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# Hydrogeology of the Little River Animal Agriculture Environmental Research Unit and Impacts of Dairy Operations on Groundwater

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Larry D. McKay, Major Professor

We have read this thesis and recommend its acceptance:

Edmund Perfect, Jaehoon Lee

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

# Hydrogeology of the Little River Animal Agriculture Environmental Research Unit and Impacts of Dairy Operations on Groundwater

A Thesis Presented for the Master of Science Degree

The University of Tennessee, Knoxville

Robert Wesley Hunter

December 2013

# DEDICATION

I dedicate this work to my children, Wes, Alle, and Anne, in the hope that you will always understand that you can accomplish anything if you are willing to dedicate yourself, set your mind to the task and apply the energy and time required to complete your goal.

# ACKNOWLEDGEMENTS

Family, friends and faculty, thank you all for your support, prayers and encouragement during this thesis. Without it, this accomplishment would not have been possible.

This thesis would not have been possible without the graduate assistanceship for Mr. Tim Gangaware, Institute for a Secure and Stainable Environment, Tennessee Water Quality Research Center.

I would also like to acknowledge my committee members Dr. Larry McKay, Dr. Ed Perfect and Dr. Jaehoon Lee for your kindness and patience with me. I will be forever grateful for this.

I would also like to thank UT AgResearch, UTIAI and the staff at the Little River Dairy Farm for their collective kindness and cooperation on this project. In particular, I would like to thank Dr. Bobby Simpson who I admire and respect.

# ABSTRACT

This thesis describes the development of an integrated hydrogeologic/hydrologic site assessment and groundwater/surface water quality monitoring program at the University of Tennessee – Little River Dairy Farm, located near Townsend, TN.  Hydrologic/hydrogeologic investigations of streams and groundwater at the site have been underway for more than 5 years, and these are expected to provide background data for assessing impacts of dairy wastes.  The lower half of the ~180 ha site consists of low-relief fields used for row crops, which are underlain by 4 – 9 m of alluvial deposits on top of black shale or limestone that include sinkhole features. The fields are bounded on two sides by the Little River and on the third side by Ellejoy Creek, which is on the state's 303(d) list for impairment by nutrients, sediment and fecal microorganisms. These fields are now being fertilized with treated dairy wastes and are the main area of concern for offsite migration of contaminants through groundwater, drainage ditches and a tile drain system. Long term water quality monitoring of runoff, streams, drainage ditches and groundwater is planned, with the intent of measuring environmental impact of dairy operations and testing the effectiveness of different management practices.

Research findings indicate groundwater flow systems move toward the central ditch, Little River and Ellejoy Creek.  Well hydrographs show rapid recharge in the floodplain. Geochemistry shows seasonal and short term variations, which are consistent with rapid recharge. Nitrate levels vary across the floodplain and in a few cases appear to be increasing slightly.  *E. coli* is present before and after application of manure and major sinkholes could provide fast pathways to the Little River.

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# CHAPTER 1

## 1.1 Agriculture: Sources of Surface and Groundwater Contamination

The overall goal of this research project is to develop a better understanding of the impacts of small size dairy farm operations on groundwater quality because there are few instrumented dairy sites that can be used to assess impacts or Best Management Practices (BMPS) and none that have good background data. Possible dairy related sources of groundwater contamination include wash water from freestall barn and milking parlor, waste transfer systems, liquid and solid manure storage areas and pits and land application of liquid manure. The impact of livestock operations on streams and rivers has been recognized for decades in many, if not most, agriculturally dominated watersheds (EPA, 1972). However, few dairy farms have been rigorously monitored for extended periods of time to assess potential contaminant migration of dairy related nutrients, sediments, pathogens, pesticides and salts into surface water and groundwater systems. Furthermore, at dairy farm sites where water quality is monitored, it is often difficult to distinguish dairy contamination from other agricultural or residential. Research objectives for this thesis are: 1) to assess background water quality at LRDF prior to implementation of large scale dairy operations; 2) to perform a detailed hydrogeologic characterization in the floodplain; 3) to assess seasonal groundwater levels with a monitoring program; and, 4) to assess any changes in the groundwater quality from potential contaminant migration of dairy related nutrients, sediments, pathogens and salts into groundwater systems.

Springs, creeks and rivers represent pathways for biologic, geologic (naturally occurring) and anthropogenic material transport in the form of surface runoff and groundwater flow. Natural ecosystems depend on these natural waters, which are also essential to human populations for subsistence, agriculture, industrial production, hydropower, recreation, transportation of commercial goods and its waste disposal (Meyer et al., 1988). Declining water quality affects all populations and is one of the greatest challenges confronting society. Agriculture practices are the number one cause for declining water quality on a worldwide basis (Davis and Hirji, 2003). Feeding a planet of an estimated 8 billion by 2030 will require greater food production with less water use. In addition to human needs, steps must be taken to ensure that high quality surface and groundwater flows required to sustain fragile ecosystems are not only maintained but improved.

The influence of barnyard and agricultural practices on surface and groundwater quality has long been recognized (Hem, 1985). Although progress has been made in reducing pollutant emissions from point and nonpoint sources (including agriculture), agriculture is still the "leading source of remaining impairments in the Nation's rivers and lakes" (USDA, 2006). Dairy farms typically produce large quantities of manure and other waste products which are often stored or treated in lagoons and later applied to local fields as fertilizer. Contamination of nearby streams by dairy farm wastes through surface runoff, drainage tile discharge, direct release of wastes or inundation of waste storage facilities during seasonal flooding is a major environmental concern (Arnon et al., 2008; Bakhsh et al., 2005; Domagalski et al., 2008; Kumar et al., 2005; Schilling and Helmers, 2008; Zhao et al., 2010).

Much less attention has been paid to fate and transport of dairy wastes in the subsurface and their potential impact on water quality in aquifers or in groundwater discharge to streams (Barker and Sewell, 1973; Gale et al., 2000; Goss and Barry, 1995; Hamilton and Helsel, 1995; Richards et al., 2004). Potential pathways for such waterborne transport are strongly influenced by the hydrogeology of the underlying soils, unconsolidated sediments and bedrock (Bailly-Comte et al., 2010; Boyer et al., 2009). Installation of field drainage tiles creates new preferential flow paths which can result in rapid discharge of contaminated soil water and groundwater into stream systems (Blanford et al., 2005; Deborde et al., 1999; Malik et al., 2004; Schilling and Helmers, 2008; VanderZaag et al., 2010). Primary agricultural pollutants are sediment, nutrients, pesticides, salts and pathogens. A study by the U.S. Geological Survey (Smith et al., 1994) estimated that 71% percent of U.S. cropland (nearly 300 million acres) was located in watersheds where at least one of four common surface water contaminants exceeded criteria for supporting water-based recreation standards. Well water sampling studies by EPA and USGS have found evidence of agricultural pesticides and nitrogen, possibly threatening water supplies (Capel et al., 2004; Capel et al., 2008). Estimated damages from most sources of agricultural pollution are lacking, however, soil erosion alone is estimated to cost water users $2 billion to $8 billion annually (Ribaudo, 2009).

### 1.2 Federal and State Regulatory Environment for Dairy Farming

The U.S. Environmental Protection Agency (EPA) defines point source of pollution as “discrete conveyances, such as pipes or man-made ditches that discharge pollutants into waters of the United States. This includes not only discharges from municipal sewage plants and industrial facilities, but also collected storm drainage from larger urban areas, certain animal feedlots and fish farms, some types of ships, tank trucks, offshore oil platforms, and collected runoff from many construction sites” (EPA, 2008). Non-point source contamination is defined as contaminates that do not originate from a point source which is a discernible, confined and discrete conveyance of water pollution. Nonpoint source pollution generally results from land runoff, precipitation, atmospheric deposition, drainage, seepage or hydrologic modification. Point source regulations are largely inappropriate for nonpoint sources due the difficulties in measurement, variability of discharges, and the site-specific nature of the facilities. As a consequence, federal water quality laws such as the Clean Water Act, 1972 (CWA) as amended generally do not regulate agricultural pollution but, instead, pass most of the responsibility on to the States (EPA, 1972, 2008).

Clean Water Act programs over the last decade shifted from a program-by-program, source-by-source, and pollutant-by-pollutant approach to more holistic watershed-based strategies. Under the watershed approach, equal emphasis is placed on restoring impaired waters and protecting healthy waters. Involvement of stakeholder groups in the development and implementation of strategies for achieving and maintaining state water quality and other environmental goals is an important component of this approach.

Congress amended the Clean Water Act (CWA) in 1987 to establish the section 319 Nonpoint Source Management Program, Section 401 (Total Maximum Daily Load, TMLD), Section 404 (Wetlands) and the State Revolving Fund (SRF). These amendments were made in recognition of the need for greater federal leadership to help focus State and local nonpoint source efforts. Under section 319, State, Territories, and Indian Tribes receive grant money supporting a wide variety of activities including technical assistance, financial assistance, education, training, technology transfer, demonstration projects, and monitoring to assess the success of specific nonpoint source implementation projects.

Agriculture's impacts on water resources are widespread, considered significant, and the control of agricultural pollution is a challenge (USDA, 2006). Pollution from agriculture is generally considered "nonpoint source" in nature. Four important characteristics bearing on policies for reducing nonpoint source emissions and improving water quality are:

1. Nonpoint source contaminants are generally diffused over a broad land area. It is generally not cost effective to accurately monitor nonpoint source contaminants due to multiple exit points from fields using current technology.

2. Nonpoint emissions (and their transport to water or other resources) are subject to significant natural variability due to weather-related events and other environmental characteristics.
3. Nonpoint emissions and the associated water quality impacts depend on many site-specific characteristics, such as the geologic setting, soil type, topography, proximity to the water resource(s) and climate.
4. Nonpoint pollution problems are often characterized by a large number of nonpoint polluters. (Capel et al., 2004; Harter et al., 2002; Van Drecht et al., 2003)

This has resulted in varied responses, reflecting the States' particular resource concerns and organizational capacity. Thirty-three States have laws with provisions that regulate agriculture under certain conditions, such as when voluntary approaches fail to achieve water quality goals (USDA, 2006). States commonly use technology standards that require farmers to implement conservation plans that contain recommended management practices (Davis and Hirji, 2003; Ribaudo, 2009), such as conservation tillage, nutrient management, pesticide management, and irrigation water management.

### 1.3 Contaminants Associated with Agricultural Production and Dairy Farming

Point and nonpoint source barnyard practices and agricultural crop production are well known as the primary contributor of pollutants water quality in rivers, streams, lakes, estuaries and groundwater. USDA reports that 25,823 bodies of water (stream reaches or lakes) are impaired nationwide (USDA, 2006). Pathogens, sediment, and nutrients are among the top sources of impairment, and agriculture is a major source of these pollutants in many areas. Major categories of pollutants include sediments, chemical nutrients applied as fertilizers, pesticides, insecticides, pharmaceuticals, herbicides, rodenticides, termite chemicals, disinfectants and sanitizers. In addition to nutrients, pathogens and pesticides, air quality is adversely affected by odor, particulates, carbon dioxide, methane, nitrous oxide and ammonia. (Capel et al., 2008; Ribaudo, 2009; USDA, 2006). Sediments are by far, the largest single contaminate of surface waters by weight and volume (Boulton et al., 2010; Capel et al., 2004; Martin-Queller et al., 2010; Negrel et al., 2003; USDA, 2006; Van Drecht et al., 2003). Sediment as a contaminant ranks number one in rivers and streams, fourth in lakes and build up reduces the useful life of man-made reservoirs and natural lakes.

The US EPA provided an assessment of water quality in their 2002 Water Quality Inventory and National Water Quality Inventory Report, January 2009, surveying 44 states and 2 territories. Sixteen percent (16%) of the nation's 3.5 million miles of rivers and streams were included in the report. Forty-four percent (44%) were reported as impaired or not clean enough to support their designated uses, such as fishing and swimming. States found the remaining 56% to be fully supporting all assessed uses. Pathogens, habitat alterations, and organic enrichment/oxygen depletion were cited as the leading causes of impairment in rivers and streams, and top sources of impairment included agricultural activities and hydrologic modifications (such as water diversions and channelization). Impaired lakes, ponds, and reservoirs accounted for thirty nine (39%) during the 2004 report. Mercury, polychlorinated biphenyls (PCBs), and nutrients were cited as the leading causes of impairment in lakes. Top sources of pollutants to lakes, ponds, and reservoirs included atmospheric deposition, unknown/unspecified sources, and agriculture. 29% of the nation's 87,791 square miles of bays and estuaries for the 2004 reported 30% were impaired, and the remaining 70% fully supported all assessed uses. Pathogens, organic enrichment/oxygen depletion, and mercury were reported as the leading causes of impairment in bays and estuaries. Top sources of impairment to bays and estuaries included atmospheric deposition and municipal discharges/sewage.

Data compiled from the 2007 General Dairy Management Survey reported chemical insecticide use estimates for dairy cattle and dairy cattle facilities in 17 states that accounted for 91 percent of the milk cow inventory in the United States. The most common insecticides used on dairy cattle were for flies and lice, Piperonyl butoxide at 44,800 lbs (convert lbs), for flies, lice, hornets and wasps, Permethrin (42,300 lbs) and for lice larva, Tetrachlorvinphos (37,600 lbs) in 2006. These three (3) active ingredients accounted for 72% of the total pounds of active ingredients applied to dairy cattle.

### 1.4 Dairy Farming Past, Present and Future

How can we sustain small private dairy operations while protecting water resources and improving water quality in rivers and streams? The three major uses of land in the 48 contiguous States are grassland pasture and range, forest-use land, and cropland, in that order (USDA, 2006). Total cropland (used for crops, used for pasture, and idled) declined 6 percent over 1969-2002 and farm policy changes have reduced the acreage idled under Federal Programs since 1996 (Ribaudo, 2009; USDA, 2006). Since the 1960's dairy farming has experienced significant progress as well as setbacks. In the 1960's, artificial insemination took hold and transformed the industry. States began to require refrigerated on-farm bulk tanks and separate milk houses. Suburban migration and growth dictated distribution eliminating many "local bottlers" as supermarkets took over the distribution channels. Nearly half (1,000,000) of the all US dairy farms were lost in the mid 60's in a three year period and 80% of the farms had fewer than 20 cows.

A 2010 report released by USDA and NASS indicates a continuing trend of dairy farm consolidation and decline. For example, in 2001, dairy farms numbered 97,460 dairies compared with 65,000 in 2009, a 33% reduction. Despite a large decrease in dairy cow operations, both milk production and milk cow numbers have increased for the same period. During this period, milk production increased by 15%. Volumes increased from 75,000 kilograms or 165,332 million pounds to 85,728 kilograms or 189,320 million pounds. Milk production has shifted to the western half of the United States and operations with 500 – 5,000 cows or more accounted for 5% of milk cow operations, 60% of milk production and 56% of milk cows. “Fluid milk” no longer drives the dairy industry. Cheese markets now control 90% of the basic formula price which is the price driver for the industry.

Statistics compiled by a 2011 University of Tennessee Extension report W284 on the Tennessee Dairy Industry reported 450 Grade A dairies operating in 65 of Tennessee’s counties with 42,340 dairy cows, or approximately 94 cows per dairy. Compared to 2009 State statistics, this represents a loss of nearly 14,000 cows through 2011. The report cited the average herd size also decreased from 2009 from 106 to 94 in 2011 (Figure 1.1 & Figure 1.2). Approximately forty percent 40% of the state’s dairy cows for Grade A dairies are located in seven (7) counties accounting for 17,051 head. They are Greene (3,345), McMinn (2,975), Monroe (2,834), Marshall (2,346), Loudon (2,035), Robertson (1,764) and White (1,752) (Moss et al., 2011).

The report notes that milk production in the state as well as the Southeast is in decline due to a corresponding decline in the number of dairy farms in the state. A fifty percent (50%) decline in the number of Grade A dairies occurred between 2002-2010. Milk production per cow in 1990 was 11,900 pounds, growing to 16,232 pounds by 2010 representing a thirty-six percent (36%) increase in production. This production figures remains less than the national average for milk production per cow of 20,567 pounds, ranking Tennessee 41st in the country. Since 1990, the herd size has declined from ~175,000 cows to 42,340 in 2011 (Moss et al., 2011). These factors and others have created net fluid milk deficits in Tennessee, which is a part of a broader trend across the Southeastern United States. This trend is projected to continue based on current pricing, supply and demand.

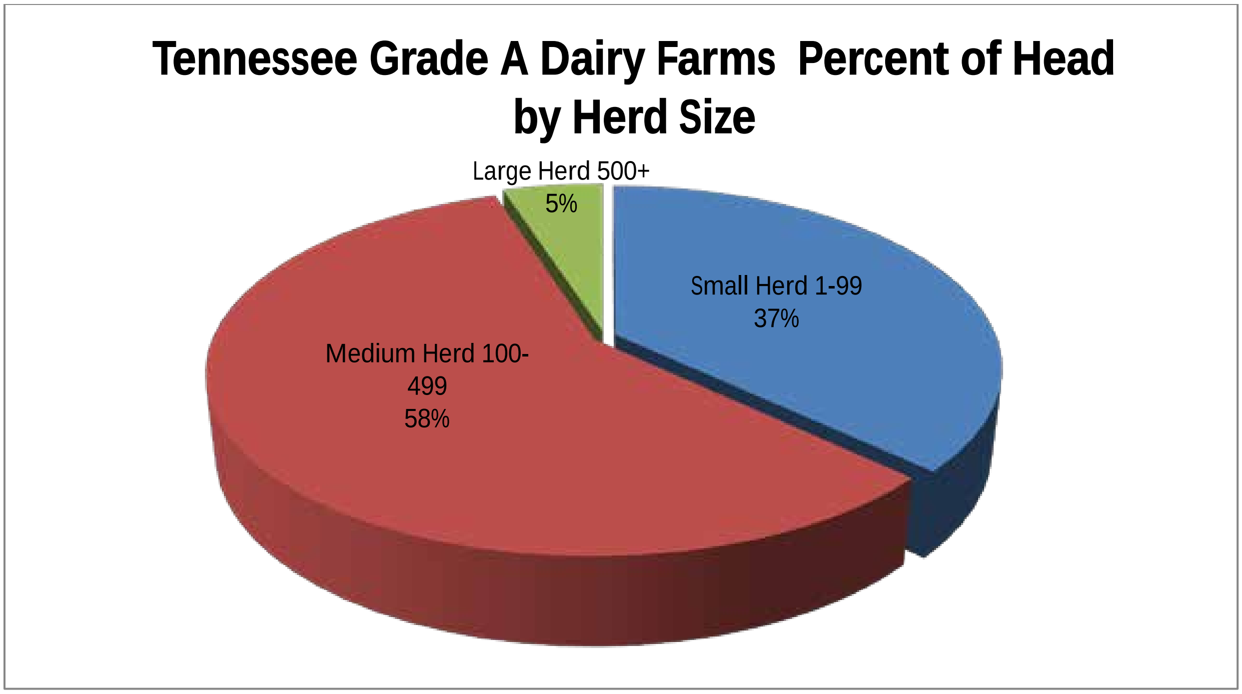


Figure 1.1 - Percent of Head by Herd Size. Adapted from (Moss et al., 2011).

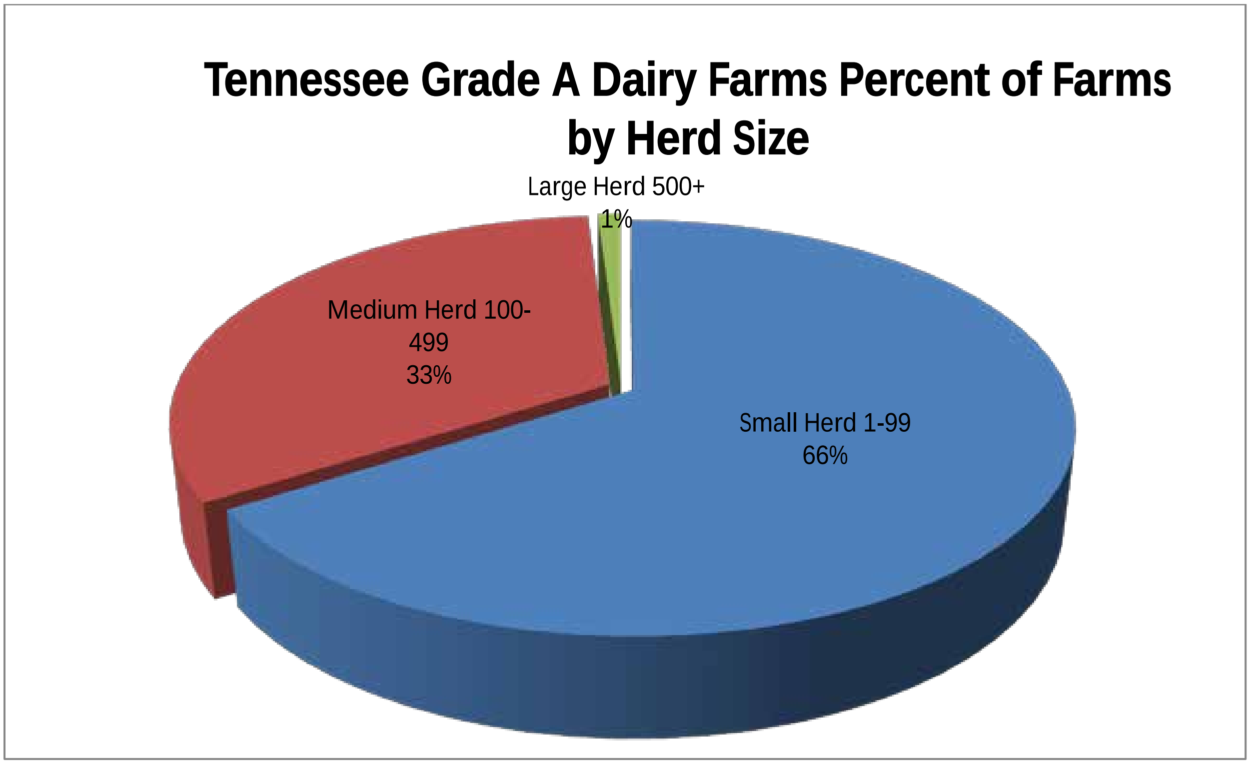


Figure 1.2 - Percent of Farms by Herd Size. Adapted from (Moss et al., 2011).

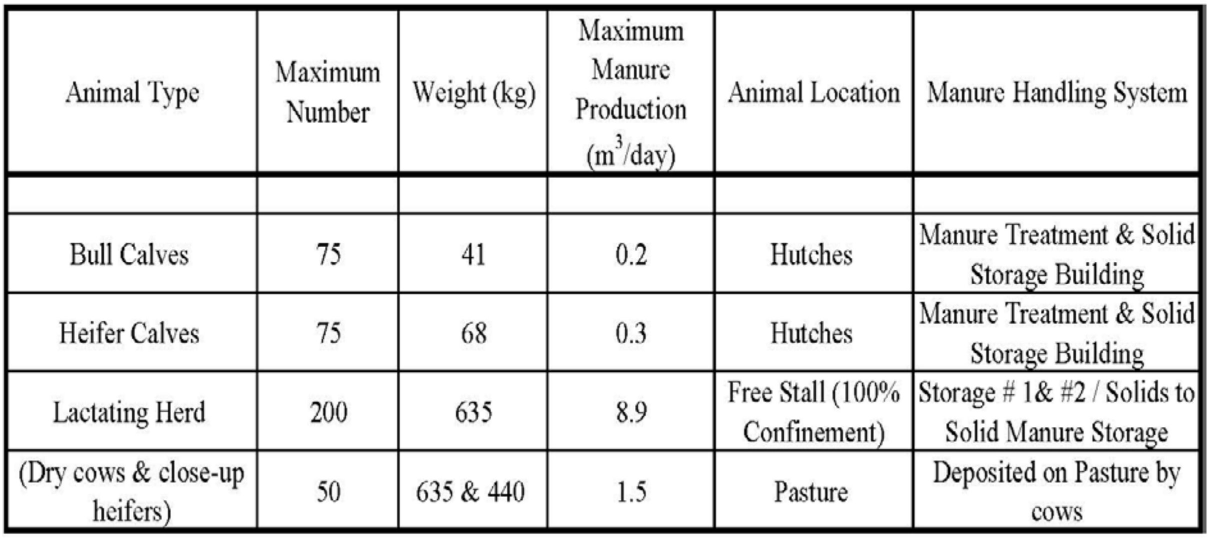
# CHAPTER 2 – UT LITTLE RIVER DAIRY FARM

## 2.1 History and Site Development

East Tennessee AgResearch and Education Center Little River Unit, commonly referred to as the Little River Dairy Farm, (hereafter LRDF), is the subject of this MS thesis. The main purpose is to characterize the hydrogeologic properties of the subsurface, evaluate the groundwater flow paths that could contribute to off-site transport of contaminants, determine pre-dairy groundwater quality conditions and carry out a preliminary assessment of the possible impact of dairy operations on groundwater. Data presented in this study may also be utilized for future studies of the impact of dairy operations and best management practices on groundwater quality, once the dairy has implemented full scale operations and established a performance record.

The 225 hectare Little River Dairy Farm, positioned at the confluence of the Little River and Ellejoy Creek in Blount County, TN, is located approximately 21 kilometers SSE of Knoxville TN. The farm is bounded by the Little River to the west and southwest and by Ellejoy Creek which forms the northeastern boundary until the point where it flows into the Little River. The dairy plans to maintain a lactating herd similar to the typical size of private dairy farms in East Tennessee. The LRDF Comprehensive Nutrient Management Plan reports an annual average of 175 cows with a maximum number of 200 for lactating animals will be managed at any given time. In addition, a dry cow herd with an annual average of 25 cows (maximum number of 50 dry Holstein cows) will also be housed at the facility (Table 2.1) (Burns, 2010b).

Table 2.1 – Expected Maximum Livestock Numbers & Types on the Little River Animal Agriculture Environmental Research Unit, (Burns, 2010b).



| Animal Type | Maximum Number | Weight (kg) | Maximum Manure Production ($m^3$/day) | Animal Location | Manure Handling System |
|---|---|---|---|---|---|
| | | | | | |
| Bull Calves | 75 | 41 | 0.2 | Hutches | Manure Treatment & Solid Storage Building |
| Heifer Calves | 75 | 68 | 0.3 | Hutches | Manure Treatment & Solid Storage Building |
| Lactating Herd | 200 | 635 | 8.9 | Free Stall (100% Confinement) | Storage # 1& #2 / Solids to Solid Manure Storage |
| (Dry cows & close-up heifers) | 50 | 635 & 440 | 1.5 | Pasture | Deposited on Pasture by cows |

Milk producing Holstein cows (average weight 635 kilograms) will be confined 100% of the time in a free-stall barn.  Calf bearing heifers are included in the dry cow count; however, bull calves born at the Little River Dairy will be transported off-site when they are three days of age with an average weight of 40 kilograms.  Heifer calves at three weeks of age with average weight of 68 kilograms will also be transported off site.  Manure and wastewater generated in the free-stall barn, and milking parlor will be collected and stored as liquid slurry in a concrete manure storage tank. Solid manure collected from calves will be stored in a roofed manure storage and treatment facility on-site until used as fertilizer Figure 2.1 (Burns, 2010b).

Dairy construction began in February 2009 with the first cows arriving on site in August of 2011.  In September of 2012, the herd was made up of approximately 150 cows with herd growth to be accommodated by onsite calving over time.  A portion of the manure produced by the herd will be treated, and then used as fertilizer for row-crops in low-lying areas, pastures and hay fields adjacent to the Little River and Ellejoy Creek. Manure and wastewater from the storage tanks will be applied topically and injected into the shallow sub-surface to provide nitrogen as fertilizer for the crop fields where corn silage and hay will be produced in rotation.  Nutrient needs will be met with manure and commercial fertilizers for hay production and on row crop fields (Table 2.2).  The farm is designed to be self-sustaining by producing feed in the form of hay, corn, wheat and silage as feedstock for the herd along with the sale of milk and excess manure to the general public.

Table 2.2 - Planned Utilization of Crop and Hay Fields on the Little River Animal Agriculture Environmental Research Unit & Recommended Annual Nutrient Application Rates, (Burns, 2010b) (Plant Available Nitrogen Application (PAN) Rate). See Figure 2.4 for field number locations.

| Field ID | Total Hectares | Spreadable Hectares | Nutrient Source | Season / Crop | (PAN) Rate (kg / hectare) | $P_2O_5$ Rate (kg / hectare) | $P_2O_5$ Rate (kg / hectare) |
|---|---|---|---|---|---|---|---|
| 1 | 8.3 | 8.1 | Liquid Manure | Spring / Corn Silage | 68 | 36 | 109 |
| | | | Liquid Manure | Fall / Small Grain Haylage | 48 | 18 | 36 |
| 2 | 14.6 | 14.1 | Liquid Manure | Spring / Corn Silage | 68 | 0 | 73 |
| | | | Liquid Manure | Fall / Small Grain Haylage | 48 | 0 | 18 |
| 3 | 5.5 | 5.3 | Inorganic | Spring / Fescue Hay | 48 | 0 | 27 |
| 4 | 12.7 | 12.6 | Liquid Manure | Spring / Corn Silage | 68 | 36 | 73 |
| | | | Liquid Manure | Fall / Small Grain Haylage | 48 | 18 | 18 |
| 5 | 12.9 | 12.4 | Liquid Manure | Spring / Corn Silage | 68 | 0 | 0 |
| | | | Liquid Manure | Fall / Small Grain Haylage | 48 | 0 | 0 |
| 6 | 7.4 | 6.4 | Liquid Manure | Spring / Corn Silage | 68 | 0 | 0 |
| | | | Liquid Manure | Fall / Small Grain Haylage | 48 | 0 | 0 |
| 7 | 2.9 | 2.8 | Solid Manure | Spring / Fescue Hay | 48 | 27 | 14 |
| 8 | 8.9 | 8.1 | Inorganic | Spring / Fescue Hay | 48 | 27 | 27 |
| 9 | 10.7 | 10.7 | Liquid Manure | Spring / Corn Silage | 68 | 36 | 109 |
| | | | Liquid Manure | Fall / Small Grain Haylage | 48 | 18 | 36 |
| 10 | 6.1 | 5.7 | Solid Manure | Spring / Fescue Hay | 48 | 27 | 14 |
| 11 | 8.1 | 7.8 | Liquid Manure | Spring / Corn Silage | 68 | 73 | 109 |
| | | | Liquid Manure | Fall / Small Grain Haylage | 48 | 36 | 36 |

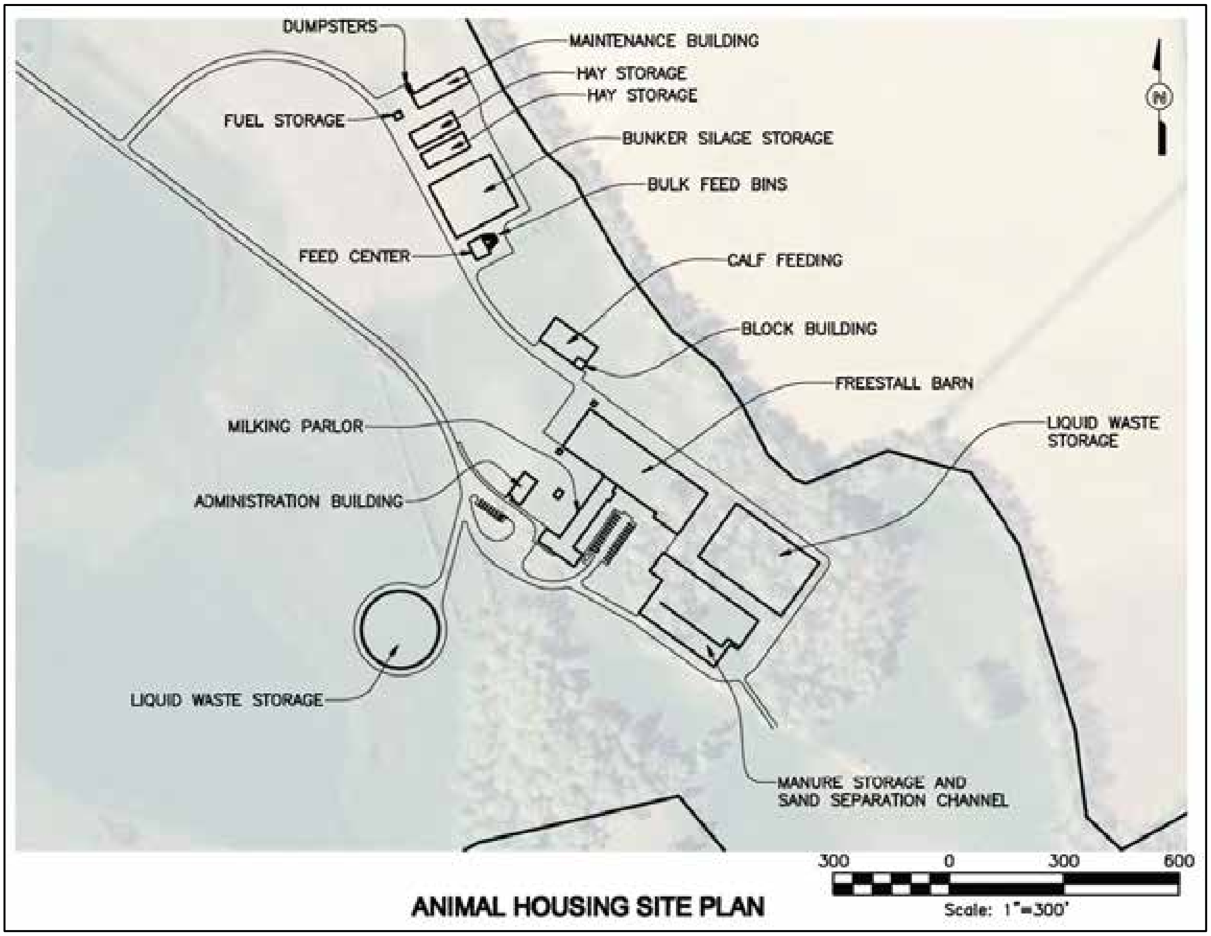


Figure 2.1 - Manure and wastewater generated in the free-stall barn, and milking parlor will be collected and stored as liquid slurry in liquid waste storage tank. Solid manure collected from calves will be stored in a roofed manure storage and treatment facility on-site until used as fertilizer (Burns, 2010b).

This site, with the dairy property bound on three sides by streams, provides an unusually well-constrained setting for evaluating the impacts of dairy operations on water quality (Figure 2.2). Geologically, floodplain alluvium rests on shale or soluble dolomite/limestone while the upland regions of the farm where the dairy barns are located are underlain by mudstone/siltstone shale which is often highly weathered. A regional and site specific geologic overview is provided later in this chapter.

Construction of the physical plant and facilities at LRDF began in 2009. The dairy officially opened on October 2nd, 2011 with 1000 local farmers and members of the interested public attending. The dairy plant and facilities consist of a milking parlor, freestall barn, administrative and conferencing buildings, bunker silage storage, bulk feeding bins, calf feeding station, two (2) roofed hay storage locations, maintenance building, feed center along with two (2) liquid waste storage facilities, manure storage and sand separation pit (Figure 2.3). Hay and production fields are numbered and correspond to Figure 2.4.

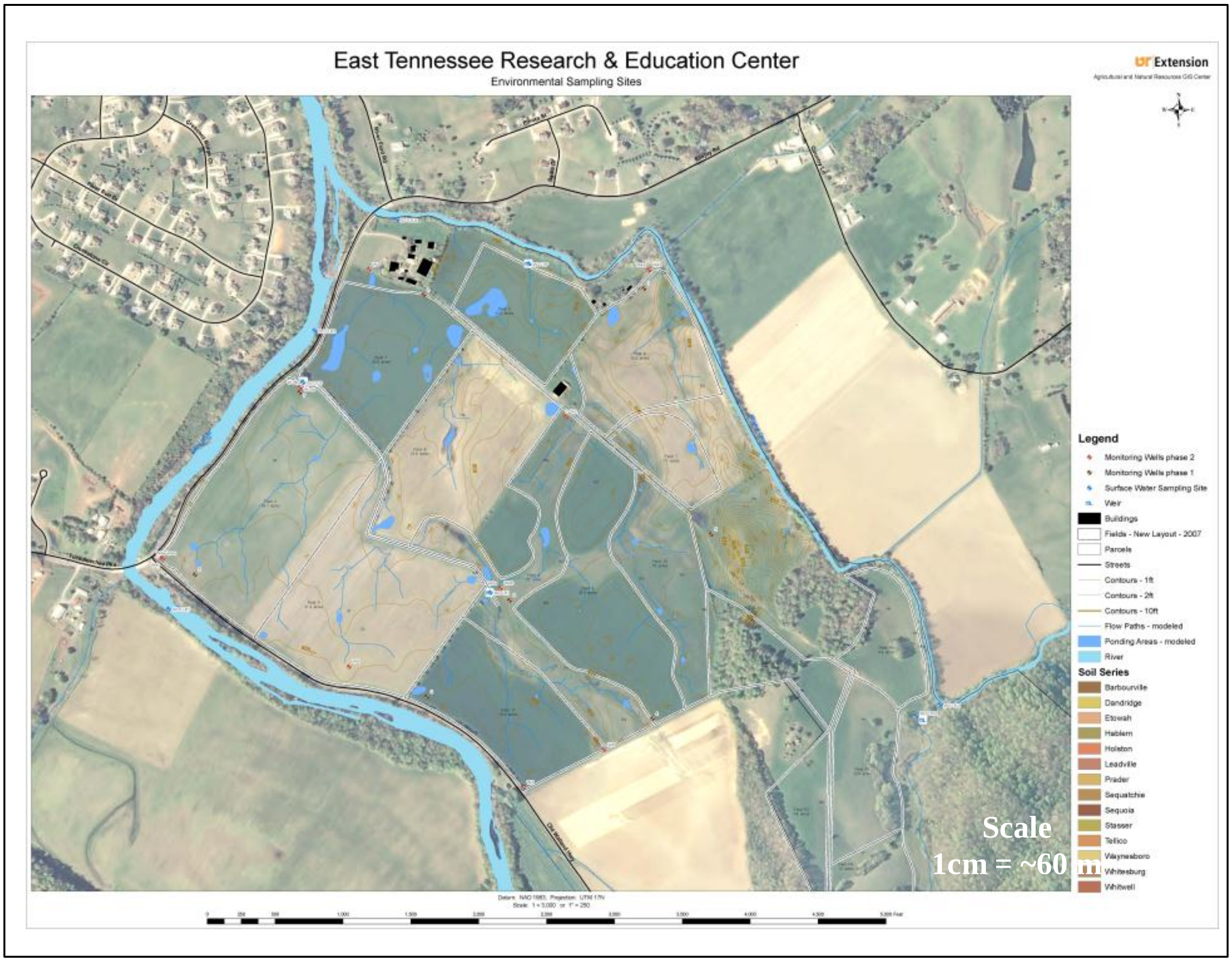


Figure 2.2 - Little River Dairy Farm – Site Overview (UT AgResearch GIS 2011).

Figure 2.3 – Little River Dairy Farm – Plant and Facilities, (Burns, 2010b)

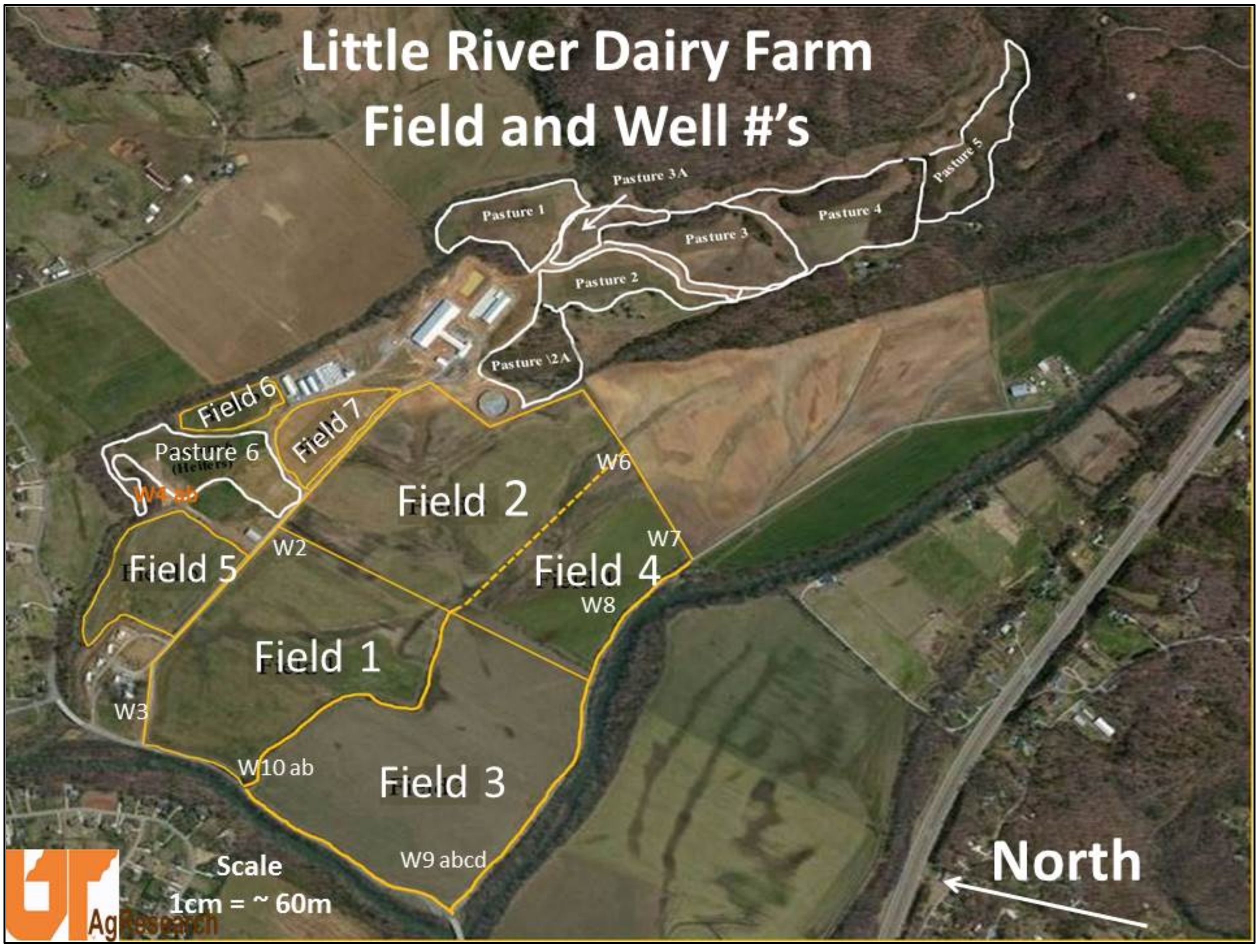


Figure 2.4 – Little River Dairy Farm - Field number locations.

## 2.2 Watershed Characteristics

The Little River originates in the Clingman's Dome area of the Great Smoky Mountain National Park then flows west until with its terminus in the Tennessee River (Figure 2.5). This waterway serves as a source of drinking water for 100,000 residents with US Census estimates for 2015 population projections of 140,000. It also provides water supplies for farmers; businesses and industry in the area and supports recreational activities for both residents and the 1,600,000 tourists who visit this area annually. In 2005, the Little River was designated as an EPA targeted watershed, and is classified as an Outstanding Natural Resource Water in its headwaters in the Great Smoky Mountain National Park. Downstream portions are threatened by increased agricultural and development practices, urban runoff, and failing septic tanks (US Environmental Protection Agency, 2005). Since 2005, TDEC added two additional federal endangered species in 2010 up from four (4) to six (6) federally endangered fish, mussels and snail species (2.3) (TDEC, 2005, 2010, 2012). The Little River watershed is a HUC-10 watershed located within the Ft. Loudon Lake watershed (HUC 06010201).

Table 2.3 - Little River Endangered Species (TDEC, 2005, 2010, 2012).

| | |
|---|---|
| **Fish** | |
| | Duskytail Darter, *Etheostoma percnurum* |
| | Snail Darter, *Percina tanasi* |
| **Fresh Water Mussels** | |
| | Fine-rayed Pigtoe, *Fusconaia cuneolus* |
| | Pink Mucket Pearlymussel, *Lampsilis abrupta* |
| | Orange-foot Pimpleback Pearlymussel, *Plethobasus cooperianus* |
| **Fresh Water Snail** | |
| | Anthony's River Snail, *Athearnia anthonyi* |

A primary water quality concern is cattle watering in creek and streams in the Little River Watershed. This practice contributes to increases in stream sediment and nutrient loads, pathogens and viruses that may potentially infect cattle herds downstream.

Of the 1,030 total stream kilometers within the Little River Watershed, 370 stream kilometers are classified as impaired (US Environmental Protection Agency, 2005), [TDEC, 2004 303(d) report] and 29 kilometers are threatened by a decline in biodiversity. Bacteria, sediment, and habitat alteration are the primary causes of impairment; impacting 65%, 56%, and 34% of 303(d) listed stream segments respectively. Impaired by nitrates, siltation and *E. coli,* 8.6 stream kilometers upstream and 33 kilometers downstream of the LRDF the Little River remains listed by TDEC. Table 2.4 depicts the 2012 draft of TDEC 303(d) listed streams in Blount County, TN.

HUC-12 tributary sub-watersheds upstream of the LRDF directly affect the water quality surrounding LRDF, several of which are listed on the State of Tennessee's 2004, & 2006, 303(d) list for sedimentation and pathogens. The 303(d) list is published every two years, and lists all surface waters in the state that have been assessed and found to be impaired.

Joining the LRDF on its northeast border, Ellejoy Creek is listed on the State of Tennessee's 303(d) list for impairment by bacteria, sediments and nutrients, and has exceeded Total Maximum Daily Load (TMDL) requirements for *Escherichia coli* (*E. coli*) and sediment (TDEC, 2005, 2010, 2012). The TMDLs for Ellejoy Creek list 23.8 stream kilometers impaired by *E. coli*. The pollutant source has been identified as pasture grazing and potential residential septic tank effluent. Numerous cattle and dairy operations, real estate developments and single family homes all served by septic tanks are located along the upstream sections of Ellejoy Creek.

All of the nonpoint source impairments were cited by TDEC prior to the commencement of construction or operation of the LRDF as a working dairy farm.

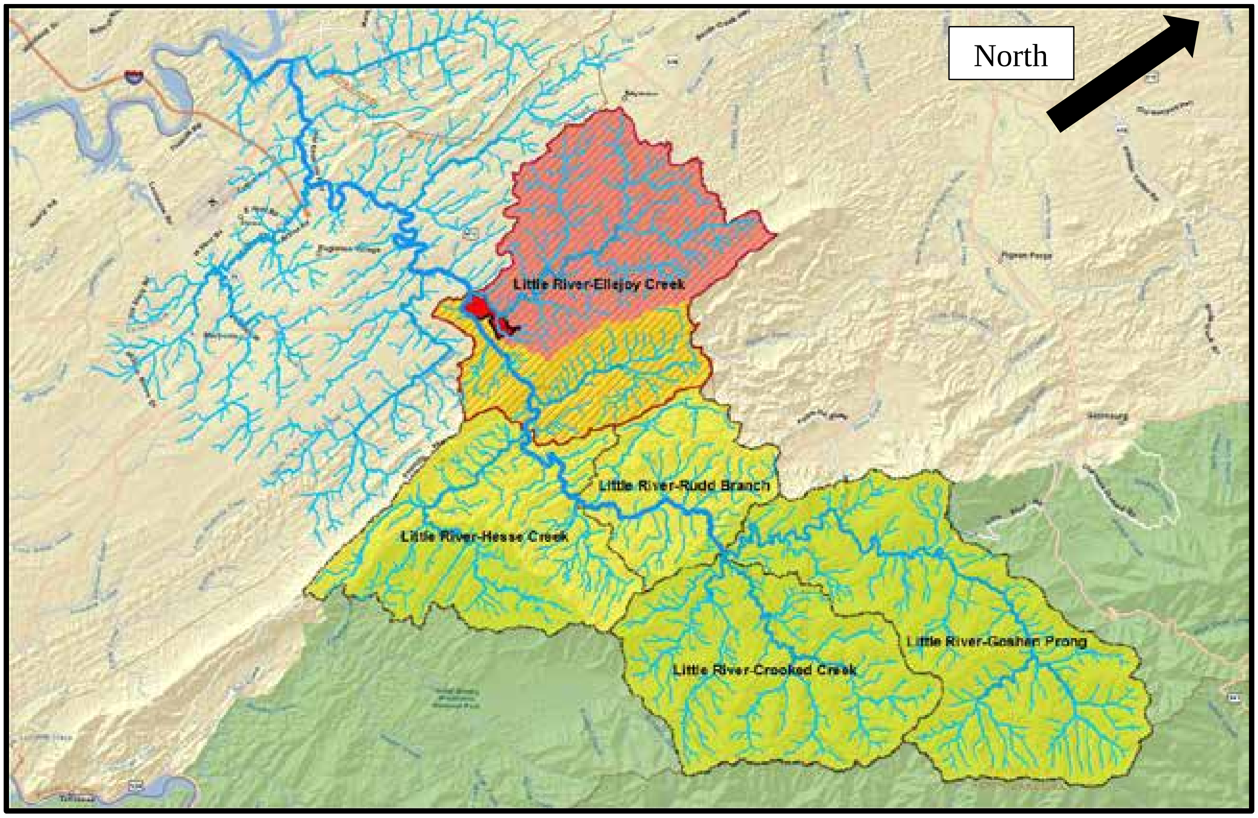


Figure 2.5 - Little River Watershed, after (Wilkerson, 2011)

Table 2.4 - 2012 Draft of TDEC 303(d) listed streams in Blount County, TN.

| Waterbody ID | Impacted Waterbody | County | Miles/Acres Impaired | CAUSE / TMDL Priority | Pollutant Source | COMMENTS |
|---|---|---|---|---|---|---|
| TN06010201 020 - 1000 | FORT LOUDOUN RESERVOIR | Knox<br>Loudon | 14066 ac | PCBs | Contaminated Sediment | Fishing advisory due to PCBs. Category 4a. EPA approved a PCB TMDL for the known pollutant. |
| TN06010201 026 – 0100 | RODDY BRANCH | Blount<br>Knox | 6.4 | Alteration in stream-side or littoral vegetative cover. Physical Substrate Habitat Alteration. Loss of biological integrity due to siltation. *Escherichia coli* | Pasture Grazing<br>Channelization | Stream is Category 4a. One or more uses impaired, but EPA has approved pathogen, siltation, and habitat alteration TMDLs that address the known pollutants. |
| TN06010201 026 – 0110 | CANEY BRANCH | Blount | 1.43 | Physical Substrate Habitat Alteration | Pasture Grazing | Category 4a. EPA approved a habitat alteration TMDL for the known pollutants. |
| TN06010201 026 – 0300 | HOLLYBROOK BRANCH | Blount | 2.78 | Unionized Ammonia M. Total Phosphorus M. Alteration in stream-side or littoral vegetative cover. Loss of | Pasture Grazing | Category 5. EPA approved a siltation/habitat alteration TMDL for some of the known pollutants. |
| TN06010201 026 – 0400 | PISTOL CREEK | Blount | 6.39 | Loss of biological integrity due to siltation. Escherichia coli | Discharges from MS4 area | Category 4a. EPA approved siltation and pathogen TMDLs for the known pollutants. |
| TN06010201 026 – 0410 | SPRINGFIELD BRANCH | Blount | 5.48 | Nitrate+Nitrite M. Loss of biological integrity due to siltation | Discharges from MS4 area | Category 5. EPA approved a pathogen TMDL for some of the known pollutants. |
| TN06010201 026 – 0420 | BROWN CREEK | Blount | 22.07 | Alteration in stream-side or littoral vegetative cover. Nitrate+Nitrite M. Loss of biological integrity. due to | Discharges from MS4 area<br>Land Development | This stream is Category 5. One or more uses impaired, but EPA has approved siltation and habitat alteration TMDLs to |
| TN06010201 026 – 0421 | DUNCAN BRANCH | Blount | 2.5 | Flow Alteration | Sand/Gravel/Rock Quarry | Category 4c. Flow alteration is not caused by a pollutant. |
| TN06010201 026 – 0430 | CULTON CREEK | Blount | 6.14 | Loss of biological integrity due to siltation. *Escherichia coli* | Discharges from MS4 area | Category 4a. EPA approved pathogen and siltation TMDLs for the known pollutants. |

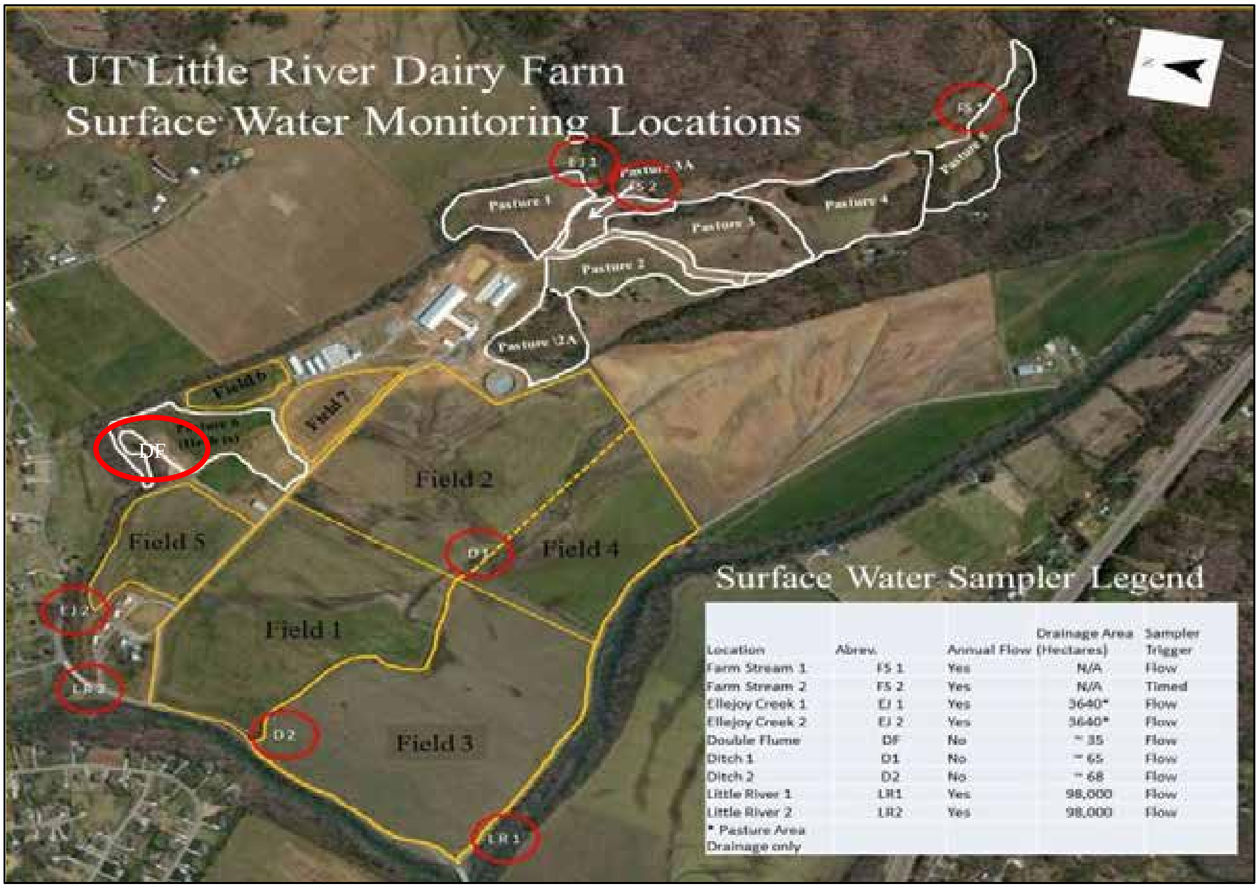
Given the existing conditions surrounding the LRDF and as a steward of the land, the UT AgResearch and Biosystems Engineering Departments have positioned LRDF as a model site for innovation and advances in the fields of animal husbandry, soil conservation, surface water, soil water, and groundwater perfection.

### 2.3 Previous Investigations

Geology 586 Field Methods Class 2007 and 2009 members, under the direction of Dr. Larry McKay, conducted a preliminary hydrogeologic characterization of the LRDF and installed and tested groundwater monitoring wells. The purpose of the initial 2007 study was to characterize the geology of the LRDF site and to identify likely groundwater flow patterns as well as assess the potential for off-site transport of agricultural contaminants. At the conclusion of the 2007 study, recommendations were made to install monitoring wells and measure hydraulic and geochemical parameters. Those observations, conclusions and recommendations are contained in the report "*Hydrogeologic Characterization of the Little River Dairy Farm* (LRDF) - 2007"(Donat et al., 2007). In 2009, the LRDF Study 2007 recommendations were approved and funded, and the Fall 2009 Geology 586 Field Methods Class members installed, developed and tested 15 groundwater monitoring wells, thus providing the basic infrastructure to begin a groundwater monitoring and sampling program. The 2009 class reported their results and preliminary findings in the report "*Installation and testing of Groundwater Monitoring Wells Little River Dairy Farm* (LRDF)-2009" (Hunter et al., 2009). This report issued a second set of recommendations to expand the monitoring well network by installing bedrock monitoring wells and to advance the monitoring program to include physical and chemical surface water, soil water (vadose zone) and groundwater characterizations. The author of this thesis was the lead author of the 2009 Geology 586 report.

## 2.4 Surface Water Stream Sampling Program

Surface water quality monitoring at LRDF dates back to 2005. The surface water monitoring program is currently under expansion with the completion and scaled operation of the dairy underway. In May 2005, UT AgResearch determined nine LRDF stream locations for long term surface water monitoring (Figure 2.6 (red circles))(Wills et al., 2005-2010).



| Location | Abrev. | Annual Flow | Drainage Area (Hectares) | Sampler Trigger |
|---|---|---|---|---|
| Farm Stream 1 | FS 1 | Yes | N/A | Flow |
| Farm Stream 2 | FS 2 | Yes | N/A | Timed |
| Ellejoy Creek 1 | EJ 1 | Yes | 3640* | Flow |
| Ellejoy Creek 2 | EJ 2 | Yes | 3640* | Flow |
| Double Flume | DF | No | ~ 35 | Flow |
| Ditch 1 | D1 | No | ~ 65 | Flow |
| Ditch 2 | D2 | No | ~ 68 | Flow |
| Little River 1 | LR1 | Yes | 98,000 | Flow |
| Little River 2 | LR2 | Yes | 98,000 | Flow |

* Pasture Area Drainage only

Figure 2.6 - Surface Water Sampling Locations (Burns, 2010b).

Four 120 degree v-notched weirs were constructed and equipped with ISCO samplers. Two are located on a perennial stream, (hereinafter “farm stream”). The first weir (FS-1) is located near the northeastern property boundary. This site allows measurement of the impact of a small residential area with many septic fields located up stream of the LRDF. A second monitoring station (FS-2) collects drainage from pastures and slopes of the eastern most section of the farm and is located approximately100 meters prior to the confluence with Ellejoy Creek (Figure 2.7).

Figure 2.7 - Farm Stream (FS-2) -120 degree V-notch weir.

Ellejoy Creek is monitored at two points; 1) above the confluence of the farm stream and Ellejoy (EJ1); and, 2) near the Ellejoy Road Bridge above the confluence with the Little River (EJ2). Two weirs and samplers (D1 & D2) were located in an excavated ditch which drains about half of the LRDF floodplain including fields 1, 2, 3 & 4 before discharging to the Little River. The recent excavation of the ditch caused the removal of sampling site D1 which has not been replaced as of this writing. A double flume is located in field 5 in a low lying area to collect ephemeral flow from appoximately 35 hectares and the effluent from a new artifical wetland located below the calf barn (Figure 2.8). Drainage area summaries and sample locations are noted in Figure 2.6.

Figure 2.8 - Double Flume (DF).

Since May 2005, surface water monitoring sites were sampled every two weeks and analyzed for nutrients then duplicate grab sampling techniques were used to collect *E. coli* samples at each location. The analytes include total solids (ppm), biochemical oxygen demand (BOD) (ppm), total nitrogen (ppm), chloride (ppm), nitrate (ppm), nitrite (ppm) and total phosphorus (ppm).

### 2.5 Storm Event Surface Water Sampling Program

Storm event surface water sampling was implemented in the Fall of 2011 to collect data at strategic locations around LRDF. The program, designed by Dr. Andrea Ludwig, calls for the implementation of monitored water quality best management practices (BMPs) to filter stormwater pollutants from runoff from the Little River Animal Environmental Unit. As part of a long-term effort to incorporate a suite of BMPs, site improvements including the installation of riparian buffer treatments and a treatment train BMP, which consists of a bio-swale and a constructed wetland. This work is innovative in that it incorporates self-design concepts by working with the existing lay of land to exploit available ecoservices onsite while not compromising the functionality of the farm. The plan is based on the hypotheses that BMPs will decrease the abundance of nitrogen, phosphorus, suspended sediment, and pathogens in surface water runoff from the manured row crop fields and pastures before discharge to the Little River and Ellejoy Creek. Research aims are to create infrastructure to monitor long-term effectiveness of water quality BMPs on an operating Dairy Farm. A water quality monitoring system for storm water runoff was established, BMPs implemented, and research questions surrounding their effectiveness and longevity for treating agricultural runoff are being developed. Samples are analyzed in BESS lab for Total Suspended Solids (TSS), *E. coli*, Nitrates ($NO_3$), ammonia ($NH_3$) and Phosphates ($PO_4$). During the sampling events continuous monitoring of water quality parameters (temperature, dissolved oxygen, turbidity, conductivity, and pH) was conducted. The specific extension aims are to provide a showcase demonstration site for various water quality BMPs on a dairy farm. The program is slated to run for three (3) years from its inception. Figure 2.9 shows sample site locations denoted with red X's. Site IDs are numbered 1 through 11. These sites may change as drainage at the facility changes over time.

