19	14	13	14
4.51	15	12.8	15
4.62	16	12.7	16
4.73	17	12.5	17
4.61	18	12.3	18
4.82	19	12.1	19
4.75	20	11.9	20
4.97	21	11.8	21
5.04	22	11.7	22
5.11	23	11.6	23
5.27	24	11.5	24
5.82	25	11.3	25
5.93	26	11.2	26
6.08	27	11.1	27
6.06	28	11.1	28
6.32	29	11	29
6.22	30	11	30
6.23	31	11	31
6.22	32	11	32
6.04	33	11	33

PS-17B

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
3.81	9	13.8	9
2.76	10	14.1	10
2.96	11	13.9	11
3.2	12	13.8	12
3.2	13	13.4	13
3.27	14	13.1	14
3.35	15	12.9	15
3.4	16	12.6	16
3.43	17	12.4	17
3.56	18	12.2	18
3.58	19	12	19
3.56	20	11.8	20
3.5	21	11.6	21
3.78	22	11.5	22
3.88	23	11.4	23

PS-17C DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
3.1	9	12.9	9
2.12	10	13.2	10
1.97	11	13.3	11
1.94	12	13.2	12
2	13	13.1	13
1.97	14	13	14
1.96	15	12.8	15
2.02	16	12.7	16
2.13	17	12.5	17
2.01	18	12.4	18

PS-17D DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
2.65	9	13.2	9
2.34	10	13.2	10
2.27	11	13.3	11
2.16	12	13.2	12
1.92	13	13.1	13
1.28	14	13	14
0.56	15	12.9	15

PS-18

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
3.36	8	12.8	8
3.95	9	12.6	9
4.46	10	12.4	10
5.02	11	12.2	11
4.77	12	11.9	12
5.27	13	11.6	13
5.37	14	11.4	14
5.16	15	11.2	15
5.46	16	11	16
5.54	17	10.8	17
5.59	18	10.6	18
5.53	19	10.4	19
5.6	20	10.2	20
5.47	21	10.2	21
5.35	22	10.2	22
5.46	23	10.2	23
5.24	24	10.2	24
5.33	25	10.2	25
5.27	26	10.1	26
5.29	27	10.1	27
5.04	28	10.1	28
4.42	29	10.1	29

PS-19 DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
5.31	8	13.1	8
3.17	9	13.3	9
2.88	10	13.1	10
3.02	11	12.8	11
3.66	12	12.6	12
3.54	13	12.3	13
3.84	14	12.1	14
3.87	15	11.8	15
3.93	16	11.5	16
4.21	17	11.3	17
4.23	18	11.1	18
4.39	19	11	19
4.34	20	10.9	20
5.05	21	10.8	21
4.63	22	10.8	22
4.51	23	10.8	23
4.48	24	10.6	24
4.51	25	10.5	25
4.16	26	10.5	26
4.38	27	10.4	27
4.22	28	10.4	28
3.94	29	10.4	29
4.02	30	10.3	30

PS-20

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
4.85	8	14.3	8
3.8	9	13.8	9
3.15	10	13.5	10
3.03	11	13.3	11
3.22	12	13	12
3.45	13	12.7	13
3.34	14	12.5	14
3.4	15	12.2	15
3.37	16	12	16
3.5	17	11.8	17
3.89	18	11.8	18
3.43	19	11.5	19
3.91	20	11.5	20
4.85	21	11.4	21
6.48	22	10.9	22
5.92	23	10.8	23
6.04	24	10.8	24
5.99	25	10.8	25
6.18	26	10.7	26
6.01	27	10.7	27
5.91	28	10.7	28
5.9	29	10.7	29
5.33	30	10.7	30
4.9	31	10.8	31

PS-21

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
4.17	9	13.8	9
3.15	10	14	10
3	11	13.8	11
2.99	12	13.6	12
3.08	13	13.3	13
3.18	14	13.1	14
3.29	15	12.8	15
2.84	16	12.6	16
2.68	17	12.4	17
3.66	18	12.2	18
3.59	19	12.1	19
3.6	20	12	20
2.8	21	12	21
3.02	22	12	22
0.19	23	11.8	23