Figure 2.9 - Stormwater runoff sampling locations. Site 1 A&B: culverts source from adjacent property; Site 2, Weir; Site 3, Weir; Site 4, Little River; Site 5, Wetland before entering culvert; Site 6, Wetland before entering culvert; Site 7, Before gravel road; Site 8: Flume, Site 9: Ellejoy Creek, Site 10: Below headwall, Site 11: just before outlet to Ellejoy Creek. (Ludwig, 2011). Note: Dr. Ludwig's monitoring program uses some of the same sampling locations as the previous surface water monitoring program (Figure 2.6) but uses different designations for the sites.

In 2011, two shallow water treatment zones were constructed in three phases for future research. These catchments are located adjacent to the calf barn and below the dairy operating facilities located in Pasture 1 (Figures 2.10 – 2.13). Construction and excavation commenced in February 2012 and annual rye mix cover crop was established along with woody species plantings and emergent vegetation plantings. Wetland plants were established to test the influence of vegetation selection and management on treatment performance (Figure 2.11). ISCO automated samplers sample during storm events at the wetland inlets and outlet (Figure 2.12).

Figure 2.10 Constructed wetland underway (Ludwig, 2011).

Figure 2.11 - Constructed wetland after with wetland plantings (Ludwig, 2011).

Figure 2.12 ISCO automated sampler unit for the constructed wetland (Ludwig, 2011).

Figure 2.13 A second constructed wetland was installed in Pasture 1 (see Figure 2.4 for location) based on knowledge of groundwater flow directions from the dairy into Pasture 1. Pasture 1 borders Ellejoy Creek to the east. The configuration of the wetland allows for catchment of stormwater runoff as well as flow from an ephemeral stream that boarders Pit 1. (Ludwig, 2011).

## 2.6 Climate and Weather – LRDF

Tennessee is divided into four (4) climatic zones. The average annual precipitation in most of the greater Knoxville area is 1,040 to 1,395 millimeters annually (41 to 55 inches) (Figure 2.14). According to data from the NOAA - National Climatic Data Center from 1981 – 2010 the annual precipitation in the area was ~ 1,214 mm (Table 2.5 & Figure 2.15). The precipitation rate increases to the south and can exceed as much as 1,675 millimeters (66 inches) at the highest elevations in east Tennessee and the northwest corner of Georgia (Tennessee Climatological Service, 2012). The maximum precipitation occurs in midwinter and midsummer, and the minimum occurs in autumn. Most of the rainfall occurs as high-intensity, convective thunderstorms. Snowfall may occur in winter. Average annual temperatures are 11 to 17 degrees C (52 to 63 degrees F), increasing to the south (National Climatic Data Center, 2012). The freeze-free period averages 205 days and ranges from 165 to 245 days and is longest in the southern part of the region and shortest at high elevations and at the northern end (Tennessee Climatological Service, 2012).

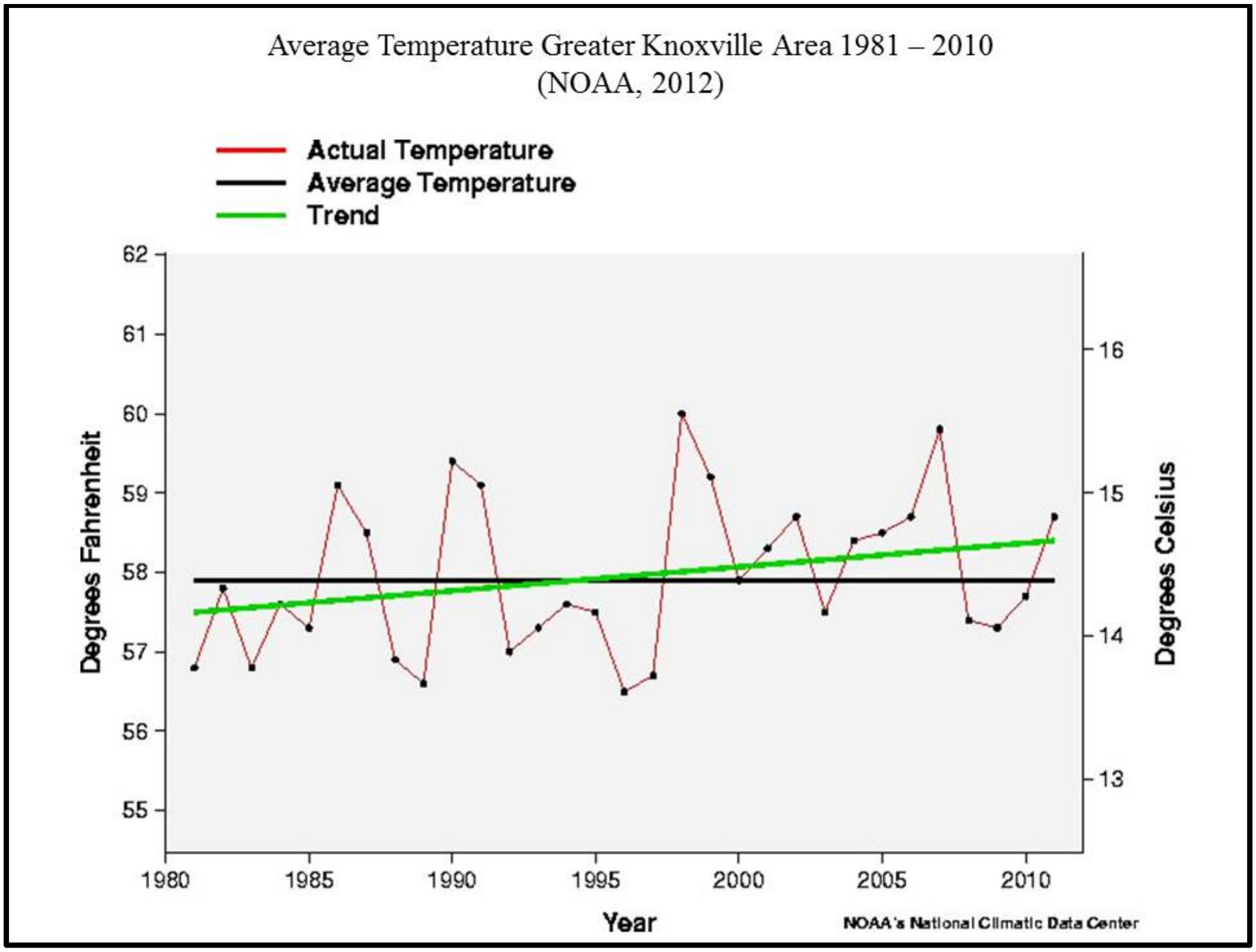
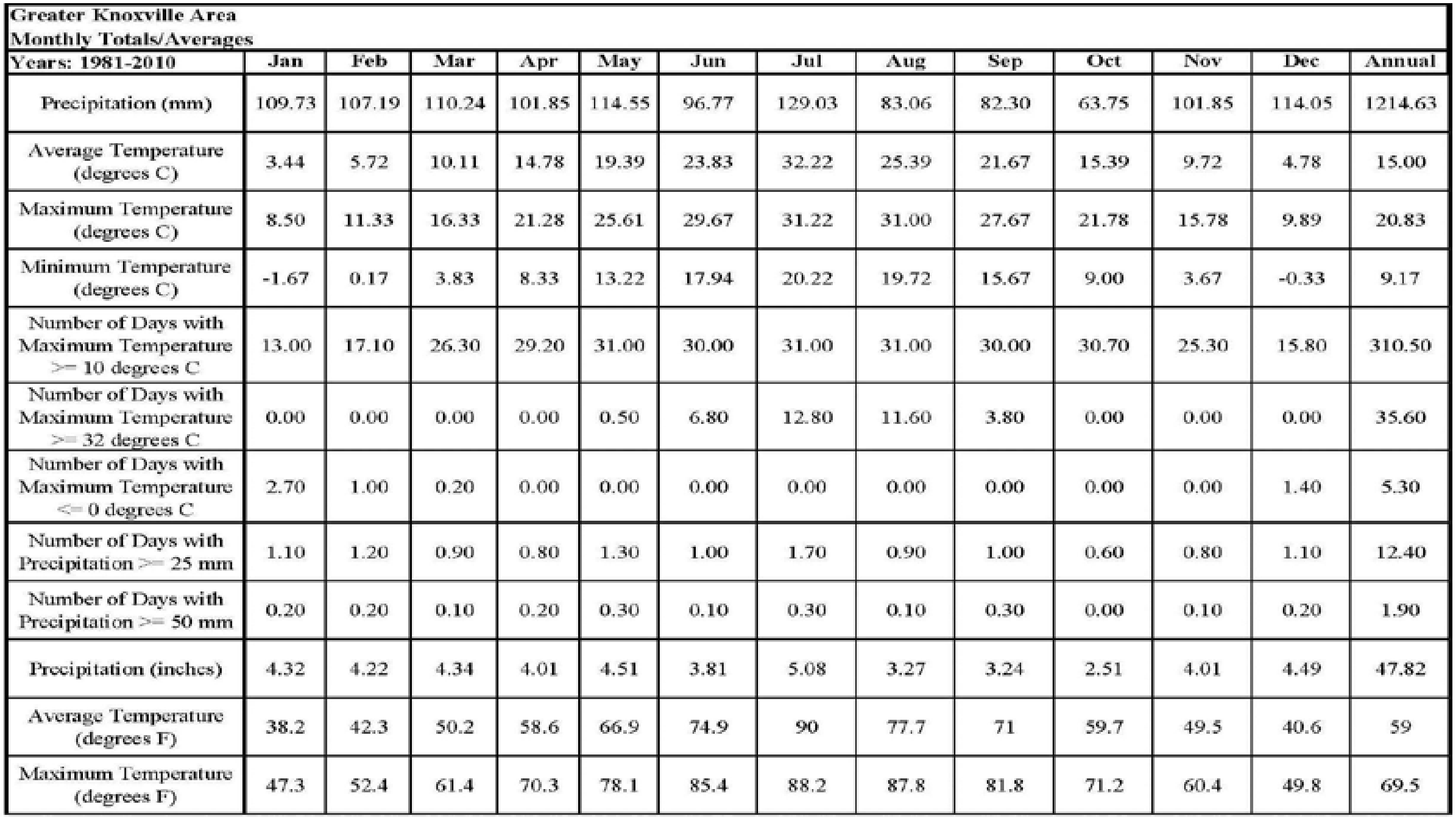


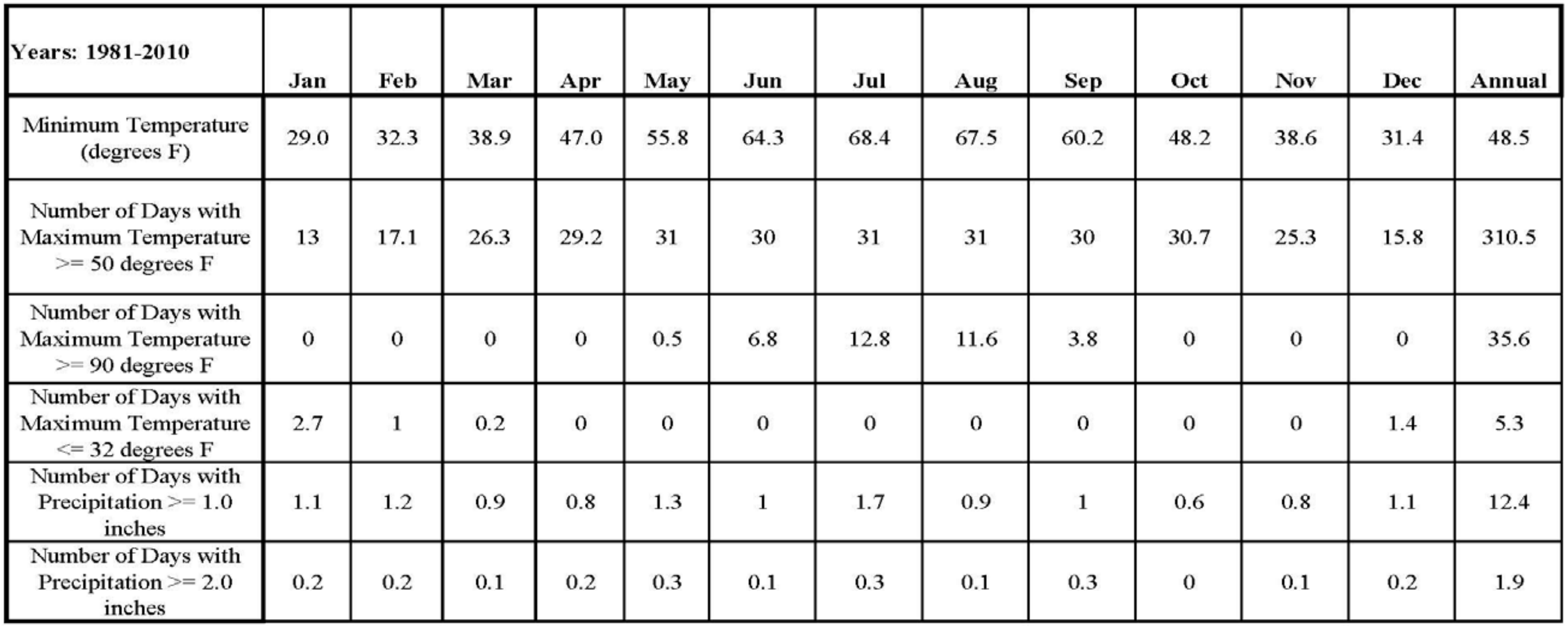
Figure 2.14 - Average Temperature Greater Knoxville Area 1981-2010 (National Climatic Data Center, 2012)

Table 2.5 - Greater Knoxville Area Monthly Climate Averages 1981-2010 (National Climatic Data Center, 2012).



| Greater Knoxville Area Monthly Totals/Averages Years: 1981-2010 | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Precipitation (mm) | 109.73 | 107.19 | 110.24 | 101.85 | 114.55 | 96.77 | 129.03 | 83.06 | 82.30 | 63.75 | 101.85 | 114.05 | 1214.63 |
| Average Temperature (degrees C) | 3.44 | 5.72 | 10.11 | 14.78 | 19.39 | 23.83 | 32.22 | 25.39 | 21.67 | 15.39 | 9.72 | 4.78 | 15.00 |
| Maximum Temperature (degrees C) | 8.50 | 11.33 | 16.33 | 21.28 | 25.61 | 29.67 | 31.22 | 31.00 | 27.67 | 21.78 | 15.78 | 9.89 | 20.83 |
| Minimum Temperature (degrees C) | -1.67 | 0.17 | 3.83 | 8.33 | 13.22 | 17.94 | 20.22 | 19.72 | 15.67 | 9.00 | 3.67 | -0.33 | 9.17 |
| Number of Days with Maximum Temperature >= 10 degrees C | 13.00 | 17.10 | 26.30 | 29.20 | 31.00 | 30.00 | 31.00 | 31.00 | 30.00 | 30.70 | 25.30 | 15.80 | 310.50 |
| Number of Days with Maximum Temperature >= 32 degrees C | 0.00 | 0.00 | 0.00 | 0.00 | 0.50 | 6.80 | 12.80 | 11.60 | 3.80 | 0.00 | 0.00 | 0.00 | 35.60 |
| Number of Days with Maximum Temperature <= 0 degrees C | 2.70 | 1.00 | 0.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.40 | 5.30 |
| Number of Days with Precipitation >= 25 mm | 1.10 | 1.20 | 0.90 | 0.80 | 1.30 | 1.00 | 1.70 | 0.90 | 1.00 | 0.60 | 0.80 | 1.10 | 12.40 |
| Number of Days with Precipitation >= 50 mm | 0.20 | 0.20 | 0.10 | 0.20 | 0.30 | 0.10 | 0.30 | 0.10 | 0.30 | 0.00 | 0.10 | 0.20 | 1.90 |
| Precipitation (inches) | 4.32 | 4.22 | 4.34 | 4.01 | 4.51 | 3.81 | 5.08 | 3.27 | 3.24 | 2.51 | 4.01 | 4.49 | 47.82 |
| Average Temperature (degrees F) | 38.2 | 42.3 | 50.2 | 58.6 | 66.9 | 74.9 | 90 | 77.7 | 71 | 59.7 | 49.5 | 40.6 | 59 |
| Maximum Temperature (degrees F) | 47.3 | 52.4 | 61.4 | 70.3 | 78.1 | 85.4 | 88.2 | 87.8 | 81.8 | 71.2 | 60.4 | 49.8 | 69.5 |

Table 2.5 (Continued) - Greater Knoxville Area Monthly Climate Averages 1981-2010.



| **Years: 1981-2010** | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** | **Oct** | **Nov** | **Dec** | **Annual** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Minimum Temperature (degrees F) | 29.0 | 32.3 | 38.9 | 47.0 | 55.8 | 64.3 | 68.4 | 67.5 | 60.2 | 48.2 | 38.6 | 31.4 | 48.5 |
| Number of Days with Maximum Temperature >= 50 degrees F | 13 | 17.1 | 26.3 | 29.2 | 31 | 30 | 31 | 31 | 30 | 30.7 | 25.3 | 15.8 | 310.5 |
| Number of Days with Maximum Temperature >= 90 degrees F | 0 | 0 | 0 | 0 | 0.5 | 6.8 | 12.8 | 11.6 | 3.8 | 0 | 0 | 0 | 35.6 |
| Number of Days with Maximum Temperature <= 32 degrees F | 2.7 | 1 | 0.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.4 | 5.3 |
| Number of Days with Precipitation >= 1.0 inches | 1.1 | 1.2 | 0.9 | 0.8 | 1.3 | 1 | 1.7 | 0.9 | 1 | 0.6 | 0.8 | 1.1 | 12.4 |
| Number of Days with Precipitation >= 2.0 inches | 0.2 | 0.2 | 0.1 | 0.2 | 0.3 | 0.1 | 0.3 | 0.1 | 0.3 | 0 | 0.1 | 0.2 | 1.9 |

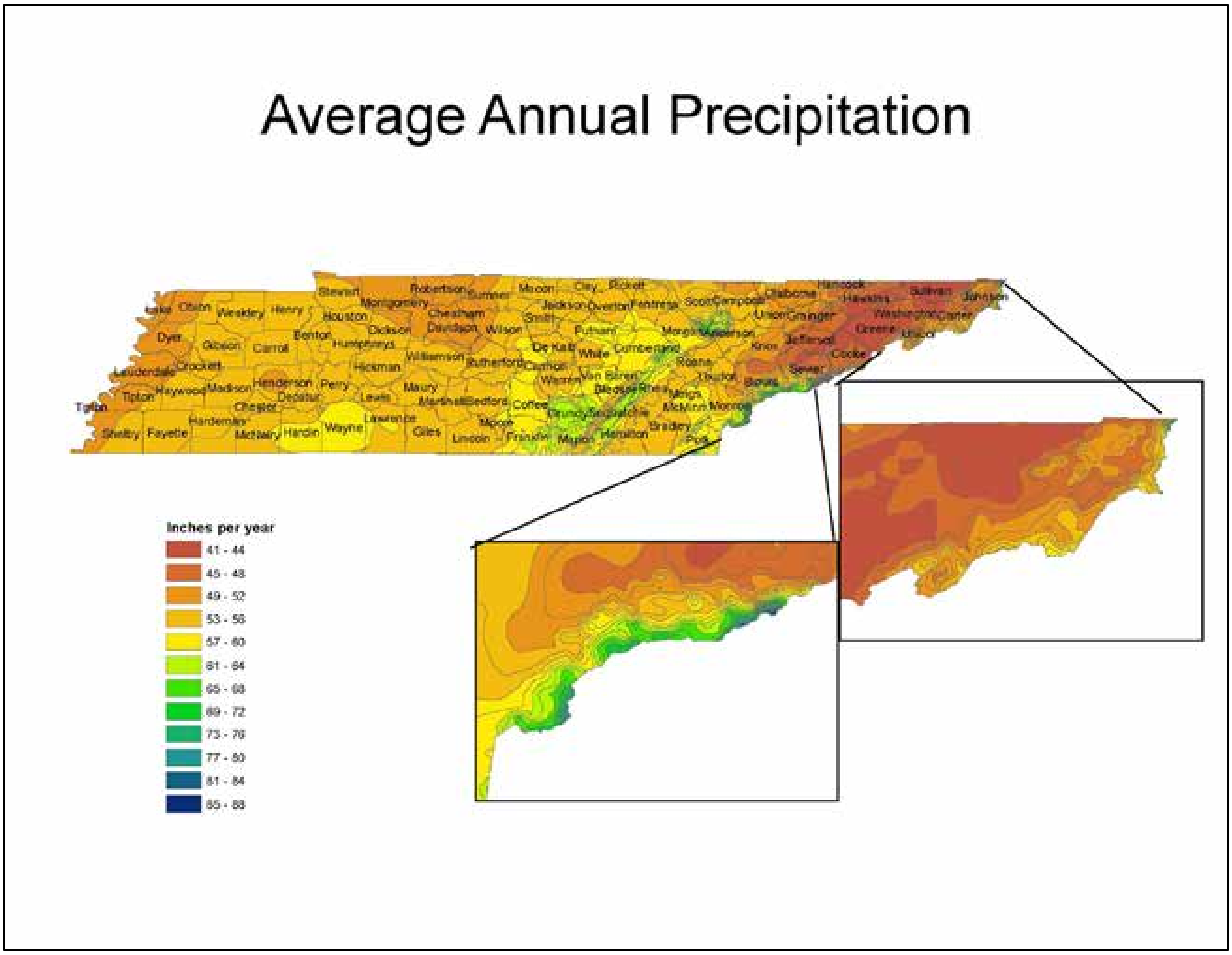


Figure 2.15 - Average Annual Precipitation, Tennessee Climatological Service (Tennessee Climatological Service, 2012).

The LRDF on site weather station measurements include wind speed and direction, rainfall, soil temperature at 15 cm depth, humidity, incident sunlight and air temperature. Instruments record data an hourly basis (Figure 2.16).

Figure 2.16 - Little River Dairy Farm Weather Station - The total annual precipitation data and mean temperatures presented in Table 2.6 are in close agreement with the averages presented by Tennessee Climatological Service and National Climatic Data Center.

Table 2.6 - LRDF Weather Station Data Summary - 2006 – 2010
Note: For 2010, 5 months of weather data was lost during transfer and conversion per Gary Honea. (Wills et al., 2005-2010) .

| 2006 | Rain (mm) | RH pct | WD 0-360$^0$ | WS mps | WS mph | Soil Temp (C) | Amb Temp (C) | Max Temp (C) | Min Temp (C) | Amb Temp (F) |
|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 3.06 | 72.2 | 161 | 1.8 | 4.1 | 15.9 | 14.55 | 21.6 | 8.4 | 58.2 |
| STD | 7.45 | 10.7 | 43 | 1.2 | 2.6 | 7.6 | 8.29 | 8.5 | 8.6 | 14.9 |
| Maximum | 68.07 | 95.6 | 261 | 7.2 | 16.1 | 28.0 | 27.77 | 36.8 | 22.3 | 82.0 |
| Minimum | 0.00 | 39.2 | 56 | 0.6 | 1.4 | 3.1 | -6.45 | 0.5 | -11.8 | 20.4 |
| Annual Total | 1117.86 | | | | | | | | | |
| | | | | | | | | | | |
| **2007** | **Rain (mm)** | **RH pct** | **WD 0-360$^0$** | **WS mps** | **WS mph** | **Soil Temp (C)** | **Amb Temp (C)** | **Max Temp (C)** | **Min Temp (C)** | **Amb Temp (F)** |
| Mean | 2.02 | 66.8 | 161 | 1.8 | 4.1 | 15.9 | 14.72 | 22.0 | 7.8 | 58.5 |
| STD | 5.58 | 10.9 | 40 | 1.1 | 2.5 | 7.6 | 8.93 | 9.6 | 9.0 | 16.1 |
| Maximum | 38.61 | 94.5 | 249 | 7.1 | 15.9 | 28.3 | 29.43 | 38.5 | 22.5 | 85.0 |
| Minimum | 0.00 | 29.8 | 61 | 0.7 | 1.6 | 1.7 | -4.53 | -2.1 | -11.9 | 23.8 |
| Annual Total | 707.63 | | | | | | | | | |
| **2008** | **Rain (mm)** | **RH pct** | **WD 0-360$^0$** | **WS mps** | **WS mph** | **Soil Temp (C)** | **Amb Temp (C)** | **Max Temp (C)** | **Min Temp (C)** | **Amb Temp (F)** |
| Mean | 2.94 | 68.7 | 162 | 1.9 | 4.3 | 15.7 | 14.02 | 20.9 | 7.3 | 57.2 |
| STD | 6.72 | 11.0 | 42 | 1.3 | 2.9 | 7.7 | 8.67 | 9.3 | 8.8 | 15.6 |
| Maximum | 40.39 | 94.5 | 266 | 6.9 | 15.5 | 27.3 | 27.47 | 34.7 | 22.1 | 81.4 |
| Minimum | 0.00 | 39.1 | 71 | 0.7 | 1.5 | 2.7 | -7.93 | -4.5 | -13.1 | 17.7 |
| Annual Total | 1076.96 | | | | | | | | | |
| | | | | | | | | | | |
| **2009** | **Rain (mm)** | **RH pct** | **WD 0-360$^0$** | **WS mps** | **WS mph** | **Soil Temp (C)** | **Amb Temp (C)** | **Max Temp (C)** | **Min Temp (C)** | **Amb Temp (F)** |
| Mean | 3.51 | 73.7 | 163 | 1.8 | 4.0 | 15.4 | 13.95 | 20.1 | 8.2 | 57.1 |
| STD | 7.91 | 11.2 | 46 | 1.2 | 2.7 | 7.8 | 8.49 | 8.7 | 9.0 | 15.3 |
| Maximum | 70.10 | 94.6 | 290 | 7.7 | 17.3 | 27.4 | 27.99 | 33.7 | 23.3 | 82.4 |
| Minimum | 0.00 | 37.4 | 45 | 0.5 | 1.1 | 1.6 | -10.36 | -5.7 | -14.3 | 13.4 |
| Annual Total | 1276.36 | | | | | | | | | |
| | | | | | | | | | | |
| **2010** | **Rain (mm)** | **RH pct** | **WD 0-360$^0$** | **WS mps** | **WS mph** | **Soil Temp (C)** | **Amb Temp (C)** | **Max Temp (C)** | **Min Temp (C)** | **Amb Temp (F)** |
| Mean | 3.19 | 73.6 | 160 | 1.3 | 2.8 | 17.4 | 15.13 | 22.4 | 9.2 | 59.2 |
| STD | 7.70 | 7.3 | 40 | 0.6 | 1.3 | 9.8 | 10.76 | 11.6 | 10.8 | 19.4 |
| Maximum | 50.29 | 93.5 | 263 | 3.9 | 8.7 | 30.1 | 29.47 | 36.8 | 24.5 | 85.0 |
| Minimum | 0.00 | 53.2 | 72 | 0.6 | 1.4 | -0.1 | -8.56 | -3.9 | -14.6 | 16.6 |
| Annual Total | 587.25 | | | | | | | | | |

## 2.7 Geology - Overview Wildwood Quadrangle

LRDF is situated in the southwestern portion of the USGS Wildwood quadrangle, about 26 kilometers south of Knoxville in eastern Tennessee. This area is largely within the Valley and Ridge physiographic province, but its southeastern corner is in the Blue Ridge province. To the southeast, Chilhowee Mountain, supported by resistant quartzite of the Chilhowee group, rises to 866 meters (2,843 feet) above sea level at the Millstone Gap Lookout Tower. By contrast, to the northwest where the rocks are less resistant sandstones, shales and limestones, only a few places exceed 426 meters (1,400 feet) in elevation. Most of this lower area is divided into small farms and is now experiencing significant urban growth. The community of Wildwood, for which the quadrangle is named, is a suburb of Maryville and Alcoa, TN, commercial and industrial centers about 6 miles to the west. Highways, paved roads, and good graded roads afford convenient access to most points in the quadrangle. The Middle Ordovician rocks in the southeastern half of the quadrangle were mapped by Robert B. Newman in 1949 as part of a comprehensive stratigraphic study. Most of the remaining area was mapped in the spring of 1955 with the assistance of A.N. Bove (Neuman R.B., 1955). The Chilhowee Mountain area was mapped in 1948 and 1947 by George Swingle of the University Of Tennessee as a part of a thesis under the over site of the Division Of Geology (Neuman, 1960).

Outcropping rocks of the Wildwood quadrangle, totaling about 5,181 meters in thickness are all of sedimentary origin. Quartzites, sandstones, and shales crop out in traceable bands, but the more soluble limestones and dolomites, particularly of the Knox group, are largely mantled by surficial material. Formations of the Knox group were identified in most places by the distinctive properties of its weathering profile (residuum), confirmed in a few places by fossils taken from outcrop. (Neuman, 1960).

Typical Appalachian bedrock structures are displayed in the quadrangle. Faults across the quadrangle were traced by John Rodgers and D.F. Kent in 1948 and 1953 (Rodgers, 1953; Rodgers and Kent, 1948). The Dumplin Valley, Guess Creek, Great Smoky, and Miller Cove faults make up the major faults and the anticline of Pea Ridge and the adjacent shallow syncline were mapped by Keith (1895) with essentially the same form as shown in the Robert B. Neuman 1960 mapping.

In the northwest corner of the quadrangle, rocks northwest of the Dumplin Valley fault lie in a syncline whose trough is broken by a reverse fault with a throw of about 600 meters. Rocks to the southeast of this fault dip steeply or are overturned, with overturning becoming more pronounced near the Dumplin Valley fault. The Dumplin Valley fault, a major dislocation of the region, ranges in dip from about 35° SE, parallel to the fault surface; the footwall is formed of gray limestone assigned to the Newala, here dipping gently northwest and cut by numerous southeast-dipping fractures, apparently strongly affected by the fault.

The Wildwood fault is considered to be a folded reverse fault with its main trace emerging along a somewhat irregular but continuous line trending northeast from the town of Wildwood, and with isolated downfolded parts on the northwest. The main trace itself is strongly folded near Providence where fold axes can be traced from footwall into hanging-wall rocks. Weaker folding affects the fault and upthrust rocks to the southwest, about a kilometer west of Eusebia Church. Elsewhere the main trace of the fault surface appears to have a steep to moderate southeast dip. The Wildwood fault developed in two stages with a portion of the overriding block became detached from the main block, and was in folded into shales of the overridden block at the same time that movement continued along the main surface. Fold structures dominate southeast of the Wildwood fault. A shallow syncline plunging gently northeast containing a narrow belt of Middle Ordovician shale is bordered on the southeast by an anticline with a similar plunge that exposes Copper Ridge dolomite in its core along Pea Ridge. The syncline is somewhat unusual for this area in that its axial plane dips steeply to the northwest whereas through most of the region axial plans dip southeastward.

On the Great Smoky fault, another major fault of the region, the Cambrian and Precambrian rocks of Chilhowee Mountain, were thrust northwestward at least 12-13 kilometers (Neuman, 1951). Fault slices derived from both the footwall and handing wall have been found in several places along the northwest face of Chilhowee Mountain. Two such slices occur in the present area; one is formed of Jonesboro limestone and presumably was derived from the footwall, and the other, formed of the Cochran formation, was derived from the hanging wall. No exposures of the Great Smoky fault surface were found in the Wildwood quadrangle, but dips of 30° to 40° SE were calculated from its mapped trace on the topography. Within the Wildwood quadrangle, beds above the Great Smoky fault dip somewhat more steeply than the fault along Chilhowee Mountain and, in the eastern part of the quadrangle, seem to have a more easterly strike.

## 2.8 Geology - Site

The Little River Dairy Farm (LRDF) floodplain deposits rest on the Blockhouse and Tellico Formation shales, Lenoir Formation and Knox Group dolostones in the floodplain portion of the property. Upland portions of the site are underlain by in-situ derived saprolitic soils over shale deposits of variable thickness in the upland portions of the site. The bedrock contact between the shale, limestone and dolostone strikes in a northeast/southwest line and is located under the northwestern portion of the property. Descriptions of the Longview Dolomite, Newala Limestone, Lenoir Limestone, Blockhouse Shale and Tellico Shale follows from (Neuman, 1960) (Figure 2.17). A geologic cross-section Figure 2.18 from Neuman 1960 outlines the location of the karst activity along the Newala/Lenoir Limestone contact zone. The sinkhole in the photo was excavated, lined with a synthetic liner then filled in with layers of crushed rock during 2012.

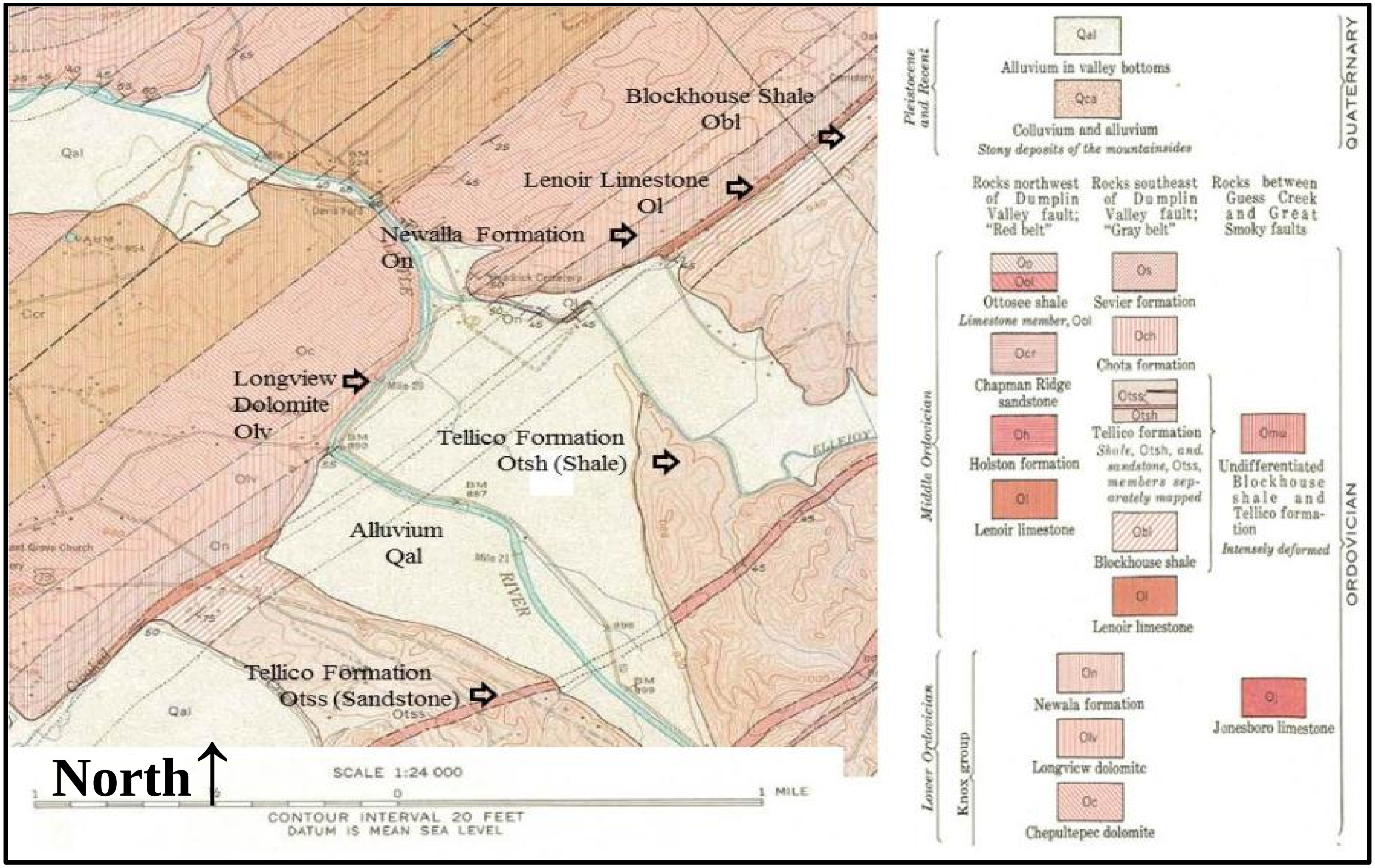


Figure 2.17 - Geologic Units of the Little River Dairy Farm, Geology of the Wildwood Quadrangle (Modified from Neuman 1960)

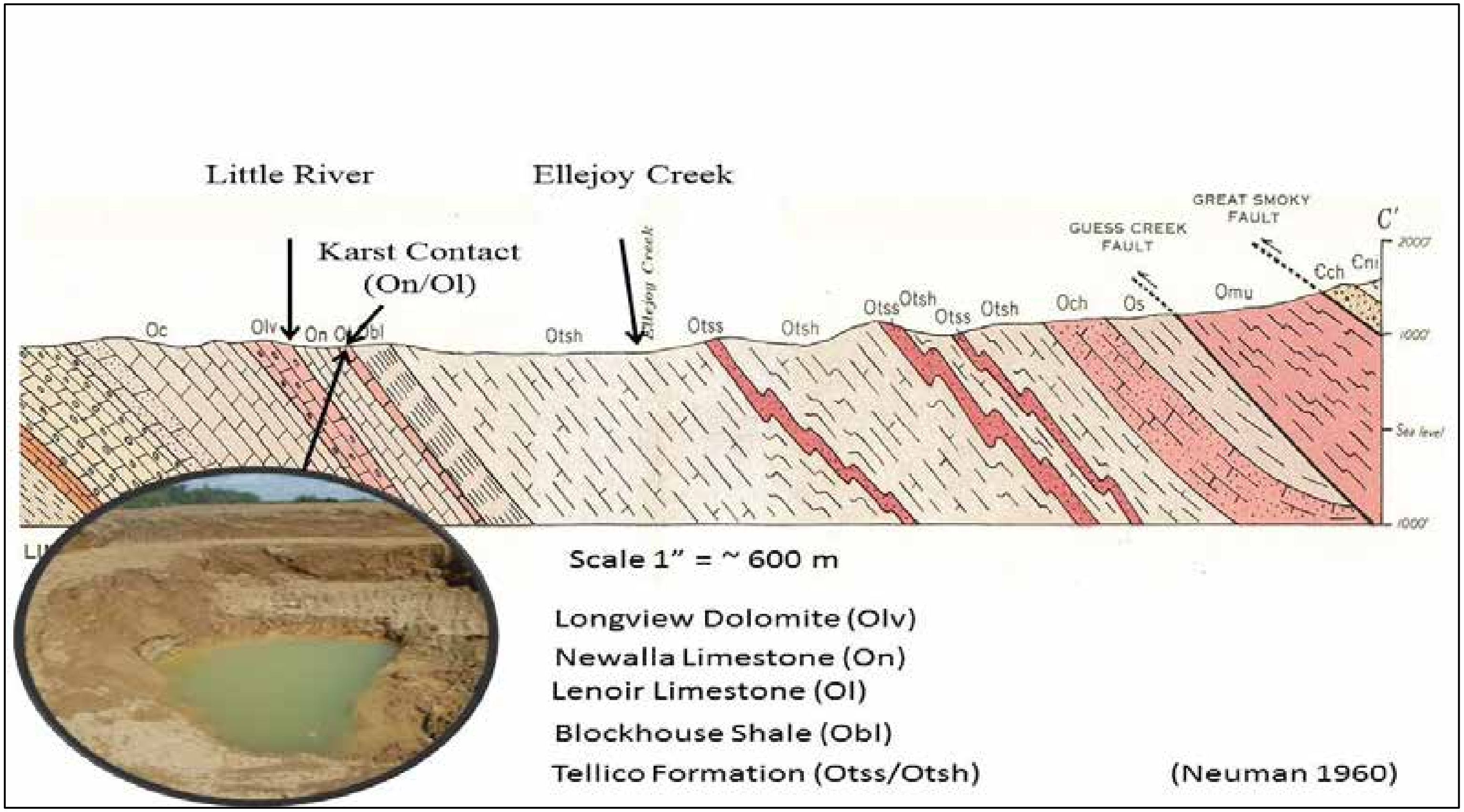


Figure 2.18 - Geologic Cross-section from Neuman 1960 showing the location of the karst activity along the Newala/Lenoir Limestone contact zone. The sinkhole was excavated, lined with a synthetic liner then filled in multi-layered stone sequences.

The floodplain alluvium consists of near-surface sediment of terrace colluvium and alluvial floodplain deposits laid down by past meanders and floods of the Little River and Ellejoy Creek, and underlying residuum derived from *in situ* decomposed bedrock. The overburden ranges from 3 to 9 meters in thickness (confirmed by core drilling) and is Quaternary in age. Neuman, (1960) describes the alluvium bottoms as follows: "Broad, flat-surfaced flood plains beside the major streams through most of their courses in the area are formed of layered, unconsolidated deposits of sand, silt, and clay. An Ellejoy Creek deposit about 2 meters thick consists of pale gray, yellow and brownish-yellow, partly mottled clay, silt and fine sand resting on upturned beds of Tellico (Shale) that have been altered to saprolite. The base of the alluvium is commonly exposed in adjoin stream beds; maximum thickness of the alluvium determined from the height of stream banks is about 4-5 meters near the confluence of Ellejoy Creek and the Little River. A break in slope marks the boundary between alluvial deposits and colluvium of the adjacent hillsides, and in some places colluvial debris appears to overlap alluvium which is the case at LRDF. Thus, the material incorporated in the alluvium was apparently derived from slopes adjacent to present streams as well as from slopes in the headwater areas (Neuman, 1960).

The Longview dolomite (Olv) is 120 to 150 meters thick as mapped and consists of gray fine to coarse-grained dolomite with distinctive weathered chert which characterizes the Longview dolomite. The chert is generally white and porcellaneous, with abundant casts of small dolomite rhombs. In outcrop, chert occurs as irregular masses and nodules in dolomite rather than as beds; however, in a few places ledges of chert project from the residuum with the same strike and dip of nearby bedrock and appear to represent local concentrations. Dolomite beds are 15 to 45 centimeters thick, commonly massive and featureless, but some coarse-grained beds show faint mottling, and a few very fine grained beds are evenly laminated. The coarse-grained rock has been interpreted to be the product of recrystallization (Bridge, 1955 ). Criteria for locating the boundary between the Longview and the overlying Newala are few and indistinct, based on the highest stratigraphic appearance of the characteristic Longview chert, verified in a few places by outcrops of the more distinctive Newala formation.

In the Wildwood quadrangle, the Newala Formation (On) consists of sparsely cherty dolomite and limestone. Medium- to course- grained dolomite forms most of the lower part. Weathered surfaces are intricately mottled in some beds, but others are more massive. Greenish shale in thin partings between some beds aids in distinguishing these dolomites from those of the Longview. Higher in the formation in the position of the Mascot dolomite, light-gray fine-grained limestone, much of which is marked by thin argillaceous partings, is interbedded with evenly laminated fine-grained dolomite. Sandy limestone as much as 3 meters (10 feet) thick occurs in this part of the formation; the sand grains are generally larger and better rounded than those of the Chelpultepec. A disconformity at the top of the Newala formation is clearly indicated at several places by fragmental rocks at the base of the overlying Lenoir limestone. Relief on this disconformity may be responsible for the variable thickness of the Newala which ranges from 150 to 200 meters.

Lenoir limestone (Ol) is characterized as a nodular, argillaceous, gray fine grained limestone and in places basal sedimentary breccia, conglomerate and quartz sandstone. Outcrops are visible at LRDF both on the Little River and Ellejoy Creek. The most notable exposure is located on Ellejoy Creek where contact with the Newala formation cause a 90 degree turn in the creek. At Ellejoy baseflow, the Lenoir is exposed and visible for approximately 200 meters along the creek (Figure 2.19). On the Little River, the Lenoir outcrop is exposed approximately 150 meters east (upstream) of the Ellejoy Road Bridge along the contacts of the Newala Formation and the Blockhouse Shale.

Figure 2.19 - Lenoir limestone outcropping along strike at baseflow conditions on Ellejoy Creek, LRDF.

The Blockhouse shale is described as dark-gray fissile finely laminated shale with an argillaceous limestone at the base that is known as the Whitesburg limestone member. The main body of this shale is characterized by the lack of sand and silt along with the fine laminations. Whitesburg is about 3 meters thick while the entire Blockhouse unit is approximately 150 meters thick. Contact boundaries are readily visible in the Little River adjacent to the site during base flow.

The Tellico formation contains two distinct units. The Tellico shale (Otsh) is known as a calcareous shale, medium gray, silty or sandy with irregular laminations and coarser fissility than the Blockhouse shale. The Tellico sandstone (Otss) is described as fine to medium grained, gray in color and commonly feldspathic sometimes forming thin beds separated by shale partings. The Tellico formation is approximately 1,375 meters thick.

### 2.9 Soils

In the fall of 2006, the UT Extension Soil, Plant and Pest Center conducted detailed soil survey of the Little River Dairy Farm for incorporation into the University of Tennessee Little River Animal Agriculture Environmental Research Unit Comprehensive Nutrient Management Plan (CNMP), (Burns, 2010a). Analytical results from the soil samples are published in the CNMP. In 2007, the USDA Natural Resources Conservation Service (NRCS) provided the results of a custom soil survey for the farm. This report was also made a part of the CNMP and a summary of this report is provided below.

The farm soils are divided into fourteen (14) series types. The alluvial floodplain group accounts for ~ 52.7 % of the coverage area on the farm. Alluvial soil series are: Etowah (Ee), Hamblen (Hb), Prader (Pc), Sequatchie (sub-series Sc & Sd), Strasser (sub-series Sk & Sl), and

Whitwell (We). Three predominant textures are present in the alluvium: silt loam, fine sandy loam, and loam. Infiltration rates (Ksat) for the alluvial soils range from 1.52 cm/hr to 5.08 cm/hr. Figure 2.20 shows a soil fertility map of the alluvium. Table 2.7 provides a legend description for the soil fertility map.

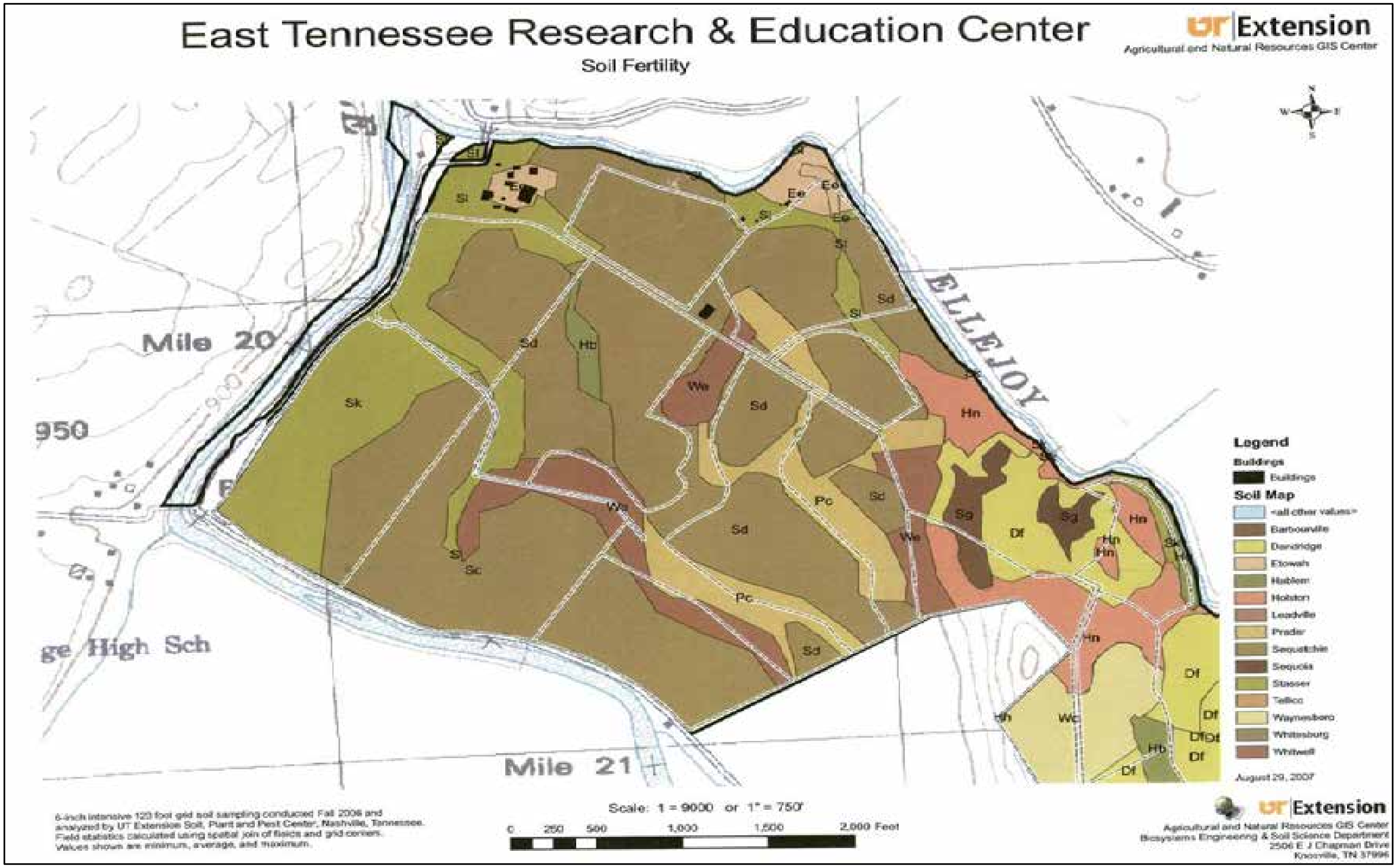
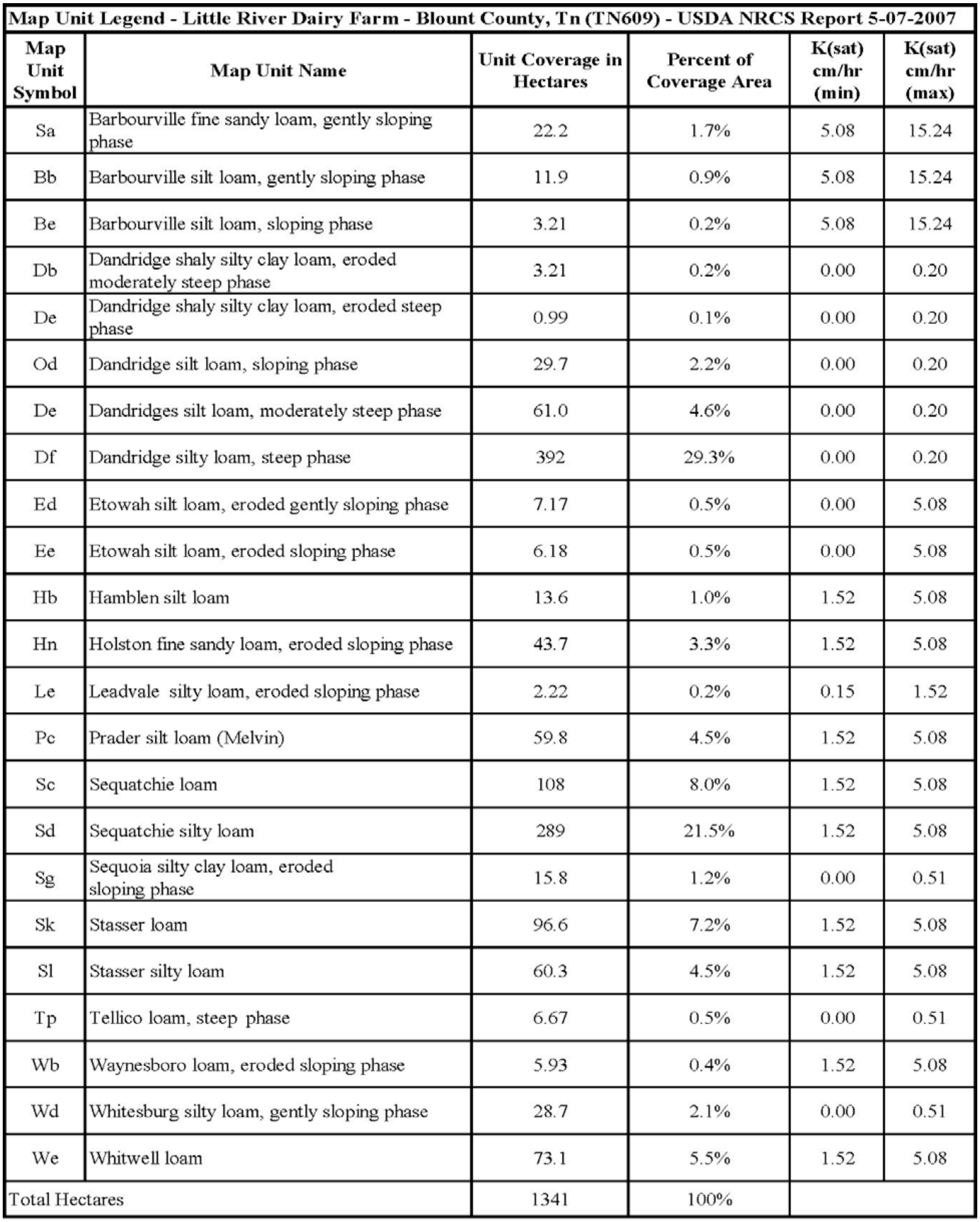


Figure 2.20 – Little River Dairy Farm – Soil Fertility Map (UT Agricultural and Natural Resources GIS Center, 2007).

Table 2.7 – Soil Fertility Map Unit Legend.  (Adapted from USDA, NRCS Report)(Burns, 2010a).



**Map Unit Legend - Little River Dairy Farm - Blount County, Tn (TN609) - USDA NRCS Report 5-07-2007**

| Map Unit Symbol | Map Unit Name | Unit Coverage in Hectares | Percent of Coverage Area | K(sat) cm/hr (min) | K(sat) cm/hr (max) |
|---|---|---|---|---|---|
| Sa | Barbourville fine sandy loam, gently sloping phase | 22.2 | 1.7% | 5.08 | 15.24 |
| Bb | Barbourville silt loam, gently sloping phase | 11.9 | 0.9% | 5.08 | 15.24 |
| Be | Barbourville silt loam, sloping phase | 3.21 | 0.2% | 5.08 | 15.24 |
| Db | Dandridge shaly silty clay loam, eroded moderately steep phase | 3.21 | 0.2% | 0.00 | 0.20 |
| De | Dandridge shaly silty clay loam, eroded steep phase | 0.99 | 0.1% | 0.00 | 0.20 |
| Od | Dandridge silt loam, sloping phase | 29.7 | 2.2% | 0.00 | 0.20 |
| De | Dandridges silt loam, moderately steep phase | 61.0 | 4.6% | 0.00 | 0.20 |
| Df | Dandridge silty loam, steep phase | 392 | 29.3% | 0.00 | 0.20 |
| Ed | Etowah silt loam, eroded gently sloping phase | 7.17 | 0.5% | 0.00 | 5.08 |
| Ee | Etowah silt loam, eroded sloping phase | 6.18 | 0.5% | 0.00 | 5.08 |
| Hb | Hamblen silt loam | 13.6 | 1.0% | 1.52 | 5.08 |
| Hn | Holston fine sandy loam, eroded sloping phase | 43.7 | 3.3% | 1.52 | 5.08 |
| Le | Leadvale  silty loam, eroded sloping phase | 2.22 | 0.2% | 0.15 | 1.52 |
| Pc | Prader silt loam (Melvin) | 59.8 | 4.5% | 1.52 | 5.08 |
| Sc | Sequatchie loam | 108 | 8.0% | 1.52 | 5.08 |
| Sd | Sequatchie silty loam | 289 | 21.5% | 1.52 | 5.08 |
| Sg | Sequoia silty clay loam, eroded sloping phase | 15.8 | 1.2% | 0.00 | 0.51 |
| Sk | Stasser loam | 96.6 | 7.2% | 1.52 | 5.08 |
| Sl | Stasser silty loam | 60.3 | 4.5% | 1.52 | 5.08 |
| Tp | Tellico loam, steep  phase | 6.67 | 0.5% | 0.00 | 0.51 |
| Wb | Waynesboro loam, eroded sloping phase | 5.93 | 0.4% | 1.52 | 5.08 |
| Wd | Whitesburg silty loam, gently sloping phase | 28.7 | 2.1% | 0.00 | 0.51 |
| We | Whitwell loam | 73.1 | 5.5% | 1.52 | 5.08 |
| Total Hectares |  | 1341 | 100% |  |  |

## 2.10 Summary

In cooperation with the University of Tennessee Agricultural Institute and AgResearch, the UT Earth and Planetary Department has developed of an integrated hydrogeologic/ hydrologic site assessment and groundwater/surface water quality monitoring program at the University of Tennessee – Little River Dairy Farm, located near Townsend, Tennessee, USA. The dairy was completed in late 2011 and in the summer of 2012 operates with 150 cows and 200 for full operation. Hydrologic/hydrogeologic investigations of streams and groundwater at the site have been underway for more than 4 years, and these are providing background sampling data using *E. coli* and a suite of nutrients to help assess impacts of dairy wastes and for testing the effectiveness of different management practices. The lower half of the ~180 ha site consists of low-relief fields used for row crops, which are underlain by 4 – 8 m of alluvial deposits (mainly medium to fine-grained sands interbedded with silt) on top of middle Ordovician black shale, limestone, and dolomite. Active sinkholes are present in the vicinity of a limestone/dolomite contact zone. The site is bounded on two sides by the Little River, a popular recreational river, and on the third side by Ellejoy Creek, which is on the state's 303(d) list for impairment by nutrients, sediment, and fecal microorganisms derived from upstream agricultural and rural residential development. Fields will be fertilized with treated dairy wastes and are the main area of concern for offsite migration of contaminants through groundwater, drainage ditches, and (eventually) a tile drain system. A secondary area of concern is the dairy waste treatment pond, located near the dairy barns on the upland portion of the site, underlain by 1-2 m of clay-rich residual soils developed on fractured shale bedrock. The monitoring program was recently expanded to include selected bovine pathogens at points of entry to, and exit from, the dairy farm property.

# CHAPTER 3 – HYDROGEOLOGY AND WATER QUALITY MONITORING IN THE ALLUVIAL FLOODPLAIN

## 3.1 – Introduction

This chapter describes physical hydrogeologic characteristics of sedimentary deposits in the LRDF alluvial floodplain, as well as development of conceptual models for groundwater flow, including discharges to ditches and streams in the floodplain. The chapter also provides background data on groundwater quality prior to the start of dairy operation and some preliminary data on the impact of manure spreading on groundwater quality. The study incorporates some preliminary data from monitoring wells installed as a part of Geology 586 Field and Lab Methods in Hydrogeology class projects (Donat et al., 2007; Hunter et al., 2009) as well as data collected for this thesis. The influence of karst sinkholes along a limestone-dolomite contact located on the northwest side of the property is also included in the hydrostratigraphic flow systems overview.

Groundwater quality data in the chapter was collected intermittently over the period from 2009 – 2012. Dairy operations at the site started in November 2011 and the herd is expected to grow for several more years, to a full design capacity of approximately 250 cows. As a result, the water quality data presented here covers only the preliminary site development and impacts of dairy operations. The monitoring program was designed so that it could continue for a decade or more and could be used to assess long term impacts on water quality. It can also be used for testing management methods to reduce impacts of dairy wastes on groundwater and surface water.

## 3.2 Methods

### 3.2.1 Statistics

Statistics for many of the physical or water quality parameters were calculated using Microsoft Excel 2010 Data Analysis “Descriptive Statistics” function. The reported statistics in many cases include the mean, median, mode, standard deviation, sample variance, kurtosis, skewness, range, minimum, maximum, and count. The *mean* is the arithmetic average of the data. The *median* is the value for which 50 percent of the values are greater and 50 percent are less. The *mode* is the value that occurs most frequently in the dataset. The data set has no *mode* if there are no values that appear more frequently than others. The *standard deviation* is the square root of the sample variance that indicates the spread of the values in a dataset about the mean, and is reported in the same units as the values in the dataset. The *sample variance* is calculated assuming that the sample mean is the expected value by computing the average of the sum of the squared differences between each sample value and the mean of all values. *Kurtosis* is a statistical measure of the shape or “peakedness” of the distribution of the values. A large kurtosis value indicates that most of the values surround the mean, and the tails of the distribution are small, with the opposite being true for a small kurtosis value. *Skewness* is a measure of the asymmetry of the sample distribution and can be positive or negative. The sign of the skewness relates to the direction of the asymmetry (a negative value indicates more values are far less than the mean, with the opposite being true for a positive value). If the tail of the distribution is far to the left of the mean, the median would typically be less than the mean. Skewness close to zero implies a symmetric distribution. The *range* accounts for the dispersion of the data. The *maximum* is the largest value, the *minimum* is the smallest value, and the range is the absolute difference between them. The *count* is the total number of values used to calculate the statistics. (Davis, 2002)

### 3.2.2 Boreholes and Well Installation

Test boreholes were drilled at 10 sites (Figure 3.1) in the floodplain in 2007 using a direct-push coring method by contractor S&ME, Inc., formerly Soil & Material Engineers, Inc. Cores were collected, examined and stored in 1.2 meter clear plastic tubes for use in the characterization of sediments and future tests (Donat et al., 2007). Boring logs based on visual sediment descriptions at 0.31 m intervals logs were recorded and are included in Appendix A. These boring logs and cores were used in the selection of monitoring well locations and for particle size analyses described later in this chapter. The visual descriptions tended to overestimate the content of silt and clay, so revised logs (based on grain size analysis) are presented later in this chapter. The test holes were sealed with bentonite after sampling was complete.

A hollow stem auger rig was used to install the monitoring wells in the unconsolidated overburden material in November 2009. Samples of the cuttings were collected for textural analysis as they were carried to the surface. After the auger reached the top of the planned well screened interval well depth, a split-spoon sampler was used to collect a 0.76 m long by 0.08 m diameter sample of the geologic material (soil, sediment or residuum) located at the depth of the screened interval of the well. This sample was described and bagged for later analysis. The well casing was placed in the borehole and a 0.05 m diameter polyvinyl chloride (PVC) pipe was used for the well casing and the screened interval. The 0.45 m long PVC screen (slot size 1.5 – 5.4

mm) was capped on the bottom end and connected to the well casing by a threaded joint. Coarse-grained sand was added to the borehole to create a filter pack around the screened interval. The filter pack extended to a minimum of 0.3 m above the screened interval. The sand filter pack was sealed above the screened interval with approximately 0.9 meters of bentonite chips that were tamped for compaction. The remainder of each bore hole was filled with a cement grout from the top of the bentonite layer to ground surface and completed with flush-mounted steel caps. The water-tight caps were needed to prevent surface water run-off from entering the wells.

Well development was performed using 1 liter plastic bailers, dropped into the well and manually raised and lowered for 1 hour to force water into and out of the well screen to help remove fine sediments. In addition, the wells were pumped from 1 – 4 hours to further remove fine sediments from the sand pack and well screen as recommended by U.S EPA (Aller and Bennett, 1991). All wells were developed using these methods over the course of two weeks during February 2010. Well development was considered complete when the pump discharge was visually clear. See Figure 3.2 for monitoring well locations and Table 3.1 for a description of the alluvial well characteristics.

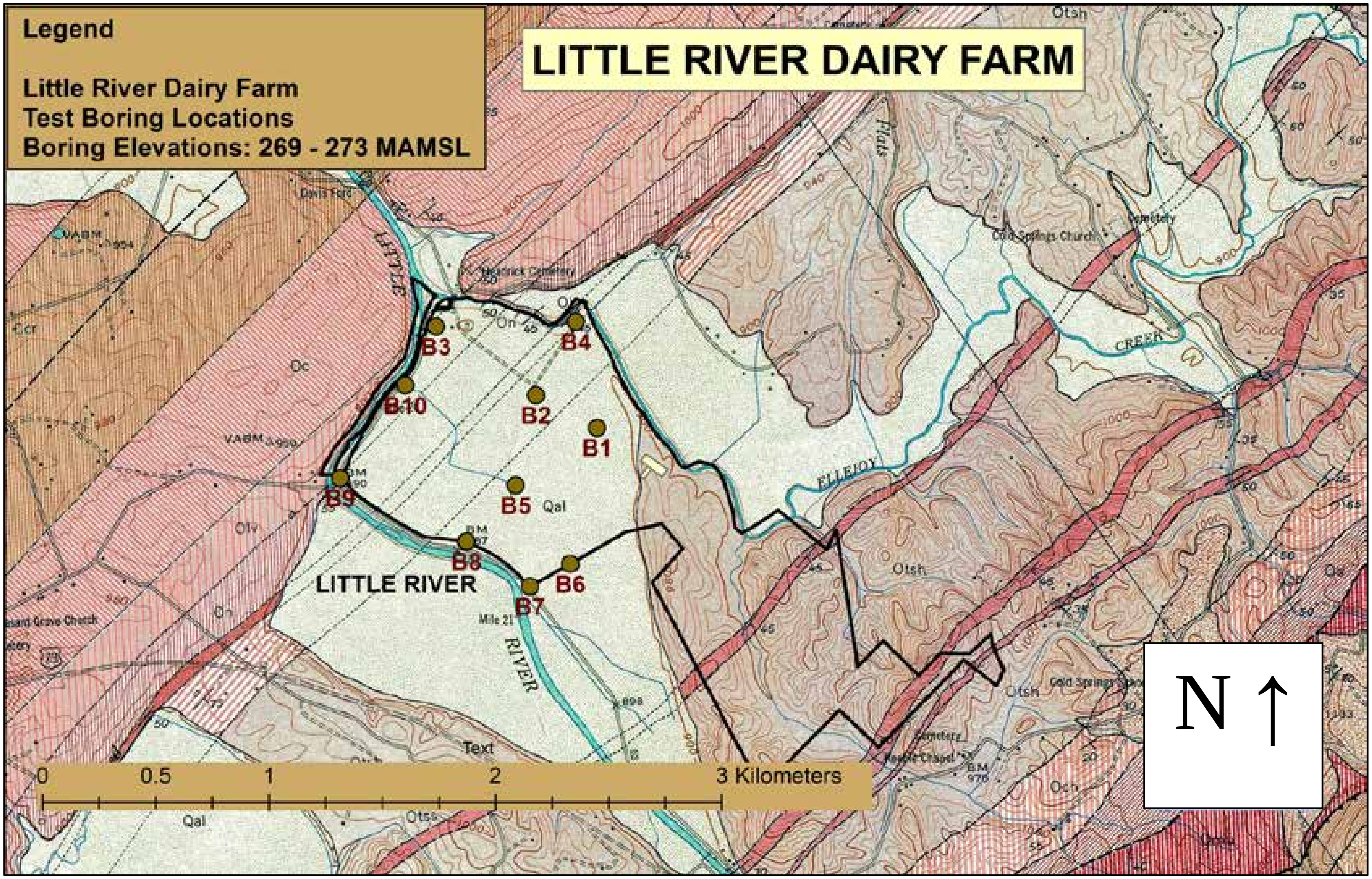


Figure 3.1 - Test Boring Locations LRDF Superimposed on Bedrock and Alluvial geology map (Hunter, 2013; Neuman, 1960).

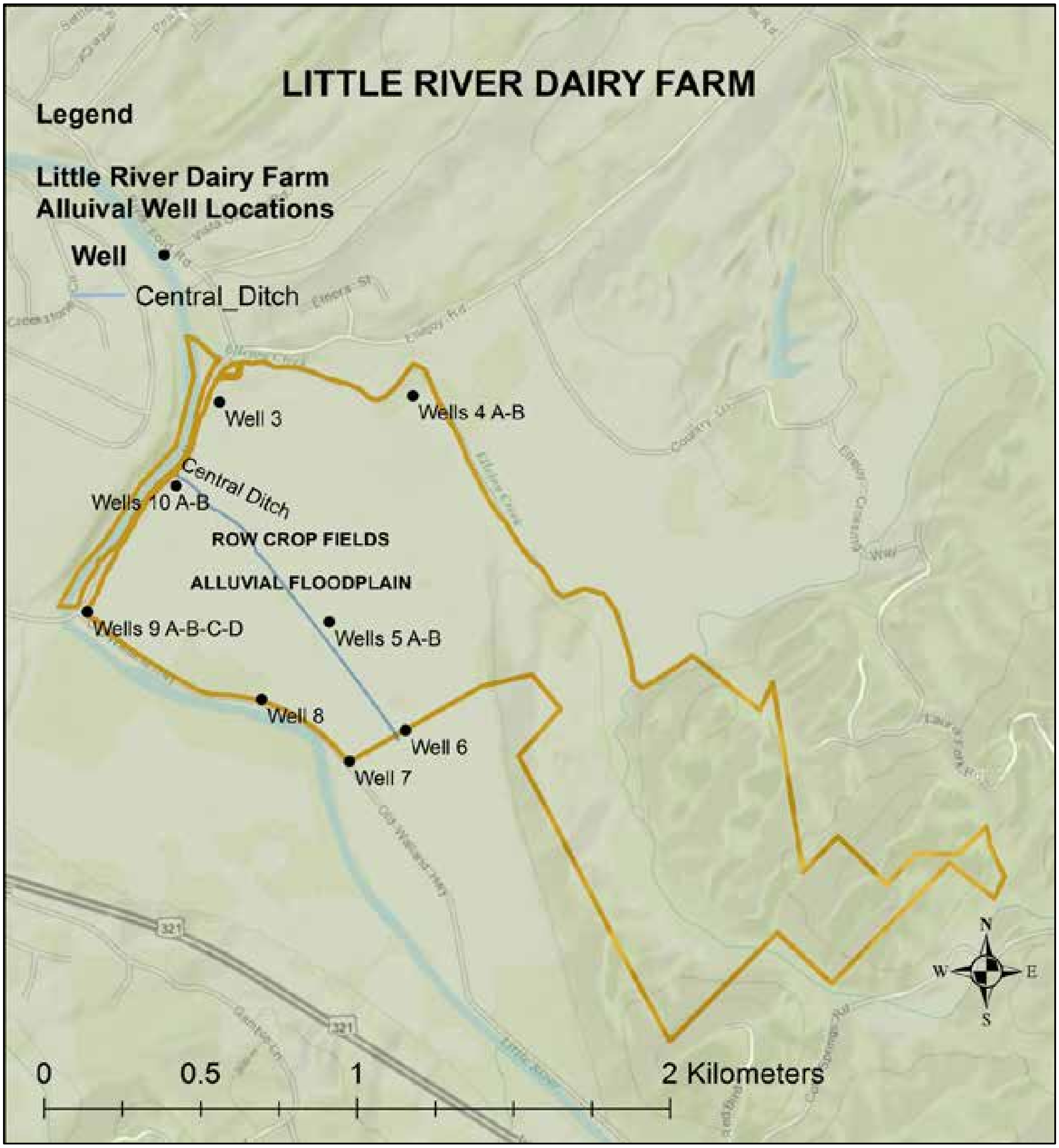


Figure 3.2 - Well locations in the alluvial floodplain at the Little River Dairy Farm.

Table 3.1 Description of the alluvial well characteristics and geologic materials at the well screened intervals.

| **Well #** | **Elevation (m)** | **Latitude (Northing)** | **Longitude (Easting)** | **Depth to Water (m)** | **Screen Depth Bottom (m)** | **Screen Depth Top (m)** | **Sand Pack Depth Bottom (m)** | **Sand Pack Depth Top (m)** | **Geologic material at screened interval and Split Spoon (SS)** |
|---|---|---|---|---|---|---|---|---|---|
| Well 1 | *Not Drilled* | | | | | | | | |
| Well 2 | 272.6323 | 529700.52 | 2607432.68 | 2.4 | 2.4 | 1.7 | 2.4 | 1.4 | Sandy SILT w/gravel |
| Well 3 | 269.1826 | 530696.46 | 2605985.96 | Dry | 3.2 | 2.4 | 3.2 | 1.8 | Medium to Coarse sands w/some gravel |
| Well 4a | 272.3044 | 530764.23 | 2608012.86 | Dry | 2.4 | 1.7 | 2.4 | 1.4 | Fine to Coarse sands w/some gravel |
| Well 4b | 272.2672 | 530767.24 | 2608014.77 | 4.6 | 7.0 | 6.2 | 7.0 | 5.8 | Fine to Coarse sands w/some gravel |
| Well 5a | 271.2613 | 528393.74 | 2607135.71 | 1.0 | 2.6 | 1.8 | 2.6 | 1.8 | SILT w/gravel |
| Well 5b | 271.3345 | 528395.87 | 2607139.65 | 1.1 | 4.0 | 3.2 | 4.0 | 3.0 | Fine sand, silt |
| Well 6 | 271.8258 | 527255.30 | 2607931.46 | 2.5 | 2.6 | 1.8 | 2.6 | 1.2 | Silty, Fine Sand |
| Well 7 | 272.5497 | 526930.64 | 2607346.37 | Dry | 2.4 | 1.7 | 2.4 | 1.4 | GRAVEL w/silt |
| Well 8 | 272.1724 | 527581.59 | 2606426.64 | 3.4 | 4.6 | 3.8 | 4.6 | 3.0 | Abundant gravel, fine to coarse sand |
| Well 9a | 271.2083 | 528497.75 | 2604596.25 | Dry | 2.4 | 1.7 | 2.4 | 1.4 | Fine to medium sand |
| Well 9b | 271.2062 | 528496.89 | 2604600.60 | Dry | 4.1 | 3.4 | 4.1 | 3.0 | Sandy SILT w/cobbles |
| Well 9c | 271.1784 | 528496.82 | 2604605.05 | 6.1 | 6.7 | 5.9 | 6.7 | 5.5 | Fine to Coarse sands w/ gravel |
| Well 9d | 271.172 | 528495.58 | 2604609.92 | 6.1 | 8.5 | 7.8 | 8.5 | 7.0 | Fine to coarse sand w/ gravel, some silt |
| Well 10a | 267.1374 | 529819.35 | 2605531.12 | Dry | 2.4 | 1.7 | 2.4 | 1.4 | SILT w/abundant gravel |
| Well 10b | 269.4719 | 529844.04 | 2605539.90 | 3.4 | 5.2 | 4.4 | 5.2 | 4.3 | SILTY/Fine sand |

### 3.2.3 Characterization of Sediments – Grainsize Distribution

Dry sieve tests were performed on 77 samples from 10 borehole cores collected in 1.2 meter intervals during the 2007 investigations. Dry sieve tests were also performed on 10 split spoon samples collected from the screened intervals of the monitoring wells. The samples were processed following the methods described Gee and Or (2002). Sieve sizes included US Sieve series No. 2 – 12.00 mm, No. 4 - 4.75 mm, No. 5 - 4.00 mm, No. 7 - 2.83 mm, No. 10 - 2.0 mm, No. 14 - 1.41 mm, No. 18 – 1.00 mm, No. 35 - 0.50 mm, No. 60 - 0.25 mm, No. 140 - 0.105 mm, and No. 270 - 0.053 mm (Gee and Or, 2002). The soils were not pretreated for the removal of organics for the dry sieve analyses.

Grainsize distributions of fine sands, silts and clay were evaluated using an ASTM No. 1, 152H Type hydrometer test with a Bouyoucos scale in g/L. The tests were carried out at room temperature (~ 20-21° C) and corrections were calculated empirically (ASTM, 2007) with a particle density of 2.65 $g/cm^3$ assumed. Eighteen composite samples from each boring and each well screened interval were processed for the hydrometer tests. To arrive at a composite sample, the < 1 mm size fraction from each sample was placed on a paper then divided into four equal quadrants. A random sample (~ 10 grams) from each quadrant was placed in aluminum foil pan and weighed to yield a sample (~40.0 grams). Next, using a 300 mesh (< 0.0476 mm) sieve each composite of < 1mm material was wet sieved. The material from the 300 mesh wet sieve was placed in a new foil pan and filled to approximately 10.0 grams. The pans were then oven dried at $105^0$ C for 24 hours for further processing.

Each hydrometer test sample was placed in a glass beaker under an exhaust hood to remove any remaining organics attached to grains of sediment. Thirty percent (30%) hydrogen peroxide was added in 5-10 ml increments every 1-2 hours until all of the organics were removed which was determined when the hydrogen peroxide no longer reacted with the sediment grains. Next, each sample was dispersed using a mechanical shaker for 16 hours with a known volume (100 – 200 ml) of sodium hexametaphosphate. The sample was then quantitatively measured by weight and placed in a 1 liter glass cylinder filled with deionized water. An equal amount of sodium hexametaphosphate was added to the container along with the sample and left for a minimum of 2 hours to equilibrate at room temperature. The test period ran for 24 hours with hydrometer, and temperature measurements recorded at 10s, 30s, and then 1, 3, 10, 30, 60, 120 and 1440 minutes then particle size was determine accordingly. Particle size results are presented in Section 3.10.

### 3.2.4 Hydraulic Conductivity Estimates from Grainsize Distribution

Estimates of hydraulic conductivity (K) based on grainsize distribution were determined using the Hazen Method (Hazen, 1892) and the Shepherd Method (Shepherd, 1989). The hydraulic conductivity value determined with the Hazen Method ($K_{Hazen}$) was calculated using

$$\mathrm{K}_{Hazen} = cD_{10}^{2} \qquad (1)$$

where $K_{Hazen}$ is expressed in cm/sec, c is a constant that varies from 1.0 to 1.5, according to sediment type and $D_{10}$ is the soil particle diameter (mm) such that 10% of all soil particles are finer by weight.

Hydraulic conductivity from grainsize was also estimated using the Shepherd Method (Shepherd, 1989) for unconsolidated sediments

$$K_{\text{Shepherd}} = cD_{50(mm)}{}^{1.65\ to\ 1.85} \quad (2),$$

where K $_{\text{Shepherd}}$ is expressed in cm/sec, the exponent is an empirical value that varies with sediment type from 1.11 to 2.05 with an average value of 1.72 noting that the value of "*c*" is most often between 0.05 and 1.18 (Shepherd, 1989). Percent finer values from the well screened interval grainsize analysis were used for $D_{10}$ (mm) in the $K_{\text{Hazen}}$ method and percent finer values for $D_{60}$ were used in the K $_{\text{Shepherd}}$ method. Hydraulic conductivities for $K_{\text{Hazen}}$ and $K_{\text{Shepherd}}$ are reported in m/s.

### 3.2.5 Hydraulic Conductivity Measurements – Slug Tests

During 2009 - 2011 slug tests were performed on the following wells: 2, 4b, 5a, 5b, 8, 9c, 9d and 10b to determine a value for local-scale horizontal hydraulic conductivity. A slug of water of known volume was quickly removed from each well, then recovery was monitored over time until the water level in the well reached or nearly reached the original ground water level (Hyder et al., 1994). Wells 3, 4a, 7, 9a, 9b and 10a were dry at the time of testing, so slug tests were not carried out.

Slug test data was analyzed using the Hvorslev method (Hvorslev, 1951) , which assumes a homogeneous, isotropic, infinite porous medium where both water and soil are incompressible. The method may be used for a confined or unconfined aquifer (Repa and Kufs, 1985). The equation for the Hvorslev method is expressed by:

$$K_{Slug} = \frac{r^2 \ln\left(\frac{L}{R}\right)}{2LT_0}$$

Where $K_{\mathrm{Slug}}$ is the hydraulic conductivity, *L* is the length of the screened interval, *r* is the inner radius of the well casing, *R* is the radius of the filter pack surrounding the screened portion of the casing, and $T_0$ is determined graphically based on the time needed to reach 37% recovery on a semi-logarithmic graph of displacement (DH) verses time.

### 3.2.6 Hydraulic Conductivity Measurements - Pumping Tests

Pumping tests were performed to provide a larger scale measure of hydraulic conductivity and to determine well yields for water quality sampling. Pumping tests were carried out in the LRDF floodplain alluvial wells using a battery powered submersible pump (Typhoon, Groundwater Essentials, LLC.) or a Grundfos submersible pump powered by a portable generator. Both pump types are capable of achieving the low flow rate (typically 0.25 – 6.0 L/min) necessary for a constant discharge pumping test of short duration (2 - 12 hour) in the alluvial sediments found at LRDF. Limiting factors on pump test performance at LRDF are the seasonally variable water levels, equipment failure and restricted output due to well and screen size. These tests estimated important aquifer parameters including hydraulic conductivity ($K_{\mathrm{Pump}}$), transmissivity (T). The tests were also very valuable for determining sustainable pumping rates for the water quality sampling program.

The pump test data was analyzed using the Cooper & Jacob 1946 method. The Cooper & Jacob method is widely used by hydrogeologists for determining preliminary estimates of T and K in confined or unconfined aquifers. If the data from an observation well is available, a value of S can also be determined. Storativity cannot be calculated in single pumped well because there is not an “r “ value.

### 3.2.7 Water Level Monitoring – Hydrographs

Water level monitoring data from observation wells are the primary source of information on seasonal or short term variations in the hydrology of the flood plain sediments. Long term systematic monitoring can provide essential data needed to evaluate change in groundwater recharge, hydraulic gradients and in aquifer storage.

Solinst® Junior 3001 leveloggers were installed in all LRDF alluvial wells in August of 2010. This transducer has a range of 10 m with accuracy of 0.05 centimeters at full scale and a battery life of 5 years. Since January 2011, the leveloggers were rotated to different locations based on the immediate needs for tests and experiments. Continuous monitoring of all wells during the term of the thesis was not practical as a result the limited number of leveloggers available. Selected hydrographs (water level displacement plotted against time) are presented and described in the results section. Loggers were installed in wells to a depth at or near the bottom of the screened interval. They were secured to the well cap using monofilament fishing line.

All wells are flush mounted, with water-tight caps prohibiting well venting; therefore, measured head values are a function of both the hydraulic head in the aquifer around the well screen and the barometric pressure. Because the water table is near the ground surface and the wells are shallow (most of the sediments are < 5m thick and all are < 10m), the influence of changes barometric pressure was expected to be negligible (Butler et al., 2011; Freeze and Cherry, 1979; Hubbell et al., 2004). The frequency of water level measurements varied based on the test or experiment being evaluated. Frequencies ranged from one (1) measurement per second to one (1) measurement every ten (10) minutes. In each case, time series were adjusted to seconds, minutes or days when calculating displacement and graphing results.

Groundwater flow from the LRDF is expected to discharge into the Little River or its tributaries. Hence, comparison of groundwater head and river stage can be useful. Stage monitoring on the Little River commenced in January of 2011. Prior to this date, stage was estimated using the USGS Gauge (Little River @ Maryville) located at the intersection of US 411 and the Little River approximately 4 km downstream from LRDF. Stage data from is available at http://water.weather.gov/ahps2/hydrograph.php?wfo=mrx&gage=myvt1. A Global Water, WL16, Water Level Datalogger, and submersible pressure transducer combination designed for remote monitoring and recording of water level or pressure data was installed in 0.30m PVC pipe and secured to a large tree on the Little River bank centered between Wells 9abcd and Well 10b. This logger records 81,000 readings and has four unique recording options, fast (10 samples per second), programmable interval (1 second to multiple years), logarithmic, and exception (custom). Multiple depth ranges are available from 1 to 150 meters of water level change. A 7.5 meter vented cable is standard on the water level loggers. The unit was powered by two internal 9 Volt DC Alkaline batteries that typically power the Water Level Loggers for approximately one year even if one of the batteries fails. Data downloads were enhanced by a third lithium battery as a backup battery. The 9 Volt lithium battery life at LRDF is estimated at 8 months. This unit was on loan from Dr. Keil Neff of UT Civil and Environmental Engineering department and was removed from the monitoring location in the fall of 2012 for use at another site.

### 3.2.8 Water Sampling

Water quality sampling in the LRDF alluvial wells began in November 2009. A groundwater sampling plan was developed with the overall goal to collect water samples with minimal alteration of the groundwater chemistry and to protect against cross contamination of water samples once the dairy was operational. A secondary goal was to develop a program that could be carried out by one individual while meeting minimum analyte or assay holding times and taking into consideration laboratory staff hours. Meeting the second goal sometimes proved elusive due to the size of the site and distance between monitoring wells. To address the logistical site problems, a four wheel drive ATV and a light weight trailer were used to maneuver around the site during sampling events. Another factor that impacted well sampling was variation in seasonal weather conditions, which often contributed to low water table conditions in the wells or saturated field conditions that limited access to wells. During times of insufficient water levels in a particular well, the well was not sampled. Inability of the laboratory to consistently test samples with the recommended sample hold times also affected the quality of sampling data. This was due to constraints of lab operating hours, temporary lab equipment failure, or water quality lab work load. The samples most affected by these conditions were coliform and *E. coli* results. These samples were, more often than not, held overnight and processed. This was beyond the EPA recommended 6 hour hold times, despite extensive efforts to deliver the samples in the hold time window.

The construction of the monitoring well system was consistent with EPA protocols for low flow sampling as discussed in Section 3.2. Two primary types of submersible pumps were used from one sampling event to another. These were the same pumps used for hydraulic conductivity tests described in Section 3.6. A battery powered Proactive Typhoon Low Flow engineered submersible pumping system and a Grundfos Redi-Flo Variable Frequency Drive ground water monitoring well pump were both used for water quality monitoring. Each pump is designed to pump 0.25 - 6 liters per minute or more depending on head loss. The electric pump is powered by a heavy duty 12 volt battery while the Grundfos Redi-Flo pump is powered by gasoline portable generator system. The battery powered submersible pumps were most effective for alluvial well sampling runs, owing to the quick setup and take down times. The Grundfos variable drive pump was most effective for conducting longer duration pump tests that required constant low flow rate pumping.

Sampling monitoring wells in the unconsolidated alluvium required trial and error to initially determine the ideal flow rates needed to achieve a satisfactory sample from each well. Early on, bailers were used to sample the alluvial wells. Sampling procedures changed over the course of the thesis to incorporate more rigorous sampling protocols and control measures to prevent cross-contamination of the wells by the sampling equipment once the dairy was in operation. Prior to dairy operations, pumps and hose assemblies were cleaned in the field using a 10% bleach solution that was recycled through the pump and hose for several minutes then rinsed using deionized water. This process was conducted again after 3 sampling events for each well. Once dairy operations commenced, the pumps and hose assemblies were cleaned in the field then kept in heavy duty plastic garbage bags while being transported between wells to decrease the possibility of well contamination from liquid manure applied to the fields where the wells were located. In addition, the hose assemblies were changed more frequently along with the bleach and deionized water rinsing process.

A monthly sampling schedule was set in advance with the lab manager and a copy was provided to the farm manager. The lab manager was contacted a few days prior to the scheduled sampling event to confirm lab availability and to coordinate sample drop off times. When the samples were ready to be transported from the field to the laboratory, the lab manager was contacted to provide notice of sample arrival time. Pumps, controllers, hose, water level tapes, pH/conductivity meters, extension cords, generators, batteries, battery charger, stocked tool box, bailers, twine, sterile sampling bottles, clean cooler, latex gloves, etc. were organized in the field equipment room or onsite at LRDF at least one day prior to sampling. Once loaded and on the site, the farm manager was contacted as a reminder and courtesy. Site conditions often dictated the starting point for the sampling day.

The initial sampling round was carried out in November of 2009 using plastic 1 liter bailers for wells 2, 4b, 5b, 6, 8, 9c, 9d, and 10b. Prior to sampling each event, well water volumes were calculated based on the well dimensions and water level to determine purging volumes prior to taking the sample. Flow rates using the submersible pumps were controlled with a flow regulator fixed to the end of the pump hose. Flow rates ranged from 0.25 L/min to 3.0 L/min and varied seasonally for each well. Three well volumes were typically purged using a bailer or submersible electric pump prior to collecting a sample. The well discharge was collected in a 19 liter plastic bucket until the appropriate purge volume was reached then the sample was collected in a 1 liter sterile container and placed in an iced cooler for transport to the lab. Typically, wells 3, 4a, 7, 8, 9a, 9b and 10a were not sampled because they were either dry or too slow to recharge on the sampling date. All samples were placed on ice or in refrigerated storage until transferred to the College of Agriculture and Natural Resource’s Water Quality Laboratory located in BESS for analysis.

### 3.2.9 Water Quality Testing

Water Quality Testing was conducted at the College of Agriculture and Natural Resource's Water Quality Laboratory located in Suite 302, Biosystems Engineering and Soil Sciences Office Building, 2506 E J Chapman Drive, Knoxville, TN 37996 under the direction of Galina Melnichenko, (Lab Manager).

Two sets of samples were delivered to the lab: one set for chemical analysis and the other for *E. coli* and total coliform assays. The samples for chemical analysis for each well were stored in 1 liter sterile polyethylene containers and the samples for *E. coli* samples were stored in 100 ml glass containers. The containers were sequentially numbered (1-10) for each particular well. Blind blanks were randomly included in these samples in the form of bottled drinking water or a duplicate sample from at least one random well. Blind blanks for *E. coli* consisted of bottled drinking water only.

Lab procedures and controls for sample processing began with lab manager's daily preparation of standards based on EPA methods for each analyte for each sampling run. Next, ten samples were run consisting of a blank, a standard and a sample for each analyte or assay. Sampling results were reported in parts per million (ppm) in an Excel™ spreadsheet.

Analyses for chloride, nitrate, nitrite and sulfates were carried out using a Dionex 100 IC, ion chromatographic system following the EPA Method 300.1 protocol.

Analyses for phosphorus was carried out by a Semi-Automated Colorimetric following Method 365.1 and the determination of total phosphorus was carried out by a Colorimetric, Automated, Block Digester AA II Auto Analyzer for total phosphorus determination following EPA Method 365.4 protocol.

Analyses for total Kjeldahl nitrogen was carried out using Skalar, automated spectrophotometer and Semi-automated colorimetry following EPA Method 351.2 protocol (EPA, 1993).

Analyses for TOC were carried out using a Shimadzu TOC-V cph analyzer. The methods and instruments used in measuring TOC analyze fractions of total carbon (TC) and measure TOC by two or more determinations. These fractions of total carbon are defined as: inorganic carbon (IC) - the carbonate, bicarbonate, and dissolved $CO_2$; total organic carbon (TOC) - all carbon atoms covalently bonded in organic molecules; dissolved organic carbon (DOC) - the fraction of TOC that passes through a 0.45 - µm - pore-diameter filter; particulate organic carbon (POC) - also referred to as nondissolved organic carbon, the fraction of TOC retained by a 0.45-µm filter; volatile organic carbon (VOC) - also referred to as purgeable organic carbon, the fraction of TOC removed from an aqueous solution by gas stripping under specified conditions; and nonpurgeable organic carbon (NPOC) - the fraction of TOC not removed by gas stripping. In most water samples, the IC fraction is many times greater than the TOC fraction. Eliminating or compensating for IC interferences requires multiple determinations to measure true TOC. IC interference can be eliminated by acidifying samples to pH 2 or less to convert IC species to $CO_2$. Subsequently, purging the sample with a purified gas removes the $CO_2$ by volatilization. Sample purging also removes POC so that the organic carbon measurement made after eliminating IC interferences is actually a NPOC determination; determine VOC to measure true TOC. In many surface and ground waters the VOC contribution to TOC is negligible. Therefore, in practice, the NPOC determination is substituted for TOC (Standard Methods, 1996).

Analyses for total coliform and *E. coli* were carried out using the Colilert assay (IDEXX Laboratories, Inc.) Samples were collected in sterile100 ml glass containers, placed in a cooler of ice which was transported to the lab for processing. All samples were delivered to the laboratory within the 6 hour hold time limit. Colilert reagent was added to the 100 ml samples which were shaken by hand until all visible reagents were removed. The solution was poured into a 200 count Quanti-Tray, sealed and placed in an incubator at 35° C for 24 hours. Results for Total Coliform and *E. coli* were reported as most probable number (MPN) per 100 colony forming units (CFU). The 100 ml glass sample containers were washed with soap and water then rinsed with a 10% HCL solution and placed in a muffle oven incubate for 24 hours. Every attempt was made to deliver the samples within the 6 hour hold time. However, instances occurred where the samples were placed in refrigerated storage overnight before processing. On November 3, 2011 Well 5b was tested for *E. Coli* and total coliforms by an experienced technician from the UT Center for Environmental Biotechnology (CEB). The sampling procedure was different from the other tests because the sample was collected after 200 L of pumping for a study on viruses in groundwater (Borchardt, personal communication). The sample was tested for E coli and total coliform using the Colilert method and was processed within the 6 hour hold time.

## 3.3 Results and Discussion

### 3.3.1 General Characteristics and Features of the Little River Floodplain

The floodplain sediments at LRDF range in thickness from 3 to 9 m and are composed of 70 – 85% medium to fine grained sands with 10 to 30% silt, a trace of clay and occasional gravel layers. The sediments were deposited largely by avulsion (diversion) and as overbank floodplain deposits of the Little River as it meandered across the floodplain over the past 2 million years (Quaternary Period), (Leopold and Wolman, 1960; Neuman, 1960; Slingerland and Smith, 2004; Wolman and Leopold, 1957). Ellejoy Creek likely played a minor role in the development of and deposition of the floodplain sediments.

Below Townsend, TN, the Little River is classified as an anabranching river that consists of multiple channels separated by semi-permanent alluvial islands. These islands may be formed within the channel or cut from the existing floodplains. Avulsions are a major source of wetlands and a dominant mechanism in the construction of river floodplains and their associated sedimentary deposits (Nanson and Knighton, 1996; Slingerland and Smith, 2004). The sediments are generally massive to faintly layered. Some distinct, but thin, silt and very fine sand layers (typically < 10 cm thick) are interspersed throughout the floodplain sediments. The continuity of these layers could not be determined. The sediments are often slightly to moderately cohesive, especially in areas with high silt content. This led previous student investigations (Geology 586 Class 2007) to erroneously classify some of the sediments as clays, which is not the case. Gravel-sized sediments were observed in all 10 core samples drilled by the Geology 586 Class in 2007 and in many cases gravel occurred as thin layers in a sandy matrix. However, distinct gravel rich layers typically ranging from 0.3 to 1.0 m in thickness were encountered in about half of the boreholes. The thickest gravel layer (about 3.0 m thick) was encountered in Borehole 9, near where the Little River makes a 90° turn towards the Northeast. An extensive gravel layer (0.5 to 2.0 m thick) was observed along the central ditch which flows northwest until it enters the Little River near Well 10. This gravel layer extends for several hundred meters, or more, and includes rounded cobbles up to 0.3 m in diameter (see Figure 3.3-3.4).

Figure 3.3 Gravel and surface rock exposed by the recent excavation of the central ditch area. This area stretches for several hundred meters. Photo shows an area between wells 6 and 5ab.

Figure 3.4 – Example of a gravel layer in the floodplain alluvium at LRDF.  Note the faint layering in silty sand above the gravel layer.

The Longview Dolomite, Lenoir and Newala limestones are the most chemically soluble rocks on the farm and are subject to the fastest weathering rates.  These dolostones and limestones are known sources of sinkholes, caves and similar karst features across the Ridge and Valley Province.  Evidence of this karst activity on the farm is noted on Figures 3.5 - 3.7.  The larger sinkhole (10 m length X 5 m width X 6 m depth) located in the southwest section of the farm was filled by farm staff in 2012 while two (2) smaller sinkholes (~ 8 m length X 3 m width X 1 m depth) have not been filled (see Figure 3.7).

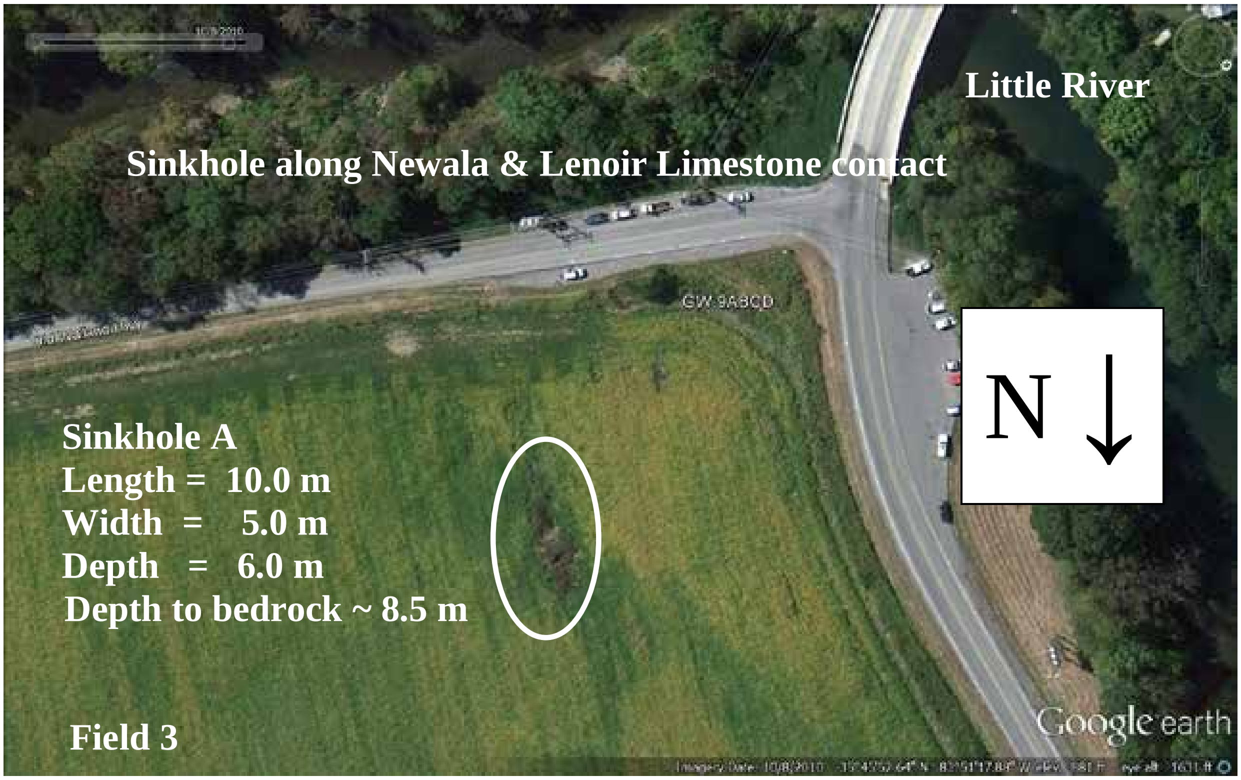


Figure 3.5 – Sinkhole (A) activity Field 3 Little River Dairy Farm. During 2010 -2012 the sinkhole expanded from 3.6 X 4.5 X 2.0 meters (L X W X D) to 9.0 X 9.0 X 5.5 meters. In late 2012, this sinkhole series was excavated to bedrock, lined with a geotextile liner and filled with rip-rap which included progressively smaller stone sizes (See Figure 3.6) (Image 10-8-2010 Google earth®.

Figure 3.6 –Rock and stone used for filling sinkhole.

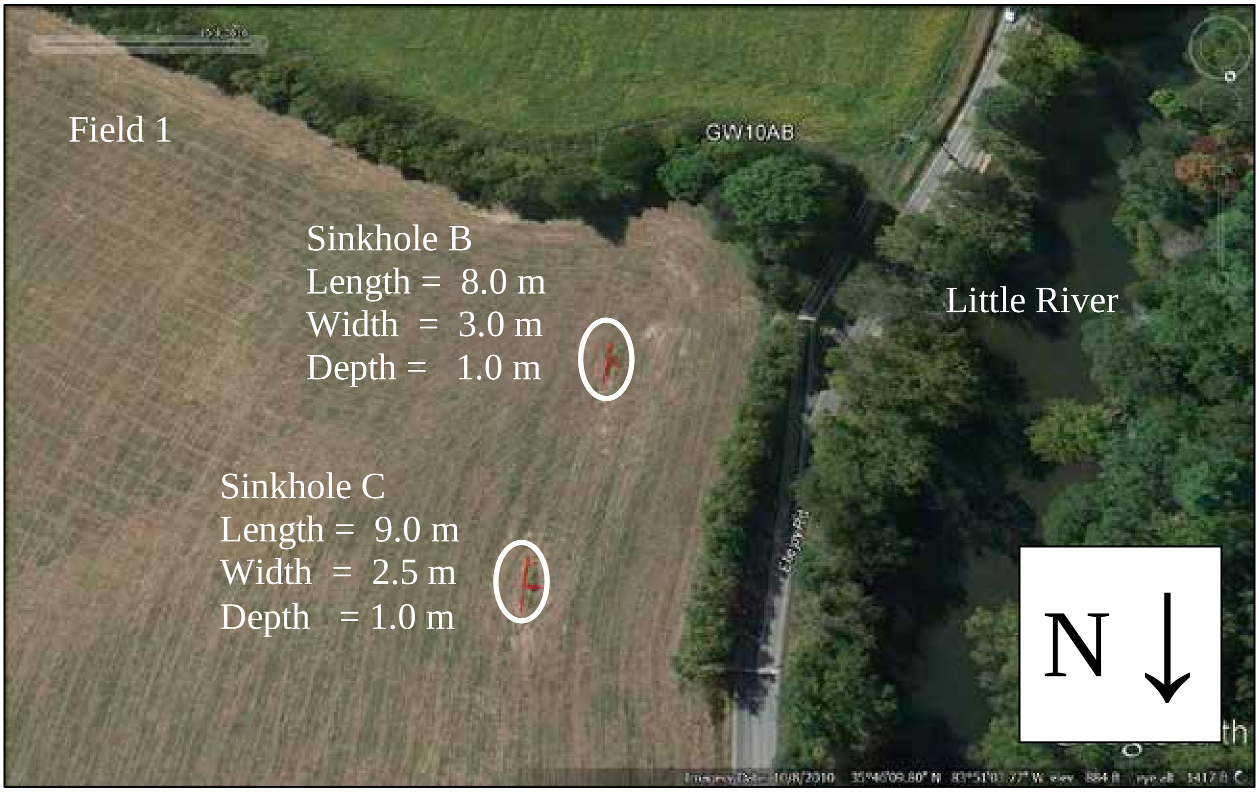


Figure 3.7 - Minor Sinkholes along Newala/Lenoir Limestone contact located in Field 1. Google earth® historical images indicate sinkholes B & C developed between January 2007 to September 2008. Sinkholes B & C have not expanded substantially in 2011-2012, based on Google earth® imagery.

### 3.3.2 Grainsize Distributions for the Floodplain Sediments

Grainsize distribution curves determined using dry sieving for 10 alluvial well splitspoon samples located at the screened interval for each well are shown on Figure 3.8. Nine of the samples tested were very similar, 12 – 45% were fine sands, 28 – 67% medium sands and 30 – 82% coarse sands. The shape of the grainsize curves indicates the alluvial sediments are poorly sorted. Excel descriptive statistics function was used to provide a statistical summary of the $D_{10}$, $D_{30}$, $D_{50}$ and $D_{60}$ grainsizes. The findings (Table 3.2) indicate an arithmetic mean for $D_{10}$ of 0.06 mm with a standard deviation of 0.02. The $D_{30}$ grainsize arithmetic mean was 0.19 mm with a standard deviation of 0.08. $D_{50}$ and $D_{60}$ mean values were 0.45 mm and 0.72 mm respectively. Figure 3.9 provides a histogram for $D_{10}$ (mm) grainsize distributions for all well screened intervals (n=10) indicating 70% of the well screened intervals have $D_{10}$ grainsizes between 0.05 – 0.07 mm. Mean $D_{10}$ grainsize for the well screened intervals was 0.06 mm indicating very fine sand.

Examples of grainsize distributions from different depths within single boreholes are shown in Figures 3.10 and 3.11. The example for Boring 6 (figure 3.10) shows a fine to medium grain sand some silt.

Many pieces of gravel and cobbles greater than 2 mm were also interspersed in samples in Boring 6, but were not included in the grainsize measurements. Figure 3.11 depicts grainsize distribution curves for Boring 9 including 13 curves representing 0.3 – 0.6 meter intervals. Figure 3.12 represent the USDA Grainsize Classification of $D_{10}$ particle size for all borings by depth. This figure shows little variability for the $D_{10}$ grainsize fraction between the borings by depth at LRDF. Grainsize was plotted against depth using the $D_{10}$, $D_{30}$ and $D_{60}$ fractions to determine any sediment layering patterns that may exist at a given boring depth.  The grainsize distribution data do not indicate layers that are continuous between wells.  Gravelly layers are a possible exception to this, but they were not reflected in the < 2 mm fraction.  Figure 3.12 shows the $D_{50}$ sediments for all borings by depth.  All grainsize distribution curves for borings and wells are outlined in Appendix B.

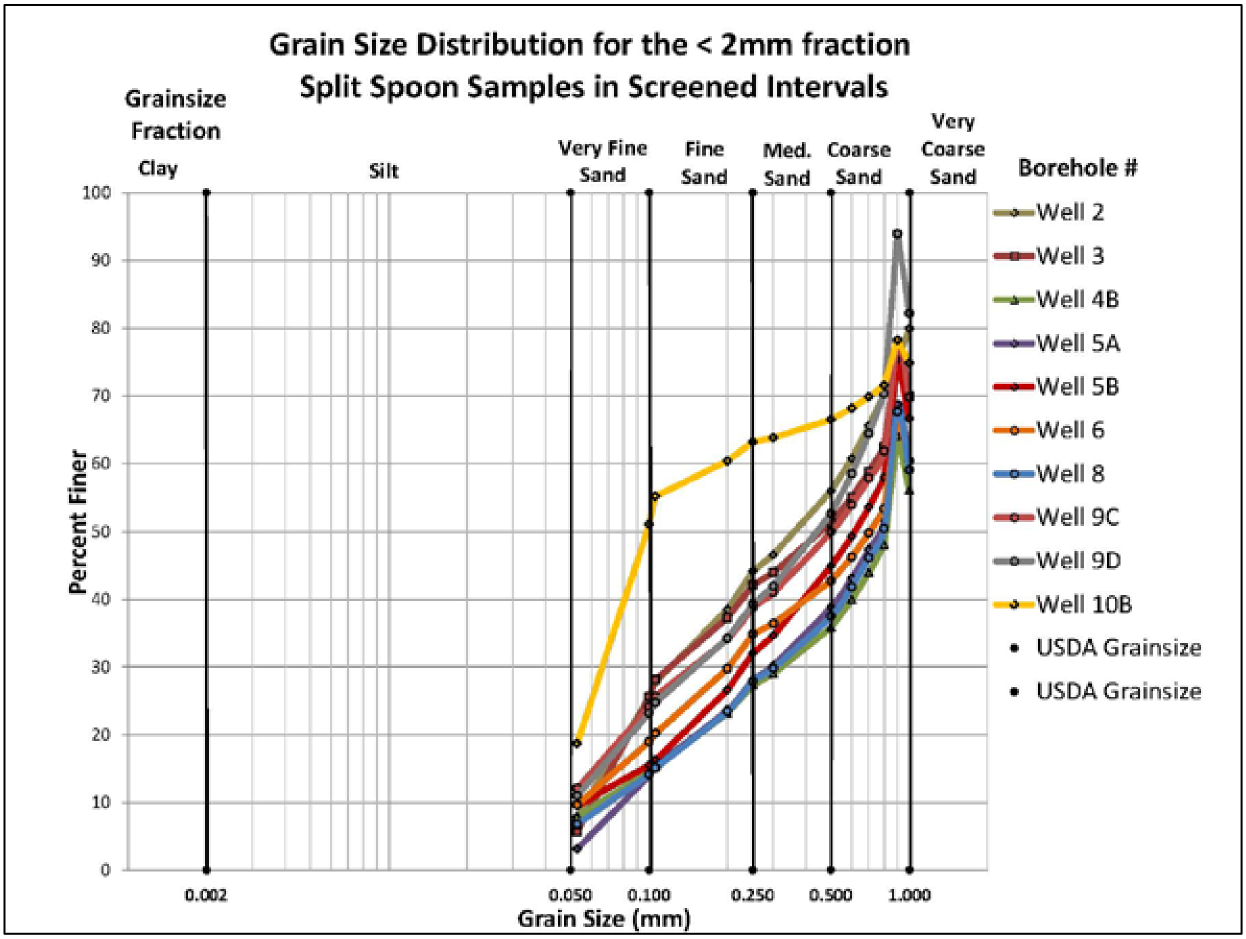


Figure 3.8 - Grainsize distribution curves determined by dry sieving for the split spoon samples from the well screened intervals. Note the similarity in grainsize distribution for all wells, except well 10B, which was screened in a very fine sand layer.

Table 3.2- Split spoon samples from Well Screened Intervals - Grainsize statistics for $D_{10}$, $D_{30}$, $D_{50}$ and $D_{60}$ grainsizes reporting the mean grainsize, standard error, median grainsize, standard deviation, sample variance and maximum and minimum grainsizes. Units are reported in mm. These data are consistent with typical alluvial floodplain deposits from overbank, debris flow and channel deposits made up of, silty sand and sands (Fogg et al., 1998).

| **Grainsize Statistics Well Screen Intervals** | **$D_{10}$ (mm)** | **$D_{30}$ (mm)** | **$D_{50}$ (mm)** | **$D_{60}$ (mm)** |
|---|---|---|---|---|
| | | | | |
| Mean | 0.06 | 0.19 | 0.45 | 0.72 |
| Standard Error | 0.01 | 0.03 | 0.03 | 0.06 |
| Median | 0.06 | 0.18 | 0.43 | 0.78 |
| Mode | 0.07 | 0.30 | 0.40 | 0.85 |
| Standard Deviation | 0.02 | 0.08 | 0.10 | 0.20 |
| Sample Variance | 0.00 | 0.01 | 0.01 | 0.04 |
| Kurtosis | -0.53 | -1.55 | -0.55 | 5.19 |
| Skewness | 0.09 | 0.20 | -0.05 | -2.17 |
| Range | 0.06 | 0.23 | 0.33 | 0.65 |
| Minimum | 0.04 | 0.08 | 0.27 | 0.20 |
| Maximum | 0.09 | 0.30 | 0.60 | 0.85 |
| Sum | 0.61 | 1.95 | 4.45 | 7.15 |
| Count | 10 | 10 | 10 | 10 |

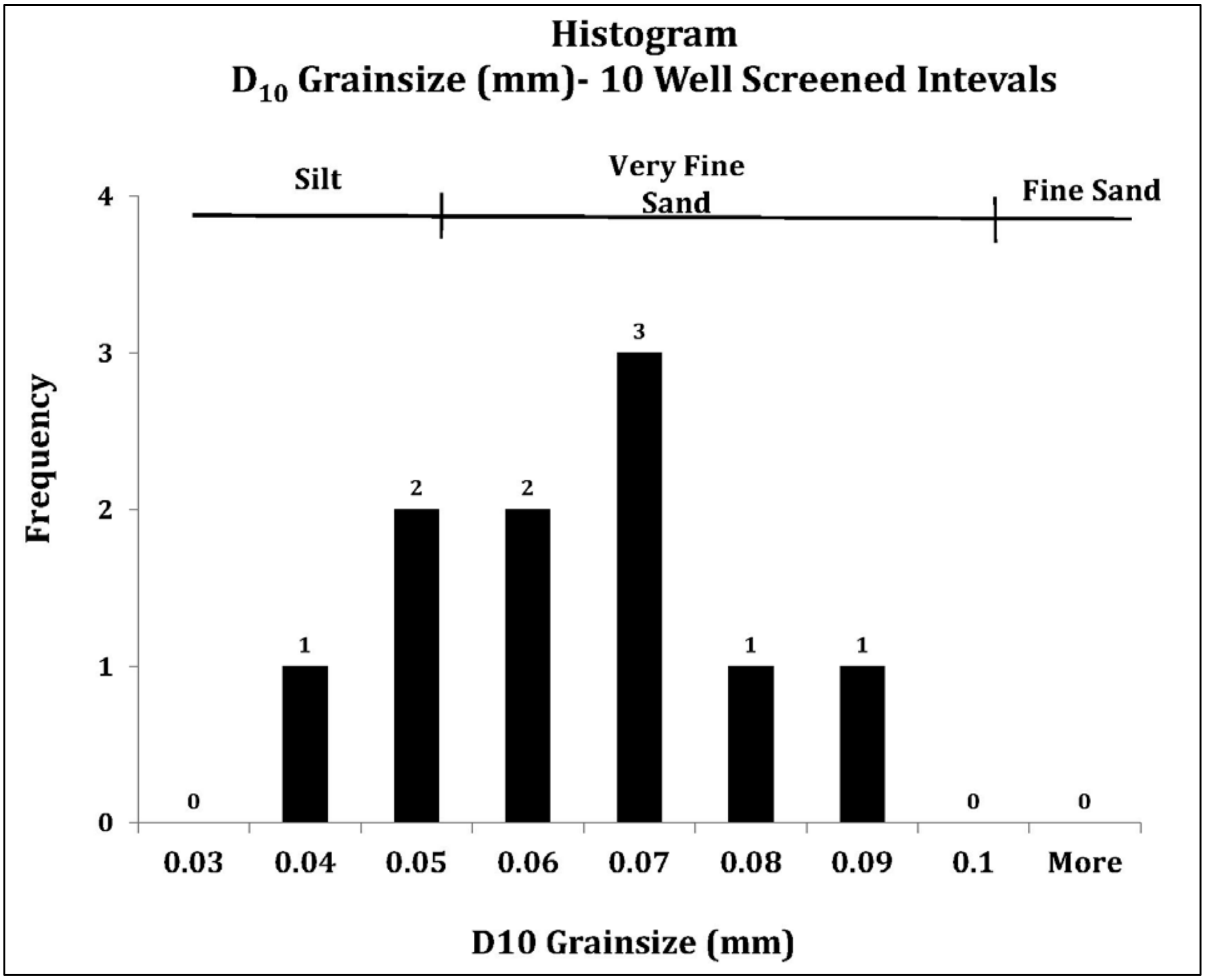


Figure 3.9 - Histogram for $D_{10}$ (mm) grainsize distributions for all well screened intervals (n =10). Arithmetic mean for $D_{10}$ grainsize for the well screened intervals was 0.06 mm indicating very fine sand for the $D_{10}$ mean grainsize. The standard deviation was 0.02.

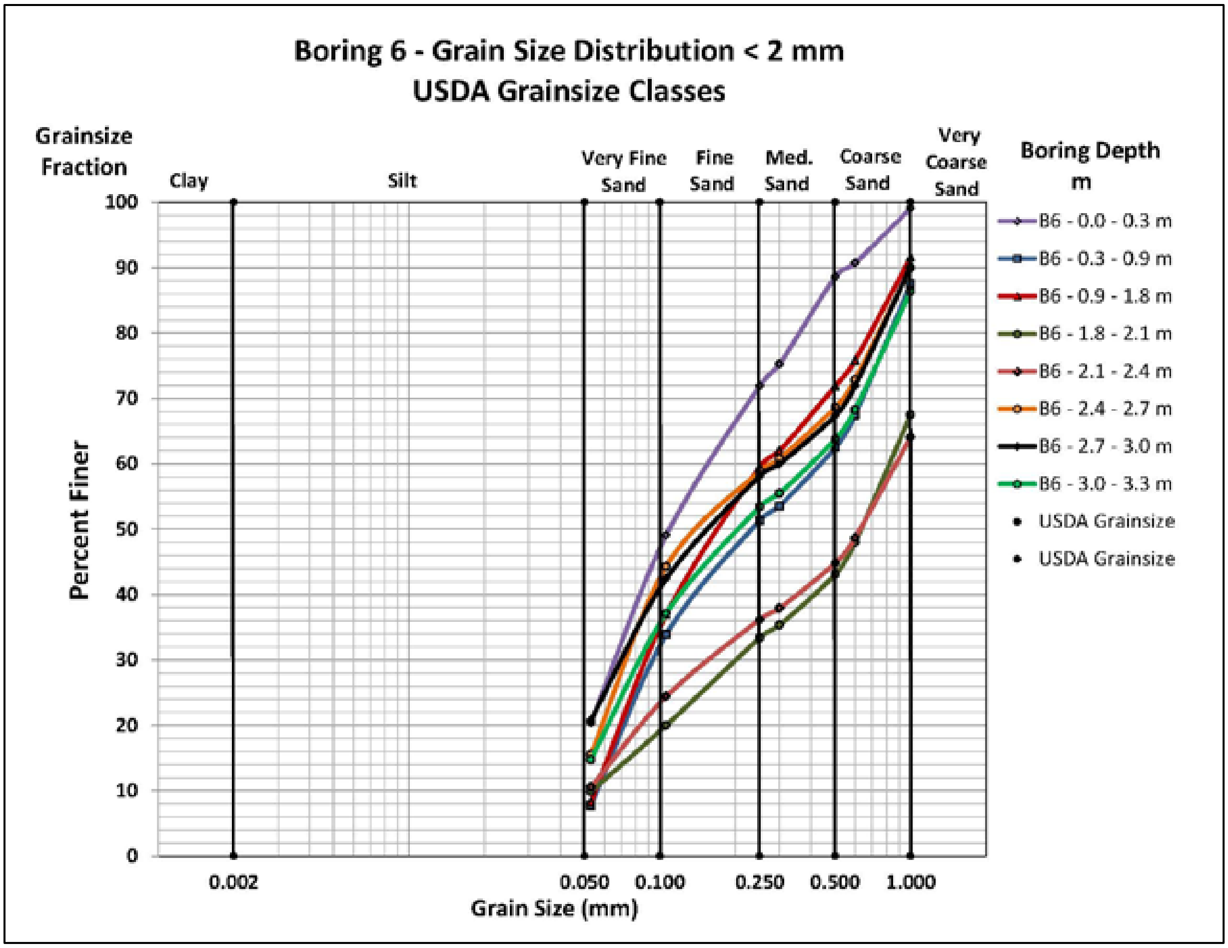


Figure 3.10 - Grainsize distribution curves for Boring 6. Separate curves are shown for 0.3 meter depth intervals. Gravel and cobbles greater than 2 mm were also interspersed in Boring 6.

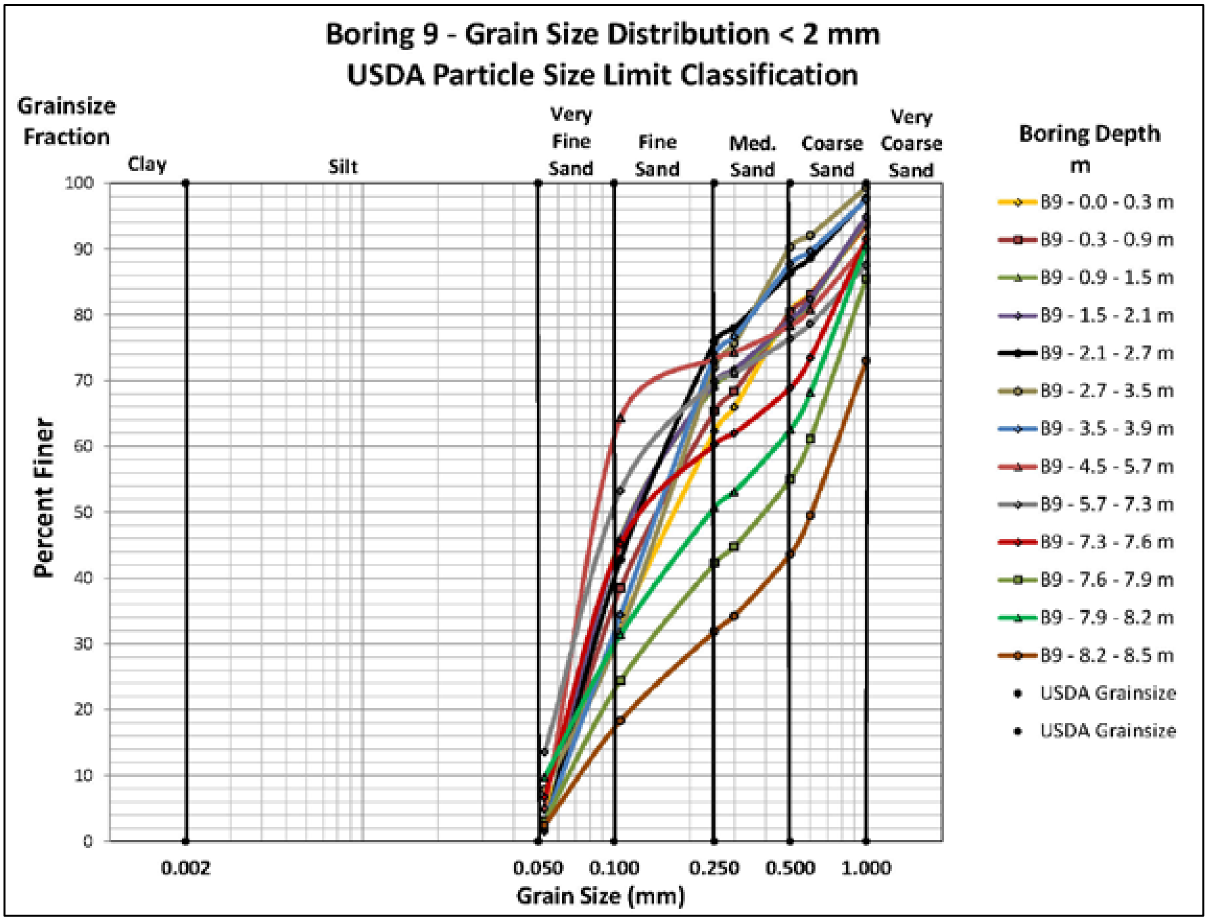


Figure 3.11 - Grainsize distribution curve for Boring 9 which includes 13 individual curves based on 0.3 – 0.6 meter intervals.