PS-22 DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
4.64	9	14.5	9
3.8	10	14.4	10
3.73	11	14.2	11
4.09	12	13.9	12
4.4	13	13.6	13
4.84	14	13.2	14
5.1	15	12.8	15
5.2	16	12.6	16
5.29	17	12.3	17
4.59	18	12	18
4.6	19	11.9	19
4.55	20	11.9	20
4.55	21	11.8	21
4.61	22	11.7	22
4.83	23	11.3	23

Dissolved Oxygen and Temperature Data from UIPSS2

MW-1

DO (mg/L)	Depth (ft)	Temp. (C)	Depth (ft)
0.4	9		
0.39	10		
0.4	11		
0.42	12		
0.38	13		

MW-2

DO (mg/L)	Depth (ft)	Temp. (C)	Depth (ft)
1.69	0	7.3	0
0.25	2	6.2	2
0.01	4	5.9	4
0	6	6.1	6
0	8	6.2	8
0	9	6.3	9
0	10	6.5	10
0	11	6.6	11
0	12	6.7	12

MW-3

DO (mg/L)	Depth (ft)	Temp. (C)	Depth (ft)
0.05	9		
0.01	10		
0	11		
0	12		

MW-4

DO (mg/L)	Depth (ft)	Temp. (C)	Depth (ft)
6.95	0	9.5	0
2.3	2	6.8	2
2.05	4	6.2	4
2.02	6	6.3	6
2	8	6.4	8
2.28	10	6.7	10
2.14	11	6.9	11
2.14	12	7	12
2.25	13	7.2	13

MW-5

DO (mg/L)	Depth (ft)	Temp. (C)	Depth (ft)
0	8		
0	9		
0	10		
0	11		
0	12		
0	13		

MW-6

DO (mg/L)	Depth (ft)	Temp. (C)	Depth (ft)
0.7	10		
0.72	11		
0.72	12		
0.73	13		

MW-15

DO (mg/L)	Depth (ft)	Temp. (C)	Depth (ft)
0.24	9		
0.25	10		
0.2	11		
0.19	12		
0.18	13		

MW-24

DO (mg/L)	Depth (ft)	Temp. (C)	Depth (ft)
0	9		
0	10		
0	11		
0	12		
0	13		

MW-25

DO (mg/L)	Depth (ft)	Temp. (C)	Depth (ft)
0.23	9		
0.2	10		
0.19	11		
0.2	12		
0.15	13		

Dissolved Oxygen and Temperature Data from UISAS

MW-1

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
5.21	8	10.8	8
0.98	9	11.8	9
0.26	10	12.1	10
0.16	11	12.2	11
0.16	12	12.2	12
0.13	13	12.3	13
0.13	14	12.4	14

MW-2

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
2.62	6	10.5	6
1.7	7	11.1	7
1.9	8	11.5	8
1.67	9	11.7	9
1.75	10	11.8	10
1.67	11	12.1	11
1.72	12	12.1	12

MW-3

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
2.33	10	12	10
2.12	11	12.4	11
1.83	12	12.6	12
2.08	13	12.8	13
2.07	14	12.8	14
2.14	15	12.9	15
2.19	16	12.9	16

MW-5D

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
2.11	5	9.8	5
2.07	6	10	6
2.03	7	10.2	7
1.98	8	10.3	8
2.01	9	10.5	9
2.06	10	10.6	10
1.95	11	10.8	11
1.84	12	11	12
1.82	13	11.1	13
1.79	14	11.2	14
1.7	15	11.3	15
1.63	16	11.4	16
1.67	17	11.4	17
1.69	18	11.4	18
1.72	19	11.5	19
1.74	20	11.5	20
1.8	21	11.5	21
1.89	22	11.5	22
1.89	23	11.5	23
1.89	24	11.5	24
1.85	25	11.5	25
1.83	26	11.5	26

MW-5S

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
5.01	4	9	4
5.02	5	9.2	5
4.73	6	9.4	6
4.49	7	9.6	7
5.04	8	9.8	8

MW-6

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
0.52	6	11.6	6
0.13	7	12	7
0.08	8	12.2	8
0.12	9	12.3	9
0.16	10	12.4	10
0.18	11	12.6	11
0.2	12	12.7	12