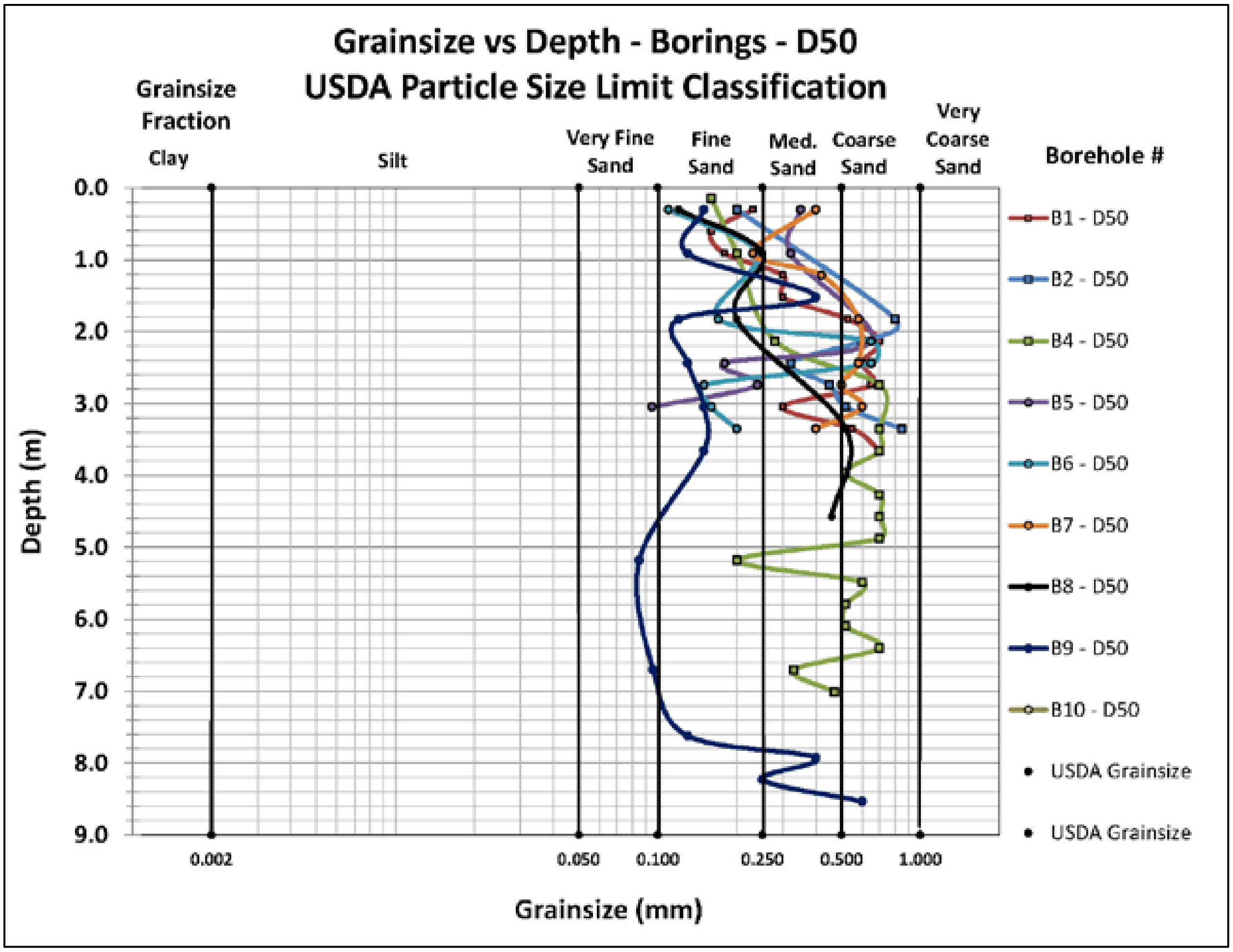
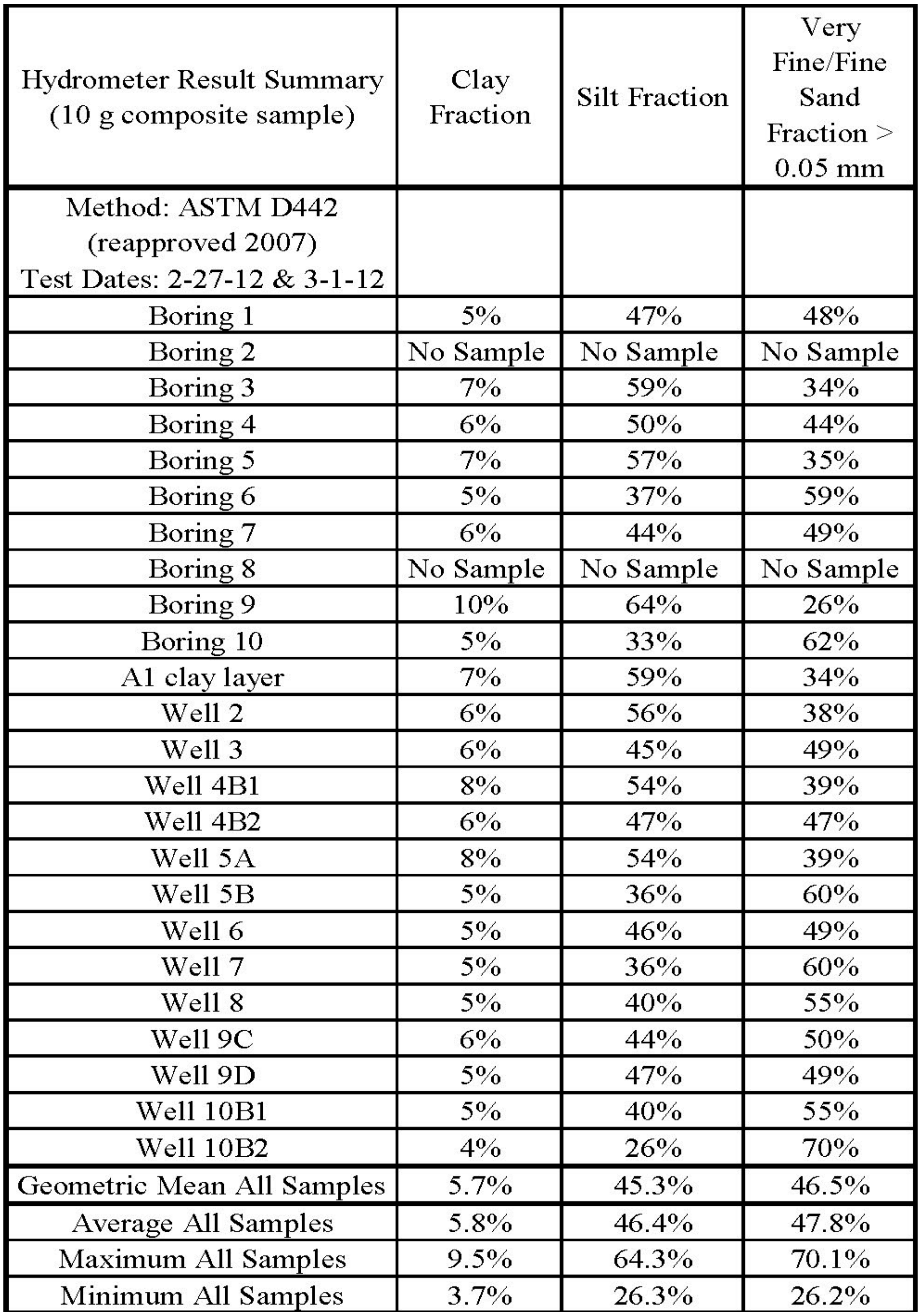


Figure 3.12 - USDA Grainsize Classification of $D_{50}$ particle size for all borings by depth. This figure shows little variability for the $D_{50}$ grainsize fraction between the borings by depth at LRDF.

Hydrometer tests were conducted on samples from eight (8) boreholes drilled in 2007 and eleven (11) split spoon samples from the 2009 well installation using ASTM 422 D (reapproved 2007). Each hydrometer sample represents 10 g sub-sample taken from the < 0.130 mm fraction of the sample used for the sieve analysis for each borehole or well screened interval sample. They are referred to as composite samples.

The results of the hydrometer test are shown in Table 3.3 and Figure 3.13. The grainsize distribution of the geometric mean of all samples suggests fine sands account for 46.53%, silts, 45.34% and clay fractions 5.70%. The < 0.130 mm fraction is remarkable similar for each sample. The standard error for fine sands is 2.34%, 2.07% for silts and 0.30% for clays and sample variances are 1.20%, 0.95% and 0.02 % respectively. The hydrometer grainsize distribution curves suggest the very fine sand, silt and clay fractions are poorly sorted which is consistent with periodic deposition during overbank flooding events and low velocity river channel deposition. Figure 3.14 shows one of eleven photographs from grainsize fractions 0.177 – 0.053 mm depicting rounded to angular shaped particles with some grain cementation present. A Nikon LV100D POL polarizing petrographic microscope with long working distance objectives (2.5x, 5x, 10x, 20x, 50x, 100x) was utilized to capture the images. The zoom for each photo varied and was not recorded for any of the photos. Photographs for grain size fractions for other samples are shown in Appendix B

Table 3.3 - Hydrometer Test Results Summary by Fraction Percentage and Statistical Summary of Particle Size Fraction for the boring and well screened intervals. The geometric mean of all samples suggests fine sands account for 46.53%, silts, 45.34% and clay fractions 5.70%. The standard error for fine sands is 2.34%, 2.07% for silts and 0.30% for clays and sample variances are 1.20%, 0.95% and 0.02 % respectively.



| Hydrometer Result Summary (10 g composite sample) | Clay Fraction | Silt Fraction | Very Fine/Fine Sand Fraction > 0.05 mm |
|---|---|---|---|
| Method: ASTM D442 (reapproved 2007)<br>Test Dates: 2-27-12 & 3-1-12 | | | |
| Boring 1 | 5% | 47% | 48% |
| Boring 2 | No Sample | No Sample | No Sample |
| Boring 3 | 7% | 59% | 34% |
| Boring 4 | 6% | 50% | 44% |
| Boring 5 | 7% | 57% | 35% |
| Boring 6 | 5% | 37% | 59% |
| Boring 7 | 6% | 44% | 49% |
| Boring 8 | No Sample | No Sample | No Sample |
| Boring 9 | 10% | 64% | 26% |
| Boring 10 | 5% | 33% | 62% |
| A1 clay layer | 7% | 59% | 34% |
| Well 2 | 6% | 56% | 38% |
| Well 3 | 6% | 45% | 49% |
| Well 4B1 | 8% | 54% | 39% |
| Well 4B2 | 6% | 47% | 47% |
| Well 5A | 8% | 54% | 39% |
| Well 5B | 5% | 36% | 60% |
| Well 6 | 5% | 46% | 49% |
| Well 7 | 5% | 36% | 60% |
| Well 8 | 5% | 40% | 55% |
| Well 9C | 6% | 44% | 50% |
| Well 9D | 5% | 47% | 49% |
| Well 10B1 | 5% | 40% | 55% |
| Well 10B2 | 4% | 26% | 70% |
| Geometric Mean All Samples | 5.7% | 45.3% | 46.5% |
| Average All Samples | 5.8% | 46.4% | 47.8% |
| Maximum All Samples | 9.5% | 64.3% | 70.1% |
| Minimum All Samples | 3.7% | 26.3% | 26.2% |

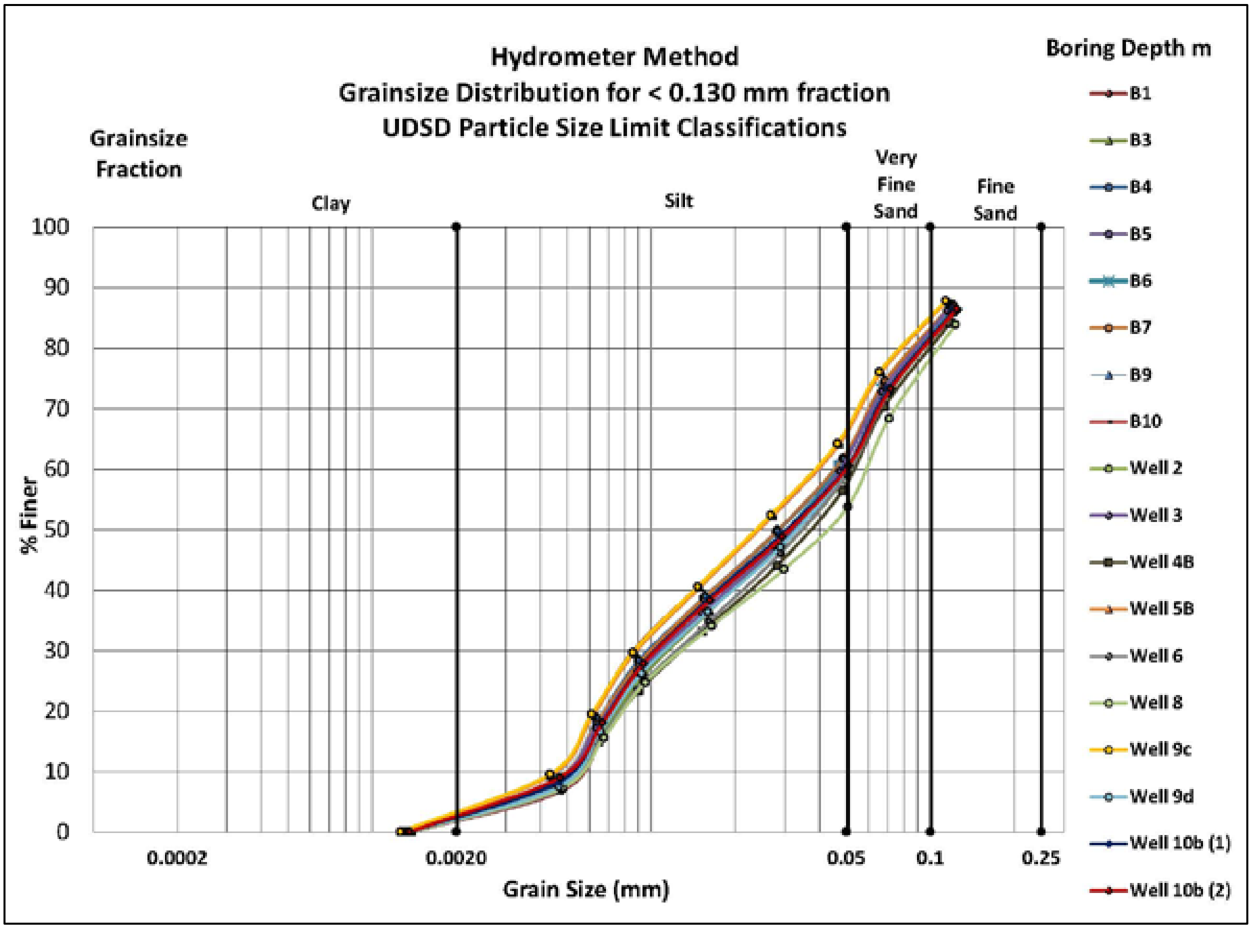
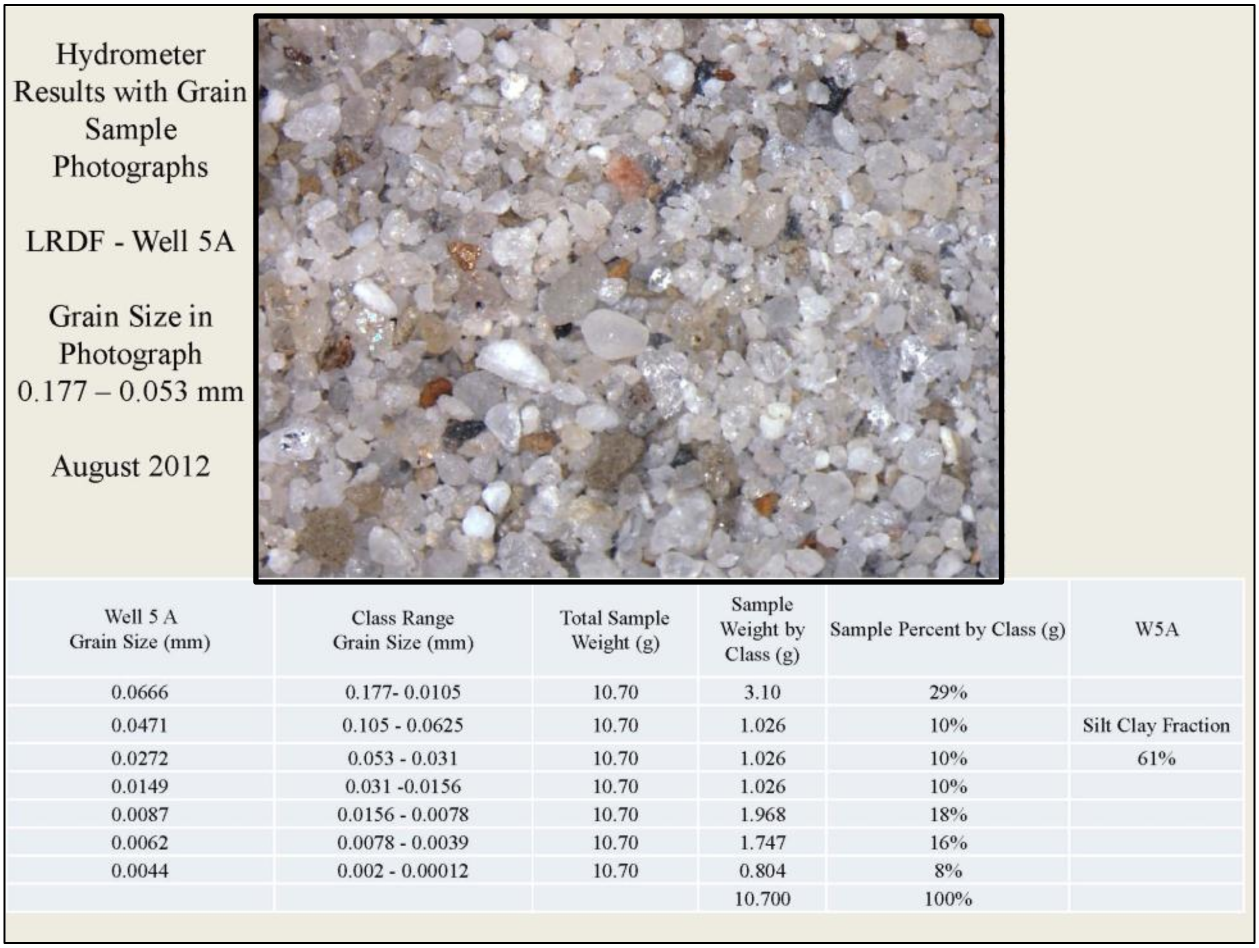


Figure 3.13 - Grainsize distribution for the < 0.130 mm fraction of composite samples from LRDF borings and well screened intervals using the Hydrometer Method. Duplicate samples are presented for wells 5b & 10b.



Hydrometer Results with Grain Sample Photographs

LRDF - Well 5A

Grain Size in Photograph 0.177 – 0.053 mm

August 2012

| Well 5 A Grain Size (mm) | Class Range Grain Size (mm) | Total Sample Weight (g) | Sample Weight by Class (g) | Sample Percent by Class (g) | W5A |
|---|---|---|---|---|---|
| 0.0666 | 0.177- 0.0105 | 10.70 | 3.10 | 29% | |
| 0.0471 | 0.105 - 0.0625 | 10.70 | 1.026 | 10% | Silt Clay Fraction |
| 0.0272 | 0.053 - 0.031 | 10.70 | 1.026 | 10% | 61% |
| 0.0149 | 0.031 -0.0156 | 10.70 | 1.026 | 10% | |
| 0.0087 | 0.0156 - 0.0078 | 10.70 | 1.968 | 18% | |
| 0.0062 | 0.0078 - 0.0039 | 10.70 | 1.747 | 16% | |
| 0.0044 | 0.002 - 0.00012 | 10.70 | 0.804 | 8% | |
| | | | 10.700 | 100% | |

Figure 3.14 – Example of a photograph from grainsize fractions 0.177 – 0.053 mm depicting rounded to angular shaped particles with some grain cementation present. A Nikon LV100D POL polarizing petrographic microscope with long working distance objectives (2.5x, 5x, 10x, 20x, 50x, 100x) was utilized to capture the images. The zoom for each photo varied and was not recorded for any of the photos. These high quality photos are located in Appendix B

### 3.3.3 Stratigraphic Cross-sections through the Floodplain Sediments

Stratigraphic profiles were developed along four (4) cross-section transects for the floodplain alluvium (Figure 3.15). These profiles were based on the geologic cross-sections of R.B Neuman (1960) which were updated and modified to reflect the depth and thickness of bedrock and alluvial material derived from borehole data and field measurements described in this thesis. Ground surface elevations were estimated from survey data collected by Dr. Andrea Ludwig, Robert Hunter and Joe Sarten, P.E. (Ludwig, 2011; Sarten, 2012-2013). Cross-section transects were labeled A-A’, B-B’, C-C’ and D-D’. These stratigraphic transects do not include depictions of the water table levels which are described in the hydrostratigraphic cross-sections that follow.

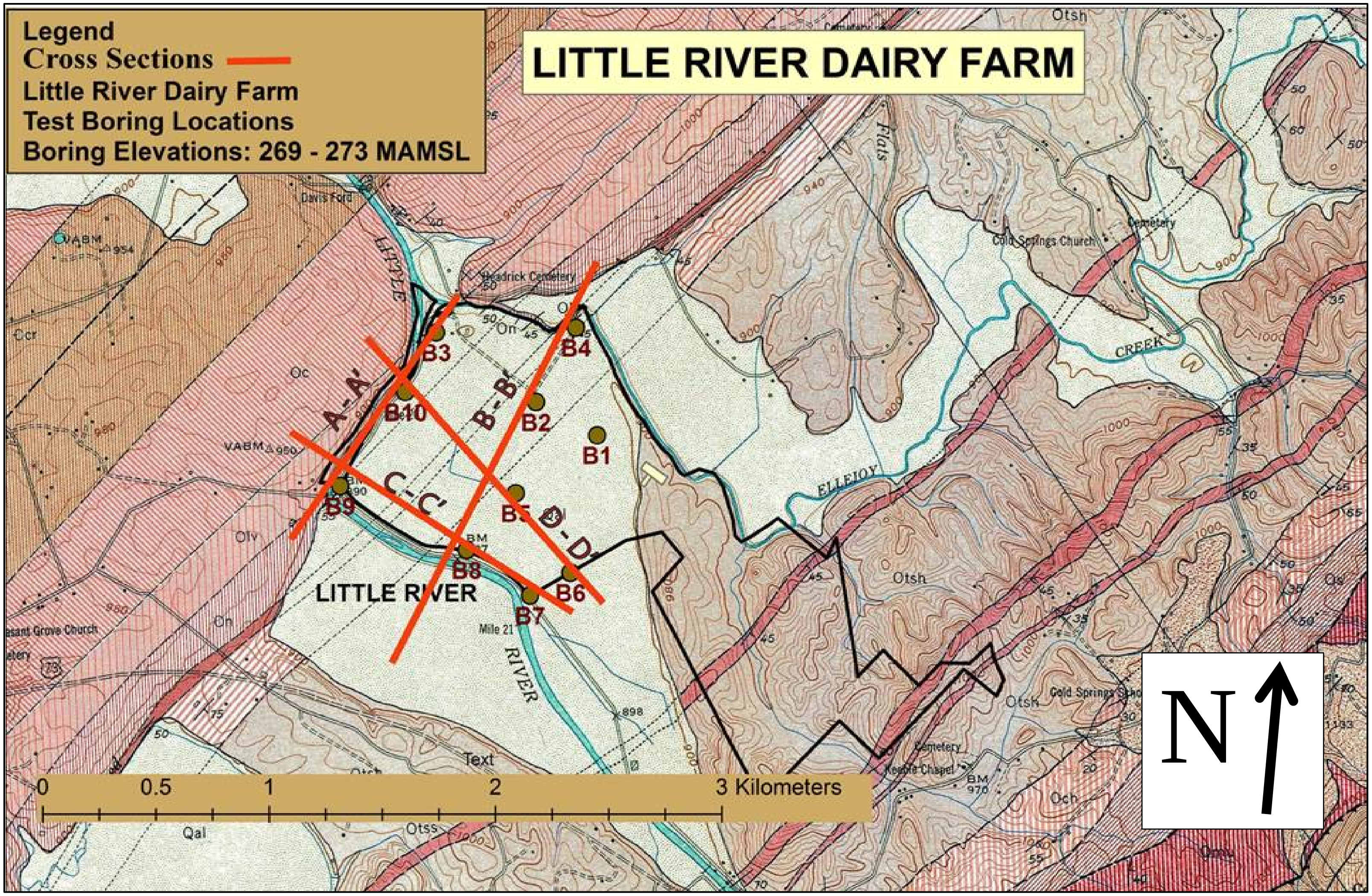


Figure 3.15 – Stratigraphic Cross-section Transects – A-A', B-B', C-C' and D-D' (After Neuman 1960).

Transect A-A’ represents a linear distance of approximately 1,250 meters extending from the Little River to Ellejoy Creek and includes Well 9abcd, 10ab and Well 3 (Figure 3.16). Bedrock beneath Transect A-A’ is primarily the Longview Dolomite (Olv) except near the northwest end of the transect where the Chepultepec Dolomite (Oc) outcrops near Ellejoy Creek. Major features in cross-section A-A’ include several sinkholes, central ditch and a 4.7 m thick gravel rich layer the near the Little River and Well 9 series.

Gravel deposits are common in 8 of 10 borings from 2007. They are at depths of 1.0 – 4.0 meters then abundantly from 7.0 – 8.5 meters. Boring log descriptions from the 2009 well installation indicate abundant gravel from 1.2 – 3.2 meters; Well 10ab indicates abundant gravel from 1.5 –5.3 meters; and, Well 9cd contains significant gravel, cobbles and boulders near the Little River. A Google Earth satellite image review suggests that the sinkhole was not present in 1992. By April of 2006, the sinkhole formed measuring approximately 9.0 X 2.0 meters. Over time the feature expanded in width from 2.0 meters to approximately 7.5 meters. In 2012 the sinkhole was excavated measuring 20 $m^2$ with a maximum depth of 8.8 meters. A geotextile liner was placed near the bottom of the excavation then backfilled with shot rock in an attempt to slow the expansion approximately. This excavation confirmed a thick gravel layer imbedded in alluvial materials (Figure 3.17 and 3.18) which rests on bedrock. This new feature acts as a large drain for field and in combination with gravel wedge around Well 9 supplies the large spring depicted in Figure 3.41 which enters the Little River to the southwest. Further study may define the limits of these gravel layers which are probably remnants from past point bar deposition.

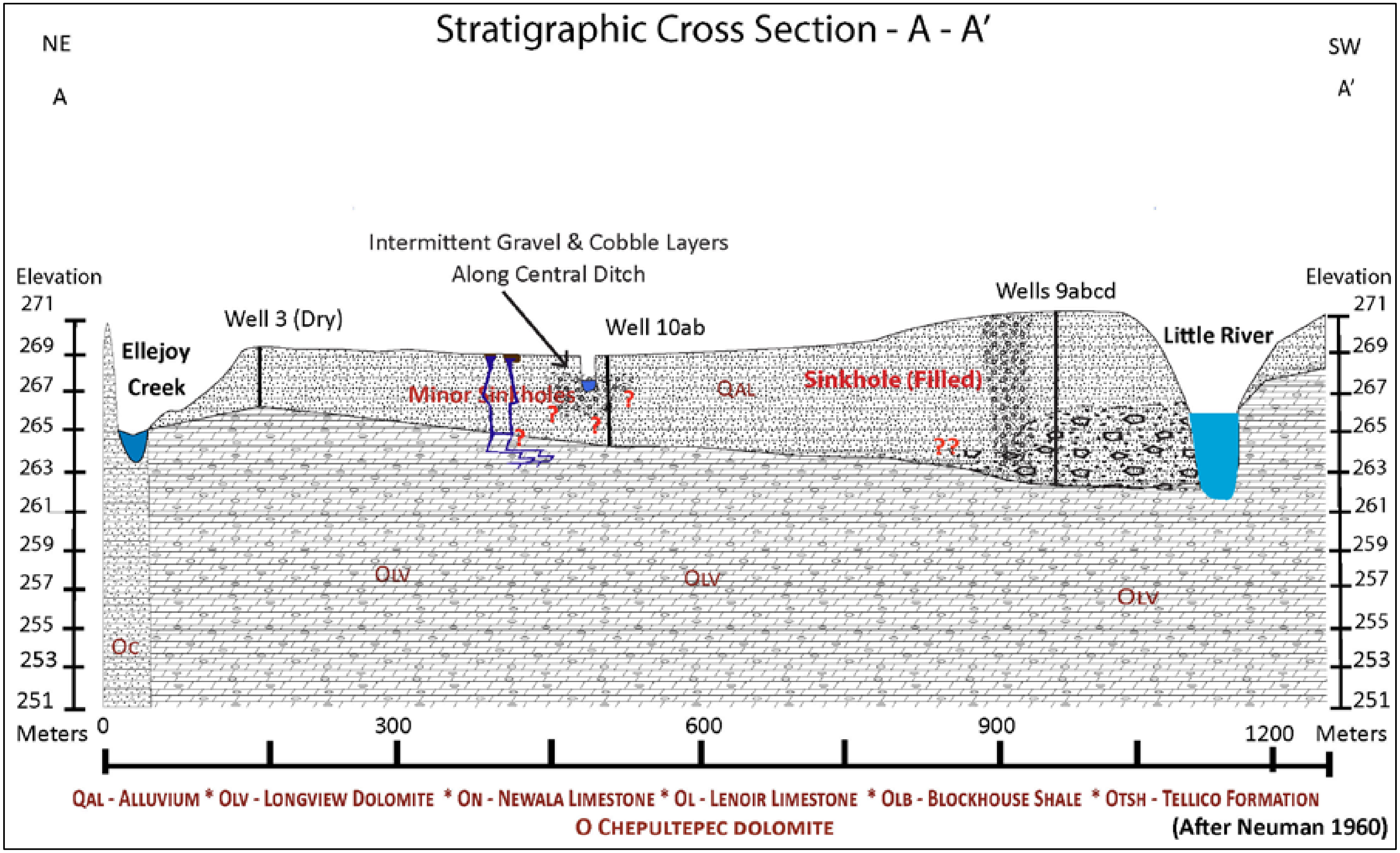


Figure 3.16 – Stratigraphic Cross-section Transect A - A' (After Neuman 1960).

Figure 3.17 – Alluvial sediments with gravel, cobbles and boulder size alluvial deposits just above the bedrock in the sinkhole excavation.

Figure 3.18 – Sinkhole excavation near Well 9 before backfilling with shot rock. Bedrock (right side) was exposed and measured below the water level. The bedrock contains an open cavity dipping toward the southwest below the waterline.

Transect B-B’ represents a linear distance of approximately 1,500 meters extending from the Little River to Ellejoy Creek and includes Wells 8, 5ab, 2 and 4ab (Figure 3.19). Bedrock beneath Transect B-B’ is the Tellico Formation, Blockhouse Shale and Lenoir Limestone. Major features depicted in Transect B-B’ include the alluvium/bedrock contact, possible saprolite at the bottom of Well 5b and a gravel layer (~ 1.8 m thick) at the bottom of Well 8.. Well 8 is very close to the Little River (~ 30 m) and the gravel layer was likely deposited in the river bed before shifting to its present position. This differs from a gravel/cobble layer near Wells 8 and 9, because instead of being deposited on top of the bedrock, is deposited on top of the main sequence of silty sand sediments. Other notable features along B-B’ are the constructed wetland near Well 2 and shot rock fill (from the Tellico Formation) adjacent to Wells 4ab.

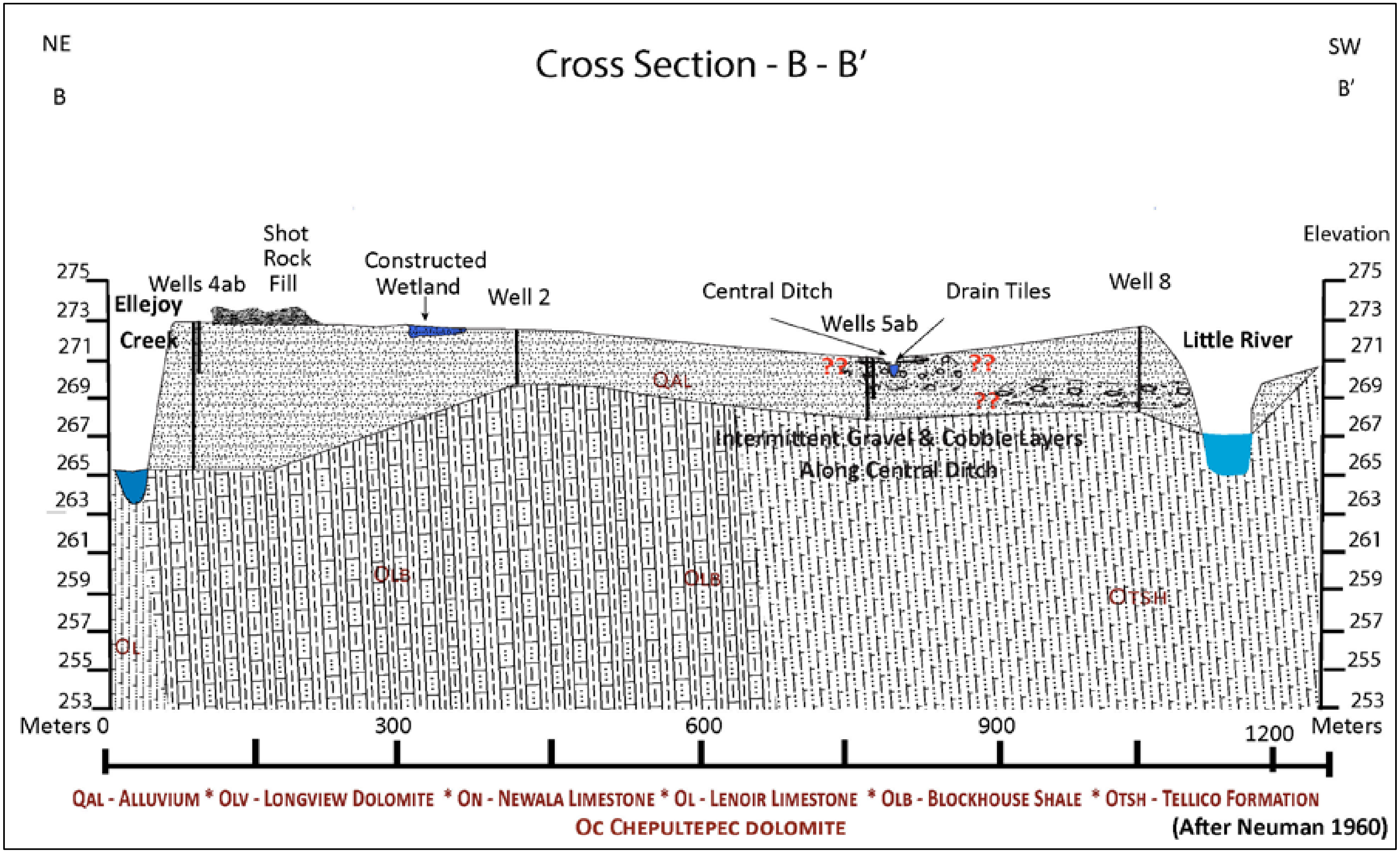


Figure 3.19 - Stratigraphic Cross-section Transect B - B' (After Neuman 1960).

Transect C-C’ represents a linear distance of approximately 1,240 meters extending from well 7 to the Little River and includes Wells 8 and 9abcd along a bearing of 35° 45’ 58” N, 83° 51’18” W (Figure 3.20). Bedrock geology beneath Transect C-C’ is the Tellico Formation, Blockhouse Shale, Lenoir Limestone, Newala Limestone and Longview Dolomite. Major features included in C-C’ include gravel and boulder layers beneath Wells 7, 8 and 9, as well as in the sinkhole. It is likely that this gravel layer is continuous and parallels the Little River. The gravel layer was almost certainly deposited by the Little River before it moved to present position.

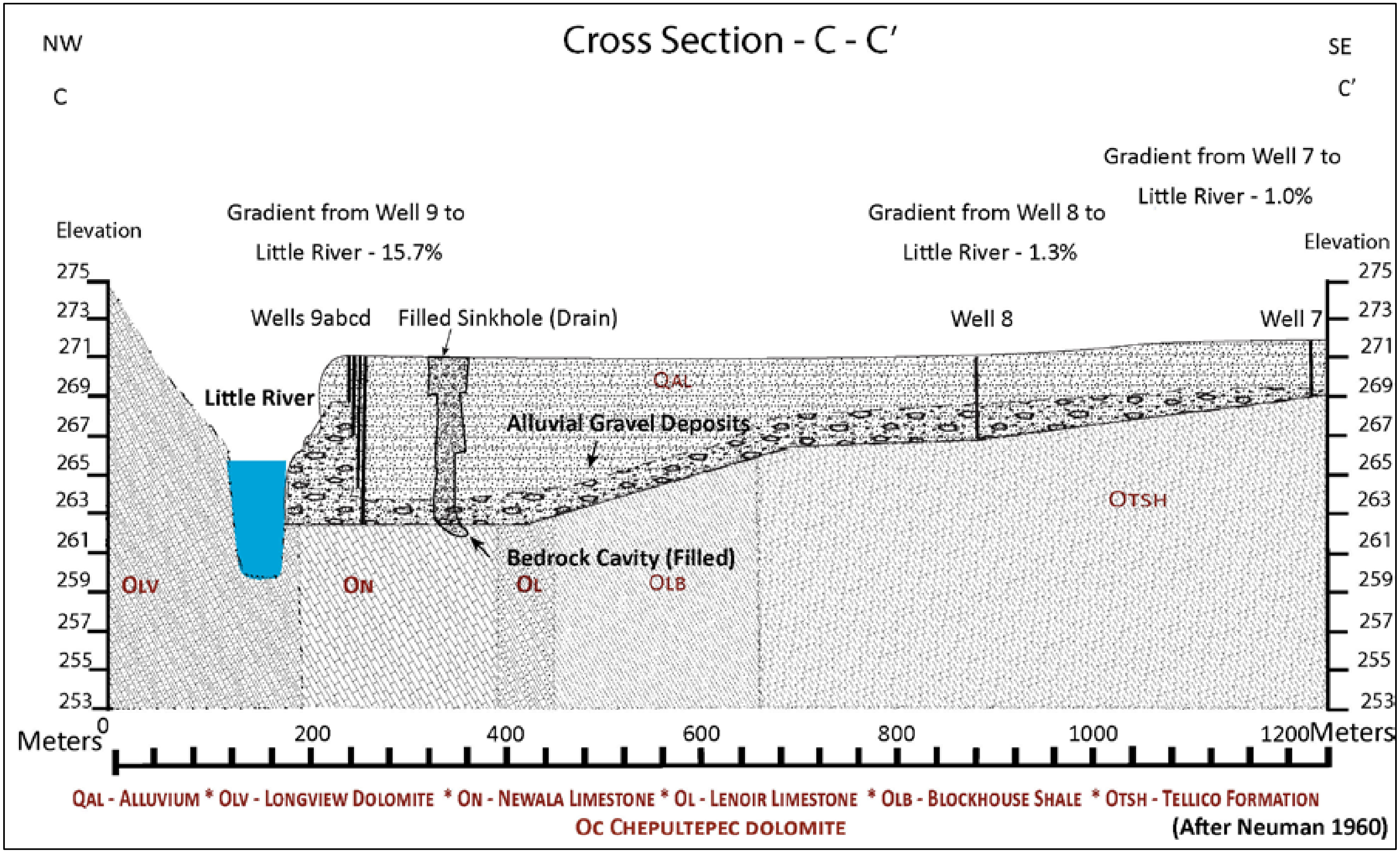


Figure 3.20 - Stratigraphic Cross-section Transect C - C’ (After Neuman 1960).

Transect D-D’ stretches approximately 1,250 meters between Well 6 and Well 10b to the Little River (Figure 3.21). Bedrock beneath Transect C-C’ is the Tellico Formation, Blockhouse Shale, Lenoir Limestone, Newala Limestone and Longview Dolomite. The major feature in this transect is a layer of gravel or gravelly sand, which may extend (intermittently) the entire length of the transect. In well 6, at the upslope end of the transect, the gravel layer is only 0.1 m thick and occurs at ` 2.3 m depth. At well 5,(about 300 m to the NW), the gravel layer is found at a depth of 1.1to 2.2 m. In well 10, at the NW end of the transect, the gravel layer is at 2.4 to 2.7 m depth.

However, recent excavations to depths of 2 – 10 meters between wells 5 and 6 show there is a lot more gravel than is represented by the borings. As previously shown in Figure 3.4, a layer of gravel, cobbles and small boulders (up to 0.5 m diameter) is exposed in the walls of the ditch. The gravel in the ditch is overlain by about 0.5 to 1.0 m of silty sand. Further to the southeast of well 6 (on an adjoin property) abundant cobbles and boulders on the surface of the ground over an area of approximately 150,000 $m^2$. This feature appears to gradually dip below the surface before it reaches the LRDF property line. Other indicators of an underlying gravel layer in this section of the farm are the many small sinks in the wetland areas between Well 6 and 5ab which may have developed as the result of seepage and erosion of the fine sand and silts into a highly transmissive gravel layer. These extensive gravel layers, which overly finer grained silty sands along the transect were likely deposited by the Little River prior to moving to its present position. The period of deposition may have been relatively brief, because the river did not scour down to the bedrock, as it has done in its present location.

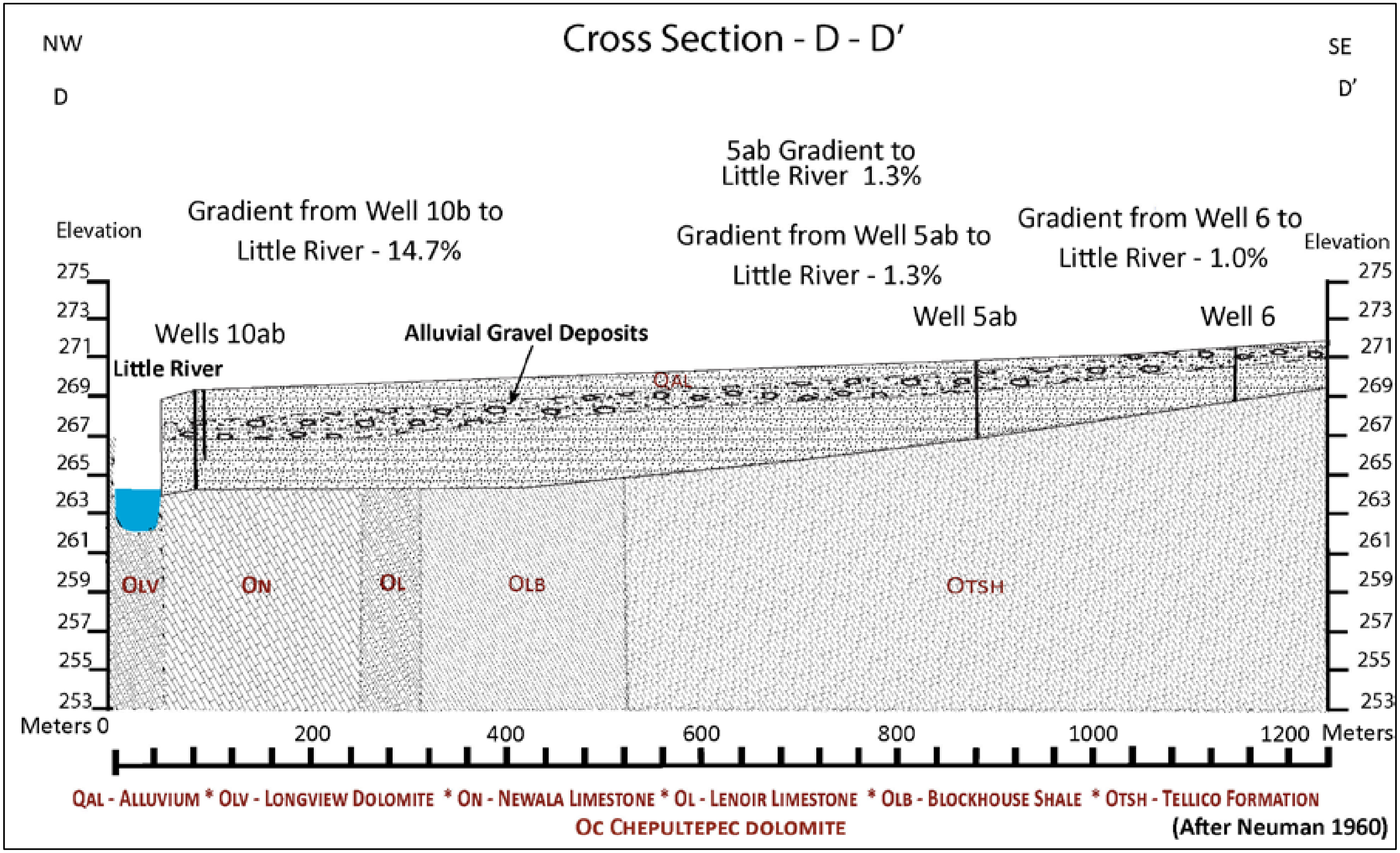


Figure 3.21 - Stratigraphic Cross-section Transect D - D' (After Neuman 1960).

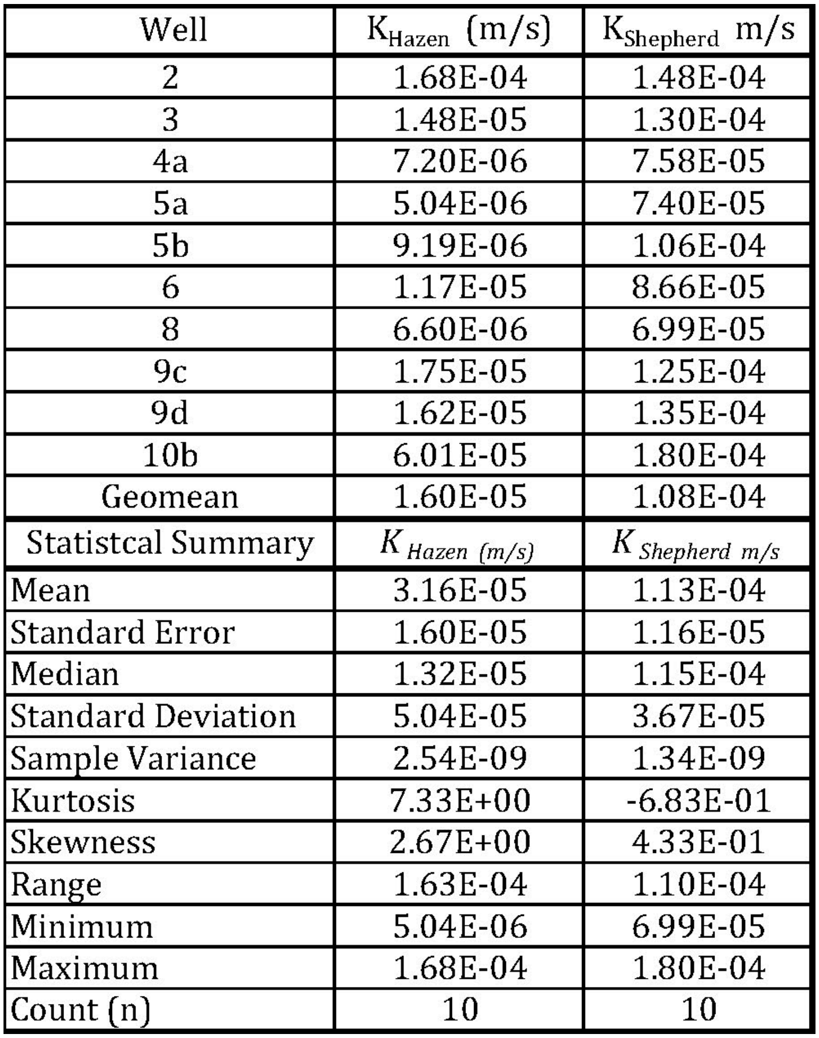
### 3.3.4 Hazen and Shepherd Method Hydraulic Conductivity Estimates

Hydraulic conductivity and grainsize distribution were evaluated using the Hazen Method (Hazen, 1892) expressed by $K_{Hazen} = CD_{10}^2$ , where $K_s$ is expressed in cm/sec, C is a constant that varies from 1.0 to 1.5, and $D_{10}$ is the soil particle diameter (mm) such that 10% of all soil particles are finer by weight. The Hazen method described by Fetter defines C in terms of a number between 40 to 150 related to particle sizes ranging from very fine sand to coarse sands from poorly sorted with fines to well sorted clean grains. The constant C = 40 was chosen for this study due to channel deposits and immature grain sizes. The results are reported in m/s for consistency purposes. The geometric mean of the K values for 10 alluvial wells using $K_{Hazen}$ was 1.60E-05 m/s with a standard deviation of 5.04E-05.

The Shepherd method employs the general formula: $K_{Shepherd} = C\ D_{50}^{j}$. Where K is the hydraulic conductivity; C is a shape factor; $D_{50}$ is the median grain-size (mm) and "j" is an empirical exponent ranging from texturally mature sediments (j=2) to texturally immature sediments (j=1.5) (Fetter, 2001). The median grain-size, $D_{50}$, is the grain-size diameter at which 50% by weight of the sediments are finer and 50% are coarser and the $D_{50}$ sizes were derived for each well during the particle size analysis. The LRDF unconsolidated sediments are made up known river channel sediments so an exponent, j of 1.5 and a C value of 100 were chosen in estimating K based on inference from channel deposits and the idealized regression graph formulated by Shepherd. The geometric mean of the K values for 10 alluvial wells using $K_{Shepherd}$ was 1.08E-04 m/s with a standard deviation of 3.67E-04.

Estimated values for $K_{Shepherd}$ and $K_{Hazen}$ fall within the range of values expected for silty sand deposits of $10^{-3}$ to $10^{-7}$ m/s (Freeze and Cherry, 1979). The small standard deviation for the K-values estimated with each method reflects the fact that there was very little variation in the grainsize distribution for the samples. The Hazen and Shepherd methods are used for estimating hydraulic conductivity and are generally considered less reliable than hydraulic conductivies based on slug test or pumping tests methods (Table 3.4).

Table 3.4 – Estimated Hydraulic Conductivies, based on grainsize distribution using Hazen & Shepherd Methods.



| Well | $K_{Hazen}$ (m/s) | $K_{Shepherd}$ m/s |
|---|---|---|
| 2 | 1.68E-04 | 1.48E-04 |
| 3 | 1.48E-05 | 1.30E-04 |
| 4a | 7.20E-06 | 7.58E-05 |
| 5a | 5.04E-06 | 7.40E-05 |
| 5b | 9.19E-06 | 1.06E-04 |
| 6 | 1.17E-05 | 8.66E-05 |
| 8 | 6.60E-06 | 6.99E-05 |
| 9c | 1.75E-05 | 1.25E-04 |
| 9d | 1.62E-05 | 1.35E-04 |
| 10b | 6.01E-05 | 1.80E-04 |
| Geomean | 1.60E-05 | 1.08E-04 |
| Statistcal Summary | $K_{Hazen\ (m/s)}$ | $K_{Shepherd\ m/s}$ |
| Mean | 3.16E-05 | 1.13E-04 |
| Standard Error | 1.60E-05 | 1.16E-05 |
| Median | 1.32E-05 | 1.15E-04 |
| Standard Deviation | 5.04E-05 | 3.67E-05 |
| Sample Variance | 2.54E-09 | 1.34E-09 |
| Kurtosis | 7.33E+00 | -6.83E-01 |
| Skewness | 2.67E+00 | 4.33E-01 |
| Range | 1.63E-04 | 1.10E-04 |
| Minimum | 5.04E-06 | 6.99E-05 |
| Maximum | 1.68E-04 | 1.80E-04 |
| Count (n) | 10 | 10 |

### 3.3.5 Slug Test Results

Thirty-four (34) slug tests were performed in the alluvial wells over a 2 year period following the procedure for the Hvorslev Method. The results for the tests were evaluated in two ways. When the slug test was conducted in the field with the assistance of a student, the field data was recorded and often graphed in the field. Alternatively, when a slug test was conducted using a pressure transducer to record displacement and recovery, the test was evaluated when the data was collected from the transducer. In each case, the results were analyzed using an Excel spreadsheet and graphed. Eight (8) graphs representing Twenty-two slug tests are presented in Appendix C.

Hydraulic conductivity values calculated from the slug test data are shown in Table 3.5. Each well was tested between 1 and 7 times, except well 3 which did not contain enough water for testing. The geometric mean of all hydraulic conductivities for repeated slug tests in each well was calculated to determine a representative K-value for that well. These values ranged from a low of 6.19E-09 m/s in well 9d to a high of 3.02E-05 m/s in well 5b. This range of 4 orders of magnitude is greater than expected based on the relative uniform nature of the sediments.

Variability in slug test hydraulic conductivity values can arise from a variety of sources. These include: 1) well screens may encounter layers of differing hydraulic conductivities such as a gravel or clay layers; 2) seasonal water level variations can result in different sediment layers contributing to recovery of water levels in the well during the test or can result in changes in the "static" water level used in the calculations encountered during multiple tests in the same well.

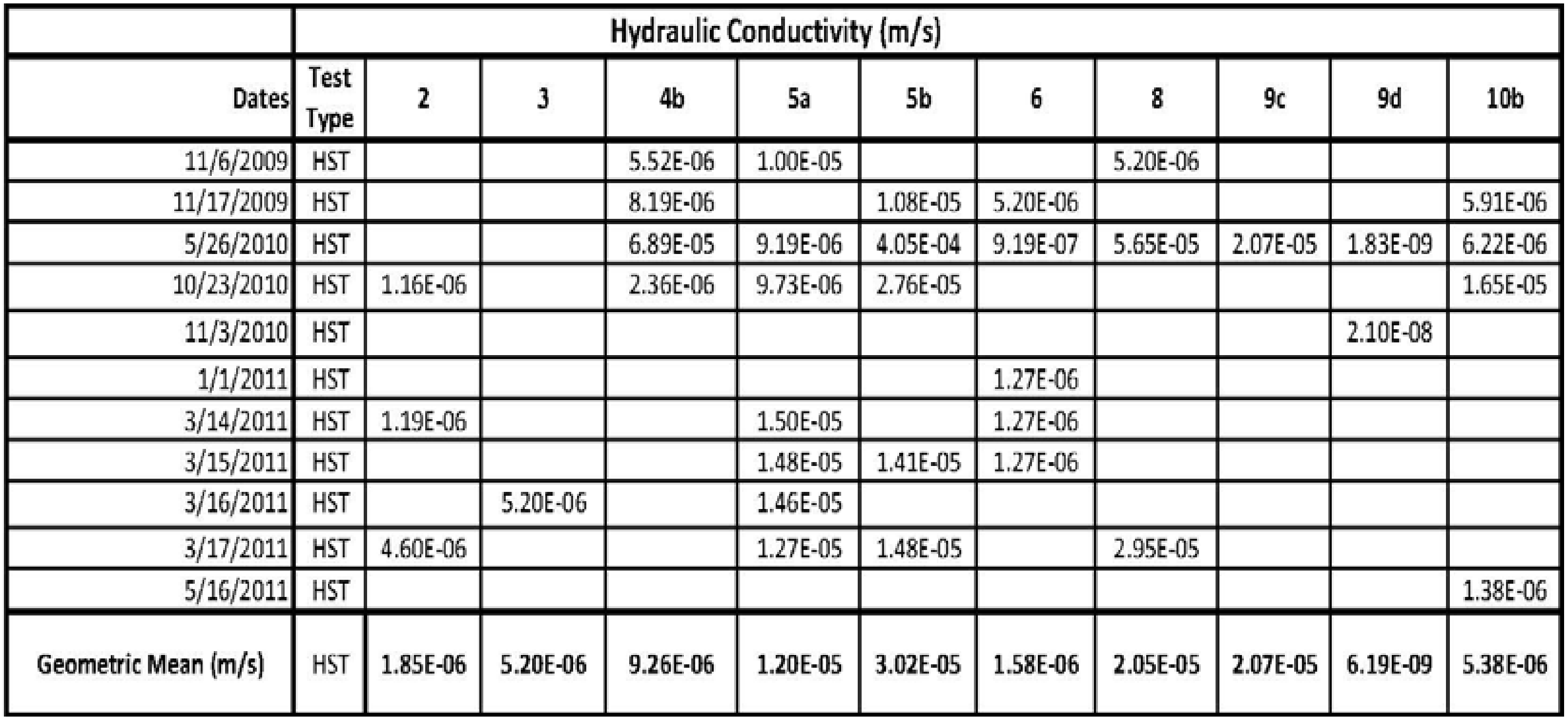
3) Silt may clog the well screen, resulting in slower recovery for repeated tests in the same well; affecting water table yield; 4) Vertical flow from the water table may contribute to

variability because the slug test method assumes horizontal radial flow in a confined aquifer; and, measurement errors or equipment problems.

An example of variation due to seasonal water level variation is provided in Figure 3.22. Three tests were conducted in Well 6 at different times. Test one (1) was conducted during a period of a receding groundwater table on 5-26-2010 using the standard Hvorslev method. An exponential trendline fit for this test produced an $R^2$ value of 0.98 and a K value of 9.19E-07 m/s. Early recovery data (first 100 seconds) from this test is similar to the later tests, however later recovery was slower with 37% recovery occurring at $t_o$ = 1,200 seconds compared to tests two (2) and three (3) with $t_o$ = 640 and 650 seconds respectively representing a 54% faster recovery rate.

Another example of non-ideal response is shown in Figure 3.23. A slug test was performed on Well 10B on 5/26/2010. The initial response was very rapid, but after ~ 100 seconds the rate of recovery slowed substantially and then increased after ~ 700 seconds. This appears to be at least partially related to a clogged well screen, because when the well was later redeveloped to remove the sediments in the sand pack subsequent tests on 10/23/2010 and 5/16/2011 showed faster recovery and indicating higher K-values. All slug test results are summarized in Table 3.5.

Table 3.5 - Slug Test Summary - Alluvial Wells.



| | Hydraulic Conductivity (m/s) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Dates | Test Type | 2 | 3 | 4b | 5a | 5b | 6 | 8 | 9c | 9d | 10b |
| 11/6/2009 | HST | | | 5.52E-06 | 1.00E-05 | | | 5.20E-06 | | | |
| 11/17/2009 | HST | | | 8.19E-06 | | 1.08E-05 | 5.20E-06 | | | | 5.91E-06 |
| 5/26/2010 | HST | | | 6.89E-05 | 9.19E-06 | 4.05E-04 | 9.19E-07 | 5.65E-05 | 2.07E-05 | 1.83E-09 | 6.22E-06 |
| 10/23/2010 | HST | 1.16E-06 | | 2.36E-06 | 9.73E-06 | 2.76E-05 | | | | | 1.65E-05 |
| 11/3/2010 | HST | | | | | | | | | 2.10E-08 | |
| 1/1/2011 | HST | | | | | | 1.27E-06 | | | | |
| 3/14/2011 | HST | 1.19E-06 | | | 1.50E-05 | | 1.27E-06 | | | | |
| 3/15/2011 | HST | | | | 1.48E-05 | 1.41E-05 | 1.27E-06 | | | | |
| 3/16/2011 | HST | | 5.20E-06 | | 1.46E-05 | | | | | | |
| 3/17/2011 | HST | 4.60E-06 | | | 1.27E-05 | 1.48E-05 | | 2.95E-05 | | | |
| 5/16/2011 | HST | | | | | | | | | | 1.38E-06 |
| **Geometric Mean (m/s)** | HST | **1.85E-06** | **5.20E-06** | **9.26E-06** | **1.20E-05** | **3.02E-05** | **1.58E-06** | **2.05E-05** | **2.07E-05** | **6.19E-09** | **5.38E-06** |

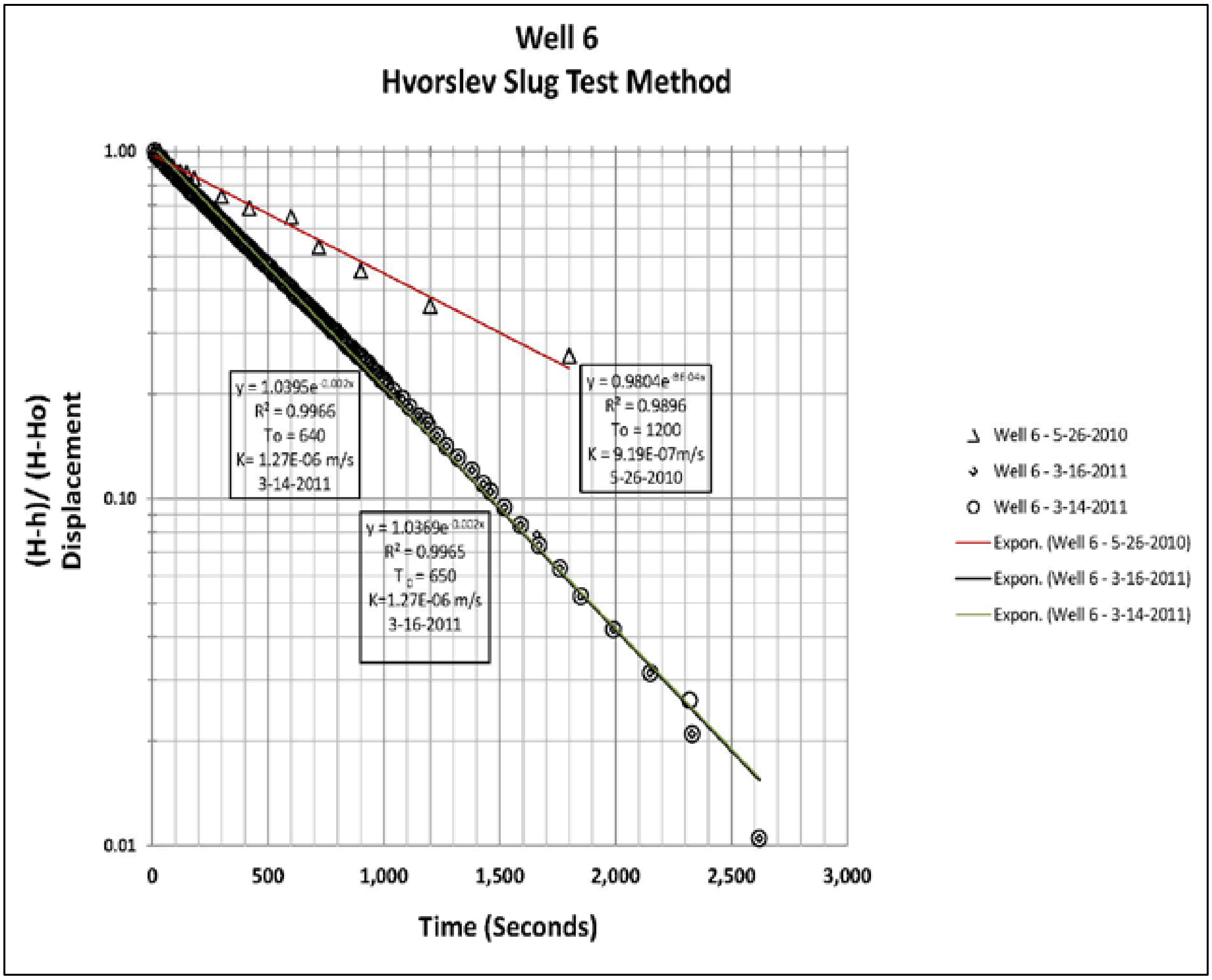


Figure 3.22 - Triplicate Slug Tests for Well 6 using the Hvorslev Slug Test Method. The variation between the 5-26-11 test and the 3-14/15-11 tests may be explained by water level variation due to seasonal water level changes.

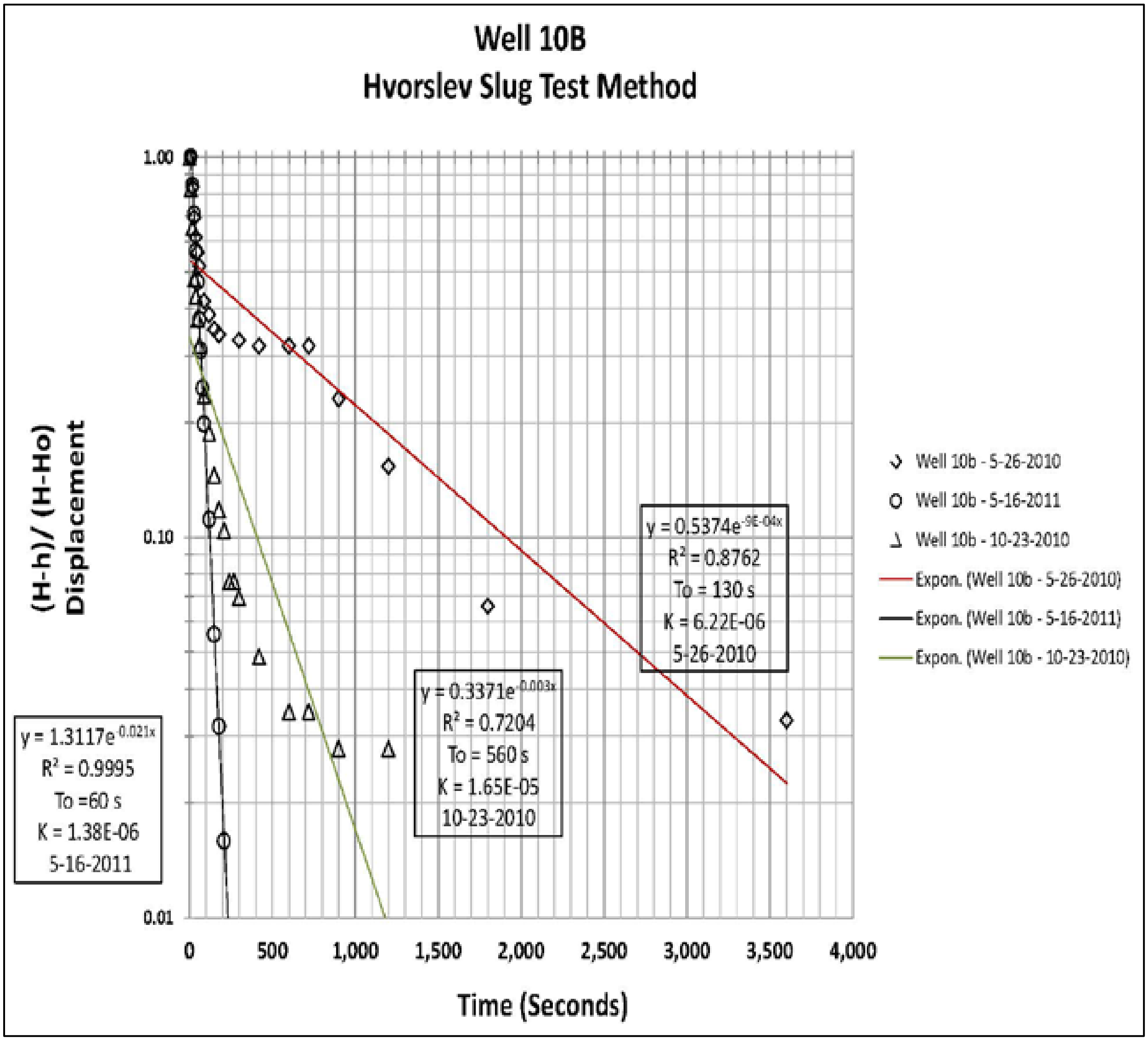


Figure 3.23 – Slug Test Well 10B. The 5/26/2010 test curve may be explained by a partially clogged well screen. Once a monitoring well is developed, silt can migrate through the sand pack and well screen into the well casing causing a decrease in hydraulic conductivity unless the well screened interval is cleaned by sustained pumping.

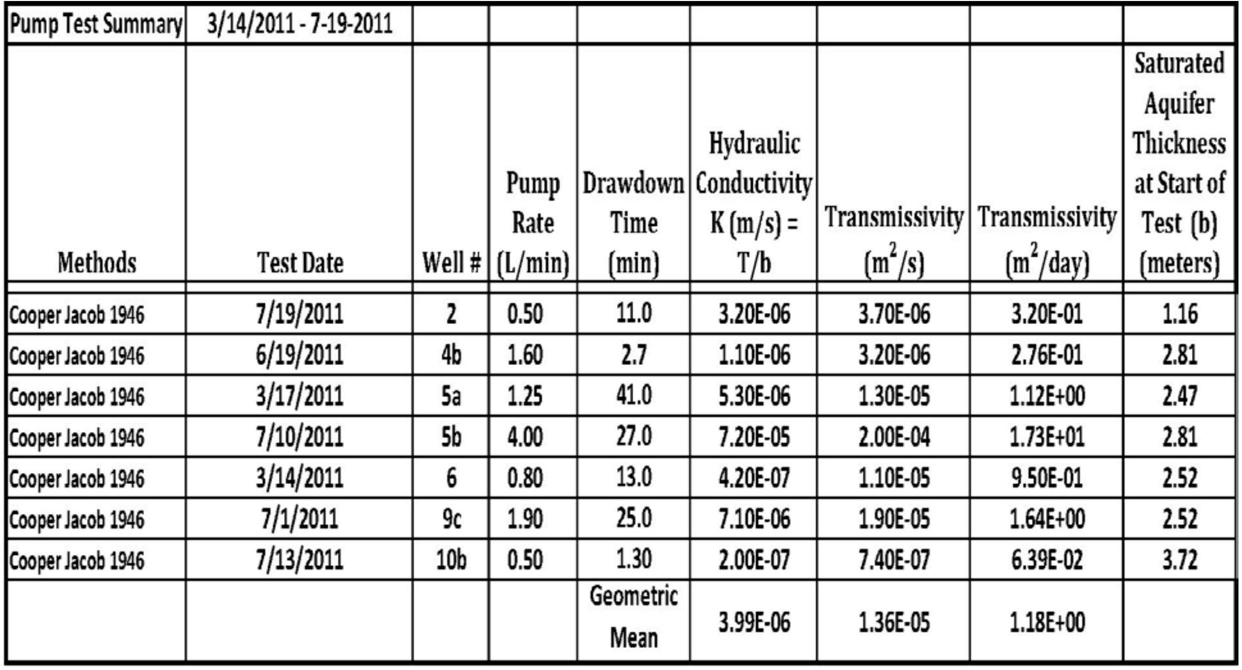
### 3.3.6 Pump Test Results

Results from seven pump tests are reported in Table 3.6. Hydraulic aquifer parameters were estimated for wells 2, 4b, 5a, 5b, 6, 9c and 10b using the Cooper Jacob Straight Line Method (Cooper and Jacob, 1946). The other wells were not tested either because of low water levels or the inability to maintain constant flow rates during the test. Storativity could not be calculated due to the lack of an observation well.

Drawdowns are presented on a semi-log plots in Figures 3.24 to 3.30 where they are discussed individually and in detail. Figure 3.31 compares K-values for all slug tests (Hvorslev Method, 1951) and seven pump tests (Cooper and Jacob, 1946) to K-values predicted by grainsize analyses using the Hazen and Shepherd Methods (Hazen, 1892; Shepherd, 1989). Hydraulic conductivities from the pump tests range from 7.20E-05 to 2.00E-07 m/s with a geometric mean of 4.06E-6 m/s for all tests (Table 3.6). Transmissivity values for the pump tests ranged from 1.73E+01 to 6.39E-02 $m^2$/day with a geometric mean of 1.71E+00 $m^2$/day. The pump test K and T values are in the expected range for a silty sand aquifer (Freeze and Cherry, 1979) and show less variability than K values measured in the same wells using slug tests. This is not unusual, because pump tests measure K values over a larger volume of the aquifer material (defined by the raduis of the drawdown curve) than is measured by a slug test.

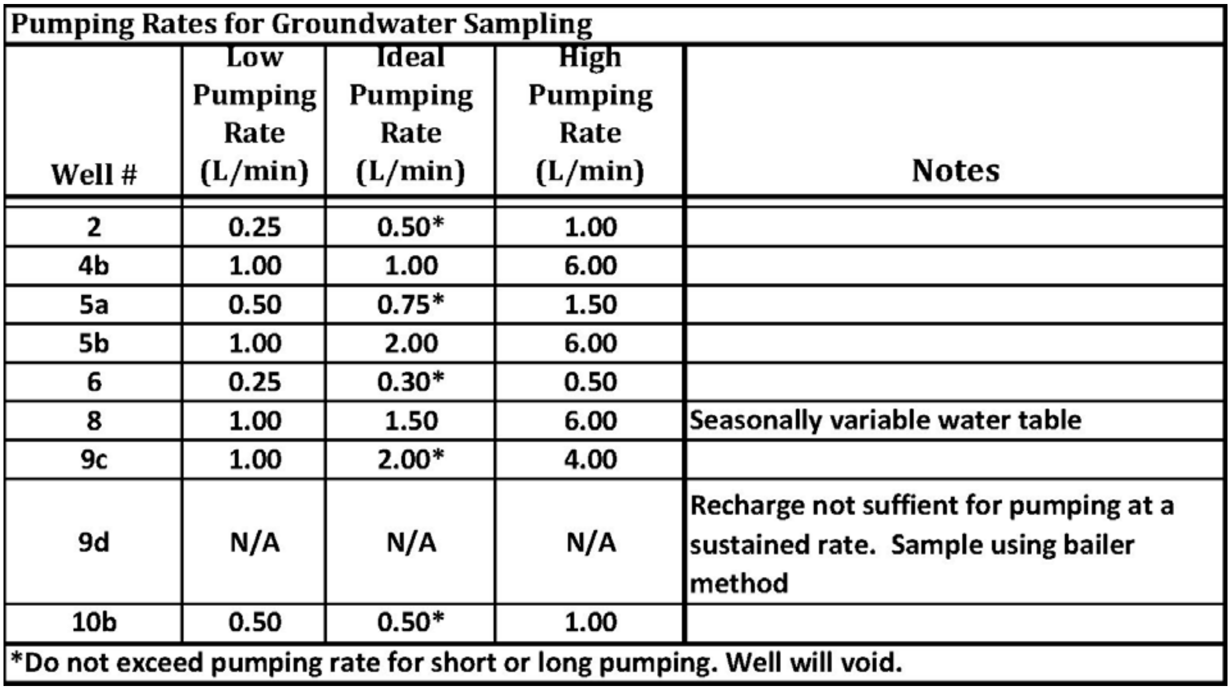
Variability in pumping rates occurred during most pumping test due to variations in tests conducted during seasonally high or low water tables and because of the soil matrix make up surrounding the well screen. This resulted in pumping rate adjustments usually during initial drawdown times. Pumping rates are well specific and vary from 0.25 – 6.0 liters per minute. Higher pumping rates were achieved during seasonally high water table; however, care must be used when increasing the pumping rates to avoid voiding the well due to sensitive recharge rates even in high water tables (See Table 3.7). Well 2 (Figure 3.24) had an average pumping rate of 0.50 L/m based on three slight rate adjustments during the first 10 minutes of the test. Well 5a (Figure 3.26) had an average pumping rate 1.28 L/min based on four pumping rate adjustments which are noted on the graph. Maintaining a constant pumping rate outside of the ideal pumping rates for groundwater sampling was difficult to achieve. Cooper and Jacob straight line method allows for a valid test for T and K by averaging the variable rates during drawdown because calculated T and K values depend on the slope of the line (straight line) and the pumping rate (Q) that may be averaged to represent the slope of the line. The straight line was applied to the data as a best fit for 1 log cycle of time. This also explains why the fitted straight lines do not begin at zero drawdown at very early pumping times.

Table 3.6 – Pump Test Summary using the Cooper Jacob Straight Line Method to estimate transmissivity (T) and hydraulic conductivity (K) (Cooper and Jacob, 1946).



| Pump Test Summary | 3/14/2011 - 7-19-2011 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Methods | Test Date | Well # | Pump Rate (L/min) | Drawdown Time (min) | Hydraulic Conductivity K (m/s) = T/b | Transmissivity ($m^2/s$) | Transmissivity ($m^2/day$) | Saturated Aquifer Thickness at Start of Test (b) (meters) |
| Cooper Jacob 1946 | 7/19/2011 | 2 | 0.50 | 11.0 | 3.20E-06 | 3.70E-06 | 3.20E-01 | 1.16 |
| Cooper Jacob 1946 | 6/19/2011 | 4b | 1.60 | 2.7 | 1.10E-06 | 3.20E-06 | 2.76E-01 | 2.81 |
| Cooper Jacob 1946 | 3/17/2011 | 5a | 1.25 | 41.0 | 5.30E-06 | 1.30E-05 | 1.12E+00 | 2.47 |
| Cooper Jacob 1946 | 7/10/2011 | 5b | 4.00 | 27.0 | 7.20E-05 | 2.00E-04 | 1.73E+01 | 2.81 |
| Cooper Jacob 1946 | 3/14/2011 | 6 | 0.80 | 13.0 | 4.20E-07 | 1.10E-05 | 9.50E-01 | 2.52 |
| Cooper Jacob 1946 | 7/1/2011 | 9c | 1.90 | 25.0 | 7.10E-06 | 1.90E-05 | 1.64E+00 | 2.52 |
| Cooper Jacob 1946 | 7/13/2011 | 10b | 0.50 | 1.30 | 2.00E-07 | 7.40E-07 | 6.39E-02 | 3.72 |
| | | | | Geometric Mean | 3.99E-06 | 1.36E-05 | 1.18E+00 | |

Table 3.7 – Pumping rates for groundwater sampling.



| Pumping Rates for Groundwater Sampling | | | | |
|---|---|---|---|---|
| Well # | Low Pumping Rate (L/min) | Ideal Pumping Rate (L/min) | High Pumping Rate (L/min) | Notes |
| 2 | 0.25 | 0.50* | 1.00 | |
| 4b | 1.00 | 1.00 | 6.00 | |
| 5a | 0.50 | 0.75* | 1.50 | |
| 5b | 1.00 | 2.00 | 6.00 | |
| 6 | 0.25 | 0.30* | 0.50 | |
| 8 | 1.00 | 1.50 | 6.00 | Seasonally variable water table |
| 9c | 1.00 | 2.00* | 4.00 | |
| 9d | N/A | N/A | N/A | Recharge not suffient for pumping at a sustained rate. Sample using bailer method |
| 10b | 0.50 | 0.50* | 1.00 | |
| *Do not exceed pumping rate for short or long pumping. Well will void. | | | | |

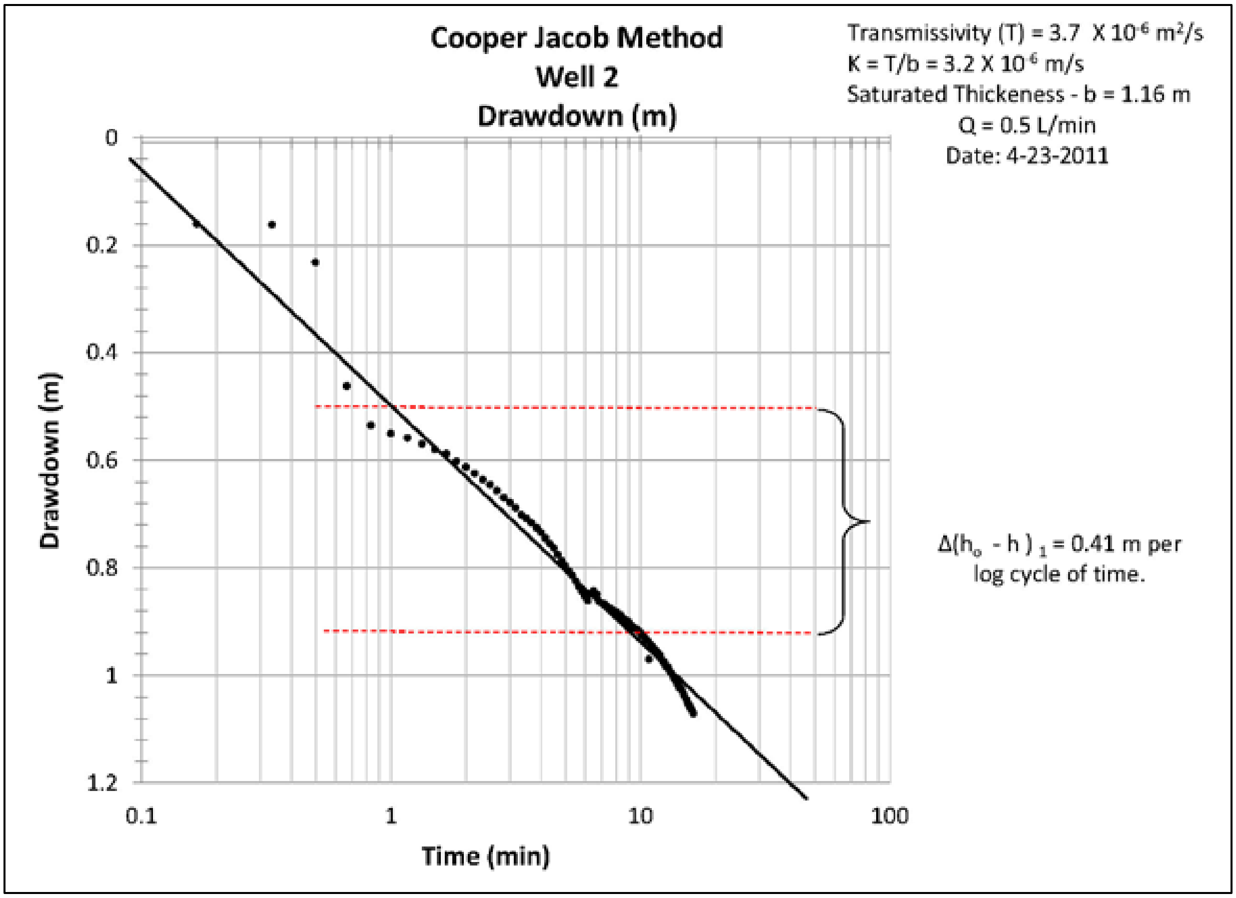


Figure 3.24 – Well 2 – A single well pump test conducted on April 23rd, 2011 estimated hydraulic conductivity of 3.2E-6 m/s and transmissivity value of 3.7E-01 $m^2$/day using the Cooper Jacob straight line method.

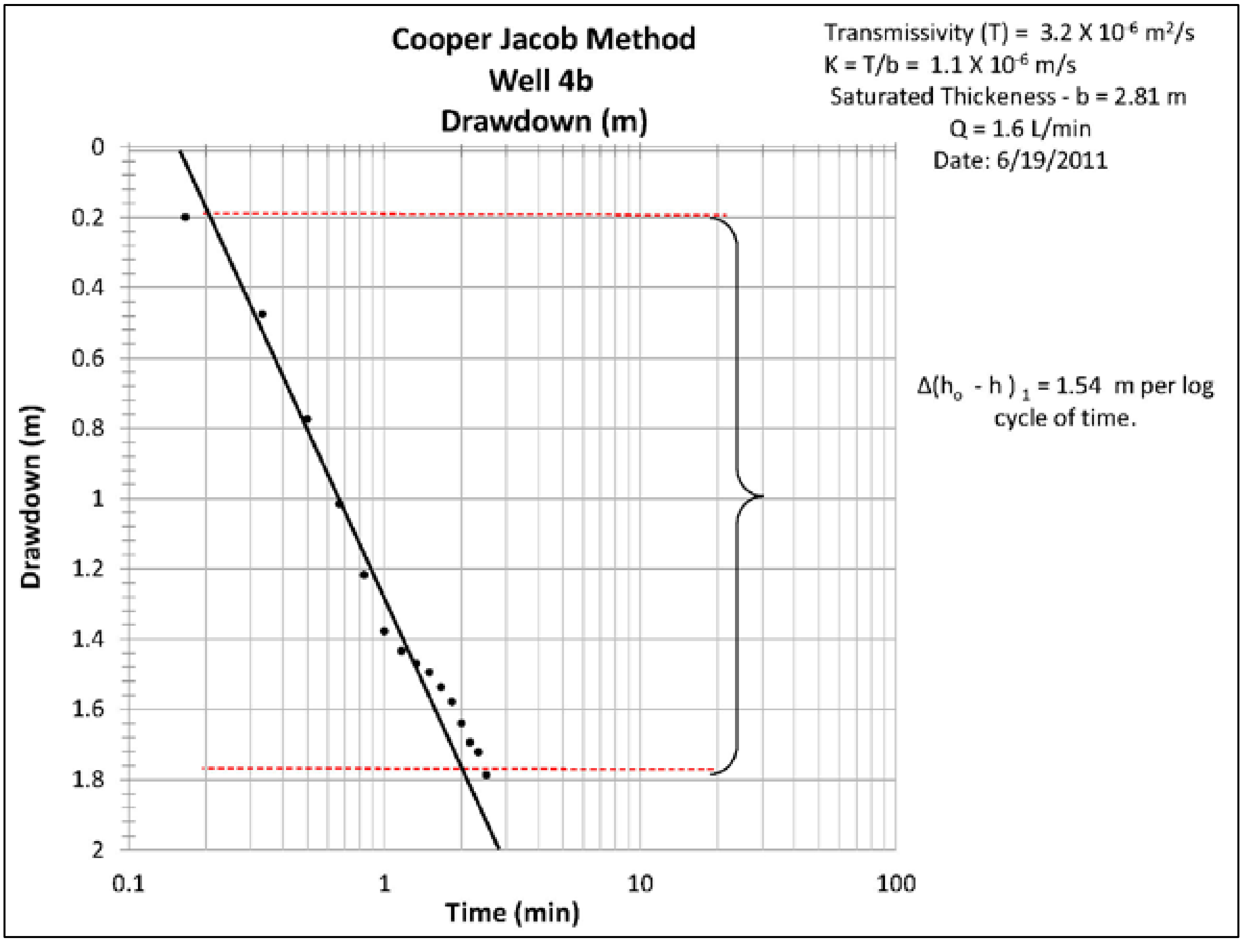


Figure 3.25 - Well 4b – Single well pump test conducted on June 19th, 2011 estimated hydraulic conductivity of 1.10E-6 m/s and transmissivity value of 3.20E-01 $m^2$/day using the Cooper Jacob straight line method.

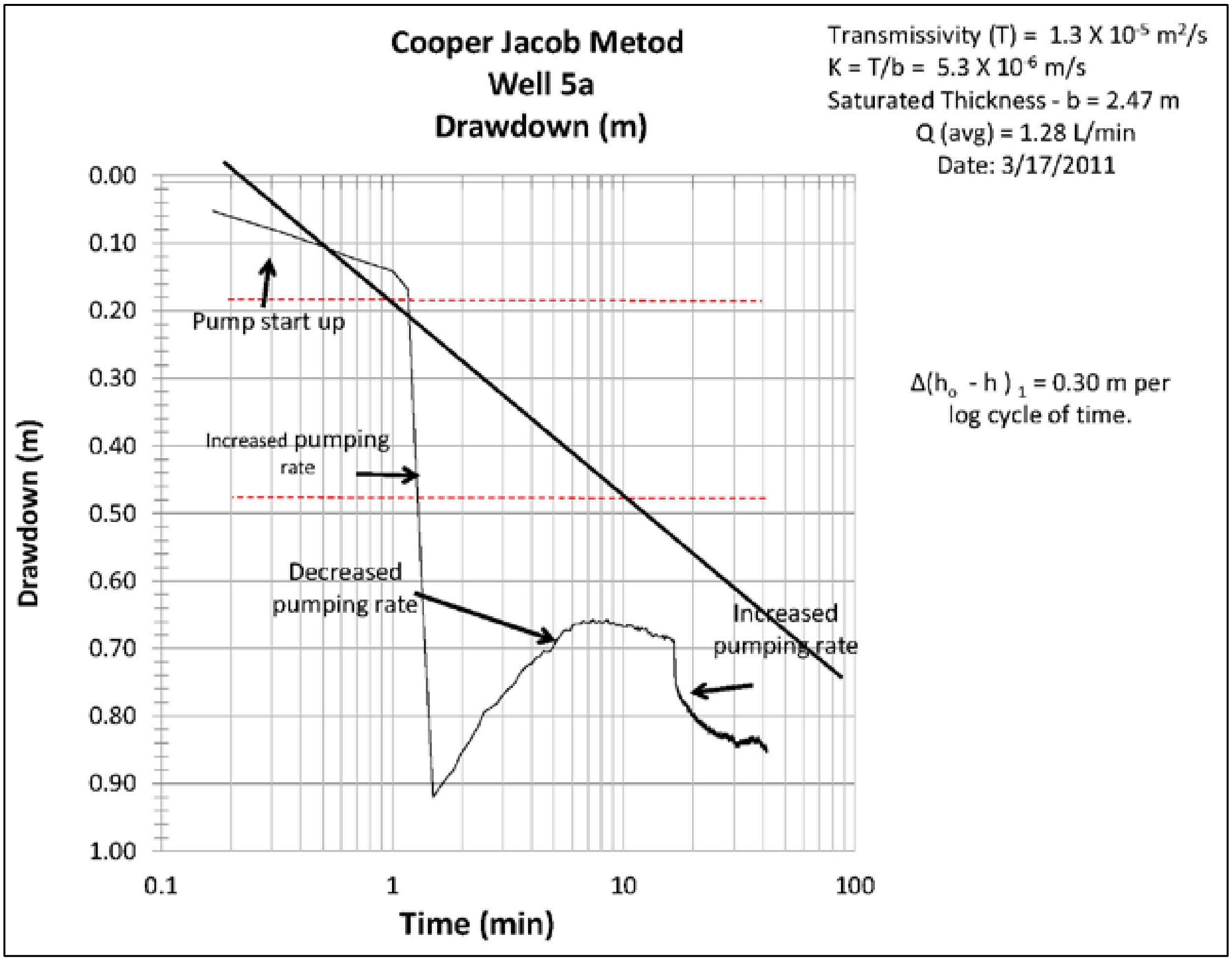


Figure 3.26 - Well 5a – A single well pump test conducted on March 17th, 2011 estimated hydraulic conductivity of 5.30E-6 m/s and transmissivity value of 1.12E+01 $m^2$/day using the Cooper Jacob straight line method with a variable pumping rate.

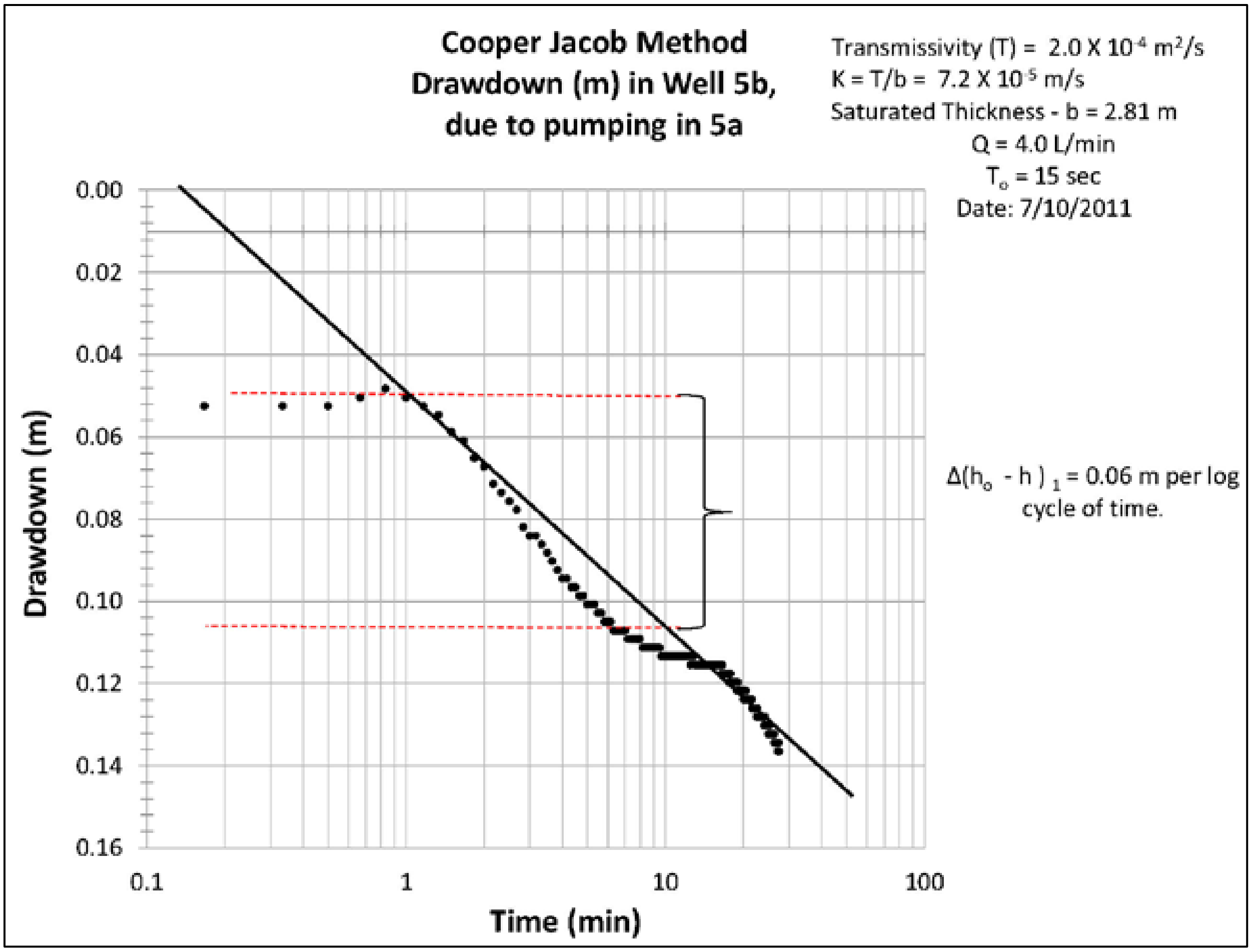


Figure 3.27 - Well 5b – Observation well drawdown for a pump test conducted on July 1st, 2011 with an estimated hydraulic conductivity of 7.20E-5 m/s and transmissivity value of 1.73E+01 m$^2$/day using the Cooper Jacob straight line method.

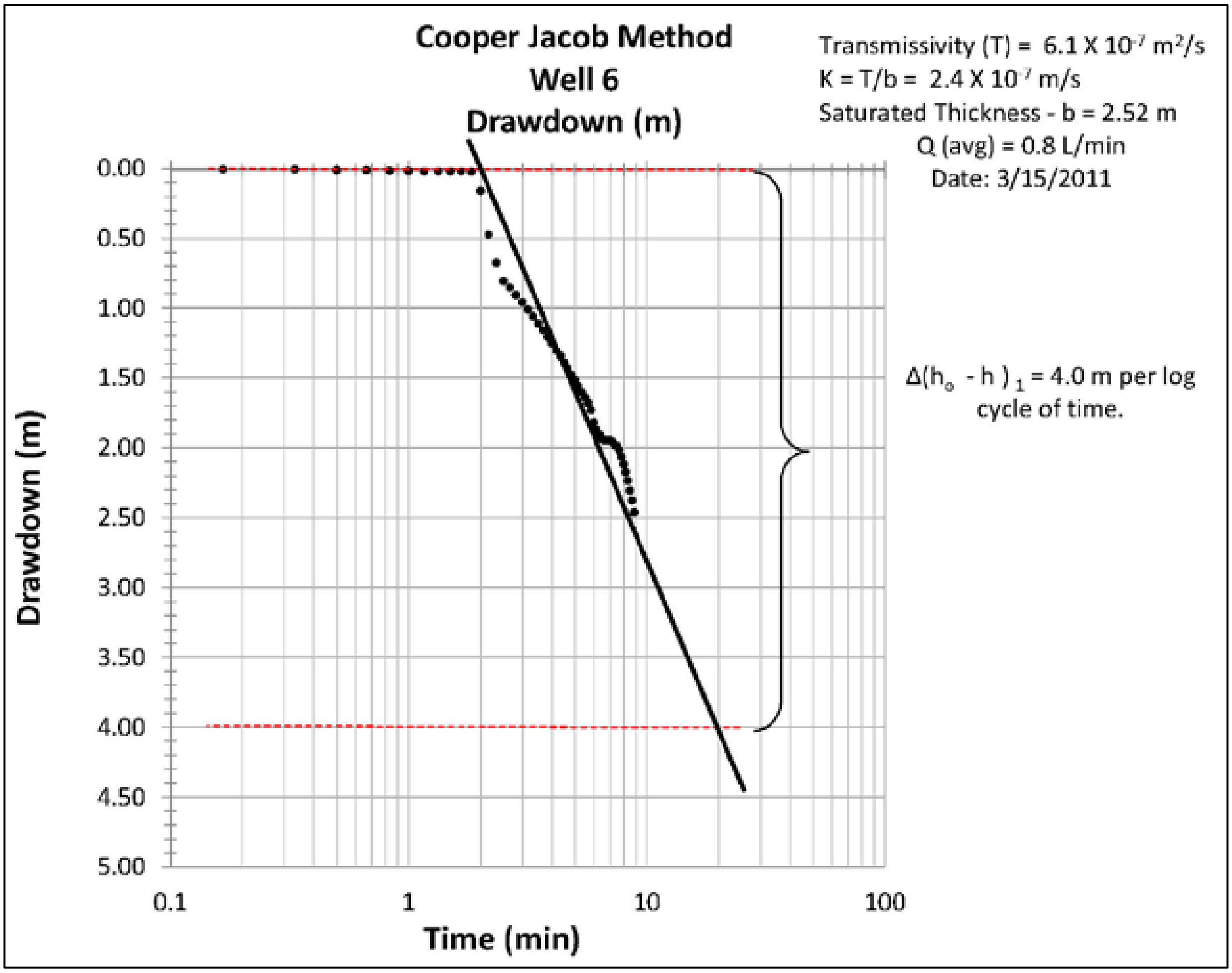


Figure 3.28 - Well 6 – Single well pump test conducted on March 15th, 2011 estimated hydraulic conductivity of 2.40E-7 m/s and transmissivity value of 9.50E-01 m$^2$/day using the Cooper Jacob straight line method.

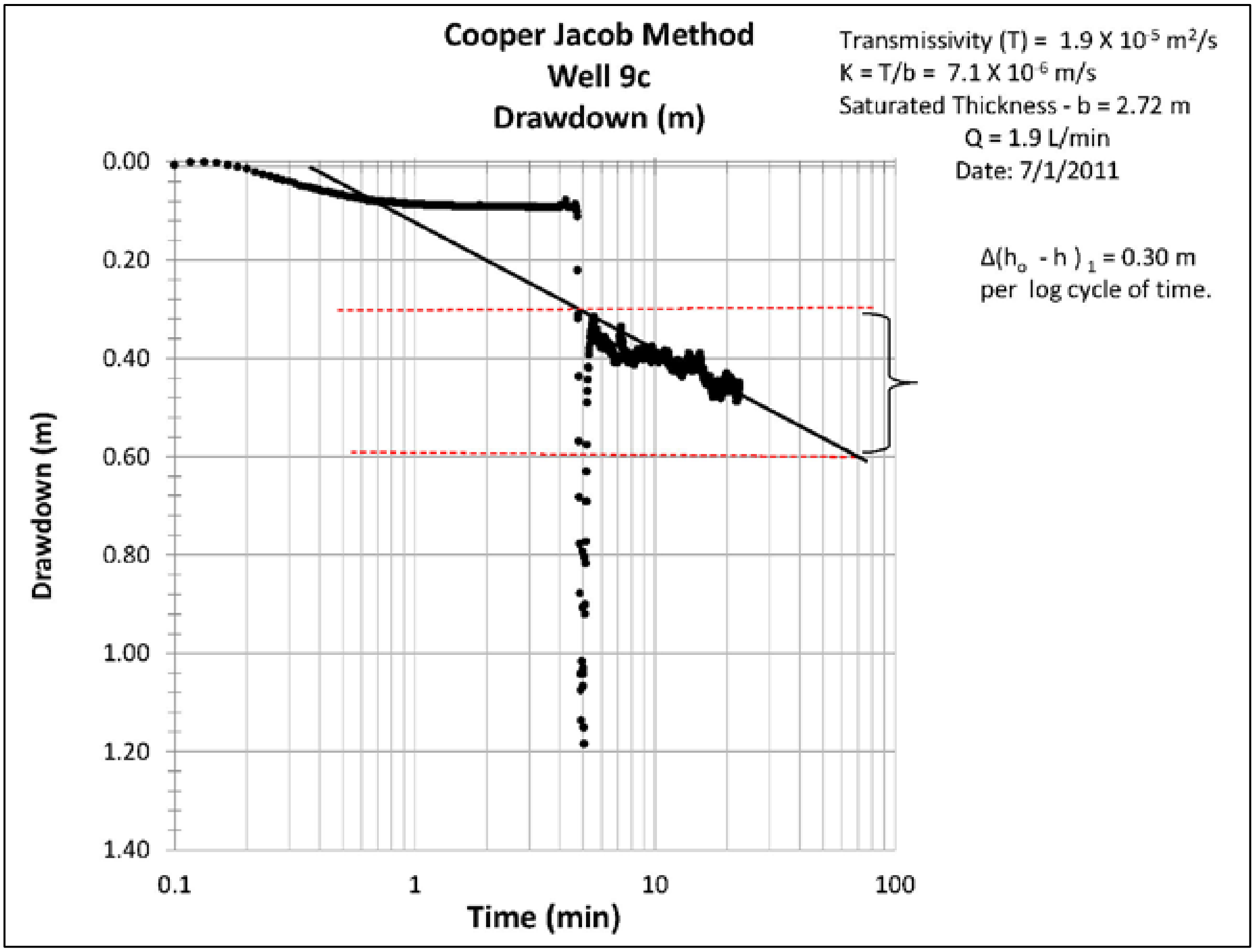


Figure 3.29 - Well 9c – Single well pump test conducted on July 1st, 2011 estimated hydraulic conductivity of 7.10E-6 m/s and transmissivity value of 1.64E+00 $m^2$/day using the Cooper Jacob straight line method.

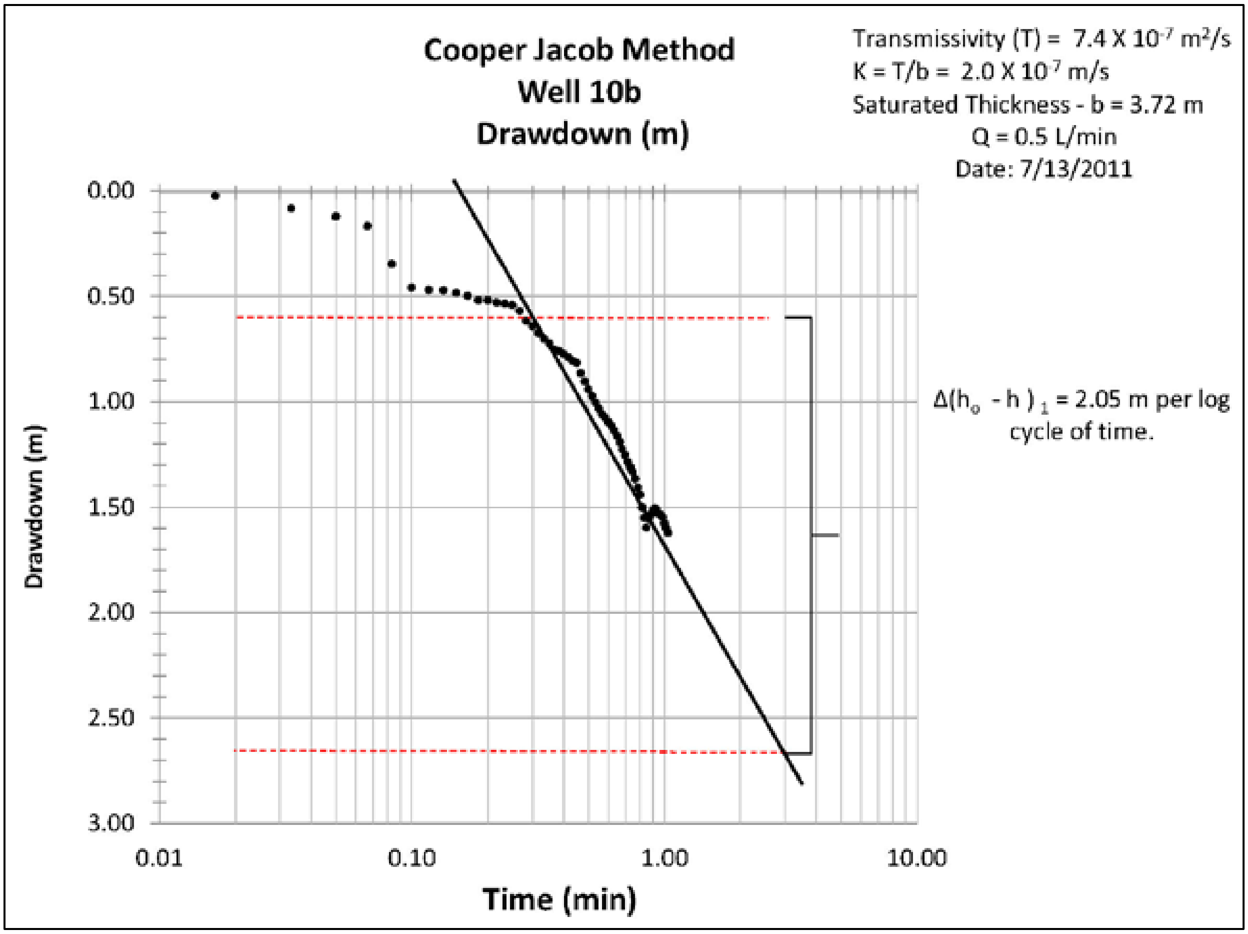
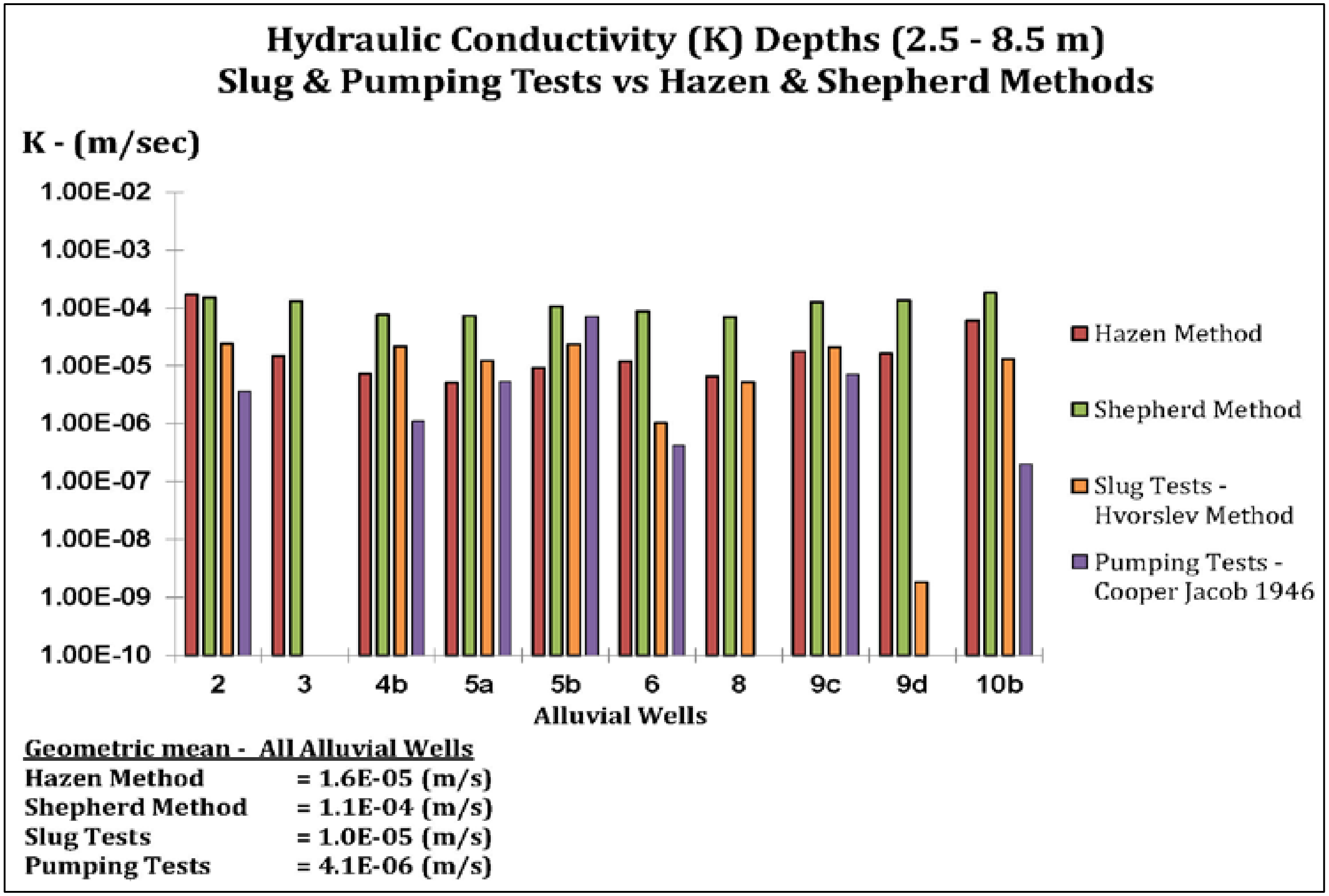


Figure 3.30 - Well 10b – Single well pump test conducted on 7-13-2011 estimated hydraulic conductivity of 2.00E-7 m/s and transmissivity value of 6.39E-02 $m^2$/day using the Cooper Jacob straight line method.



**Geometric mean - All Alluvial Wells**

**Hazen Method = 1.6E-05 (m/s)**
**Shepherd Method = 1.1E-04 (m/s)**
**Slug Tests = 1.0E-05 (m/s)**
**Pumping Tests = 4.1E-06 (m/s)**

Figure 3.31 – Comparison of K-values of the geometric mean for slug tests to the Hazen & Shepherd Methods (Hazen, 1892; Shepherd, 1989) for predicting K-values based on grainsize. The Hvorslev Method (Hvorslev, 1951) was used for slug tests and the Cooper Jacob straight line method (Cooper and Jacob, 1946) for pump tests. For pump tests, N= 1 for wells 2, 4b, 5a, 5b, 6 and 9c.

### 3.3.7 Water Level Monitoring Results – Hydrographs

Alluvial well ground water level monitoring in the alluvial wells was conducted from July 2010 to September 2011. Little River stage monitoring was conducted from January 2011 to February 2012. For most wells, monitoring concluded in March 2011 because the pressure transducers were transferred to other locations. These data are important for assessing seasonal water level trends in the aquifer and comparing them to precipitation and water levels in nearby streams (Table 3.8). For these hydrographs early and late data derived during the insertion or removal of the transducer from the well and slug and pump tests were not included in the hydrographs because these data skew statistics for the water level tendencies. See figures 3.32 to 3.39 for the alluvial well hydrographs. A short discussion of each hydrograph is provided below.

Table 3.8 – Hydrograph data statistical summary showing the mean depth to water below the top of the well (which is approximately ground surface) during 2010 – 2011.

Depth to Water Table for Hydrographs

| Well # | Mean (m) | Minimum Depth to Water(m) | Maximum Depth to Water (m) | Observation Range |
|---|---|---|---|---|
| 2 | 0.78 | -0.23 | 1.85 | July 2010 - March 2011 |
| 4b | 4.87 | 2.80 | 6.68 | " |
| 5a | 1.05 | 0.79 | 2.61 | " |
| 5b | 1.53 | 0.68 | 3.84 | " |
| 6 | 0.34 | -0.08 | 1.41 | " |
| 9c | 3.60 | 2.28 | 5.10 | " |
| 9d | 4.13 | 3.59 | 4.49 | June 2010 - September 2011 |
| 10b | 3.31 | 1.92 | 3.97 | " |

Well 2 was monitored between July 2010 and September 2011. This well is centrally located on the farm adjacent to two low wetland areas. The hydrograph shows moderate to rapid well responses to small and heavy rainfall events. Seasonal variation began in August and September with seaonally high water levels peaking Feburary through April. May begins the second major seasonal variation period for low groundwater levels peaking in September and October. From October to February the depth to water was higher than the annual mean of 0.78 (m). The hydrograph shows water levels exceeding the well cap from precipitation and groundwater recharge from February until the end of April.

Well 4b was monitored between July 2010 and March 2011. This well is located approximately 70 meters from Ellejoy Creek on the northwest section of the farm. The hydrograph shows moderate well responses to small and heavy rainfall events. Three distinct water level trends occur in 4b, a seasonal low water table averaging ~ 5.5 (m) from the surface held up for four months. In September, a second seasonal water table existed for ~ 5 months averaging 5.0 meters below the surface. Spring seasonal high levels begin in Feburary through April to May with depth to water of ~ 3.0 meters. Well 4b is likely directly connected to Ellejoy Creek through a gravel layer and it rests on a contact between the Lenior Limestone and Blockhouse Shale.

Well 5a was monitored between July 2010 and March 2011. This well is located ~ 30 meters from the central ditch near the middle point of the drainage. Hydrograph data shows moderate well responses to small and heavy rainfall events. During the seasonal highwater table, 5a was significantly influenced by groundwater recharge from the upland area to the northeast. This well reponds to precipiation and recharge in a similar manner to 4b. The well screened interval rests on a very fine sand layer covering an unknown area, however, this layer apparently extends over well 5b confining contaminants based on geochemical data and pump and slug test responses.

Well 5b is located ~ 1.0 meter from 5a. This hydrograph mirrors the responses of 5a and was productive for pumping tests.

Well 6 is located on the northeast property line of the farm adjacent to a wetland. This hydrograph shows a similar pattern of well 2. The hydrograph shows water levels remained near the ground surface from precipitation and groundwater recharge from October until the end of April. A large spring located at the base of the upland area to the northeast contributes constant recharge to well 6, field 2 and field 4 throughout the year.

Well 9c is located on the southwest section of farm approximately 50 meters from the Little River. This hydrograph shows a very similar seasonal pattern to wells 4b, 9d and 10b. The hydrograph shows less response to precipitation. The screened intervals for 9c and 9d rest in a gravel layer (see figures 3.40, 3.41 and 3.42). Well 9c does not extend to bedrock, instead, it rests on top of a very fine sand layer. A large spring (Figure 3.41) discharges to the Little River along a 200 meters of river front adjacent to and very likely through the screened intervals for wells 9c and 9d. The groundwater temperature for both wells is very similar. Groundwater temperature in 9c averages 17.0 C° on an annual basis. Well 9d which is 1.8 meters deeper has a mean annual groundwater temperture of 17.5 C° suggesting that groundwater is flowing by the screened intervals for discharge into the Little River. Alternatively, a karst window may exist that mixes groundwater and river water along the sinkhole boundary and gravel layers. The geochemcial data and physical groundwater properties indicate that 9c and 9d are connected in some manner to the Little River.

Well 9d is located in a nest of 4 wells on the southwest section of the farm approximately 50 meters from the Little River. The screened interval rests on bedrock and is surrounded by a thick very fine sand layer reducing the well resposiveness to rainfall events. This well is also the deepest well on the site.

Well 10b is located in a nest of 2 wells on the southwest section of the farm adjacent to the central ditch approximately 50 meters from the Little River. The mean depth to water for well 10b was 3.3 meters for this period.

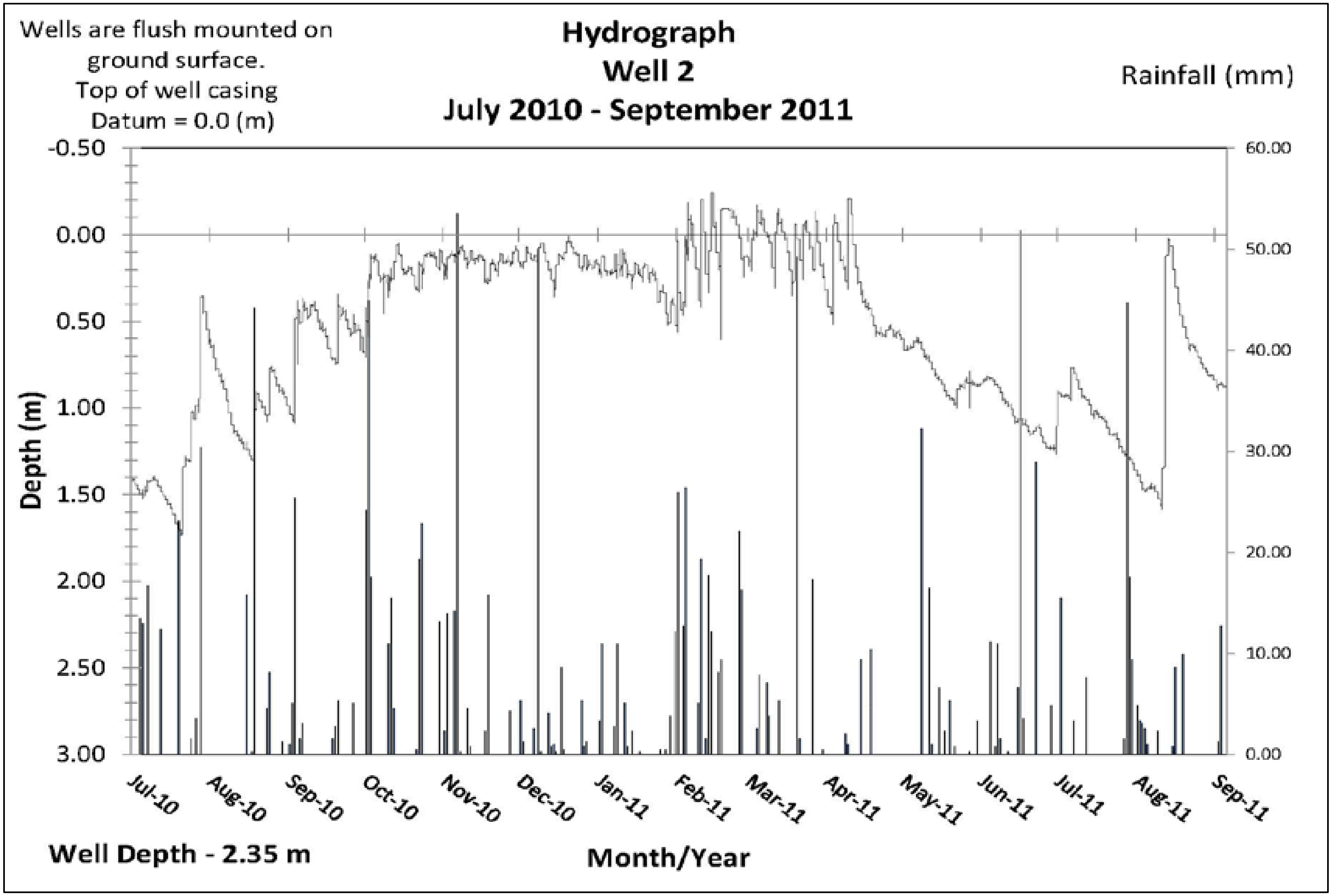


Figure 3.32 –Hydrograph - Well 2.

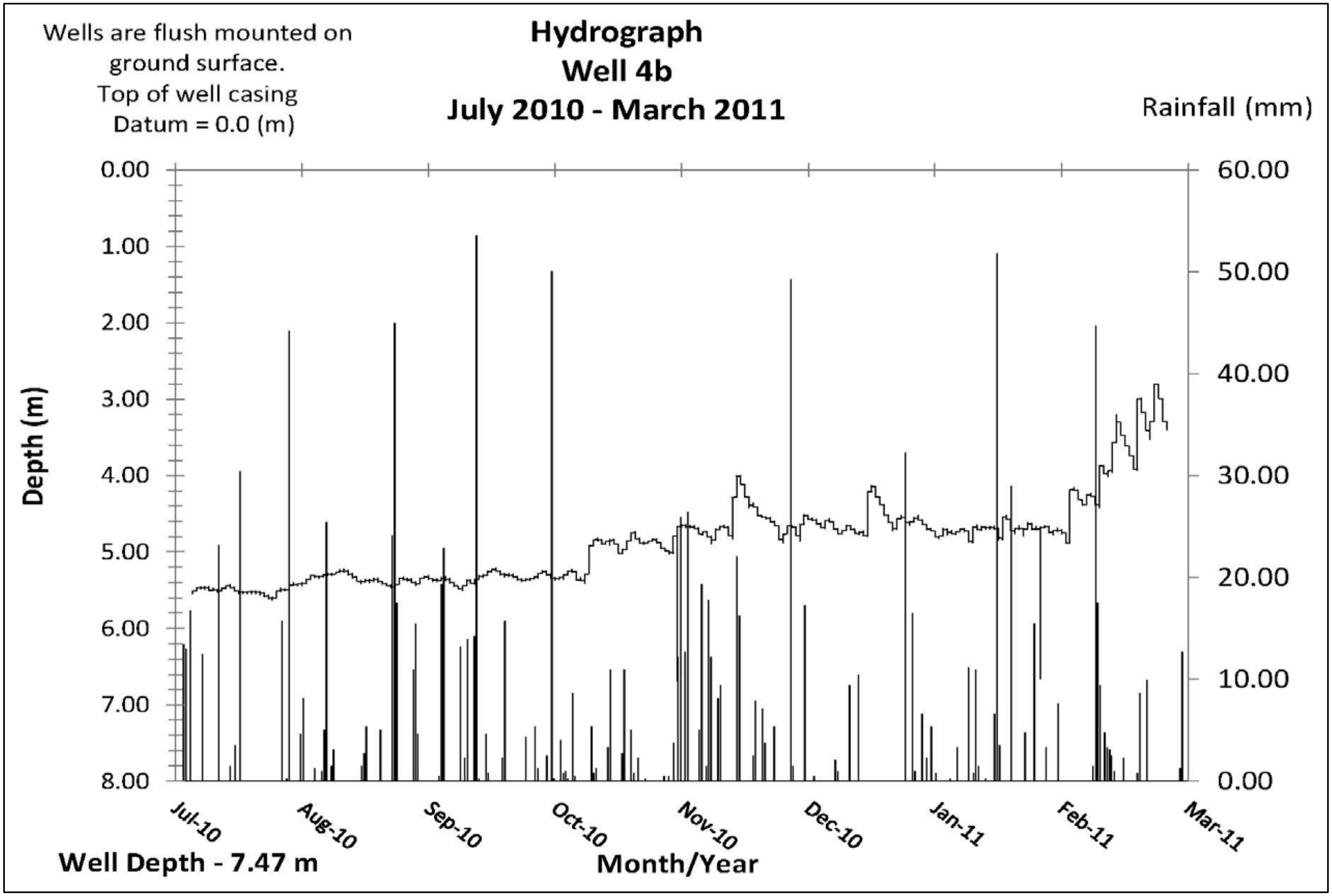


Figure 3.33 - Well Hydrograph 4b.