MW-13

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
0.57	5	11.7	5
0.39	6	11.5	6
0.36	7	11.7	7
0.32	8	11.9	8
0.34	9	12.1	9
0.4	10	12.2	10
0.42	11	12.4	11
0.32	12	12.6	12
0.31	13	12.6	13
0.31	14	12.7	14
0.3	15	12.8	15
0.24	16	12.8	16

MW-14

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
0.96	6	9.1	6
0.21	7	10.1	7
0.15	8	10.5	8
0.14	9	10.8	9
0.59	10	11.3	10
0.27	11	11.7	11
0.25	12	11.9	12
0.27	13	12	13
0.29	14	12.2	14

MW-15D

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
0.16	26	11.5	26
0.3	27	11.5	27
0.16	28	11.5	28
0.1	29	11.5	29
0.09	30	11.5	30
0.08	31	11.5	31

MW-15S

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
1.52	6	10.4	6
1.46	7	10.5	7
1.49	8	10.6	8
1.46	9	10.6	9
1.28	10	10.6	10
1.3	11	10.6	11
1.32	12	10.6	12
1.3	13	10.7	13
1.3	14	10.8	14
1.31	15	10.9	15
1.3	16	10.9	16

MW-16D

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
1.02	6	10.7	6
0.51	7	11.2	7
0.28	8	11.3	8
0.27	9	11.4	9
0.25	10	11.6	10
0.23	11	11.8	11
0.25	12	11.7	12
0.26	13	11.8	13
0.27	14	11.9	14
0.27	15	11.9	15
0.28	16	11.9	16
0.28	17	11.9	17
0.26	18	11.8	18
0.21	19	11.6	19
0.22	20	11.5	20
0.22	21	11.3	21
0.22	22	11.2	22
0.2	23	11.2	23
0.2	24	11	24
0.2	25	10.9	25
0.2	26	10.9	26
0.21	27	10.8	27

MW-16S

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
0.87	6	11.1	6
0.39	7	11.2	7
0.37	8	11.4	8
0.32	9	11.5	9
0.32	10	11.7	10
0.32	11	11.9	11
0.32	12	12	12
0.32	13	12.1	13
0.36	14	12.1	14

MW-17

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
1.49	6	11.1	6
0.65	7	11.9	7
0.56	8	12.2	8
0.49	9	12.5	9
0.53	10	12.7	10
0.54	11	12.8	11
0.57	12	12.9	12
0.62	13	13	13
0.67	14	13.1	14
0.72	15	13.2	15
0.81	16	13.2	16

MW-18

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
0.3	6	11.6	6
0.08	7	11.8	7
0.02	8	12	8
0.09	9	12.1	9
0.18	10	12.2	10
0.3	11	12.4	11
0.56	12	12.7	12
0.84	13	12.9	13
0.82	14	12.9	14
0.81	15	12.8	15
0.85	16	12.6	16

MW-19

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
0.59	6	11.9	6
0.17	7	12.2	7
0.1	8	12.3	8
0.07	9	12.5	9
0.06	10	12.6	10
0.05	11	12.7	11
0.05	12	12.7	12
0.05	13	12.8	13
0.04	14	12.8	14
0.03	15	12.9	15
0.09	16	12.9	16

MW-20

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
0.55	6	11.8	6
0.16	7	12.2	7
0.14	8	12.3	8
0.17	9	12.4	9
0.17	10	12.5	10
0.18	11	12.6	11
0.2	12	12.7	12
0.21	13	12.7	13
0.21	14	12.7	14
0.18	15	12.7	15

MW-21

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
0.5	6	11.6	6
0.24	7	11.8	7
0.14	8	12	8
0.15	9	12	9
0.17	10	12.1	10
0.23	11	12.3	11
0.21	12	12.7	12

MW-22

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
0.61	5	10.5	5
0.18	6	10.7	6
0.16	7	10.9	7
0.23	8	11	8
0.18	9	11.1	9
0.2	10	11.3	10
0.21	11	11.4	11
0.23	12	11.5	12

MW-23

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
0.45	6	11.6	6
0.23	7	11.9	7
0.22	8	12.2	8
0.35	9	12.2	9
0.48	10	12.3	10
0.65	11	12.4	11
0.7	12	12.5	12
0.69	13	12.5	13
0.67	14	12.6	14
0.67	15	12.7	15
0.47	16	12.7	16