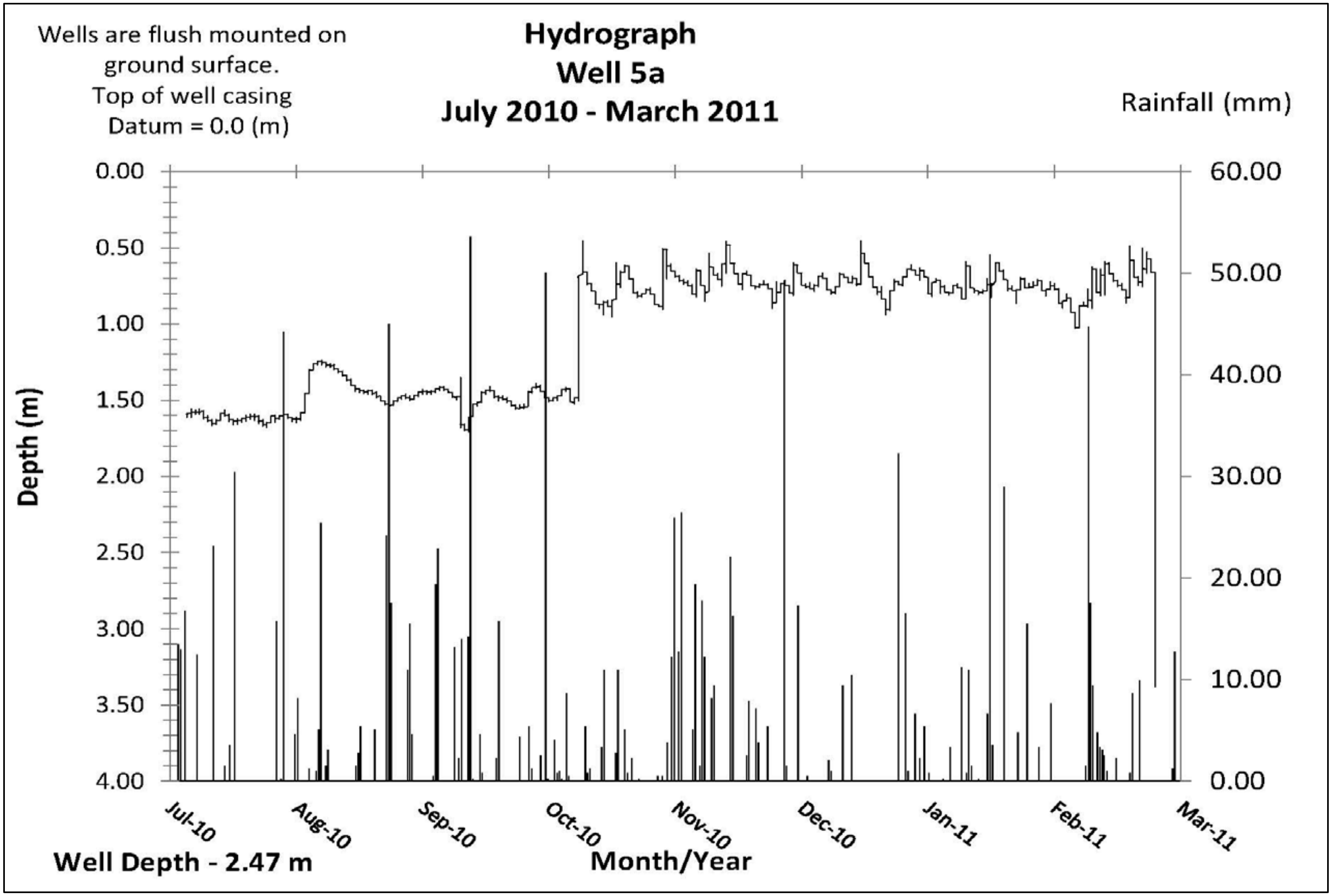


Figure 3.34 - Hydrograph Well 5a.

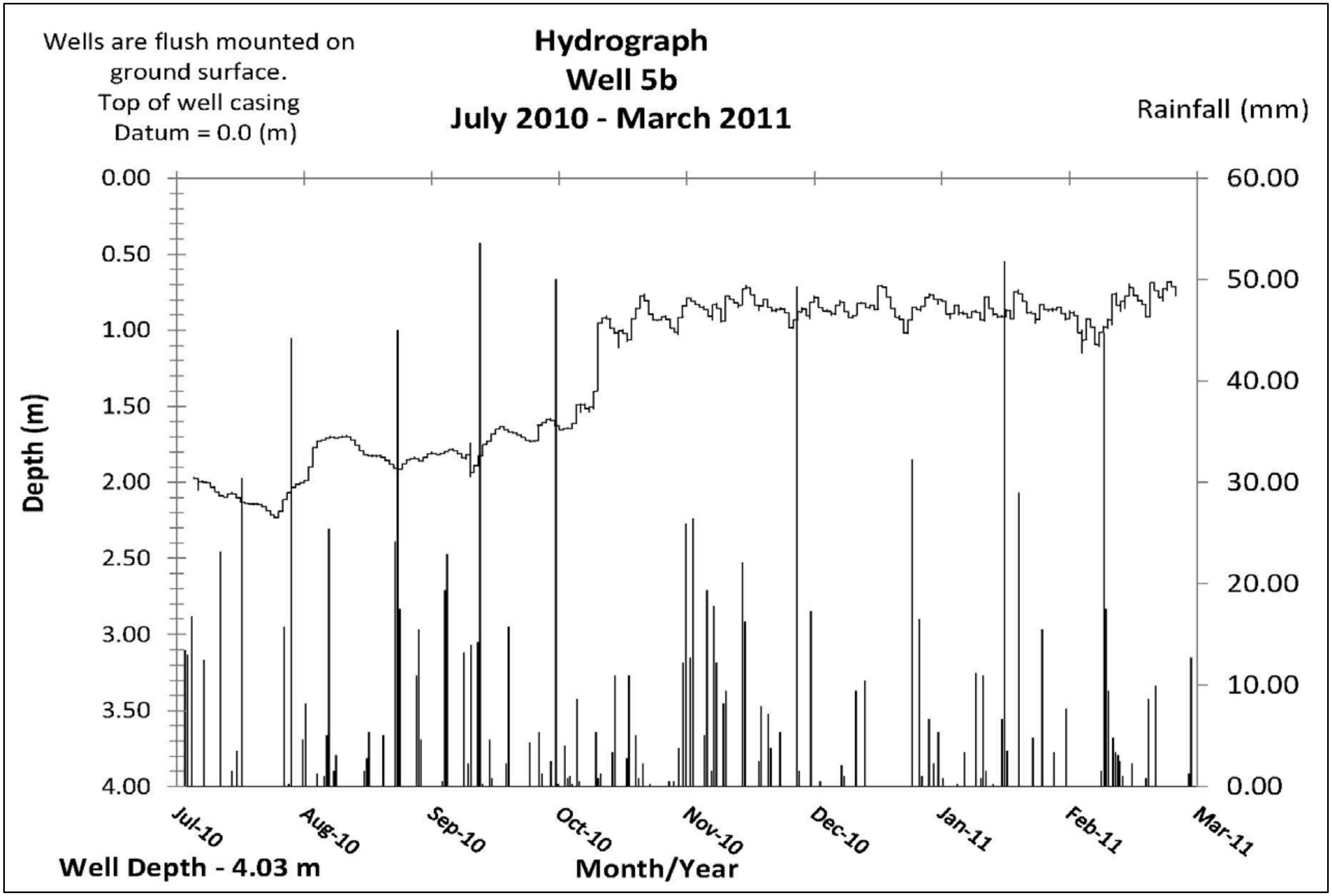


Figure 3.35 - Hydrograph well 5b.

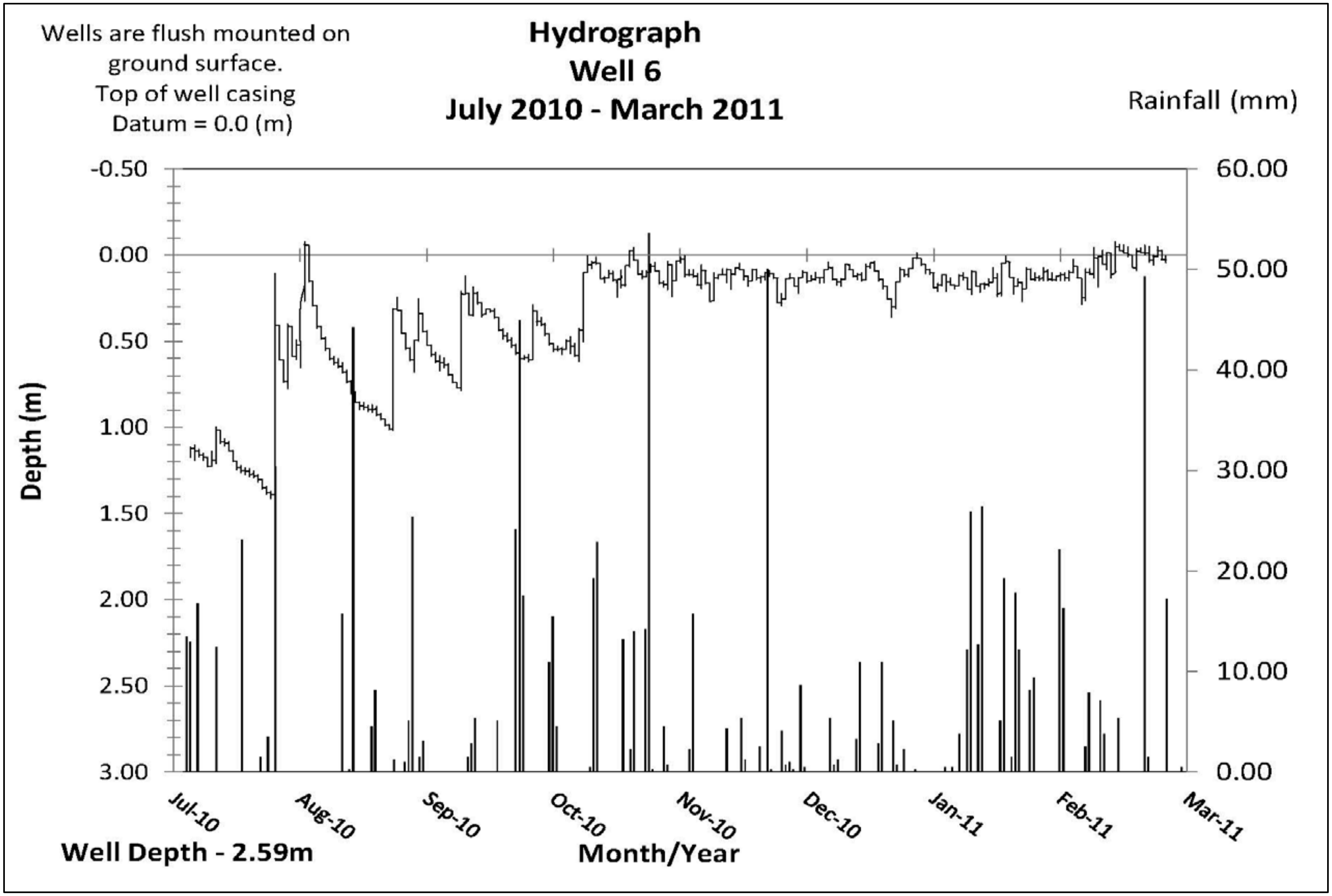


Figure 3.36 –Hydrograph well 6.

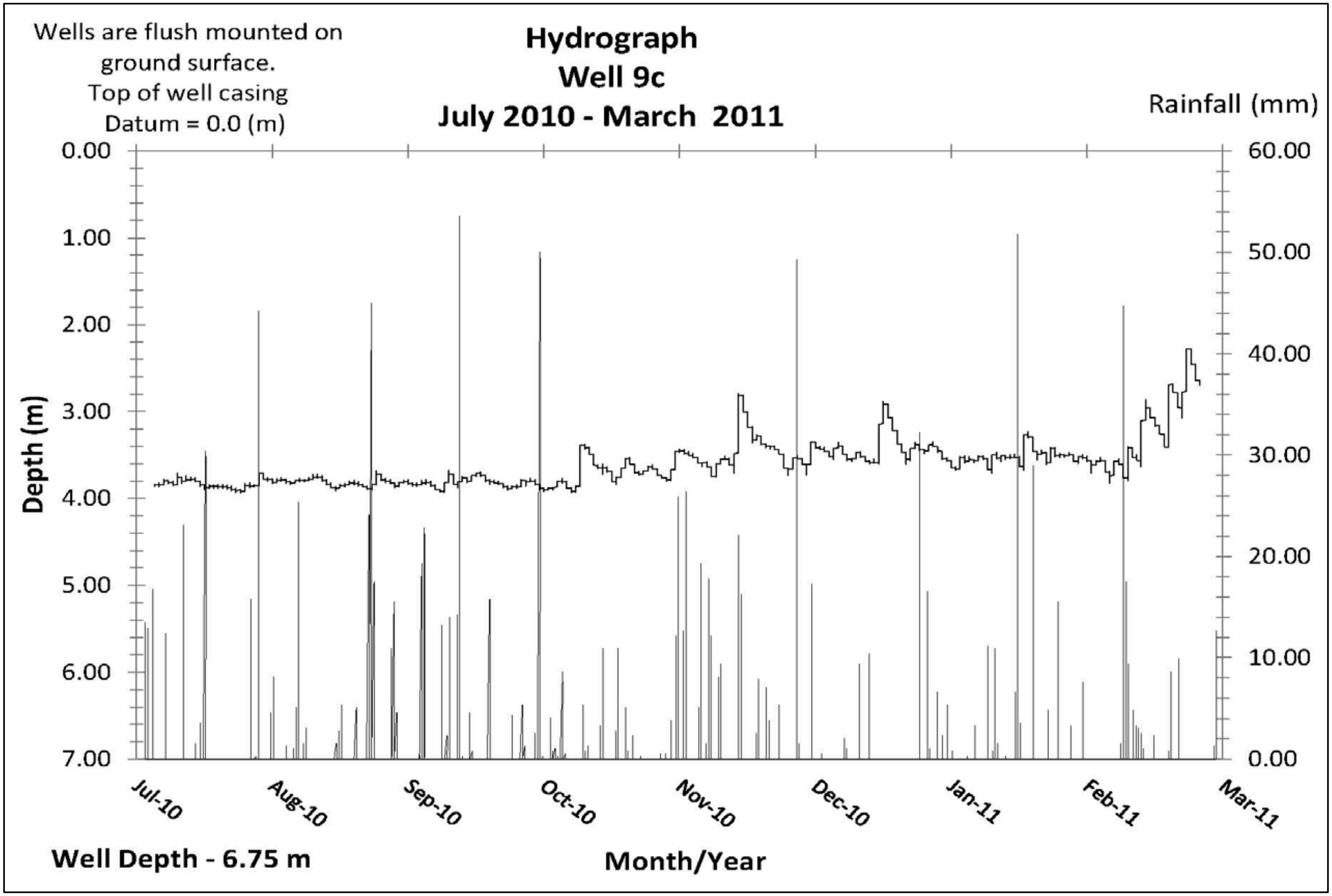


Figure 3.37– Hydrograph well 9c.

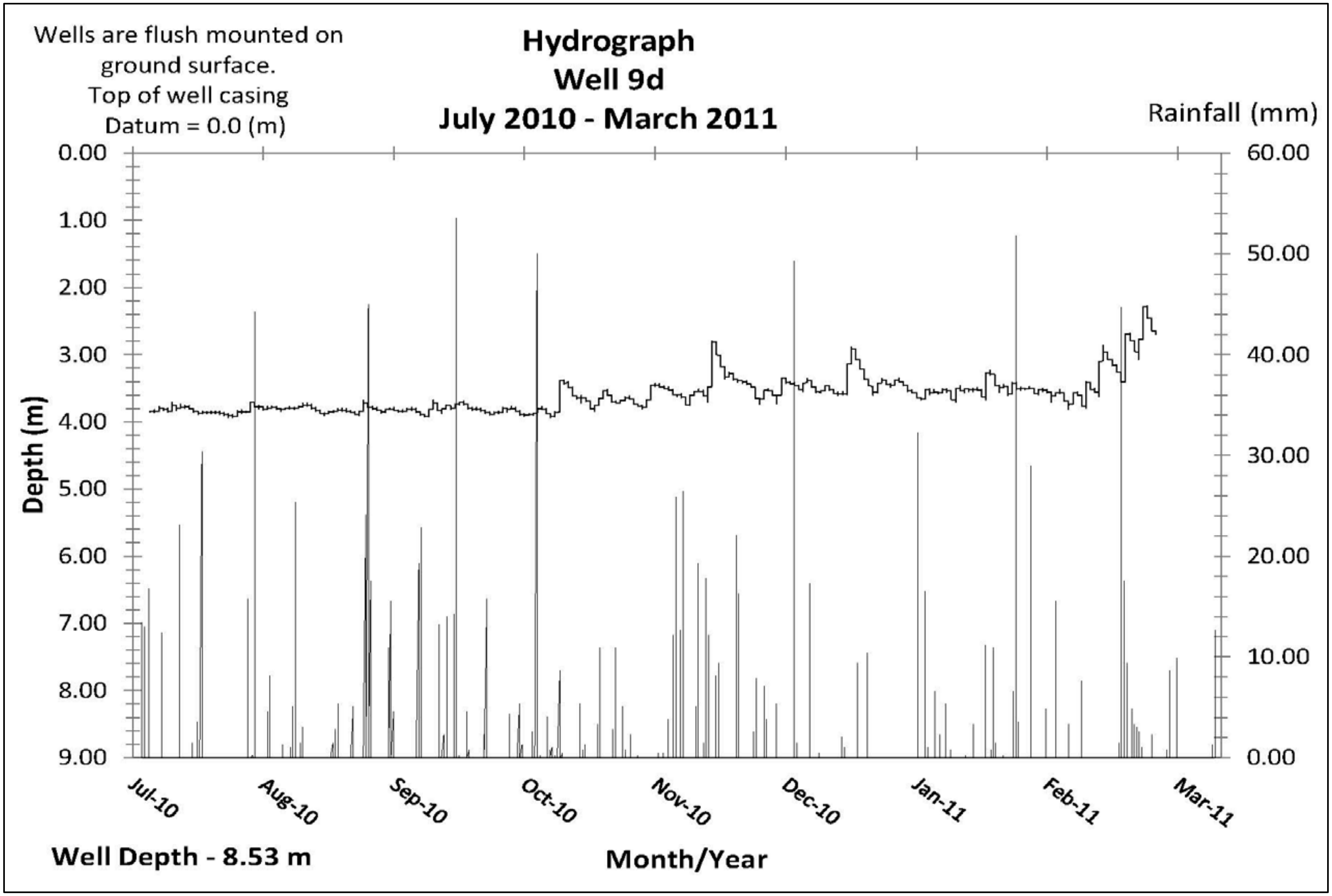


Figure 3.38 – Hydrograph well 9d.

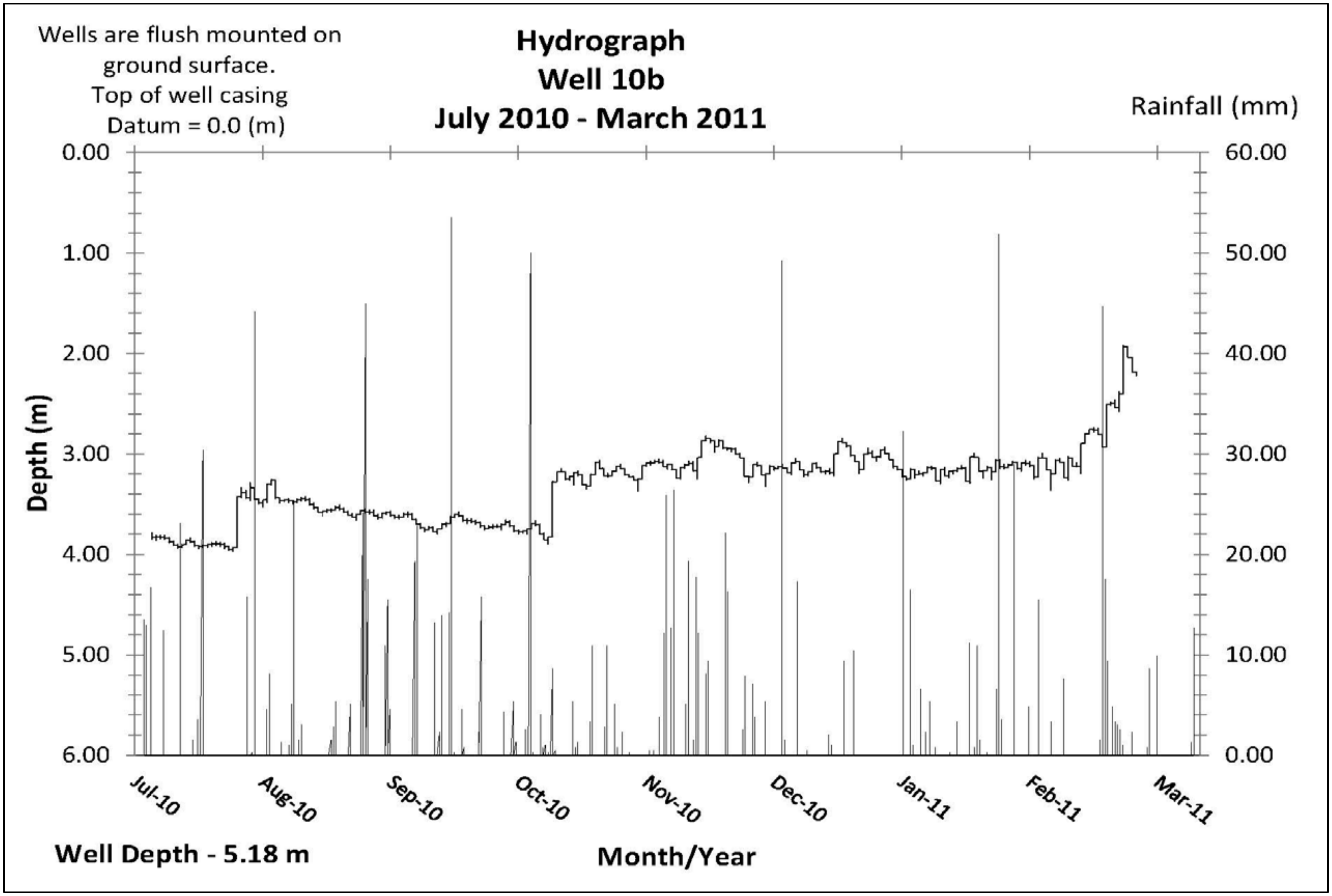


Figure 3.39 - Hydrograph well 10b.

### 3.3.8 Hydrostratigraphic Groundwater Flow Patterns

The alluvial well hydrographs shown in the previous section indicate that infiltration from ground surface to the wells is rapid, within a few hours to a few days after a rainfall event. However, below the water table, flow in the alluvium is expected to be predominantly horizontal because of the contrast in hydraulic conductivity between the alluvium and the bedrock that underlies the site. Flow in the alluvium will tend to be toward the nearest surface drain: namely, the Little River, Ellejoy Creek or the central ditch. The constructed wetland on the north side of the flood plain will also act as a local drain for groundwater flow.

Flow in the shale bedrock, which underlies about 80% of the floodplain is expect to be much less than the alluvium and will mainly follow the NE-SW strike of the Bedding, where fracture are more common. This NE-SW trend of bedrock flow has been observed at other sites in the Valley and Ridge (Cook et al., 1996). Flow in the shale bedrock under the floodplain is expected to be relatively shallow (a few meters to tens of meters) because of the usual decline in fracturing with depth and the low relief of the water table.

Flow in the limestone/dolostone is expected to be much greater than in the shale, because of the presence of solution cavities along the NE-SW line of the limestone shale contact. As a result the depth to water in the alluvium should be greater than areas underlain by shale. Again, flow in the limestone should be predominantly NE – SW, because of the cavities and conduits tend to follow strike of bedding.

Hydrostratigraphic flow profiles were also developed from the stratigraphic cross-section transects using the stratigraphic cross-sections as base maps (Figure 3.0.13).

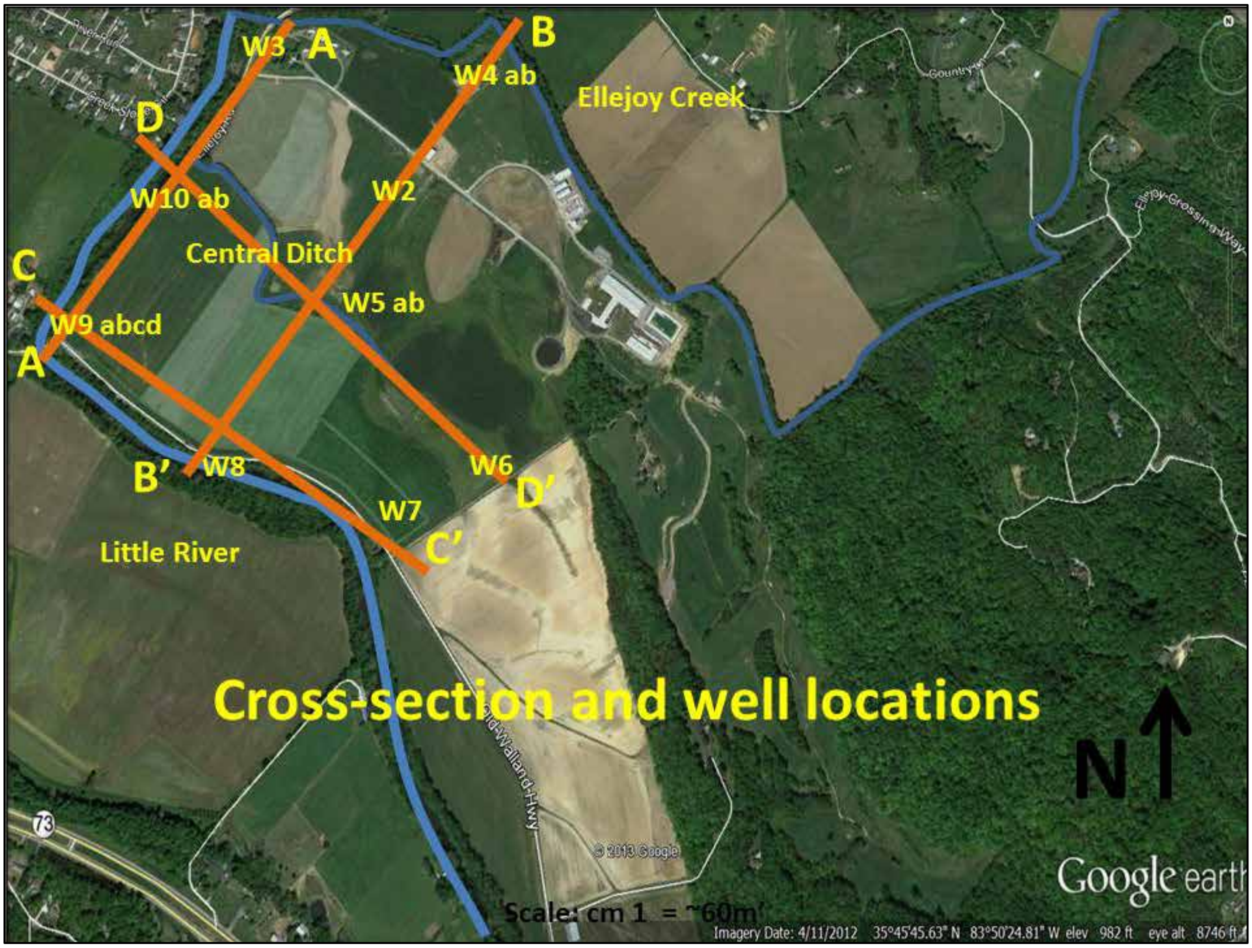


Figure 3.40 – Cross-section and well locations, Little River Dairy Farm.

Scale for the cross-sections is given meters with vertical and horizontal dimensions provided from survey data collected by Dr. Andrea Ludwig, Robert Hunter and Joe Sarten, P.E. (Ludwig, 2011; Sarten, 2012-2013). Cross-section transects were labeled A-A’, B-B’, C-C’ and D-D’ to coincide with the stratigraphic sections. The groundwater table elevations in these diagrams represent the average groundwater table over a 1 year period from 2010 to 2012 at LRDF. Head levels in the wells fluctuate approximately +/- 0.30 – 0.50 meters seasonally.

Transect A-A’ stretches approximately 1,250 meters from the Little River to Ellejoy Creek and includes Well 9abcd, 10ab and Well 3. Transect A-A’ is underlain primarily by the Longview Dolomite (Olv) with the exception of Chepultepec Dolomite (Oc) that outcrops near Ellejoy Creek. The hydraulic gradient of the Little River drops 2 meters or 0.18 % from the Little River Bridge to confluence with Ellejoy Creek. The hydraulic gradient from Well 9 groundwater table to the Little River is approximately 6.8%. The directional groundwater flow characteristics of the filled sinkhole run along strike NE to SW to the Little River. Field reconnaissance in this area by Dr. Sidney Jones and the author in Spring of 2011 revealed elevated specific conductance levels of 350 – 450 uS/cm along a 100 meter reach of dispersed groundwater discharge to the stream segment as shown by figure 3.42. The specific conductance of the Little River a few meters from the river edge ranged from 62 – 64 uS/cm indicative of groundwater discharge from the sinkhole area directly adjacent to and on strike with river (Figures 3.40 and 3.41). The hydraulic gradient from Well 3 to Ellejoy Creek is approximately 3.8 percent. Well 3 was dry since its initial installation.

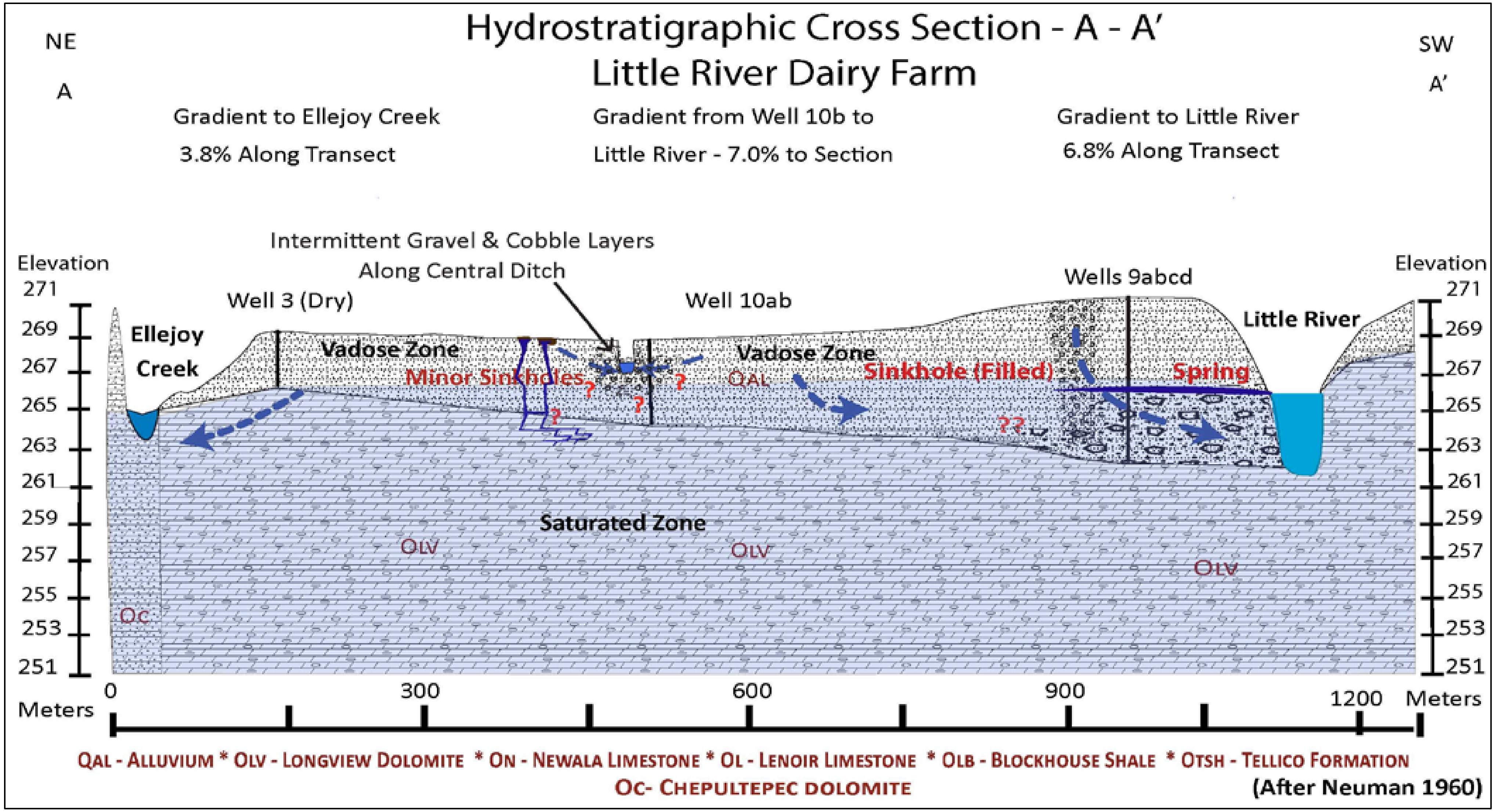


Figure 3.41 - Hydrostratigraphic Cross-section A - A’ for the LRDF property boundaries (After Neuman 1960).

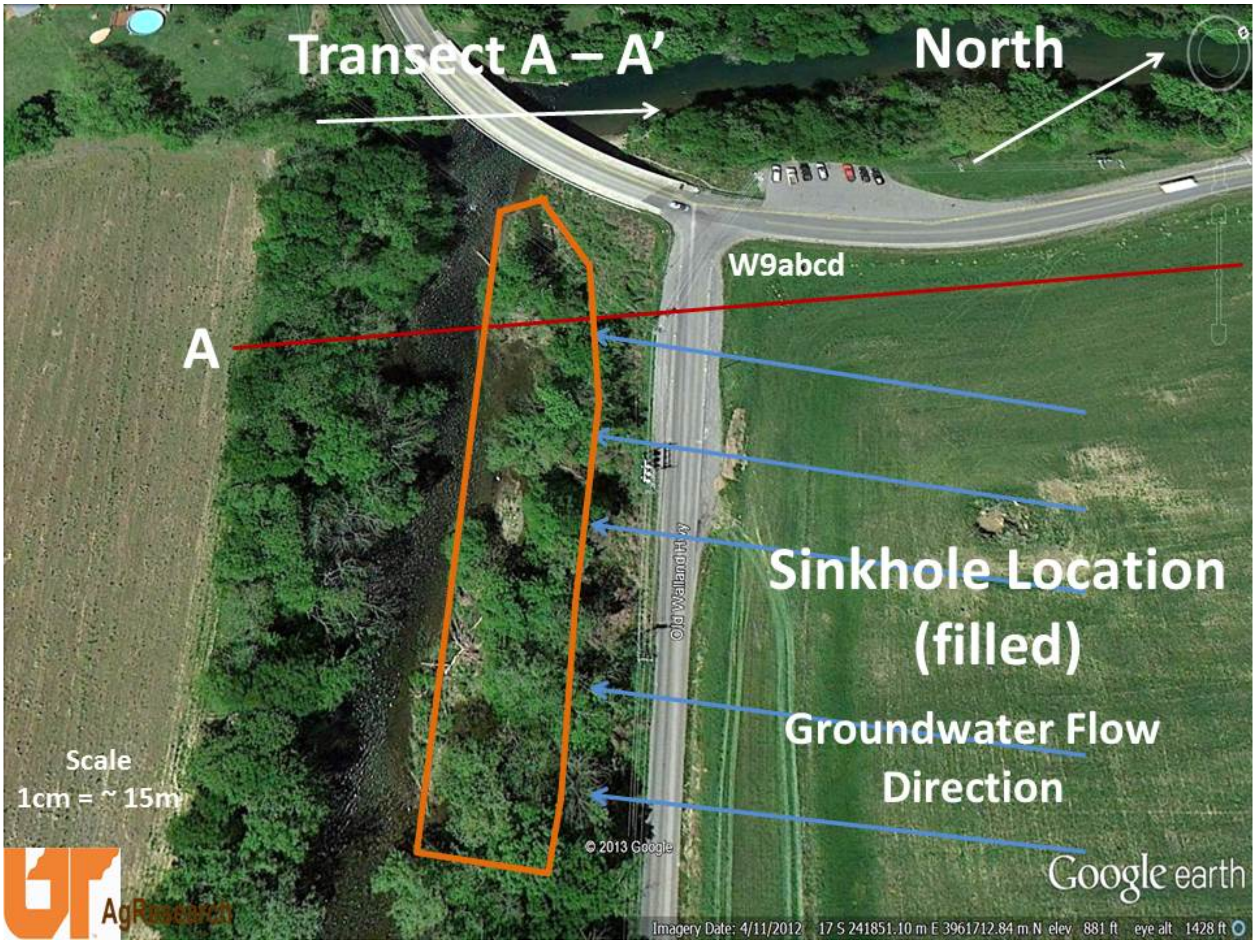


Figure 3.42 – Little River spring and sinkhole relationship. Field reconnaissance by Dr. Sidney Jones and the author in Spring of 2011 revealed elevated specific conductance levels of 350 – 450 uS/cm along a 100 meter reach of Little River (Orange outline) indicating the influence of groundwater discharge along the NE bank of the river. Little River specific conductance levels a few meters away ranged from 62 – 64 uS/cm.

Transect B-B' stretches approximately 1,240 meters from the Little River to Ellejoy Creek and includes Wells 8, 5ab, 2 and 4ab.(Figure 3.42) . Recharge from the uplands directly east of the site causes a dominant groundwater mound between wells 4ab to well 8. The groundwater in this section of the alluvium flows parallel to Ellejoy Creek and the Little River before discharging through the shallow bedrock systems. Near the location of well 2, a groundwater divide splits the groundwater flow in two opposite directions, northwest and southwest. This hydraulic gradient flows across strike or perpendicular (east to west) to the cross-section toward the Little River until it reaches Blockhouse Shale/Lenoir Limestone contact. Along these contacts, the groundwater flow direction becomes strike controlled trending either northwest or southwestwardly and should be considered dominant flow paths to Ellejoy Creek and the Little River. Along the central ditch near wells 5ab, field tiles create artificial drainages for groundwater which is converted to surface water drainage direct to the Little River. The hydraulic gradient from Wells 4ab to Ellejoy Creek is approximately 1.1%. The hydraulic gradient from Well 8 to the Little River is 7.5% gradient and only sustains groundwater during seasonal high water tables.

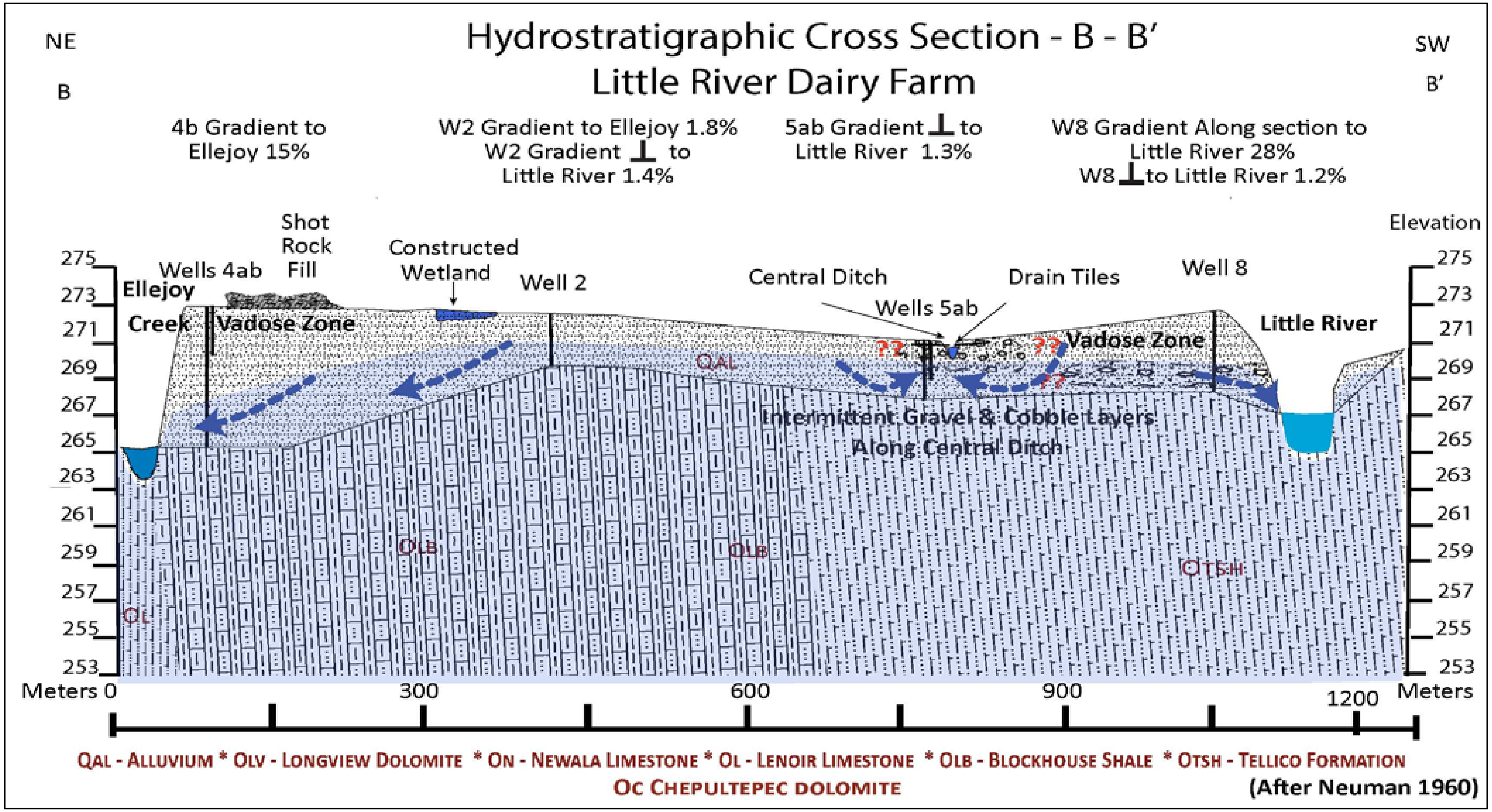


Figure 3.43 - Hydrostratigraphic Cross-section B-B'for LRDF property boundaries (After Neuman 1960).

Hydrostratigraphic transect C-C’ stretches approximately 1,240 meters between Well 7 and Well 9 to the Little River. (Figure 3.44). Bedrock geology beneath Transect C-C’ is the Tellico Formation, Blockhouse Shale, Lenoir Limestone, Newala Limestone and Longview Dolomite. Intermittent silts, fine sands and sparse clay layers coupled with observations and insights into the distribution of gravel, cobble and boulder size deposits from past river migrations across the floodplain, present a perplexing picture of groundwater flux along this transect. Hydraulic gradients along this transect range from 15.7% –1.0% to the Little River. The groundwater flow path is very similar to the B-B’ where groundwater flows perpendicular to strike across the Tellico Formation and Blockhouse shale until it reaches the Lenoir Limestone contact and begins a strike controlled flow path toward the Little River to the southwest.

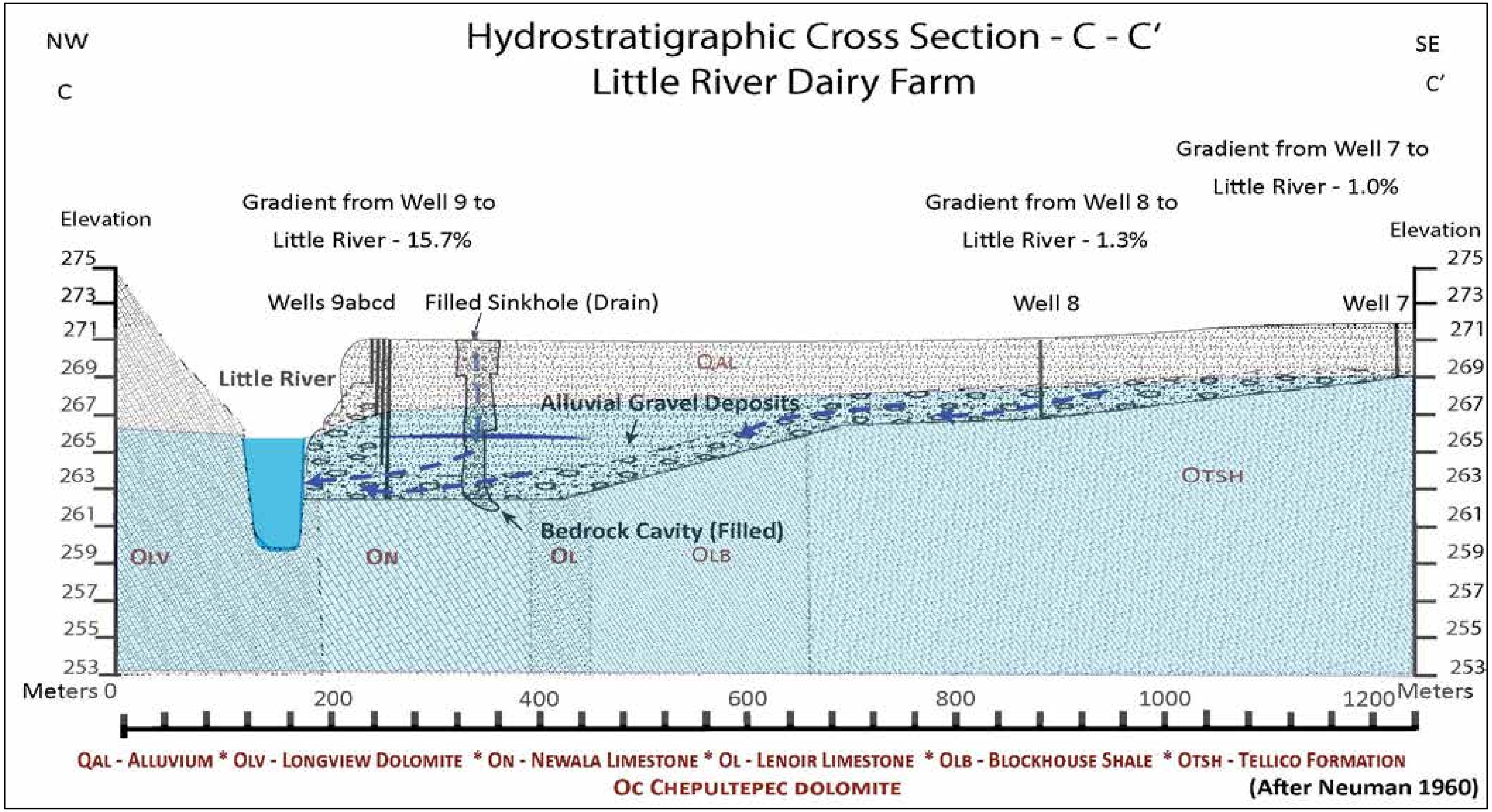


Figure 3.44 Hydrostratigraphic Cross-section C- C’for LRDF property boundaries (After Neuman 1960).

Hydrostratigraphic Transect D-D’ stretches approximately 1,200 meters between Well 6 and Well 10b to the Little River (Figure 3.45). Bedrock geology beneath Transect C-C’ is the Tellico Formation, Blockhouse Shale, Lenoir Limestone, Newala Limestone and Longview Dolomite. Intermittent silts, fine sands and sparse clay layers coupled with observations and insights into the distribution of gravel, cobble and boulder size deposits from past river migrations across the floodplain, present a perplexing picture of groundwater flux along this transect. Hydraulic gradients along this transect range from 0.7% – 2.0% to the Little River. The groundwater flow path is very similar to the B-B’ where groundwater flows perpendicular to strike across the Tellico Formation and Blockhouse shale until it reaches the Lenoir Limestone contact and begins a strike controlled flow path toward the Little River to the southwest.

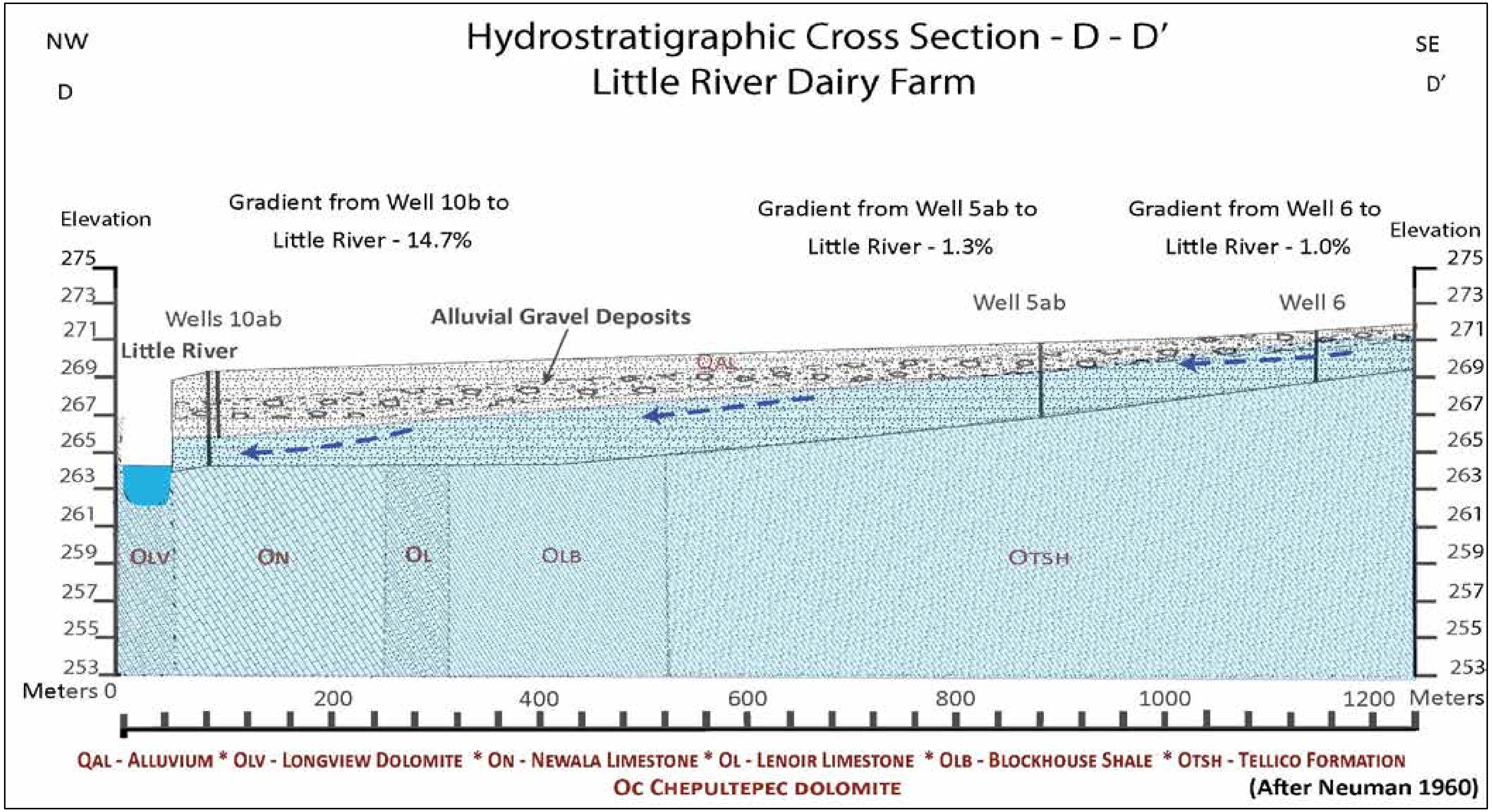


Figure 3.45 - Hydrostratigraphic Cross-section D- D' for the LRDF property boundaries (After Neuman 1960).

### 3.3.9 Water Quality

The water quality results represent four to fifteen (4-15) sampling events for the alluvial wells from November 2009 to August 2012. Efforts focused on sampling productive wells where borehole water could be pumped for a minimum of three well volumes prior to taking a sample. This is recommended by EPA, along with low flow pumping and monitoring of field parameters, to obtain samples that are representative of water in the aquifer (Aller and Bennett, 1991). The wells sampled for water quality included the following numbers: 2, 4b, 5a, 5b, 6, 8, 9c, 9d and 10b. Wells that were not sampled, because they were dry or had very low water levels, included 3, 4a, 7, 9a, 9b and 10a. Well number 1 was never drilled and hence was not sampled.

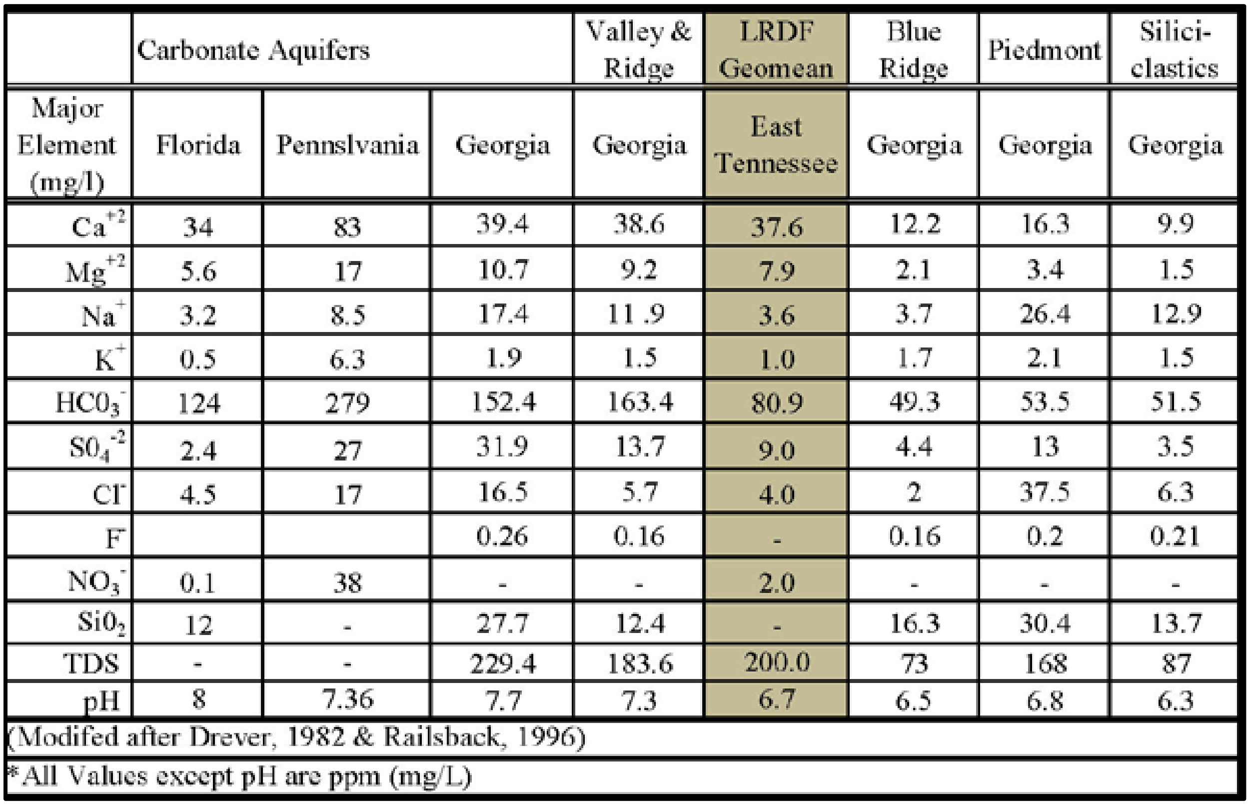
The sampling program began in November 2009 with the following analytes: total solids, total nitrogen (as N), nitrite (as N), nitrate (as N), ammonia (as N) as nitrogen, total carbon, chloride, sulfate, total phosphorus, phosphate, biochemical oxygen demand, total coliform (hereinafter referred to as coliform) and *E. coli*. In January 2012, seven (7) additional analytes were added that included total Kjeldahl nitrogen, pH, sodium, potassium, magnesium and calcium. All results are presented in ppm (mg/L), pH (pH units), coliform and *E. coli* (MPN/100ml). Field water quality parameters collected included pH, total dissolved solids (ppm), electrical conductance (μS), oxidation reduction potential (ORP mV) , temperature (C°) and electrical resistivity (ΩM) . Field parameter pH units are presented in the data graphs sets as a representative value of measured pH in the wells prior to the inclusion of the parameter by the laboratory. Only field pH values are presented in this section. The field parameters were monitored during sampling events to provide additional measures of groundwater quality and to assure that geochemical conditions in the pump discharge were stable prior to sampling. In a few cases samples were collected after less than 3 well bore volumes were pumped, because of low water level conditions.  In all, 26 parameters in 10 alluvial wells were measured by the end the thesis to determine major ion geochemistry of the water.  Complete results of all of the water quality testing for samples from the alluvial well are included in Appendix E.  The results are summarized in the following sections.

The water quality data for each well are presented in s 3.46 – 3.54 and in Table 3.10. Each graph, or subsection of the table, is divided into three (3) time periods: 1) Period 1, November 2009 to March 2011.  This period represents background data because there were no fertilizer applications or cows on site. 2) Period 2, March 2011 to May 2012. This period represents data after the introduction of cows to the farm (but not in the row crop areas where most of the alluvial monitoring wells are located) and the application of commercial fertilizers; and 3) Period 3, May 2012 to August 2012. The start of combined applications of commercial fertilizers and liquid manure on May 3, 2012 as a fertilizer for row crops in the flood plain. Commercial fertilizers were applied to the crop areas in the floodplain by UT LRDF staff beginning in the March of 2011. The tenant farmer (prior to UT taking over the property) also applied commercial fertilizers to the row crop areas, but data on fertilizer type or application rate is not available. The site was not “pristine” prior to development of the dairy, but the start of the combined application of commercial fertilizers and manure marks a major change in land use and hence was a logical point for the third division on the water quality graphs.

Application of manure to the row crop areas in fields 1 to 4 was carried out from May 3 to 7, 2012. The application consisted of a manure/water mixture which had been stored in a large open-topped holding tank (Pit 2), since the arrival of cows on the site in November of 2011. The liquid manure was sprayed on the fields from a tank pulled by a tractor. The farm operators tried to avoid spraying in the immediate vicinity (within a few meters) of individual monitoring wells, but it is likely that some of the spray landed near each of the floodplain wells. Even well numbers 4a and b, which are located in a pasture area in the floodplain, likely, received some manure near the well head, either as spray or as runoff. Incidental manure droppings were also deposited on the well caps due to cow grazing in Pasture 6. During the period of May 3-4, 2012, 15.4 liters/m$^2$ of liquid manure was applied to fields 3 and 4, which are located near wells 6, 8, 9c, 9d, 10b. From May 5 to 7, 2012, 16.6 liters/ m$^2$ of liquid manure were applied to fields 1 and 2, which are located near wells 2 and 5ab. Locations of the wells relative to the fields are shown on Figure 2.4 in Chapter 2. Properties of the liquid manure were measured in February 2012 prior to land application in May 2012 but are not reported this thesis. However, chemical analyses were carried out for liquid manure from LRDF in February and June of 2013, and these are expected to be similar to the liquid manure applied to the fields in May 2012. The liquid manure can be generally characterized as having average (n=6) levels of solids (0.46%), total nitrogen (401 mg/l), phosphorous (64.0 mg/l), potassium (386 mg/l), calcium (184 mg/l) and magnesium (103 mg/l). Microbial content in the manure was not measured, but it is expected to be high in total coliforms and could have variable levels of *E. coli*. Of the liquid manure constituents, the ones that are most likely to be of environmental importance to groundwater and to streams which receive groundwater discharge or runoff are the nitrogen compounds (ammonium, nitrate and nitrite), phosphorous and potassium, all of which are nutrients, as well as microbial pathogens.

Overall characteristics of groundwater in the floodplain alluvium are described in this paragraph, with more detailed discussions of key parameters in the following paragraphs. The groundwater is moderately conductive, neutral to weakly acidic, suboxic, and rich in calcium carbonate. This is typical of groundwater in unconfined aquifers in many areas of the United States (Drever, 1997; Hem, 1985). Three (3) geochemical characterizations of carbonate aquifers that includes the Georgia Blue Ridge, Valley and Ridge, Piedmont and Silici-clastics aquifer classifications by state (Drever, 1997; Railsback et al., 1996). This table provides a regional view of the geochemistry for LRDF compared to similar geologic settings in the eastern United States.