MW-24

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
0.84	6	11.2	6
0.84	7	11.3	7
0.91	8	11.4	8
1	9	11.5	9
1.06	10	11.6	10
0.86	11	11.9	11
0.83	12	12	12
0.85	13	12.1	13
0.89	14	12.1	14
0.93	15	12.1	15
0.92	16	12	16

PG-1

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
0.68	5	11.5	5
0.35	6	11.8	6
0.38	7	12	7
0.48	8	12.2	8
0.62	9	12.3	9
0.7	10	12.4	10
0.65	11	12.6	11
0.61	12	12.7	12
0.51	13	12.8	13
0.48	14	12.8	14
0.45	15	12.9	15
0.44	16	12.9	16

PG-2

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
0.8	4	8.3	4
0.17	5	8.9	5
0.17	6	9.4	6
0.22	7	9.6	7
0.3	8	9.9	8
0.45	9	10.2	9
0.41	10	10.4	10
0.43	11	10.4	11
0.52	12	10.5	12
0.53	13	10.9	13
0.48	14	11.4	14

PG-3D

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
2.38	15	13.1	15
1.11	16	13.4	16
0.2	17	13.5	17
0.13	18	13.4	18
0.12	19	13.2	19
0.07	20	13	20
0.08	21	12.7	21
0.09	22	12.5	22
0.11	23	12.3	23
0.13	24	12.2	24
0.13	25	12	25
0.11	26	11.9	26
0.1	27	11.9	27
0.1	28	11.8	28
0.09	29	11.8	29
0.11	30	11.8	30

PG-3S

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
0.46	5	11.6	5
0.21	6	11.8	6
0.5	7	11.9	7
1	8	12.1	8
1.26	9	12.3	9
1.46	10	12.5	10
1.58	11	12.7	11
1.65	12	12.8	12
1.7	13	12.9	13
1.69	14	13	14
1.66	15	13.1	15
1.6	16	13.3	16

PG-4

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
1.3	6	11.4	6
0.74	7	11.8	7
0.93	8	12	8
1.15	9	12.2	9
1.45	10	12.4	10
1.4	11	12.5	11
1.77	12	12.7	12
1.86	13	12.8	13
2.01	14	12.8	14

PG-5D

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
1.17	26	12	26
0.54	27	12	27
0.51	28	12	28
0.41	29	12	29
0.32	30	12	30
0.27	31	12	31
0.24	32	12	32
0.25	33	12	33
0.29	34	12	34
0.35	35	12	35
0.47	36	12	36
0.56	37	12	37

PG-5S

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
1.49	14	13.3	14
0.85	15	13.4	15
0.85	16	13.4	16

PG-6

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
0.3	5	12	5
0.2	6	12.4	6
0.27	7	12.6	7
0.28	8	12.8	8
0.3	9	13.1	9
0.29	10	13.3	10
0.29	11	13.4	11
0.29	12	13.5	12
0.29	13	13.6	13
0.29	14	13.7	14
0.29	15	13.7	15
0.29	16	13.7	16
0.31	17	13.7	17

PG-7

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
0.74	5	12.2	5
0.4	6	12.5	6
0.38	7	12.6	7
0.38	8	12.7	8
0.45	9	12.9	9
0.44	10	13	10
0.43	11	13.1	11
0.43	12	13.2	12
0.44	13	13.3	13
0.43	14	13.3	14
0.48	15	13.3	15

PG-8

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
7.75	5	7.4	5
7.83	6	7.6	6
8.1	7	7.7	7
8.32	8	7.7	8
8.02	9	8.2	9
7.5	10	8.7	10
8.05	11	8.9	11
8.39	12	9.2	12
8.25	13	8.9	13
8.2	14	9	14
8.7	15	9.1	15
8.81	16	9.1	16

PG-9

DO (mg/L)	Depth (ft)	Temp (C)	Depth (ft)
3.24	4	10.2	4
3.11	5	9.9	5
3.23	6	10	6
3.25	7	10.4	7
2.94	8	10.7	8
3.22	9	11	9
3.31	10	11.3	10
3.57	11	11.6	11
3.38	12	11.8	12
3.49	13	11.9	13
2.89	14	12.1	14
2.83	15	12.2	15

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