Table 3.9 - Major-Element Geochemistry of Florida & Pennsylvania Carbonate Aquifers and Georgia Groundwater's compared to LRDF concentrations of major elements. (Back and Hanshaw, 1970; Drever, 1982; Langmuir, 1971; Railsback et al., 1996).



| | Carbonate Aquifers | | | Valley & Ridge | LRDF Geomean | Blue Ridge | Piedmont | Silici-clastics |
|---|---|---|---|---|---|---|---|---|
| Major Element (mg/l) | Florida | Pennslvania | Georgia | Georgia | East Tennessee | Georgia | Georgia | Georgia |
| $Ca^{+2}$ | 34 | 83 | 39.4 | 38.6 | 37.6 | 12.2 | 16.3 | 9.9 |
| $Mg^{+2}$ | 5.6 | 17 | 10.7 | 9.2 | 7.9 | 2.1 | 3.4 | 1.5 |
| $Na^{+}$ | 3.2 | 8.5 | 17.4 | 11 .9 | 3.6 | 3.7 | 26.4 | 12.9 |
| $K^{+}$ | 0.5 | 6.3 | 1.9 | 1.5 | 1.0 | 1.7 | 2.1 | 1.5 |
| $HC0_3^{-}$ | 124 | 279 | 152.4 | 163.4 | 80.9 | 49.3 | 53.5 | 51.5 |
| $S0_4^{-2}$ | 2.4 | 27 | 31.9 | 13.7 | 9.0 | 4.4 | 13 | 3.5 |
| $Cl^{-}$ | 4.5 | 17 | 16.5 | 5.7 | 4.0 | 2 | 37.5 | 6.3 |
| F | | | 0.26 | 0.16 | - | 0.16 | 0.2 | 0.21 |
| $NO_3^{-}$ | 0.1 | 38 | - | - | 2.0 | - | - | - |
| $Si0_2$ | 12 | - | 27.7 | 12.4 | - | 16.3 | 30.4 | 13.7 |
| TDS | - | - | 229.4 | 183.6 | 200.0 | 73 | 168 | 87 |
| pH | 8 | 7.36 | 7.7 | 7.3 | 6.7 | 6.5 | 6.8 | 6.3 |

(Modified after Drever, 1982 & Railsback, 1996)

*All Values except pH are ppm (mg/L)

For most analytes there was substantial seasonal variability, which was expected given the hydrologic evidence of very rapid recharge through the sediments. There generally were not any major noticeable changes between groundwater samples collected prior to and after manure application, although there were variations from the background. Only two (2) samples were collected afterwards, although there were some exceptions, as discussed later. Field-measured conductance values, which can be used to estimate total dissolved solids (TDS) content in the water, ranges from approximately 30 to 450 uS/cm. This corresponds to TDS values ranging from 20 to 300 mg/L (using a conversion factor of 0.67 mg/l per uS/cm), which are below the EPA secondary drinking water standard of 500 mg/L as outlined by the Safe Drinking Water Act 1974, 1986, 1996 (SDWA) http://water.epa.gov/lawsregs/rulesregs/sdwa/index.cfm . Values of pH in the water samples vary from 6.0 to 7.8. This is higher than typical soil pH values in east Tennessee, which are often 5.5 to 6, and is likely due to buffering by calcium-rich minerals in the alluvium and bedrock. Oxidation-reduction potential (ORP) values typically range from about 50 to 300 mV, with only one well (5b) having negative values (-90 mV). These values are all within what is considered the “suboxic” range (-120 to 414 mV) and are consistent with would be expected for a shallow sedimentary aquifer with rapid groundwater recharge. Calcium is the dominant cation in most all of the samples and the predominantly calcium carbonate nature of the water is confirmed by the Piper Diagram (Figure 3.46), which shows all of the samples clustered in the calcium-rich region of the diagram. The Piper diagram is based on averages of samples collected just before and after the start of manure application, but they show the same overall characteristics. The presence of dissolved calcium carbonate in the water reflects the high content of calcium carbonate minerals in the underlying bedrock.

Nitrogen compounds (ammonium, nitrate and nitrite), which are present in both commercial fertilizers and manure are presented on Figures 3.47 to 3.55. Federal drinking water standards for nitrate and nitrite are, respectively, 10 and 1 mg/L (expressed as N). There are no health-based regulations for ammonium, but it can be converted to nitrate or nitrite by soil bacteria under oxic or suboxic conditions and hence can lead to elevated nitrate and nitrite levels in groundwater. As well, nitrogen compounds in groundwater that discharges to surface water often act as nutrients that lead to degradation of surface water quality, including eutrophication.

Dissolved nitrogen in the form of nitrate ($NO_3^-$) is the most common contaminant identified in groundwater. Other forms of dissolved nitrogen occur as ammonium ($NH^+{}_{4)}$, ammonia ($NH_3$), nitrite ($NO^-{}_2$), nitrogen (N2), nitrous oxide ($N_2O$) and nitrogen in its organic form (Freeze and Cherry, 1979). Total nitrogen TN is the sum of total Kjeldahl nitrogen (ammonia, organic and reduced nitrogen) and nitrate-nitrite. Total nitrogen at LRDF was sampled 89 times in the alluvial wells. The maximum TN value was 15.97 mg/L and the minimum measured 0.012 mg/L. Nitrite ranged from a maximum value of 0.64 mg/L to a minimum value of 0.0001 mg/L based on 23 samples from the alluvial wells. Nitrate was detected in 80 samples ranging from 15.4 mg/L to 0.012 mg/L. Ammonia was detected in 78 samples with values ranging from 7.90 mg/L to 0.001 mg/L. Total Kjeldahl nitrogen was detected in 25 samples with ranges from 0.344 mg/L to 0.006 mg/L.

Nitrate is very mobile once in groundwater as it tends not to adsorb or precipitate on aquifer solids (Hem, 1985). Nitrate concentrations in shallow aquifer tend to decrease with depth, however, depth to bedrock at LRDF is less than 9 m which hampers attenuation due to mixing with increased depth (Hudak, 2000). Denitrification requires very low oxygen concentrations (anaerobic) and the presence of electron donors, such as reactive organic C or reduced minerals (Green et al., 2008; Welch et al., 2011). Inorganic compounds such as reduced iron and sulfur are important sources of energy for subsurface microbes because organic carbon can be low in subsurface environments. This process promotes microbial interface as key component of denitrification in groundwater under anaerobic conditions (Green et al., 2008;

Welch et al., 2011). Streams and rivers act as “kidneys” in the nitrification/denitrification process by removing nitrogen from the water column because they possess aerobic and anaerobic conditions and nutrient cycling as water moves downstream (Weathers K. C. et al., 2013).

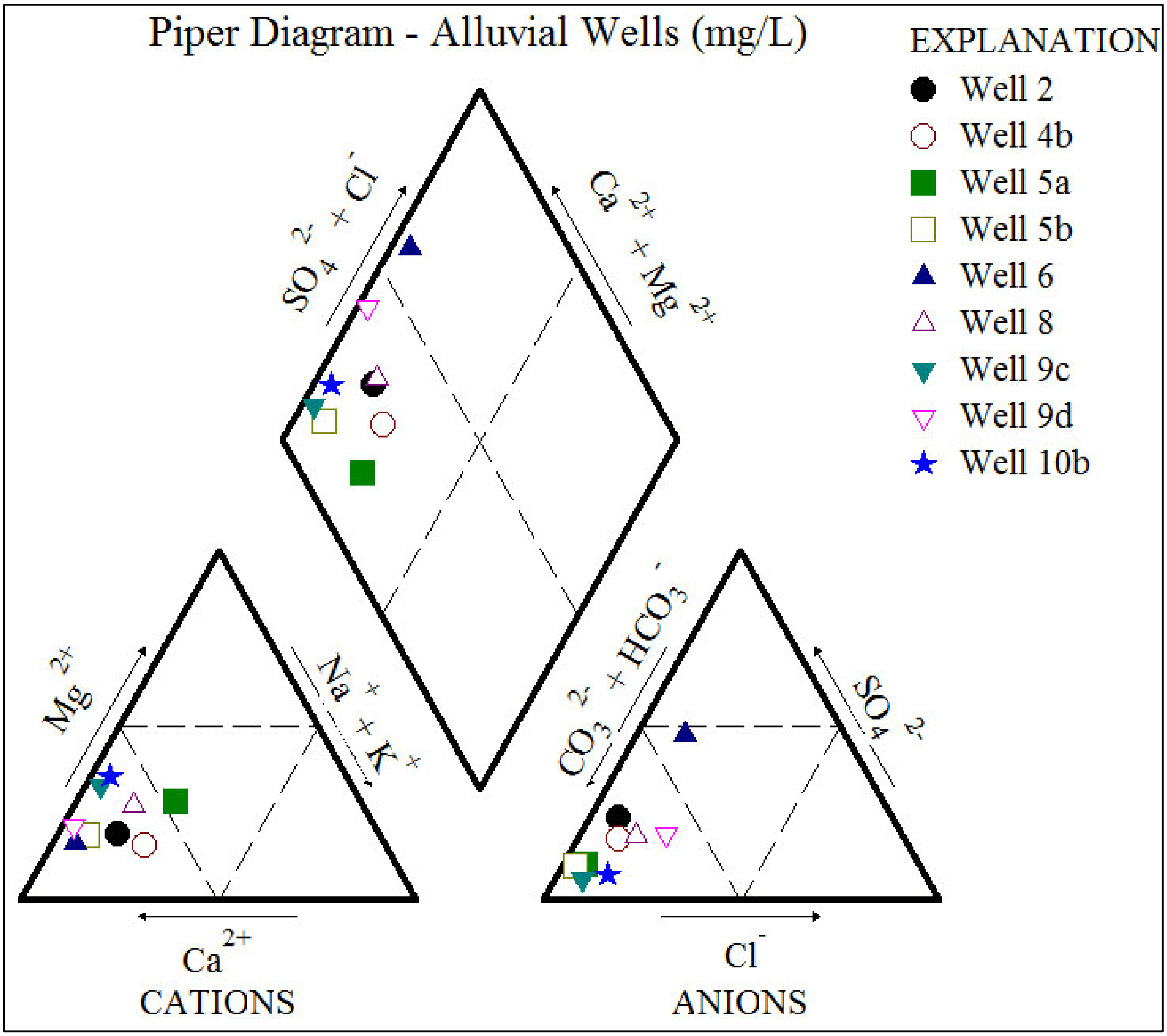


Figure 3.46 – Piper Diagram of cation and anion concentrations after manure applications in alluvial wells. The values for cations and anions reflect the geometric mean of all sampling events. The data confirm the carbonate groundwater environment in the alluvium. Diagram courtesy of USGS Groundwater Chart software available from the USGS website address: (water.usgs.gov/nrp/gwsoftware/GW_Chart/GW_Chart.htm).

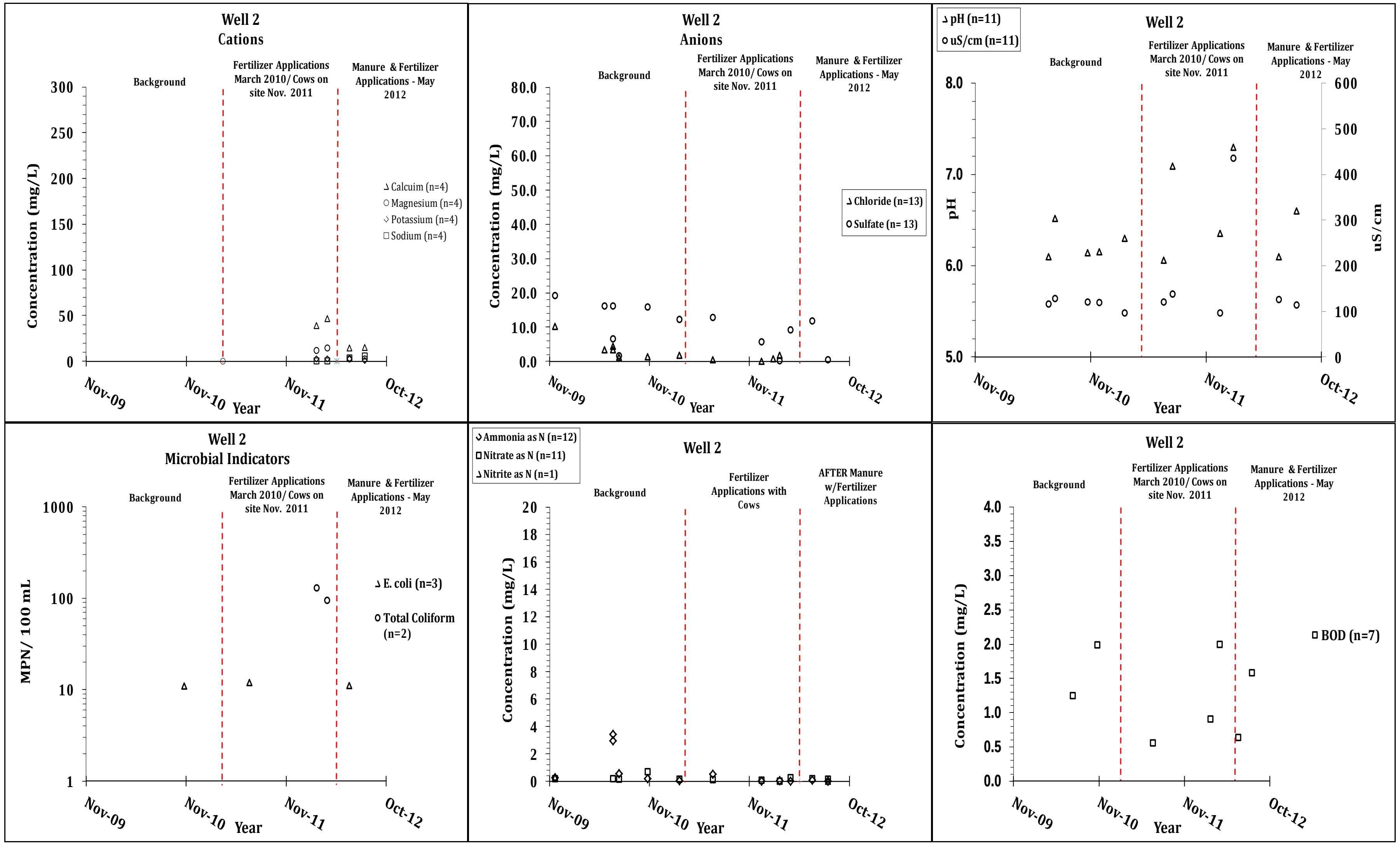


Figure 3.47 – Well 2 – Water quality for Well 2, screened at 1.8 to 2.6 m depth.

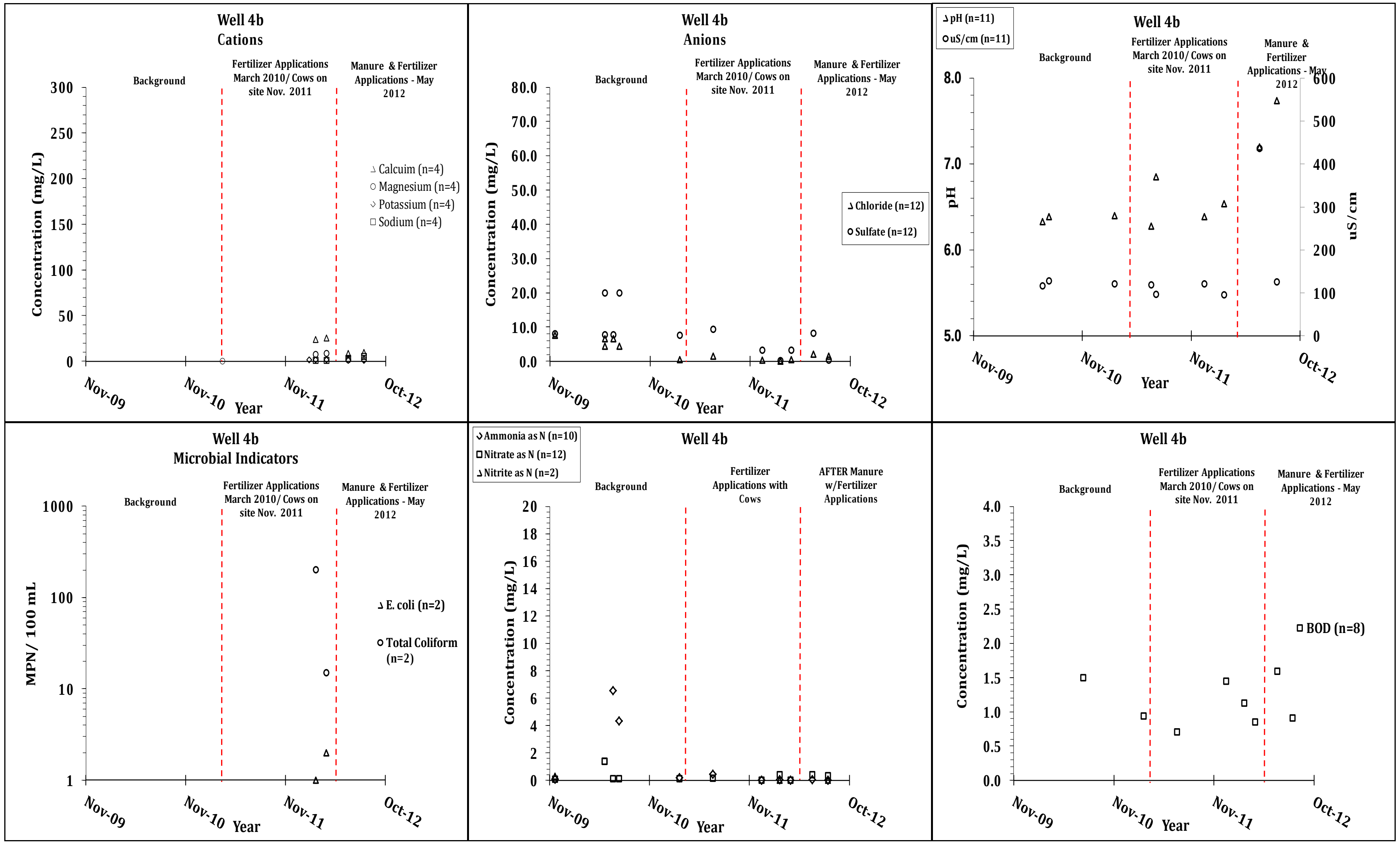


Figure 3.48 - Well 4b - Water quality for Well 4b, screened at 6.2 to 7.0 m depth.

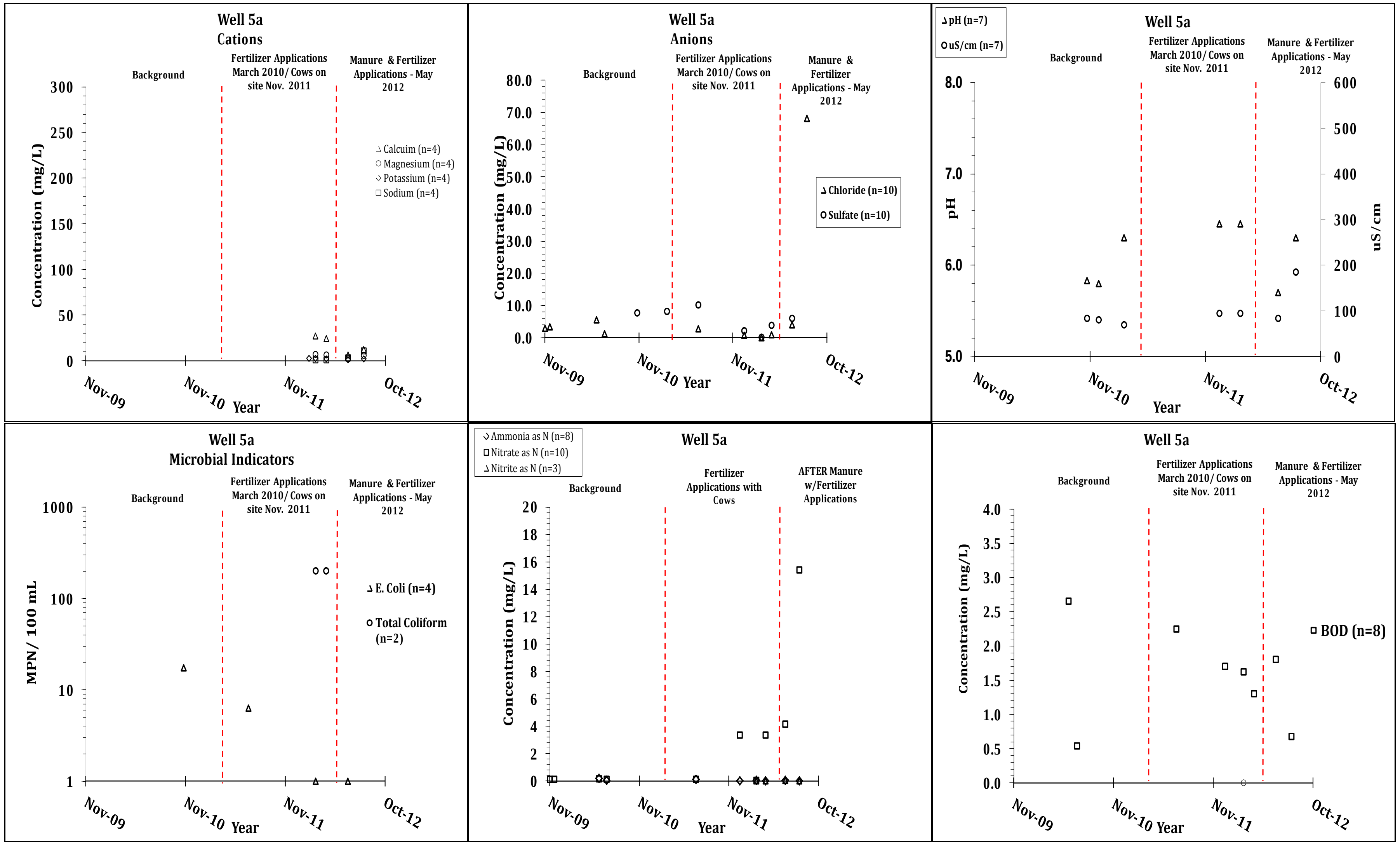


Figure 3.49 - Well 5a - Water quality for Well 5a, screened at 1.8 to 2.6 m depth.

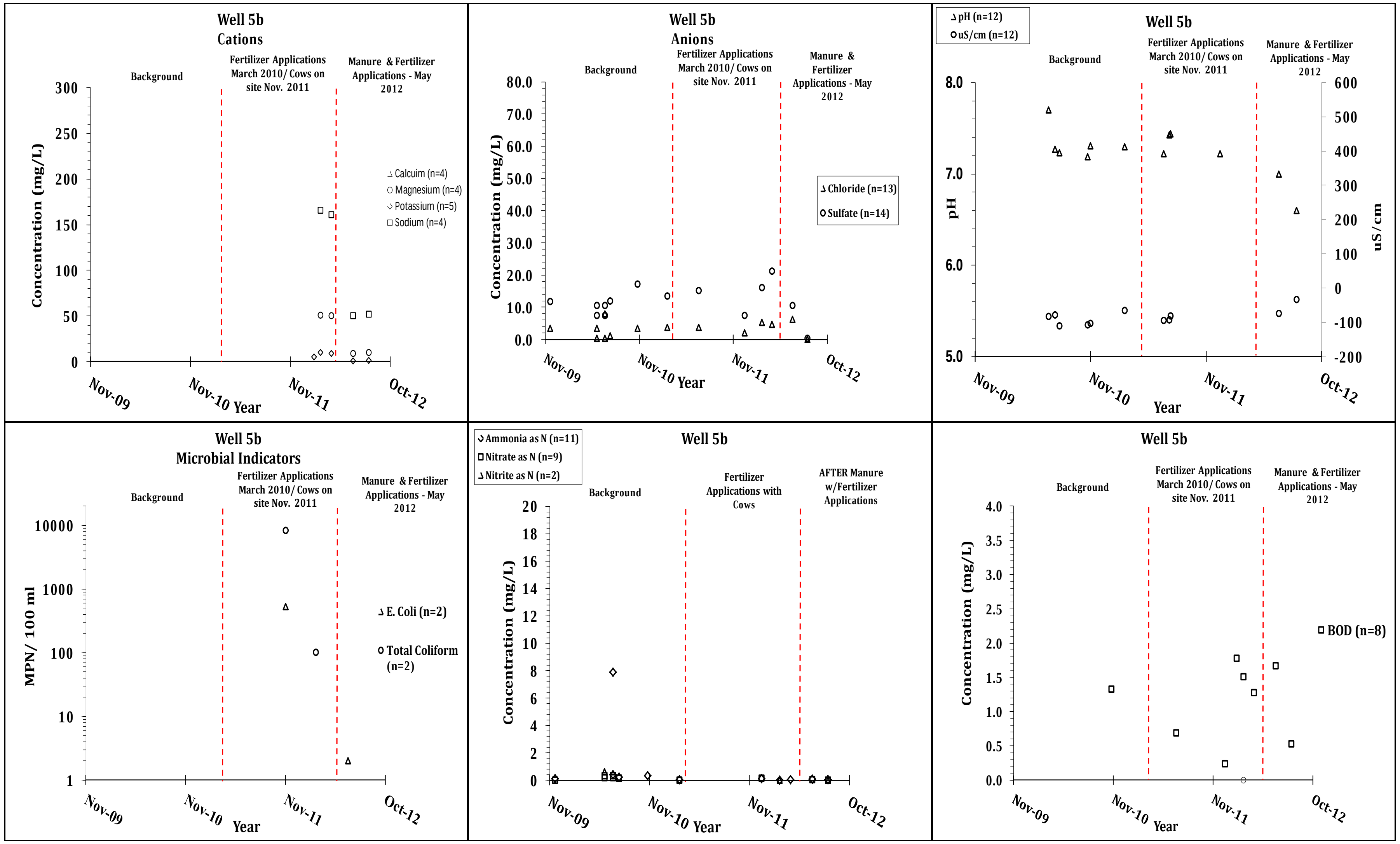


Figure 3.50 - Well 5b - Water quality for Well 5b, screened at 3.2 to 4.0 m depth.

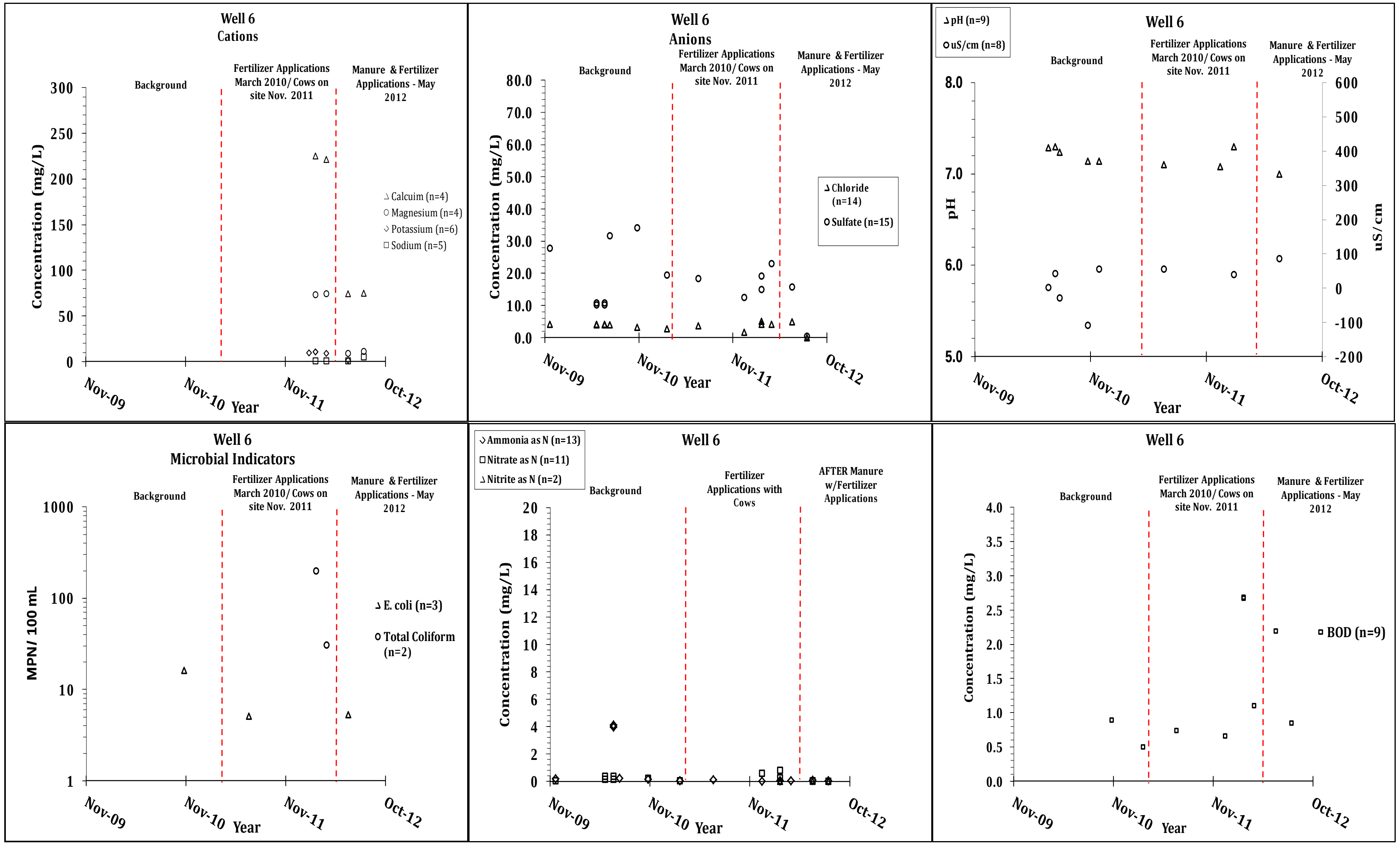


Figure 3.51 - Well 6 - Water quality for Well 6, screened at 1.8 to 2.6 m depth.

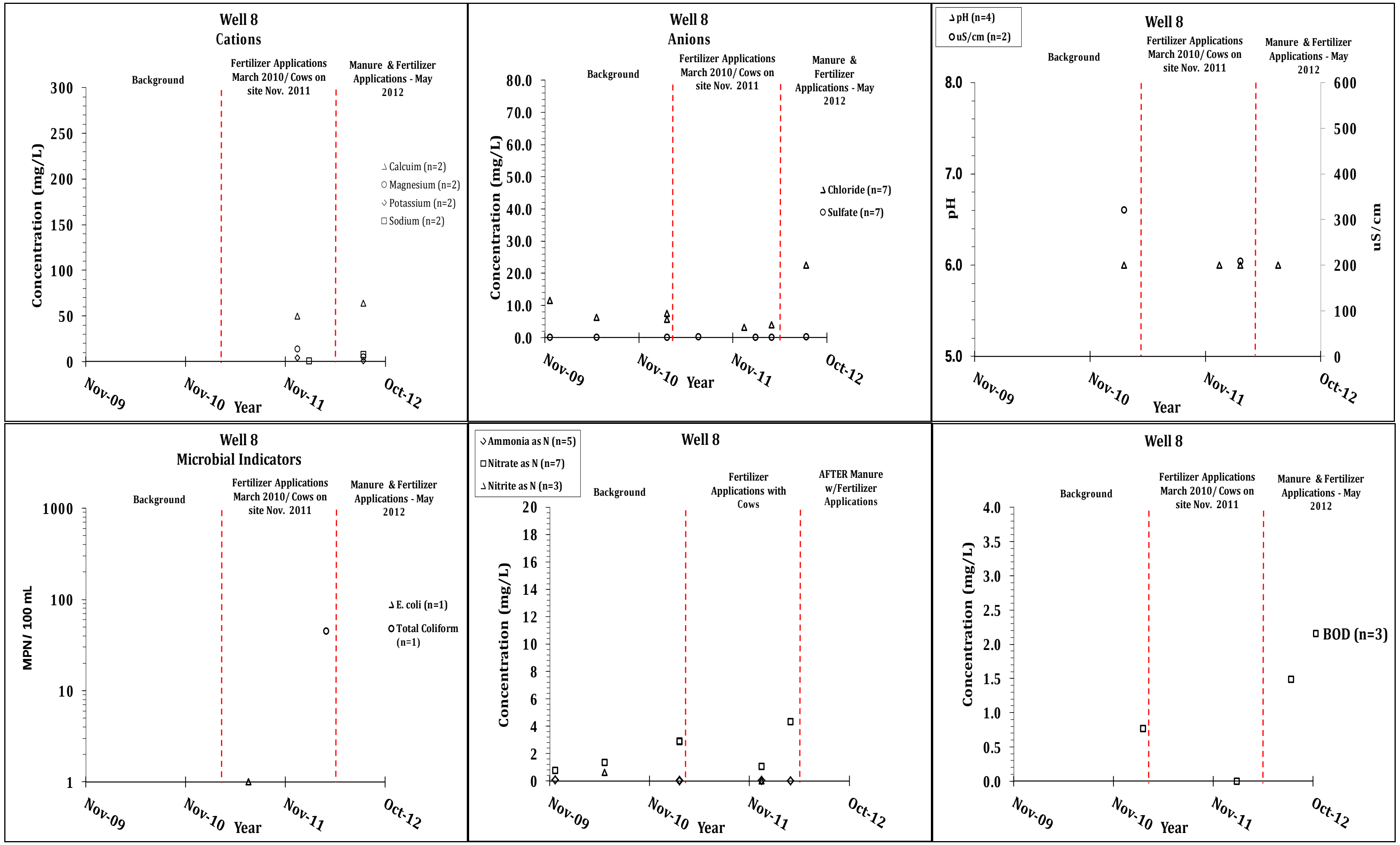


Figure 3.52 - Well 8 - Water quality for Well 8, screened at 3.8 to 4.6 m depth.

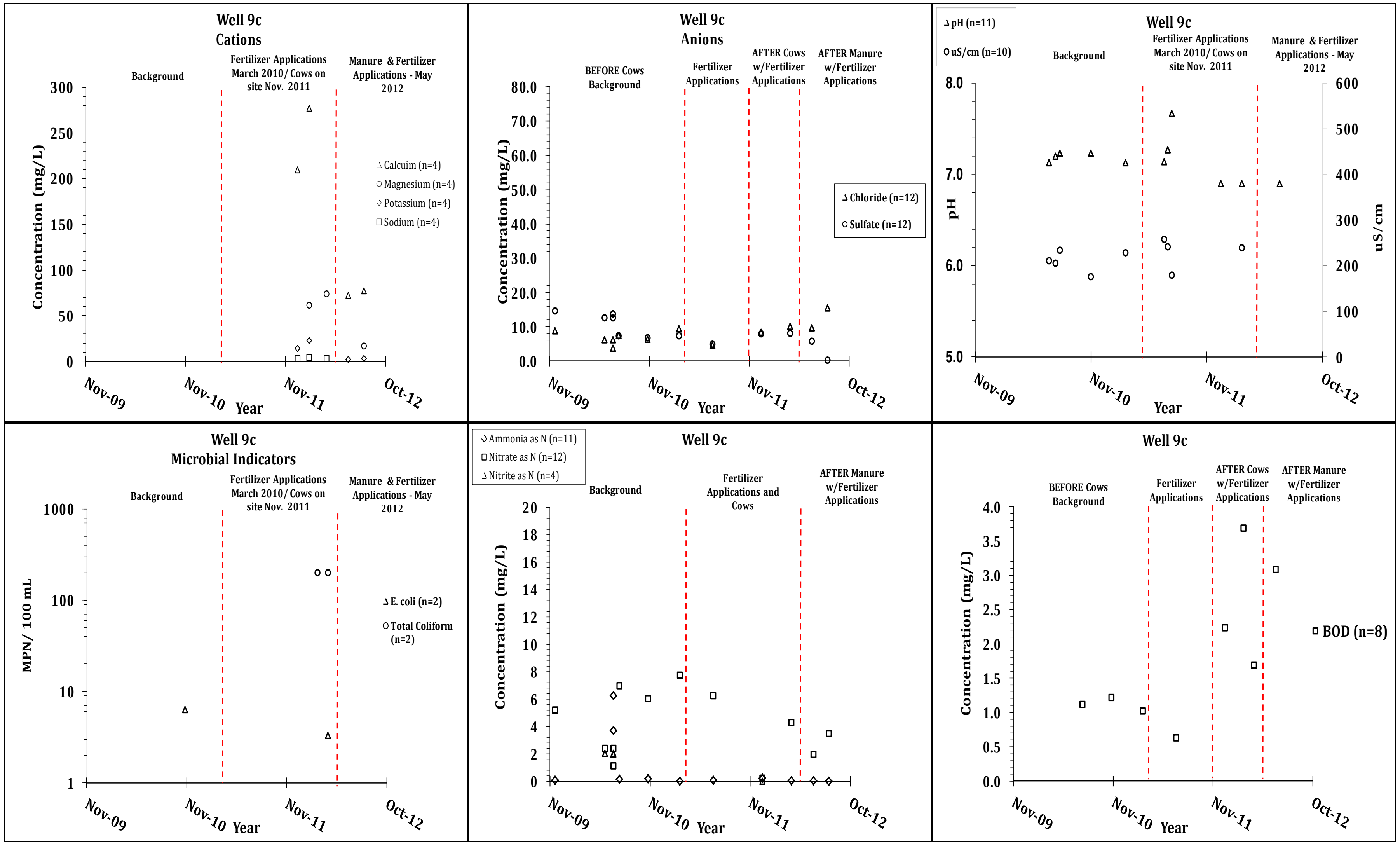


Figure 3.53 - Well 9c - Water quality for Well 9c, screened at 5.9 to 6.7 m depth.

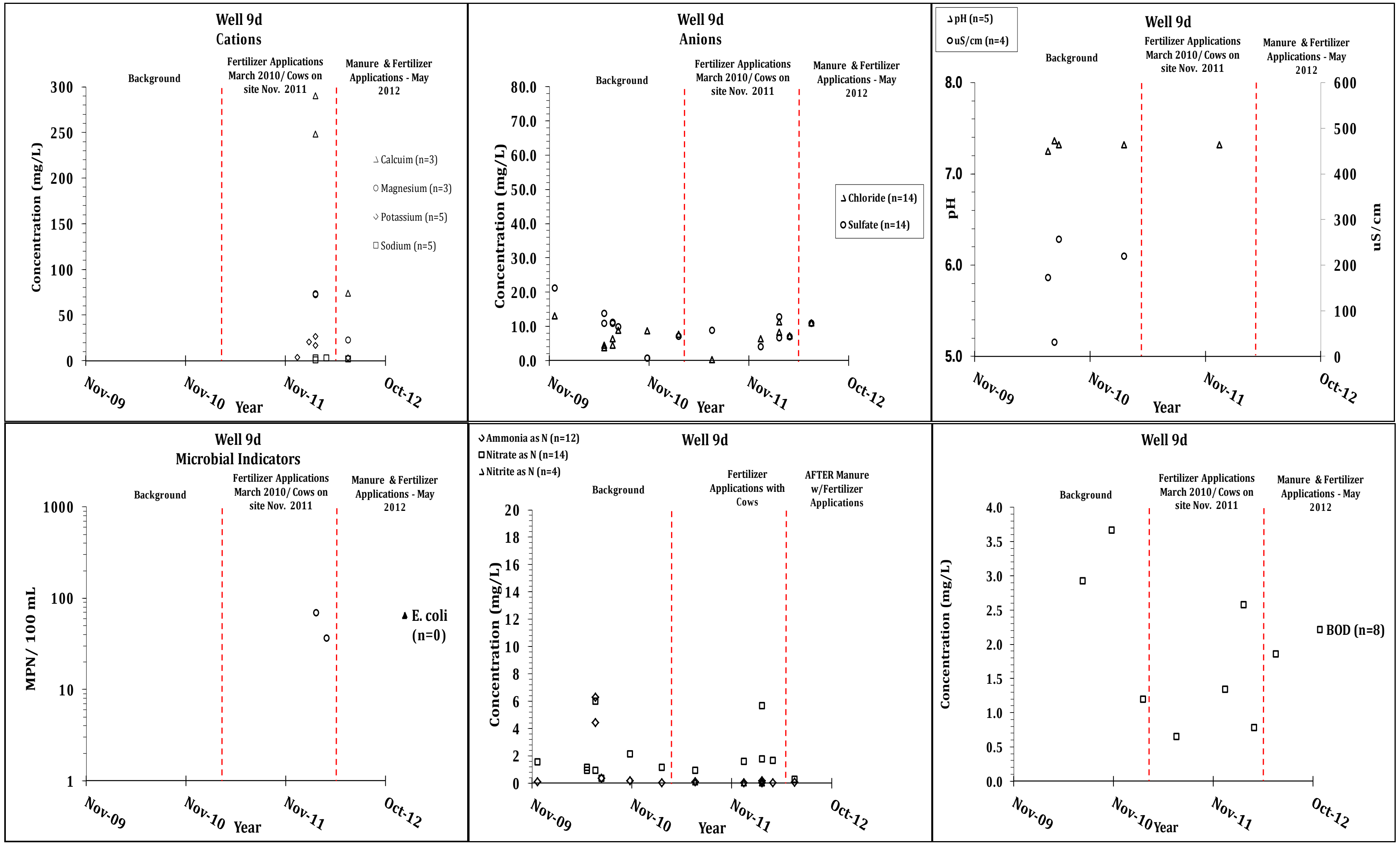


Figure 3.54 - Well 9d - Water quality for Well 9d, screened at 7.8 to 8.5 m depth.

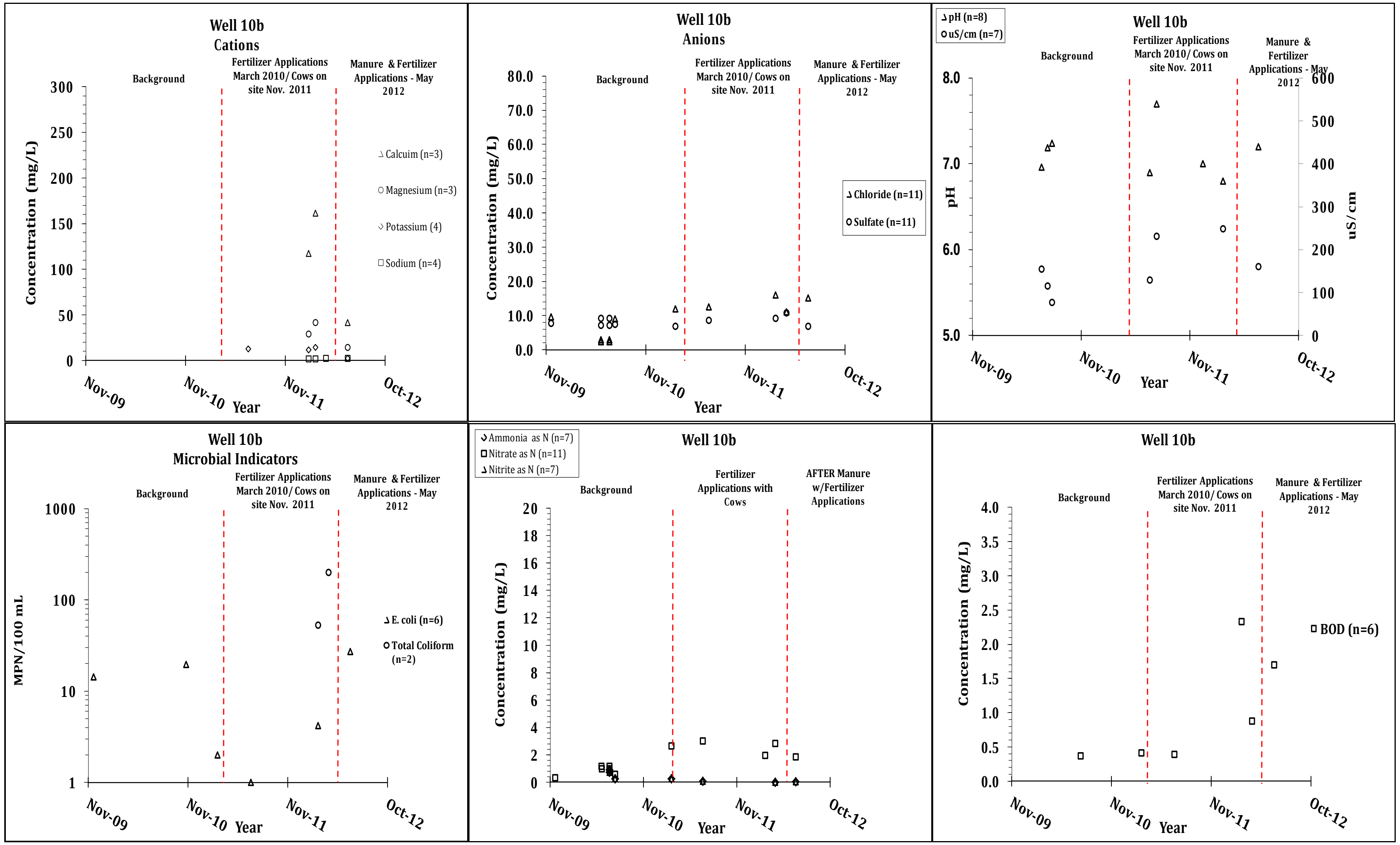
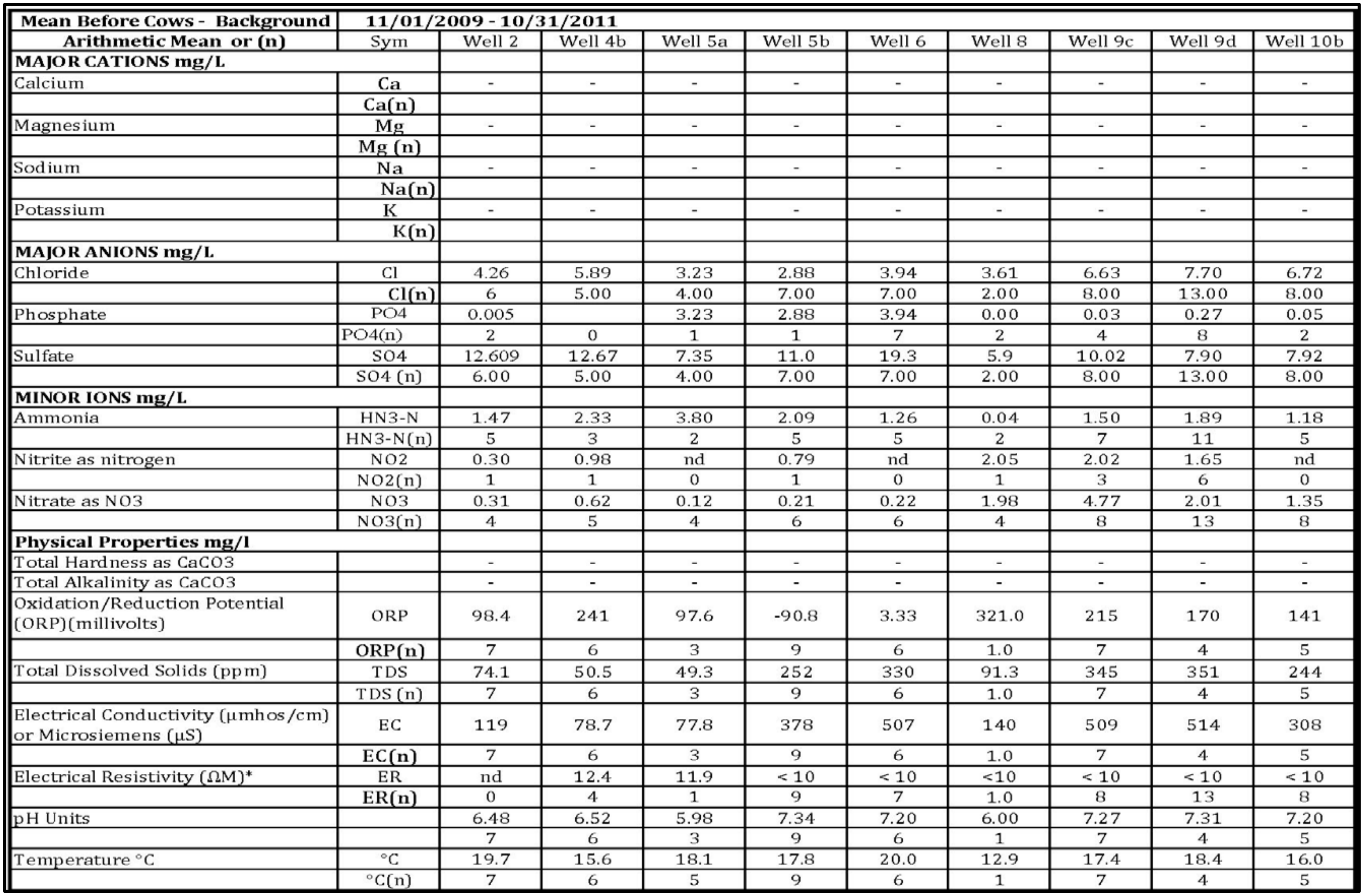


Figure 3.55 - Well 10b – Water quality for Well 10b, screened at 4.4 to 5.2 m depth.

Table 3.10 – Geochemistry Summary – Before Cows with no reported fertilizer applications. 11/01/2009 to 10/31/2011. The number of samples (N) is presented for each category for the time period. When (n) = 1 actual value displayed.

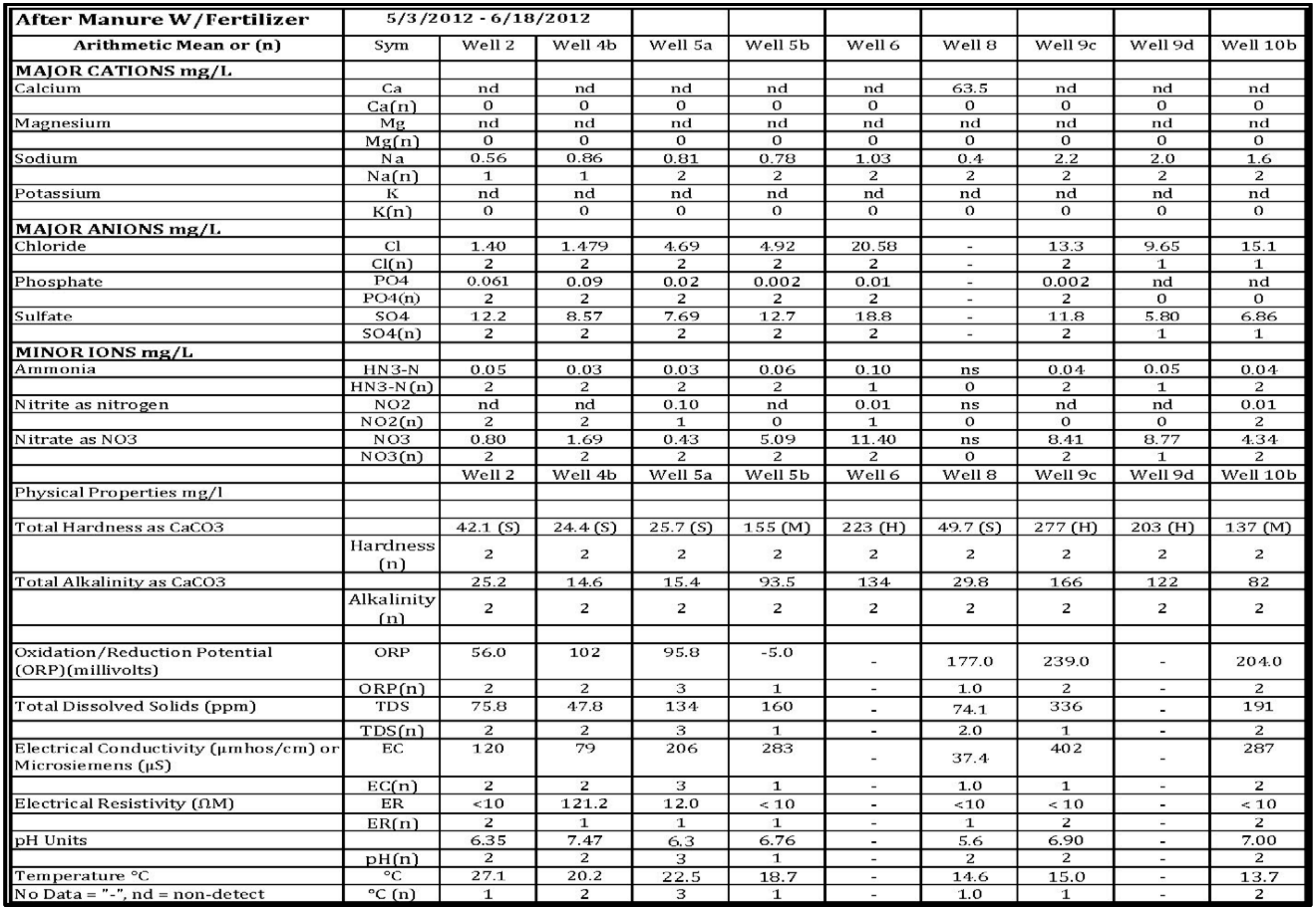


| **Mean Before Cows - Background** | **11/01/2009 - 10/31/2011** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Arithmetic Mean or (n)** | Sym | Well 2 | Well 4b | Well 5a | Well 5b | Well 6 | Well 8 | Well 9c | Well 9d | Well 10b |
| **MAJOR CATIONS mg/L** | | | | | | | | | | |
| Calcium | **Ca** | - | - | - | - | - | - | - | - | - |
| | **Ca(n)** | | | | | | | | | |
| Magnesium | **Mg** | - | - | - | - | - | - | - | - | - |
| | **Mg (n)** | | | | | | | | | |
| Sodium | **Na** | - | - | - | - | - | - | - | - | - |
| | **Na(n)** | | | | | | | | | |
| Potassium | K | - | - | - | - | - | - | - | - | - |
| | **K(n)** | | | | | | | | | |
| **MAJOR ANIONS mg/L** | | | | | | | | | | |
| Chloride | Cl | 4.26 | 5.89 | 3.23 | 2.88 | 3.94 | 3.61 | 6.63 | 7.70 | 6.72 |
| | **Cl(n)** | 6 | 5.00 | 4.00 | 7.00 | 7.00 | 2.00 | 8.00 | 13.00 | 8.00 |
| Phosphate | PO4 | 0.005 | | 3.23 | 2.88 | 3.94 | 0.00 | 0.03 | 0.27 | 0.05 |
| | PO4(n) | 2 | 0 | 1 | 1 | 7 | 2 | 4 | 8 | 2 |
| Sulfate | SO4 | 12.609 | 12.67 | 7.35 | 11.0 | 19.3 | 5.9 | 10.02 | 7.90 | 7.92 |
| | SO4 (n) | 6.00 | 5.00 | 4.00 | 7.00 | 7.00 | 2.00 | 8.00 | 13.00 | 8.00 |
| **MINOR IONS mg/L** | | | | | | | | | | |
| Ammonia | HN3-N | 1.47 | 2.33 | 3.80 | 2.09 | 1.26 | 0.04 | 1.50 | 1.89 | 1.18 |
| | HN3-N(n) | 5 | 3 | 2 | 5 | 5 | 2 | 7 | 11 | 5 |
| Nitrite as nitrogen | NO2 | 0.30 | 0.98 | nd | 0.79 | nd | 2.05 | 2.02 | 1.65 | nd |
| | NO2(n) | 1 | 1 | 0 | 1 | 0 | 1 | 3 | 6 | 0 |
| Nitrate as NO3 | NO3 | 0.31 | 0.62 | 0.12 | 0.21 | 0.22 | 1.98 | 4.77 | 2.01 | 1.35 |
| | NO3(n) | 4 | 5 | 4 | 6 | 6 | 4 | 8 | 13 | 8 |
| **Physical Properties mg/l** | | | | | | | | | | |
| Total Hardness as CaCO3 | | - | - | - | - | - | - | - | - | - |
| Total Alkalinity as CaCO3 | | - | - | - | - | - | - | - | - | - |
| Oxidation/Reduction Potential (ORP)(millivolts) | ORP | 98.4 | 241 | 97.6 | -90.8 | 3.33 | 321.0 | 215 | 170 | 141 |
| | **ORP(n)** | 7 | 6 | 3 | 9 | 6 | 1.0 | 7 | 4 | 5 |
| Total Dissolved Solids (ppm) | TDS | 74.1 | 50.5 | 49.3 | 252 | 330 | 91.3 | 345 | 351 | 244 |
| | TDS (n) | 7 | 6 | 3 | 9 | 6 | 1.0 | 7 | 4 | 5 |
| Electrical Conductivity (µmhos/cm) or Microsiemens (µS) | EC | 119 | 78.7 | 77.8 | 378 | 507 | 140 | 509 | 514 | 308 |
| | **EC(n)** | 7 | 6 | 3 | 9 | 6 | 1.0 | 7 | 4 | 5 |
| Electrical Resistivity (ΩM)* | ER | nd | 12.4 | 11.9 | < 10 | < 10 | <10 | < 10 | < 10 | < 10 |
| | **ER(n)** | 0 | 4 | 1 | 9 | 7 | 1.0 | 8 | 13 | 8 |
| pH Units | | 6.48 | 6.52 | 5.98 | 7.34 | 7.20 | 6.00 | 7.27 | 7.31 | 7.20 |
| | | 7 | 6 | 3 | 9 | 6 | 1 | 7 | 4 | 5 |
| Temperature °C | °C | 19.7 | 15.6 | 18.1 | 17.8 | 20.0 | 12.9 | 17.4 | 18.4 | 16.0 |
| | °C(n) | 7 | 6 | 5 | 9 | 6 | 1 | 7 | 4 | 5 |

Table 3.10 (continued) After Cows with Fertilizer Applications - Period from 11/1/2011 – 5/2/2012.

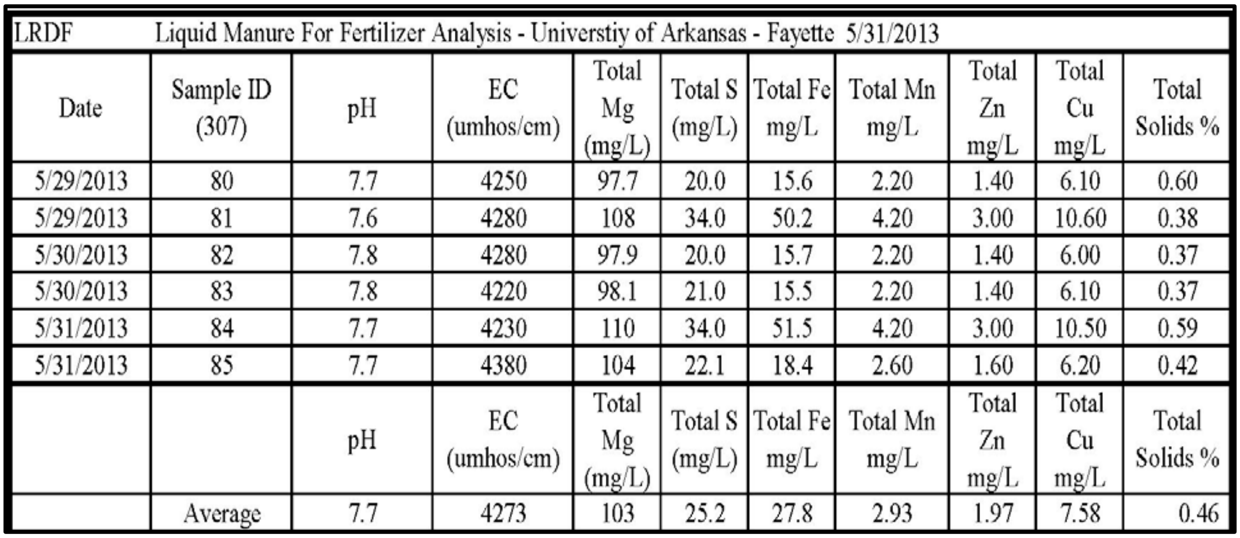
| **After Cows - W/Fertilizer** | **11/01/2011 - 5/2/2012** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Arithmetic Mean or (n)** | Sym | Well 2 | Well 4b | Well 5a | Well 5b | Well 6 | Well 8 | Well 9c | Well 9d | Well 10b |
| **MAJOR CATIONS mg/L** | | | | | | | | | | |
| Calcium | Ca | 42.6 | 24.5 | 25.3 | 163 | 223 | 49.7 | 243 | 269 | 139 |
| | Ca(n) | 2 | 2 | 2 | 2 | 2 | 1 | 2 | 2 | 2 |
| Magnesium | Mg | 13.2 | 7.79 | 6.44 | 50.3 | 73.4 | 13.5 | 67.5 | 72.7 | 34.9 |
| | Mg(n) | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Sodium | Na | 0.333 | 0.72 | 0.66 | 0.57 | 0.68 | 0.45 | 2.24 | 2.02 | 1.61 |
| | Na(n) | 2 | 2 | 2 | 2 | 3.0 | 1 | 2 | 2 | 2 |
| Potassium | K | 2.28 | 1.22 | 2.36 | 7.66 | 9.74 | 3.89 | 18.1 | 16.6 | 12.7 |
| | K(n) | 3 | 2 | 2 | 2 | 4 | 1 | 2 | 2 | 2 |
| **MAJOR ANIONS mg/L** | | | | | | | | | | |
| Chloride | Cl | 0.89 | 0.55 | 1.09 | 3.86 | 3.56 | 3.61 | 9.30 | 8.29 | 13.55 |
| | Cl(n) | 3 | 4 | 3 | 5 | 6 | 2 | 2 | 4 | 2 |
| Phosphate | PO4 | 0.085 | 0.15 | 0.08 | 0.00 | 0.03 | 0.00 | 0.02 | 0.01 | 0.01 |
| | PO4(n) | 3 | 3 | 3 | 2 | 4.0 | 2 | 1 | 3 | 1 |
| Sulfate | SO4 | 8.075 | 4.69 | 4.02 | 14.7 | 17.9 | 5.9 | 8.04 | 7.59 | 9.93 |
| | SO4(n) | 5 | 4 | 3 | 5 | 6 | 2 | 2 | 4 | 2 |
| **MINOR IONS mg/L** | | | | | | | | | | |
| Ammonia | HN3-N | 0.13 | 0.14 | 0.05 | 0.06 | 0.05 | 0.04 | 0.13 | 0.06 | 0.01 |
| | HN3-N(n) | 3 | 4 | 3 | 4 | 6 | 3 | 2 | 4 | 1 |
| Nitrite as nitrogen | NO2 | nd | nd | 0.05 | 0.06 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| | NO2(n) | 3 | 3 | 3 | 4 | 2 | 1 | 1 | 3 | 2 |
| Nitrate as N | NO3 | 0.12 | 0.14 | 1.71 | 0.08 | 0.43 | 2.71 | 2.27 | 2.68 | 2.40 |
| | NO3(n) | 3 | 4 | 4 | 2 | 2 | 2 | 2 | 4 | 2 |
| | | | | | | | | | | |
| **Physical Properties mg/l** | | Well 2 | Well 4b | Well 5a | Well 5b | Well 6 | Well 8 | Well 9c | Well 9d | Well 10b |
| Total Hardness as CaCO3 | | 42.1 (S) | 24.4 (S) | 25.7 (S) | 155 (M) | 223 (H) | 49.7 (S) | 277 (H) | 203 (H) | 137 (M) |
| | Hardness (n) | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Total Alkalinity as CaCO3 | | 25.2 | 14.6 | 15.4 | 93.5 | 134 | 29.8 | 166 | 122 | 82 |
| | Alkalinity (n) | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Oxidation/Reduction Potential (ORP)(millivolts) | ORP | 41.0 | 257 | - | -82.0 | - | 209.0 | - | - | - |
| | ORP(n) | 1 | 2 | - | 1 | 0 | 1 | 0 | - | 0 |
| Total Dissolved Solids (ppm) | TDS | 298.0 | 45.5 | - | - | - | 76.2 | - | - | - |
| | TDS(n) | 1 | 1 | - | 0 | 0 | 1 | 0 | - | 0 |
| Electrical Conductivity (μmhos/cm) or Microsiemens (μS) | EC | 436 | 75 | - | 373 | 422 | 118 | 402 | - | 229 |
| | EC(n) | 1 | 2 | - | 1 | 1 | 1 | 1 | - | 1 |
| Electrical Resistivity (ΩM) | ER | 94.0 | 13.9 | - | < 10 | < 10 | < 10 | < 10 | - | < 10 |
| | ER(n) | 1.0 | 1.0 | - | 1.00 | 1.00 | 1.00 | 1.00 | - | |
| pH Units | | 7.30 | 6.47 | - | 7.22 | 7.08 | 6.00 | 6.90 | - | 7.00 |
| | pH(n) | 1.00 | 1.00 | - | 1.00 | 1.00 | 1.00 | 1.00 | - | 1.00 |
| Temperature °C | °C | 12.2 | 16.0 | - | - | - | 13.5 | - | - | - |
| No Data = "-", nd = non-detect | °C (n) | 1 | 1 | - | - | - | 1 | - | - | - |

Table 3.10 (continued) After Manure Applications with Fertilizer - Period from 5/3/2013 – 6/18/2012.



| **After Manure W/Fertilizer** | **5/3/2012 - 6/18/2012** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Arithmetic Mean or (n)** | Sym | Well 2 | Well 4b | Well 5a | Well 5b | Well 6 | Well 8 | Well 9c | Well 9d | Well 10b |
| **MAJOR CATIONS mg/L** | | | | | | | | | | |
| Calcium | Ca | nd | nd | nd | nd | nd | 63.5 | nd | nd | nd |
| | Ca(n) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Magnesium | Mg | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| | Mg(n) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sodium | Na | 0.56 | 0.86 | 0.81 | 0.78 | 1.03 | 0.4 | 2.2 | 2.0 | 1.6 |
| | Na(n) | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Potassium | K | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| | K(n) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **MAJOR ANIONS mg/L** | | | | | | | | | | |
| Chloride | Cl | 1.40 | 1.479 | 4.69 | 4.92 | 20.58 | - | 13.3 | 9.65 | 15.1 |
| | Cl(n) | 2 | 2 | 2 | 2 | 2 | - | 2 | 1 | 1 |
| Phosphate | PO4 | 0.061 | 0.09 | 0.02 | 0.002 | 0.01 | - | 0.002 | nd | nd |
| | PO4(n) | 2 | 2 | 2 | 2 | 2 | - | 2 | 0 | 0 |
| Sulfate | SO4 | 12.2 | 8.57 | 7.69 | 12.7 | 18.8 | - | 11.8 | 5.80 | 6.86 |
| | SO4(n) | 2 | 2 | 2 | 2 | 2 | - | 2 | 1 | 1 |
| **MINOR IONS mg/L** | | | | | | | | | | |
| Ammonia | HN3-N | 0.05 | 0.03 | 0.03 | 0.06 | 0.10 | ns | 0.04 | 0.05 | 0.04 |
| | HN3-N(n) | 2 | 2 | 2 | 2 | 1 | 0 | 2 | 1 | 2 |
| Nitrite as nitrogen | NO2 | nd | nd | 0.10 | nd | 0.01 | ns | nd | nd | 0.01 |
| | NO2(n) | 2 | 2 | 1 | 0 | 1 | 0 | 0 | 0 | 2 |
| Nitrate as NO3 | NO3 | 0.80 | 1.69 | 0.43 | 5.09 | 11.40 | ns | 8.41 | 8.77 | 4.34 |
| | NO3(n) | 2 | 2 | 2 | 2 | 2 | 0 | 2 | 1 | 2 |
| | | Well 2 | Well 4b | Well 5a | Well 5b | Well 6 | Well 8 | Well 9c | Well 9d | Well 10b |
| Physical Properties mg/l | | | | | | | | | | |
| | | | | | | | | | | |
| Total Hardness as CaCO3 | | 42.1 (S) | 24.4 (S) | 25.7 (S) | 155 (M) | 223 (H) | 49.7 (S) | 277 (H) | 203 (H) | 137 (M) |
| | Hardness (n) | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Total Alkalinity as CaCO3 | | 25.2 | 14.6 | 15.4 | 93.5 | 134 | 29.8 | 166 | 122 | 82 |
| | Alkalinity (n) | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | | | | | | | | | | |
| Oxidation/Reduction Potential (ORP)(millivolts) | ORP | 56.0 | 102 | 95.8 | -5.0 | - | 177.0 | 239.0 | - | 204.0 |
| | ORP(n) | 2 | 2 | 3 | 1 | - | 1.0 | 2 | - | 2 |
| Total Dissolved Solids (ppm) | TDS | 75.8 | 47.8 | 134 | 160 | - | 74.1 | 336 | - | 191 |
| | TDS(n) | 2 | 2 | 3 | 1 | - | 2.0 | 1 | - | 2 |
| Electrical Conductivity (µmhos/cm) or Microsiemens (µS) | EC | 120 | 79 | 206 | 283 | - | 37.4 | 402 | - | 287 |
| | EC(n) | 2 | 2 | 3 | 1 | - | 1.0 | 1 | - | 2 |
| Electrical Resistivity (ΩM) | ER | <10 | 121.2 | 12.0 | < 10 | - | <10 | < 10 | - | < 10 |
| | ER(n) | 2 | 1 | 1 | 1 | - | 1 | 2 | - | 2 |
| pH Units | | 6.35 | 7.47 | 6.3 | 6.76 | - | 5.6 | 6.90 | - | 7.00 |
| | pH(n) | 2 | 2 | 3 | 1 | - | 2 | 2 | - | 2 |
| Temperature °C | °C | 27.1 | 20.2 | 22.5 | 18.7 | - | 14.6 | 15.0 | - | 13.7 |
| No Data = "-", nd = non-detect | °C (n) | 1 | 2 | 3 | 1 | - | 1.0 | 1 | - | 2 |

Table 3.10 – Average Liquid Manure for Fertilizer Analysis (n=6).



LRDF Liquid Manure For Fertilizer Analysis - Universtiy of Arkansas - Fayette 5/31/2013

| Date | Sample ID (307) | pH | EC (umhos/cm) | Total Mg (mg/L) | Total S (mg/L) | Total Fe mg/L | Total Mn mg/L | Total Zn mg/L | Total Cu mg/L | Total Solids % |
|---|---|---|---|---|---|---|---|---|---|---|
| 5/29/2013 | 80 | 7.7 | 4250 | 97.7 | 20.0 | 15.6 | 2.20 | 1.40 | 6.10 | 0.60 |
| 5/29/2013 | 81 | 7.6 | 4280 | 108 | 34.0 | 50.2 | 4.20 | 3.00 | 10.60 | 0.38 |
| 5/30/2013 | 82 | 7.8 | 4280 | 97.9 | 20.0 | 15.7 | 2.20 | 1.40 | 6.00 | 0.37 |
| 5/30/2013 | 83 | 7.8 | 4220 | 98.1 | 21.0 | 15.5 | 2.20 | 1.40 | 6.10 | 0.37 |
| 5/31/2013 | 84 | 7.7 | 4230 | 110 | 34.0 | 51.5 | 4.20 | 3.00 | 10.50 | 0.59 |
| 5/31/2013 | 85 | 7.7 | 4380 | 104 | 22.1 | 18.4 | 2.60 | 1.60 | 6.20 | 0.42 |
|  |  | pH | EC (umhos/cm) | Total Mg (mg/L) | Total S (mg/L) | Total Fe mg/L | Total Mn mg/L | Total Zn mg/L | Total Cu mg/L | Total Solids % |
|  | Average | 7.7 | 4273 | 103 | 25.2 | 27.8 | 2.93 | 1.97 | 7.58 | 0.46 |

Wells 5a, 8, 9d and 10b showed an increase in nitrate concentrations above national drinking water standards of 10 mg/L. From November 2011 to May 2012, twenty-five (25) samples reported $NO_3$-N concentrations from 0.12 to 2.72 mg/l. Well 6 reported $NO_3$-N concentrations from 0.05 to 1.0 mg/l for the same reporting period suggesting the well location may not receive the same fertilizer and manure load from the neighboring row crop farmer. Two sampling events were conducted on June 18, 2012 and August 12, 2012 with all alluvial wells reporting (except 9d) “after manure spreading and fertilizer applications” in the spring of 2012. Concentrations of $NO_3$-N from fifteen (15) samples reported $NO_3$-N ranging from 0.43 mg/L to 15.4 mg/L presumably due to successive loading of N compounds from the combined manure/fertilizer applications.

Wells 5a, 6 and 10b have total depths of 2.5, 2.6 and 3.5 meters respectively. Each well is located adjacent to primary surface water drainage, the “central ditch”, where row crop fields discharge groundwater via old and new field tile drains into the ditch. Hydraulic gradients from these fields also lend groundwater flow and recharge to the central ditch which operates as a direct surface water input to the Little River.

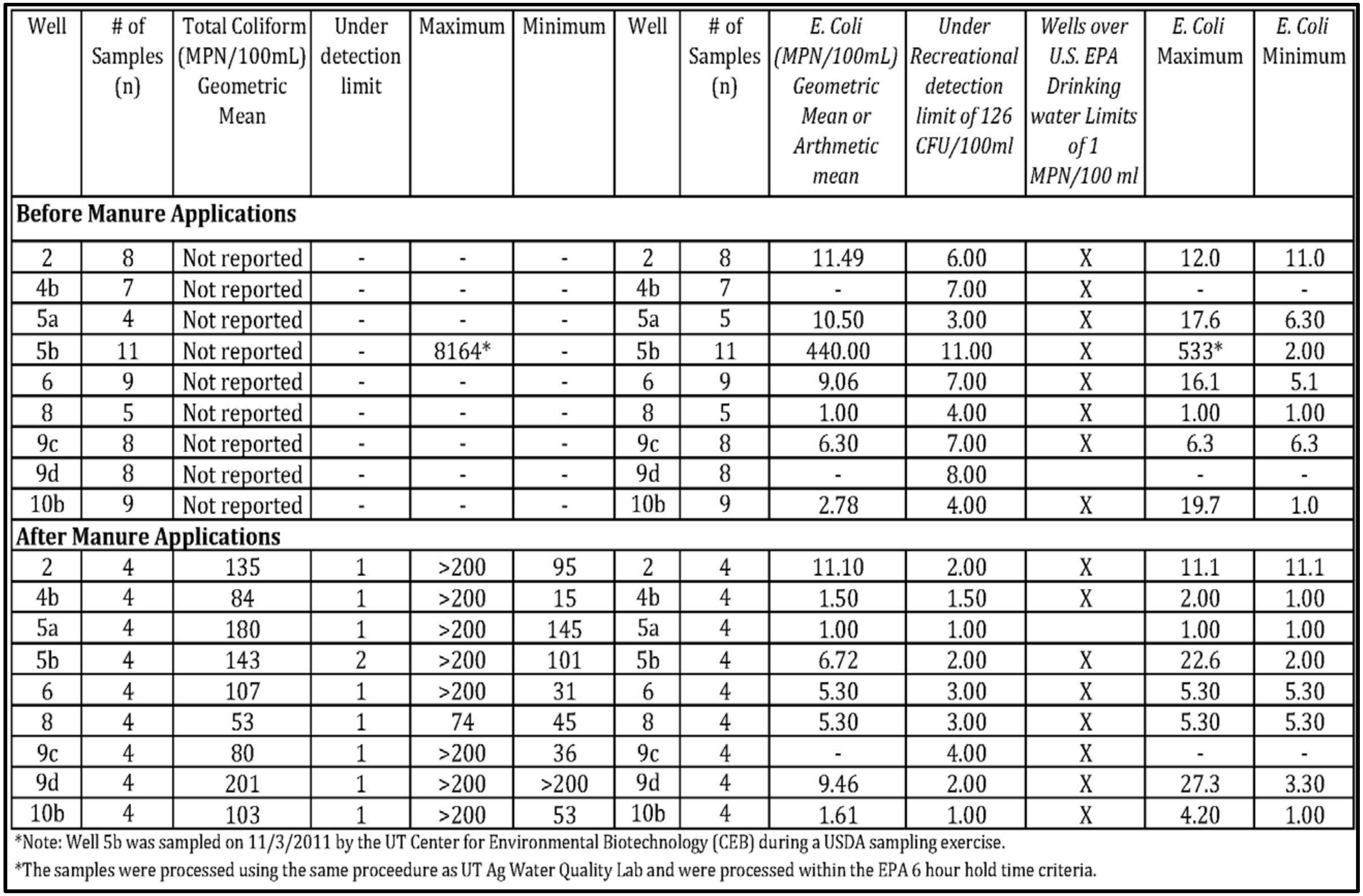
Nitrate concentrations appear to have increased slightly over time in two wells (5a, 8) and most appreciably in 2012 with the combined applications of commercial fertilizer and liquid manure. This trend is expected to increase over time and could appear in other wells.

Phosphate is also an important nutrient, which although not included in drinking water standards, can lead to algal growth and degradation of surface water quality. When combined with nitrates the algal growth may increase substantially limiting the freshwater systems functionality by starving the system of oxygen. Declines in phosphorous concentrations in fresh water systems has also resulted in the decrease of algal growth (Weathers K. C. et al., 2013).

Biochemical oxygen demand (BOD) values in the wells typically range from 0.4 to 2 mg/L, with a few values as high as 4 mg/L. In wells 6, 9c and 10b, there appears to be a noticeable increase in BOD after the application of manure. This is likely due to an influx of organic matter contained in the manure. However, in well 9d, the highest BOD value was recorded before the application of manure, suggesting that are other influxes of organic matter, such as decaying plants. There are no drinking water limits for BOD, but typical values in pristine rivers are < 1 mg/L, with moderately polluted rivers having 2 to 8 mg/L.

Coliform bacteria were detected at relatively high levels in samples from every well sampled, as shown in Figures 3.47 to 3.54 and Table 3.10. Coliforms are common in dairy manure, wildlife feces, soil and organic-rich surface water, but they generally do not reproduce in groundwater. Hence, the presence of high levels of coliform bacteria in the groundwater samples implies there is rapid recharge of water from the upper soil horizons. It also suggests that natural removal of bacteria due to filtration in the sediments is insufficient to remove the coliforms during infiltration.  Measurable *E. coli* was detected in at least one sample from every well tested, except for well 9c. Concentrations of *E. coli* ranged from 1 to 23 MPN/100 ml. These are above the EPA drinking water limit of < 1 MPN/100 ml, but substantially below the recreational surface water limit of 126 MPN/100 ml. The EPA drinking water standard for coliform and *E. coli* is defined as follows: no more than 5.0% samples total coliform-positive (TC-positive) in a month. (For water systems that collect fewer than 40 routine samples per month, no more than one sample can be total coliform-positive per month.) Every sample that has total coliform must be analyzed for either fecal coliforms or *E. coli* if two consecutive TC-positive samples, and one is also positive for *E. coli* fecal coliforms, system has an acute MCL violation (http://water.epa.gov/drink/contaminants/index.cfm).  As discussed in the Methods section, many of the coliform/E coli tests were carried out after the recommended sample hold time of 6 hours had elapsed (in some cases the samples were stored overnight before testing). Hence the measured values should be considered minimum values.

Table 3.11 - Total coliform and *E. coli* for Before Manure Applications and After Manure Applications, All Alluvium Wells - November 2009 - August 2012.



| Well | # of Samples (n) | Total Coliform (MPN/100mL) Geometric Mean | Under detection limit | Maximum | Minimum | Well | # of Samples (n) | *E. Coli (MPN/100mL) Geometric Mean or Arthmetic mean* | *Under Recreational detection limit of 126 CFU/100ml* | *Wells over U.S. EPA Drinking water Limits of 1 MPN/100 ml* | *E. Coli* Maximum | *E. Coli* Minimum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Before Manure Applications** | | | | | | | | | | | | |
| 2 | 8 | Not reported | - | - | - | 2 | 8 | 11.49 | 6.00 | X | 12.0 | 11.0 |
| 4b | 7 | Not reported | - | - | - | 4b | 7 | - | 7.00 | X | - | - |
| 5a | 4 | Not reported | - | - | - | 5a | 5 | 10.50 | 3.00 | X | 17.6 | 6.30 |
| 5b | 11 | Not reported | - | 8164* | - | 5b | 11 | 440.00 | 11.00 | X | 533* | 2.00 |
| 6 | 9 | Not reported | - | - | - | 6 | 9 | 9.06 | 7.00 | X | 16.1 | 5.1 |
| 8 | 5 | Not reported | - | - | - | 8 | 5 | 1.00 | 4.00 | X | 1.00 | 1.00 |
| 9c | 8 | Not reported | - | - | - | 9c | 8 | 6.30 | 7.00 | X | 6.3 | 6.3 |
| 9d | 8 | Not reported | - | - | - | 9d | 8 | - | 8.00 | | - | - |
| 10b | 9 | Not reported | - | - | - | 10b | 9 | 2.78 | 4.00 | X | 19.7 | 1.0 |
| **After Manure Applications** | | | | | | | | | | | | |
| 2 | 4 | 135 | 1 | >200 | 95 | 2 | 4 | 11.10 | 2.00 | X | 11.1 | 11.1 |
| 4b | 4 | 84 | 1 | >200 | 15 | 4b | 4 | 1.50 | 1.50 | X | 2.00 | 1.00 |
| 5a | 4 | 180 | 1 | >200 | 145 | 5a | 4 | 1.00 | 1.00 | | 1.00 | 1.00 |
| 5b | 4 | 143 | 2 | >200 | 101 | 5b | 4 | 6.72 | 2.00 | X | 22.6 | 2.00 |
| 6 | 4 | 107 | 1 | >200 | 31 | 6 | 4 | 5.30 | 3.00 | X | 5.30 | 5.30 |
| 8 | 4 | 53 | 1 | 74 | 45 | 8 | 4 | 5.30 | 3.00 | X | 5.30 | 5.30 |
| 9c | 4 | 80 | 1 | >200 | 36 | 9c | 4 | - | 4.00 | X | - | - |
| 9d | 4 | 201 | 1 | >200 | >200 | 9d | 4 | 9.46 | 2.00 | X | 27.3 | 3.30 |
| 10b | 4 | 103 | 1 | >200 | 53 | 10b | 4 | 1.61 | 1.00 | X | 4.20 | 1.00 |

*Note: Well 5b was sampled on 11/3/2011 by the UT Center for Environmental Biotechnology (CEB) during a USDA sampling exercise.

*The samples were processed using the same proceedure as UT Ag Water Quality Lab and were processed within the EPA 6 hour hold time criteria.

### 3.4 Summary

The floodplain sediments at LRDF range in thickness from 3 to 9 m and are composed of 70 – 85% medium to fine grained sands with 10 to 30% silt, a trace of clay and occasional gravel layers. The sediments were deposited largely by avulsion (diversion) and as overbank floodplain deposits from the Little River as it meandered across the floodplain over the past 2 million years (Quaternary Period).

Slug and pump test measured values are similar to and within the expected ranges for typical for fine to medium grain sands (Freeze and Cherry, 1979). Grainsize analysis using the Hazen and Shepherd methods for estimating hydraulic conductivity reported K values of 2.01E-05 (m/s) and 2.33E-04 (m/s) respectively (Hazen, 1892; Shepherd, 1989). The K value results from the Hazen and Shepherd Methods were typically one to two orders of magnitude higher than the geometric mean of the slug tests (3.10E-06 m/s) and pump tests (1.30E-06 (m/s). This is not unusual because Hazen and Shepherd methods often overestimate K values, relative to hydraulic measurements.

Overall, the alluvial floodplain at LRDF exhibits the following hydrologic features: 1). the flow system is shallow in the alluvial sediments with lateral flow and discharge to the streams or ditches; 2). the alluvial system is highly responsive to recharge with moderate transmissivity and hydraulic conductivity; and, 3) Karst features indicated that preferential flow paths exist along the contact between the Newala limestone and Lenoir limestone units and in some cases may be linked directly into river or creek systems. This contact zone spans the length of the farm from the Little River to Ellejoy Creek and should be carefully monitored prior to row crop harvesting to avoid potential injury due to potential sinkhole formation or collapse along this contact.

Background samples indicate the groundwater quality was similar to other natural groundwater sources in the southeastern U.S. (Drever, 1982; Hem, 1985). Data shows possible low incremental increases in nutrients as cows arrived and row crop fertilization occurred. The addition of fertilizer and later manure combined with fertilizer applications to row crop fields coincided with smaller increases in dissolved nutrient concentrations in some wells increases for nitrates, sulfates, phosphates and chlorides. In some cases nutrient concentrations exceeded primary and secondary drinking water standards, although it is unlikely that groundwater from the alluvium will ever be used for drinking water. The primary impact was noted in the wells along the central ditch and the perimeter of the farm where the hydraulic gradient increases to 7 to 15% toward the Little River to the south and west. This trend of elevated nutrient levels may continue and may increase due to groundwater contributions from the recently installed drainage tiles that terminate in the central ditch, removal of the vegetative buffer along the central ditch and the dredging of the ditch.

Future land management practices will determine the extent to which nitrates, chloride and dissolved solids increase in the alluvial sediments and in the streams and ditch that receive groundwater discharge from the alluvium or from the sinkholes that occur in the northwestern portion of the site.

# References

Aller, L., and Bennett, T. W., 1991, Handbook of Suggested Practices for the Design and Installation of Groundwater Monitoring Wells, *in* EPA, U. S., ed.: Las Vegas, Nevada, p. 1 - 224.

Arnon, S., Dahan, O., Elhanany, S., Cohen, K., Pankratov, I., Gross, A., Ronen, Z., Baram, S., and Shore, L. S., 2008, Transport of testosterone and estrogen from dairy-farm waste lagoons to groundwater: Environmental Science & Technology, v. 42, no. 15, p. 5521-5526.

ASTM, 2007, Standard Test Method for Partical Size-Analysis of Soils - D422 - 63.

Back, W., and Hanshaw, B. B., 1970, Comparison of chemical hydrology of Florida and Yucatan.: Journal of Hydrology, v. 10, p. 330-368.

Bailly-Comte, V., Martin, J. B., Jourde, H., Screaton, E. J., Pistre, S., and Langston, A., 2010, Water exchange and pressure transfer between conduits and matrix and their influence on hydrodynamics of two karst aquifers with sinking streams: Journal of Hydrology, v. 386, no. 1-4, p. 55-66.

Bakhsh, A., Kanwar, R. S., and Karlen, D. L., 2005, Effects of liquid swine manure applications on NO3-N leaching losses to subsurface drainage water from loamy soils in Iowa: Agriculture Ecosystems & Environment, v. 109, no. 1-2, p. 118-128.

Barker, J. C., and Sewell, J. I., 1973, Effects of Surface Irrigation with Dairy Manure Slurries on Quality of Groundwater and Surface Runoff: Transactions of the Asae, v. 16, no. 4, p. 804-807.

Blanford, W. J., Brusseau, M. L., Yeh, T. C. J., Gerba, C. P., and Harvey, R., 2005, Influence of water chemistry and travel distance on bacteriophage PRD-1 transport in a sandy aquifer: Water Research, v. 39, no. 11, p. 2345-2357.

Boulton, A. J., Datry, T., Kasahara, T., Mutz, M., and Stanford, J. A., 2010, Ecology and management of the hyporheic zone: stream-groundwater interactions of running waters and their floodplains: Journal of the North American Benthological Society, v. 29, no. 1, p. 26-40.

Boyer, D. G., Kuczynska, E., and Fayer, R., 2009, Transport, fate, and infectivity of Cryptosporidium parvum oocysts released from manure and leached through macroporous soil: Environmental Geology, v. 58, no. 5, p. 1011-1019.

Bridge, J., 1955 Disconformity between Lower and Middle Ordovician series at Douglas Lake, Tennessee: Geological Society of America Bulletin, v. 66, p. 725-730.

Burns, R., 2010a, Comprehensive Nutrient Management Plan For the University of Tennessee Little River Animal Agriculture Environmental Research Unit: Knoxville, Tn, University of Tennessee Institute of Agriculture, p. 1-253.

Burns, R., T., 2010b, Comprehensive Nutrient Management Plan - University of Tennessee Little River Animal Agriculture Environmental Research Unit.

Butler, J. J., Jin, W., Mohammed, G. A., and Reboulet, E. C., 2011, New Insights from Well Responses to Fluctuations in Barometric Pressure: Ground Water, v. 49, no. 4, p. 525-533.

Capel, P. D., Hamilton, P. A., and Erwin, M. L., 2004, Studies by the U.S. Geological Survey on sources, transport, and fate of agricultural chemicals: Fact Sheet - U. S. Geological Survey.

Capel, P. D., McCarthy, K. A., and Barbash, J. E., 2008, National, holistic, watershed-scale approach to understand the sources, transport, and fate of agricultural chemicals: Journal of Environmental Quality, v. 37, no. 3, p. 983-993.

Cook, P. G., Solomon, D. K., Sanford, W. E., Busenberg, E., Plummer, L. N., and Poreda, R. J., 1996, Inferring shallow groundwater flow in saprolite and fractured rock using environmental tracers: Water Resources Research, v. 32, no. 6, p. 1501-1509.

Cooper, H. H., and Jacob, C. E., 1946, A generalized graphical method for evaluating formation constants and summarizing well field history., Volume vol. 27, American Geophysics Union Transactions, p. pp. 526-534.

Davis, C. J., 2002, Statitics and data analysis in geology, New York, NY, John Wiley & Sons, 638 p.:

Davis, R., and Hirji, R., 2003, Water quality : assessment and protection: The International Bank for Reconstruction and Development/THE WORLD BANK, 26124.

Deborde, D. C., Woessner, W. W., Kiley, Q. T., and Ball, P., 1999, Rapid transport of viruses in a floodplain aquifer: Water Research, v. 33, no. 10, p. 2229-2238.

Domagalski, J. L., Ator, S., Coupe, R., McCarthy, K., Lampe, D., Sandstrom, M., and Baker, N., 2008, Comparative study of transport processes of nitrogen, phosphorus, and herbicides to streams in five agricultural basins, USA: Journal of Environmental Quality, v. 37, no. 3, p. 1158-1169.

Donat, R., Johnson, E., Knappett, P., McKenna, A., Owen, C., Riestenberg, D., and Rogers, J., 2007, Hydrogeologic Characterization of the Little River Dairy Farm (LRDF): University of Tennessee.

Drever, J. I., 1982, The Geochemistry of Natual Waters, Prentice-Hall, Inc., Englewood Cliffs, N.J. 07632.

Drever, J. I., 1997, The geochemistry of natural waters: surface and groundwater environments, Prentice Hall, 436 p.:

EPA, 1972, The Challenge of the Environment - A Primer on EPA’s Statutory Authority: Water Quality.

EPA, 2008, Introduction to the Clean Water Act - Glossary of Definitions.

EPA, U. S., 1993, Method 365.1 - Determination of Phosphorus by Semi-Automated Colorimetery.

Fetter, C. W., 2001, *Applied Hydrogeology*, Prentice Hall, Upper Saddle River, NJ 07458, “Properties of Aquifers”.

Fogg, G. E., Noyes, C. D., and Carle, S. F., 1998, Geologically based model of heterogeneous hydraulic conductivity in an alluvial setting: Hydrogeology Journal, v. 6, no. 1, p. 131-143.

Freeze, R. A., and Cherry, J. A., 1979, Groundwater, Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Gale, P. M., Mullen, M. D., Cieslik, C., Tyler, D. D., Duck, B. N., Kirchner, M., and McClure, J., 2000, Phosphorus distribution and availability in response to dairy manure applications: Communications in Soil Science and Plant Analysis, v. 31, no. 5-6, p. 553-565.

Gee, G. W., and Or, D., 2002, Methods of Soil Analysis Part 4 Physical Methods, Madison, Wisconsin, USA, Soil Science Society of America, Inc., Particle-Size Analysis, v. 5, 1692 p.:

Goss, M. J., and Barry, D. A. J., 1995, Groundwater Quality - Responsible Agriculture and Public Perceptions: Journal of Agricultural & Environmental Ethics, v. 8, no. 1, p. 52-64.

Green, C. T., Fisher, L. H., and Bekins, B. A., 2008, Nitrogen fluxes through unsaturated zones in five agricultural settings across the United States: Journal of Environmental Quality, v. 37, no. 3, p. 1073-1085.

Hamilton, P. A., and Helsel, D. R., 1995, Effects of Agriculture on Groundwater Quality in 5 Regions of the United States: Ground Water, v. 33, no. 2, p. 217-226.

Harter, T., Davis, H., Mathews, M. C., and Meyer, R. D., 2002, Shallow groundwater quality on dairy farms with irrigated forage crops: Journal of Contaminant Hydrology, v. 55, no. 3-4, p. 287-315.

Hazen, A., 1892, Some physical properties of sands and gravels: Massachusetts State Board of Health.

Hem, J. D., 1985, Study and Interpretation of the Chemical Characteristics of Natural Water, Washington, DC, U.S. Geological Survey, 263 p.:

Hubbell, J. M., Sisson, J. B., Nicholl, M. J., and Taylor, R. G., 2004, Well design to reduce barometric pressure effects on water level data in unconfined aquifers: Vadose Zone Journal, v. 3, no. 1, p. 183-189.

Hudak, P. F., 2000, Regional trends in nitrate content of Texas groundwater: Journal of Hydrology, v. 228, no. 1-2, p. 37-47.

Hunter, R. W., 2013, Little River Dairy Farm Well Boring Locations, GIS ArcMap 10.10, scale Kilometers.

Hunter, R. W., Koehen, K., Lavoie, B., Luffman, I., Moore, A., Roy, A., and Conner, F., 2009, Installation and Testing of Groundwater Monitoring Wells, Little River Dairy Farm (LRDF): University of Tennessee Earth & Planetary Science Department.

Hvorslev, M., 1951, Time Lag and Soil Permeability in Ground Water Observations: Bulletin No. 36, U.S. Army Corp of Engineers.

Hyder, Z., Butler, J. J., McElwee, C. D., and Liu, W. Z., 1994, Slug Tests in Partially Penetrating Wells: Water Resources Research, v. 30, no. 11, p. 2945-2957.

Kumar, K., Gupta, S. C., Chander, Y., and Singh, A. K., 2005, Antibiotic use in agriculture and its impact on the terrestrial environment, Advances in Agronomy, Vol 87, Volume 87, p. 1-54.

Langmuir, D., 1971, The Geochemistry of some carbonate groundwaters in central Pennsylvaina: Geochim. Cosmochium. Acta, v. 35, p. 1023-1045.

Leopold, L. B., and Wolman, M. G., 1960, RIVER MEANDERS: Geological Society of America Bulletin, v. 71, no. 6, p. 769-&.

Ludwig, A. L., 2011, Water Quality Best Management Practices for Stormwater Pollution Management - Little River Dairy Farm, *in* R.W., H., ed., p. 1-10.

Malik, Y. S., Randall, G. W., and Goyal, S. M., 2004, Fate of Salmonella following application of swine manure to tile-drained clay loam soil: Journal of Water and Health, v. 2, no. 2, p. 97-101.

Martin-Queller, E., Moreno-Mateos, D., Pedrocchi, C., Cervantes, J., and Martinez, G., 2010, Impacts of intensive agricultural irrigation and livestock farming on a semi-arid Mediterranean catchment: Environmental Monitoring and Assessment, v. 167, no. 1-4, p. 423-435.

Meyer, J. L., McDowell, W. H., Bott, T. L., Elwood, J. W., Ishizaki, C., Melack, J. M., Peckarsky, B. L., Peterson, B. J., and Rublee, P. A., 1988, ELEMENTAL DYNAMICS IN STREAMS: Journal of the North American Benthological Society, v. 7, no. 4, p. 410-432.

Moss, J., Jensen, K., English, B., and Holland, R., 2011, The Tennessee Dairy Industry and Its Value-Added Opportunities: University of Tennesse Extension.

Nanson, G. C., and Knighton, A. D., 1996, Anabranching rivers: Their cause, character and classification: Earth Surface Processes and Landforms, v. 21, no. 3, p. 217-239.

National Climatic Data Center, 2012, Greater Knoxville Area Monthly Climate Averages 1981-2010.

Negrel, P., Petelet-Giraud, E., Barbier, J., and Gautier, E., 2003, Surface water-groundwater interactions in an alluvial plain: Chemical and isotopic systematics: Journal of Hydrology, v. 277, no. 3-4, p. 248-267.

Neuman R.B., 1955, Middle Ordovician rocks of the Tellico-Sevier belt, eastern Tennessee: USGS Numbered Series, v. 274-F, p. p. 141-178.

Neuman, R. B., 1951, The Great Smoky Fault: American Journal of Science, v. v. 249, p. 740-754.

Neuman, R. B., 1960, Geology of the Wildwood quadrangle, Tennessee: U.S. Geological Survey, Geologic Quadrangle Map, GQ-130, scale 1:24000.

Railsback, B. L., Bouker, P. A., Feeney, T. P., Goddard, E. A., Goggin, K. E., Hall, A. S., Jackson, B. P., McLain, A. A., Orsega, M. C., Rafter, M. A., and Webster, J. A., 1996, A survey of the major-element geochemistry of Georgia groundwater: Southeastern Geology, v. 36, no. 3, p. 99-122.

Repa, E., and Kufs, C., 1985, Leachate Plume Management: US EPA.

Ribaudo, M., 2009, Environmental Interactions with Agriculture Production: USDA Economic Research Service, p. 11.

Richards, B. K., Schulte, B. M., Heilig, A., Steenhuis, T. S., McBride, M. B., Harrison, E. Z., and Dickson, P., 2004, Environmental impacts of applying manure, fertilizer, and sewage biosolids on a dairy farm: Journal of the American Water Resources Association, v. 40, no. 4, p. 1025-1042.

Rodgers, J., 1953, Niota, Tennessee Geology: USGS Numbered Series, scale 1:24000.

Rodgers, J., and Kent, D. F., 1948, Stratigraphic section at Lee Valley, Hawkins County, Tennessee: Tennessee Department of Conservation Division of Geology Bulletin 58.

Sarten, J. R., 2012-2013, LRAEU Drainage Survey, *in* Joe R. Sarten, P. E., ed.: University of Tennessee Agricultural Experiment Station, Bio Systems Engineering and Soil Science Department.

Schilling, K. E., and Helmers, M., 2008, Tile drainage as karst: Conduit flow and diffuse flow in a tile-drained watershed: Journal of Hydrology, v. 349, no. 3-4, p. 291-301.

Shepherd, R. G., 1989, Correlations of Permeability and Grain Size: Ground Water, v. 27, no. 5, p. 633-638.

Slingerland, R., and Smith, N. D., 2004, River avulsions and their deposits: Annual Review of Earth and Planetary Sciences, v. 32, p. 257-285.

Smith, R. A., Schwarz, G. E., and Alexander, R. B., 1994, Regional Estimates of the Amount of U.S. Agricultural Land Located in Watersheds with Poor Water Quality.

Standard Methods, 1996, Method 5310 - Total Organic Carbon (TOC) - Standard Methods for the Examination of Water and Wastewater, 19th Edition: Standard Methods.

TDEC, 2005, 2010, 2012, 303(d) LIST - Tennessee Department of Environment and Conservation.

Tennessee Climatological Service, 2012, Tennesse Climate Data, University of Tennessee, Department of Biosystems Engineering and Soil Science.

US Environmental Protection Agency, 2005, 2005 Targeted Watersheds Grants: Little River, Tennessee and North Carolina.

USDA, 2006, Agricultural Resources and Environmental Indicators United States Department of Agriculture.

Van Drecht, G., Bouwman, A. F., Knoop, J. M., Beusen, A. H. W., and Meinardi, C. R., 2003, Global modeling of the fate of nitrogen from point and nonpoint sources in soils, groundwater, and surface water: Global Biogeochemical Cycles, v. 17, no. 4.

VanderZaag, A. C., Campbell, K. J., Jamieson, R. C., Sinclair, A. C., and Hynes, L. G., 2010, Survival of Escherichia coil in agricultural soil and presence in tile drainage and shallow groundwater: Canadian Journal of Soil Science, v. 90, no. 3, p. 495-505.

Weathers K. C., Strayer, D. L., and Likens, G. E., 2013, Fundamentals of Ecosystem Science, Elsevier, 312 p.:

Welch, H. L., Green, C. T., and Coupe, R. H., 2011, The fate and transport of nitrate in shallow groundwater in northwestern Mississippi, USA: Hydrogeology Journal, v. 19, no. 6, p. 1239-1252.

Wills, J., Honea, G., and Armstrong, H., 2005-2010, East Tennessee Research and Education Center - UTIA - Little River Unit - Surface Water Monitoring Program.

Wolman, M. G., and Leopold, L. B., 1957, River flood plains; some observations on their formation: United States Geological Survey numbered series, no. 282-C, p. 87-109.

Zhao, S., Zhang, P. F., Melcer, M. E., and Molina, J. F., 2010, Estrogens in streams associated with a concentrated animal feeding operation in upstate New York, USA: Chemosphere, v. 79, no. 4, p. 420-425.

# Appendices

Appendix A - 2007 Borehole Logs in Floodplain Sediments

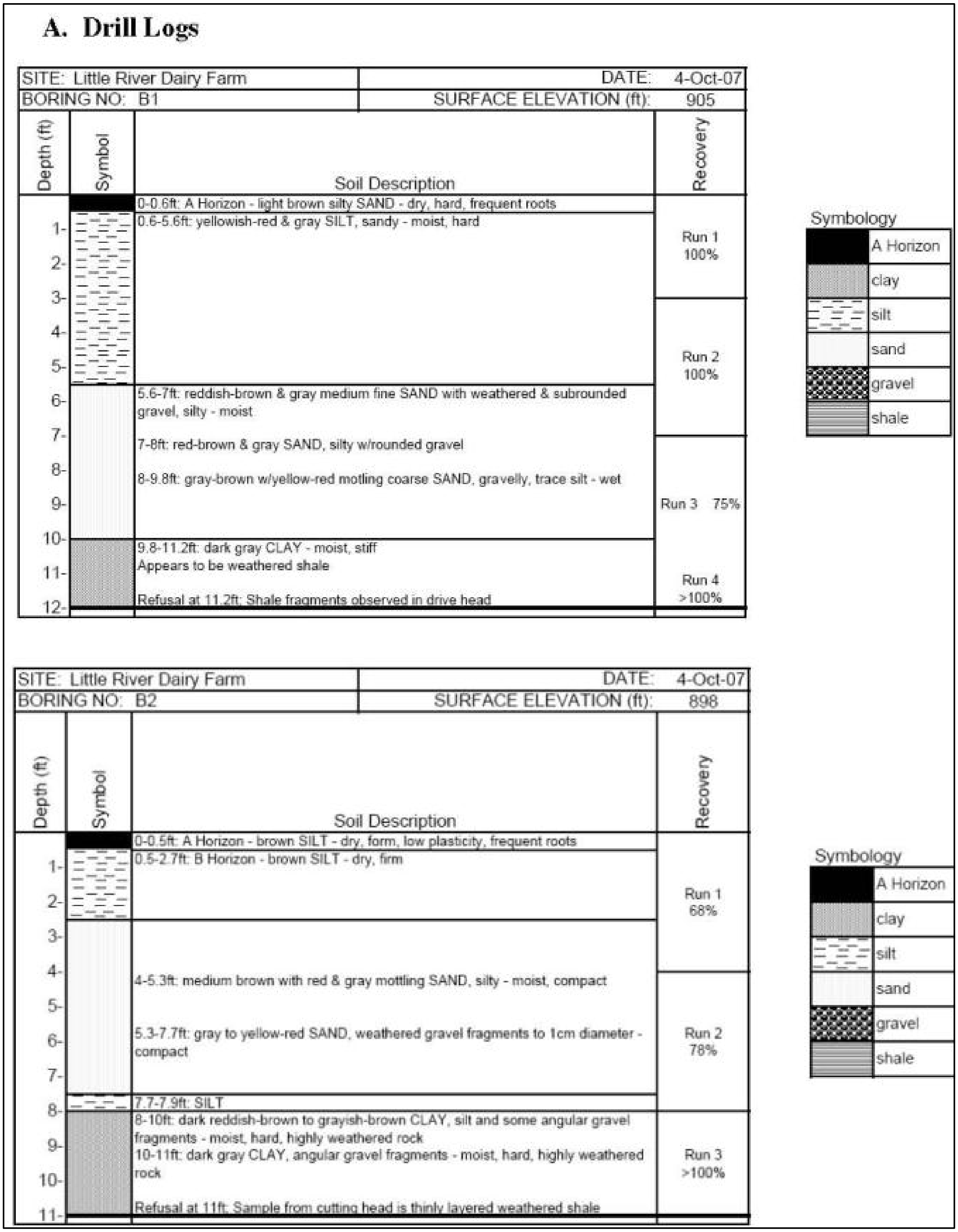
Appendix B – Alluvium Gransize and Hydrometer Analysis

Appendix C – Alluvium Charts for Slug & Pumping Tests

Appendix D – Water Quality Data

# Appendix A - 2007 Borehole Logs in Floodplain Sediments

Boring Log 1 & 2



## A. Drill Logs

| SITE: Little River Dairy Farm | | | DATE: 4-Oct-07 |
|---|---|---|---|
| BORING NO: B1 | | SURFACE ELEVATION (ft): | 905 |
| **Depth (ft)** | **Symbol** | **Soil Description** | **Recovery** |
| | ■ | 0-0.6ft: A Horizon - light brown silty SAND - dry, hard, frequent roots | |
| 1-<br>2-<br>3-<br>4-<br>5- | ┅ | 0.6-5.6ft: yellowish-red & gray SILT, sandy - moist, hard | Run 1<br>100%<br>Run 2<br>100% |
| 6-<br>7-<br>8-<br>9- | ░ | 5.6-7ft: reddish-brown & gray medium fine SAND with weathered & subrounded gravel, silty - moist<br>7-8ft: red-brown & gray SAND, silty w/rounded gravel<br>8-9.8ft: gray-brown w/yellow-red motling coarse SAND, gravelly, trace silt - wet | Run 3 75% |
| 10-<br>11-<br>12- | ▒ | 9.8-11.2ft: dark gray CLAY - moist, stiff<br>Appears to be weathered shale<br>Refusal at 11.2ft: Shale fragments observed in drive head | Run 4<br>>100% |

Symbology

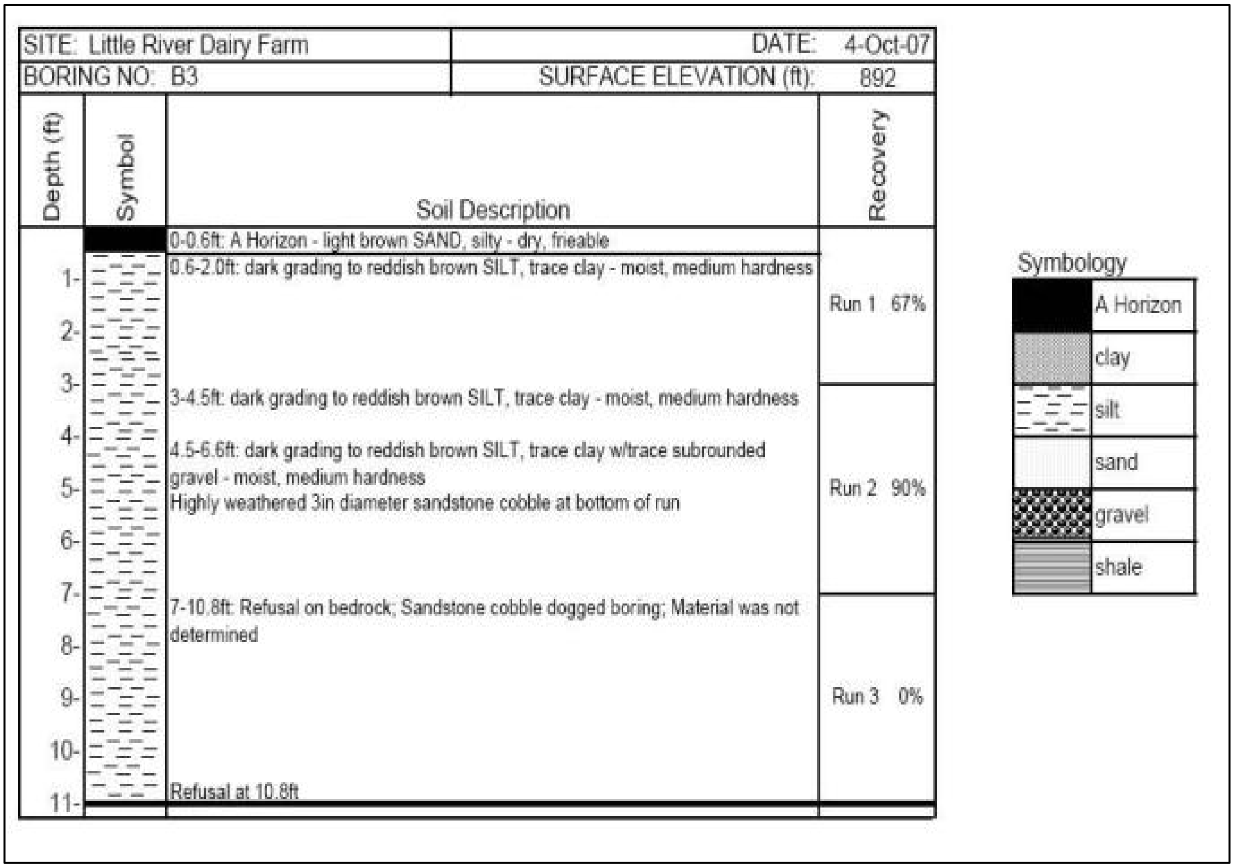
| | |
|---|---|
| ■ | A Horizon |
| ▒ | clay |
| ┅ | silt |
| ░ | sand |
| ▩ | gravel |
| ▤ | shale |

| SITE: Little River Dairy Farm | | | DATE: 4-Oct-07 |
|---|---|---|---|
| BORING NO: B2 | | SURFACE ELEVATION (ft): | 898 |
| **Depth (ft)** | **Symbol** | **Soil Description** | **Recovery** |
| | ■ | 0-0.5ft: A Horizon - brown SILT - dry, form, low plasticity, frequent roots | |
| 1-<br>2- | ┅ | 0.5-2.7ft: B Horizon - brown SILT - dry, firm | Run 1<br>68% |
| 3-<br>4-<br>5-<br>6-<br>7- | ░ | 4-5.3ft: medium brown with red & gray mottling SAND, silty - moist, compact<br>5.3-7.7ft: gray to yellow-red SAND, weathered gravel fragments to 1cm diameter - compact | Run 2<br>78% |
| | ┅ | 7.7-7.9ft: SILT | |
| 8-<br>9-<br>10-<br>11- | ▒ | 8-10ft: dark reddish-brown to grayish-brown CLAY, silt and some angular gravel fragments - moist, hard, highly weathered rock<br>10-11ft: dark gray CLAY, angular gravel fragments - moist, hard, highly weathered rock<br>Refusal at 11ft: Sample from cutting head is thinly layered weathered shale | Run 3<br>>100% |

Symbology

| | |
|---|---|
| ■ | A Horizon |
| ▒ | clay |
| ┅ | silt |
| ░ | sand |
| ▩ | gravel |
| ▤ | shale |

Boring Log 3

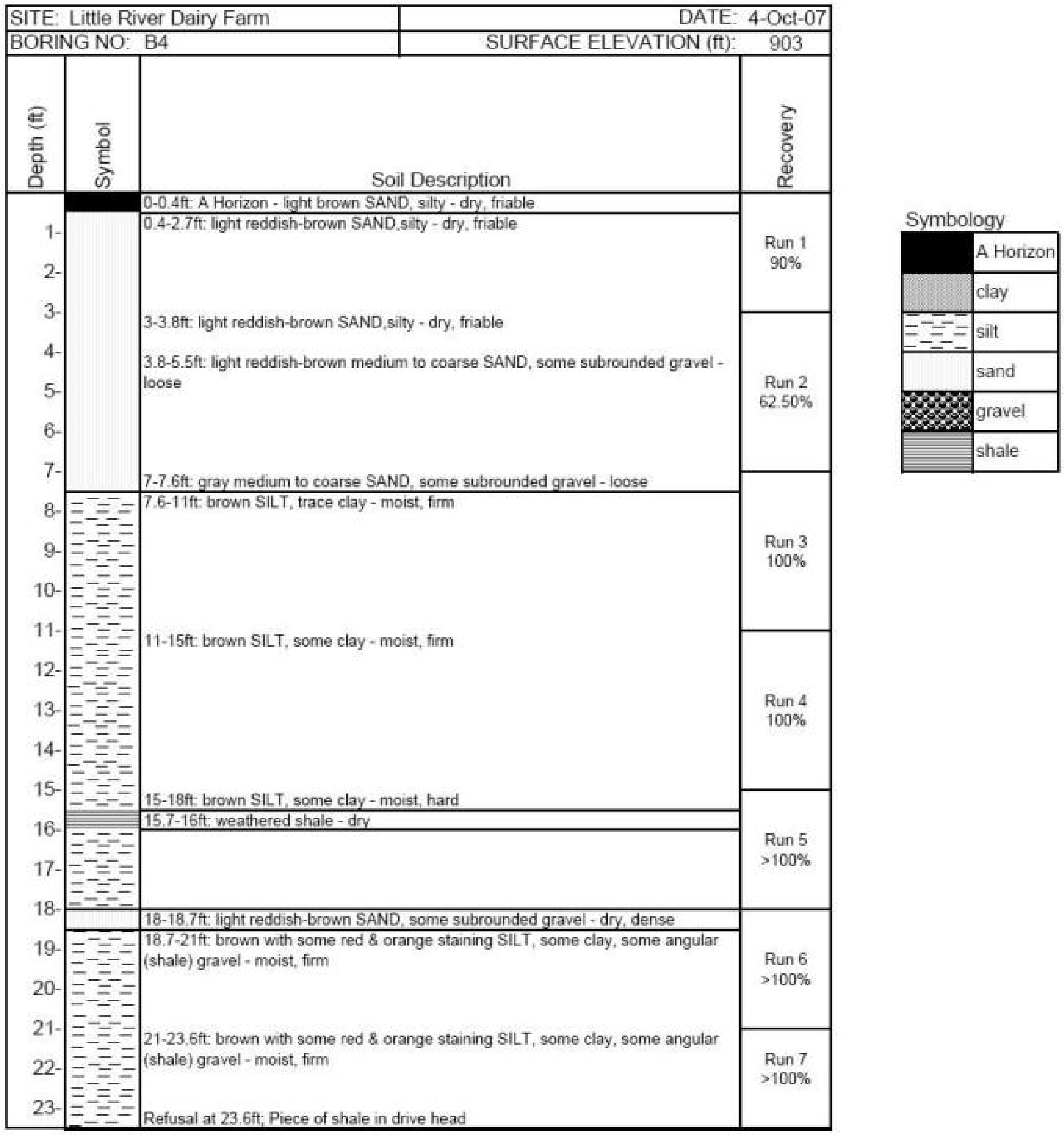


SITE: Little River Dairy Farm | DATE: 4-Oct-07

BORING NO: B3 | SURFACE ELEVATION (ft): 892

| Soil Description | Recovery |
|---|---|
| 0-0.6ft: A Horizon - light brown SAND, silty - dry, frieable | |
| 0.6-2.0ft: dark grading to reddish brown SILT, trace clay - moist, medium hardness | Run 1 67% |
| 3-4.5ft: dark grading to reddish brown SILT, trace clay - moist, medium hardness<br>4.5-6.6ft: dark grading to reddish brown SILT, trace clay w/trace subrounded gravel - moist, medium hardness<br>Highly weathered 3in diameter sandstone cobble at bottom of run | Run 2 90% |
| 7-10.8ft: Refusal on bedrock; Sandstone cobble dogged boring; Material was not determined<br>Refusal at 10.8ft | Run 3 0% |

## Boring Log 4



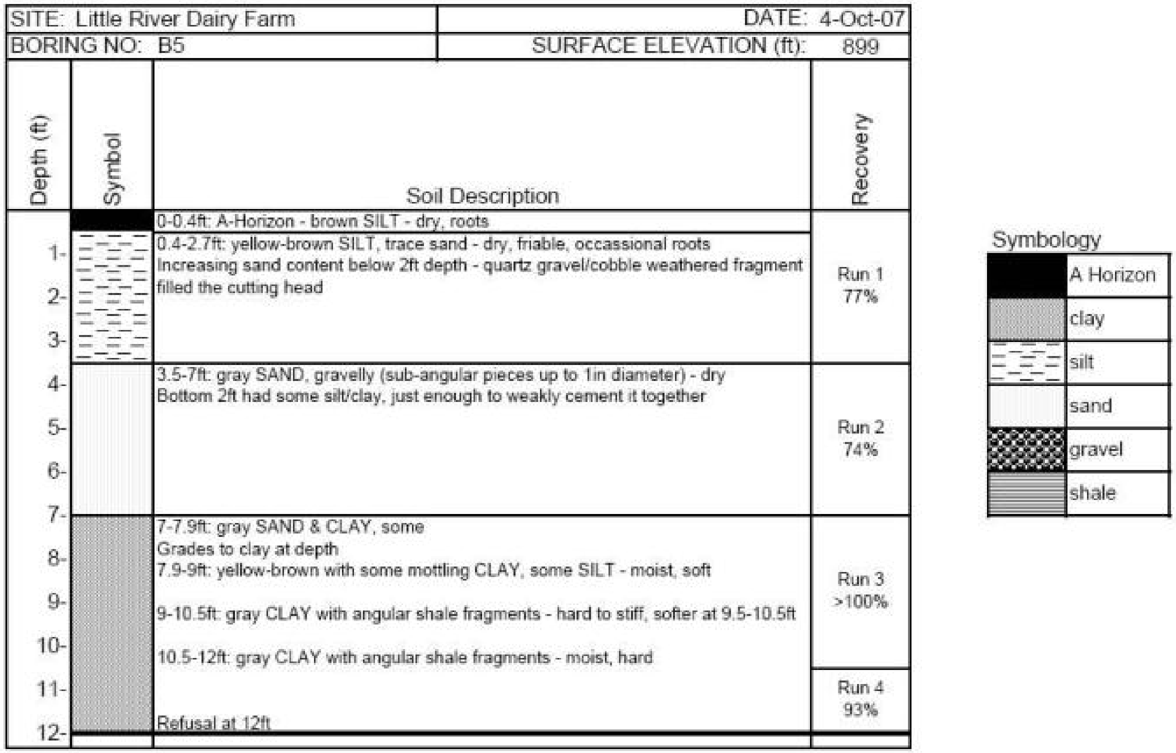
SITE: Little River Dairy Farm
DATE: 4-Oct-07
BORING NO: B4
SURFACE ELEVATION (ft): 903

| Soil Description | Recovery |
|---|---|
| 0-0.4ft: A Horizon - light brown SAND, silty - dry, friable | Run 1<br>90% |
| 0.4-2.7ft: light reddish-brown SAND,silty - dry, friable | |
| 3-3.8ft: light reddish-brown SAND,silty - dry, friable | Run 2<br>62.50% |
| 3.8-5.5ft: light reddish-brown medium to coarse SAND, some subrounded gravel - loose | |
| 7-7.6ft: gray medium to coarse SAND, some subrounded gravel - loose | |
| 7.6-11ft: brown SILT, trace clay - moist, firm | Run 3<br>100% |
| 11-15ft: brown SILT, some clay - moist, firm | Run 4<br>100% |
| 15-18ft: brown SILT, some clay - moist, hard | Run 5<br>>100% |
| 15.7-16ft: weathered shale - dry | |
| 18-18.7ft: light reddish-brown SAND, some subrounded gravel - dry, dense | Run 6<br>>100% |
| 18.7-21ft: brown with some red & orange staining SILT, some clay, some angular (shale) gravel - moist, firm | |
| 21-23.6ft: brown with some red & orange staining SILT, some clay, some angular (shale) gravel - moist, firm | Run 7<br>>100% |
| Refusal at 23.6ft; Piece of shale in drive head | |

Symbology

| | |
|---|---|
| ■ | A Horizon |
| ▒ | clay |
| ┄ | silt |
| ░ | sand |
| ▩ | gravel |
| ☰ | shale |

Boring Log 5 & 6

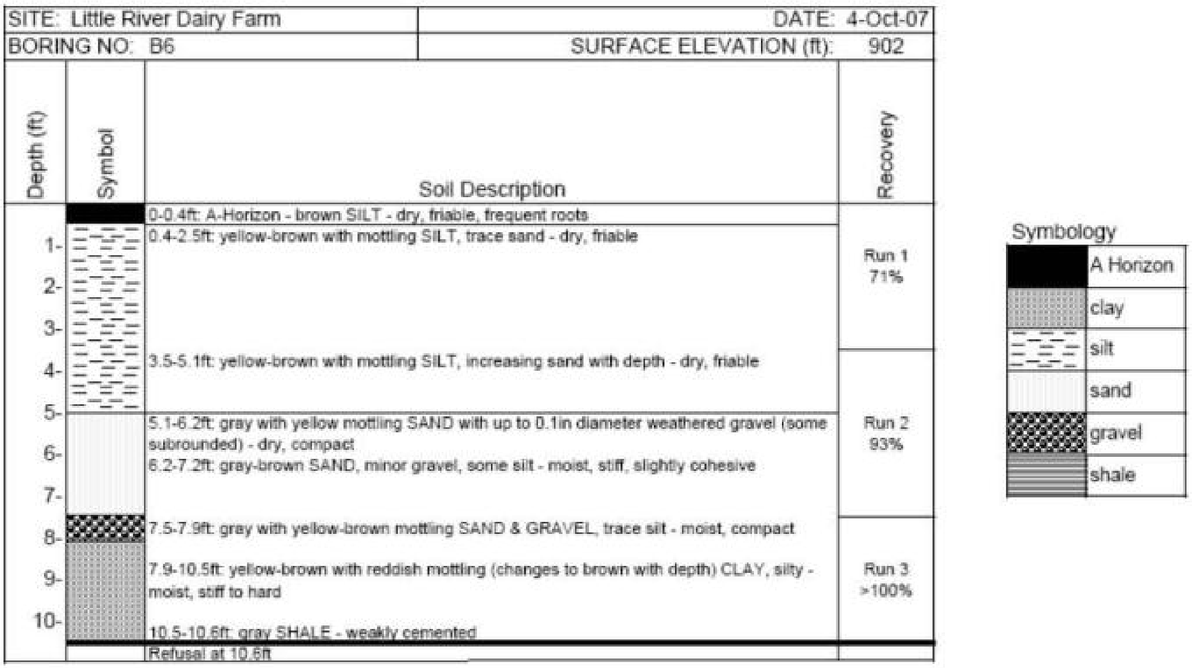


SITE: Little River Dairy Farm | DATE: 4-Oct-07
BORING NO: B5 | SURFACE ELEVATION (ft): 899

| Depth (ft) | Symbol | Soil Description | Recovery |
|---|---|---|---|
| | ■ | 0-0.4ft: A-Horizon - brown SILT - dry, roots | Run 1<br>77% |
| 1-<br>2-<br>3- | ☰ | 0.4-2.7ft: yellow-brown SILT, trace sand - dry, friable, occassional roots<br>Increasing sand content below 2ft depth - quartz gravel/cobble weathered fragment filled the cutting head | |
| 4-<br>5-<br>6-<br>7- | ░ | 3.5-7ft: gray SAND, gravelly (sub-angular pieces up to 1in diameter) - dry<br>Bottom 2ft had some silt/clay, just enough to weakly cement it together | Run 2<br>74% |
| 8-<br>9-<br>10- | ▒ | 7-7.9ft: gray SAND & CLAY, some<br>Grades to clay at depth<br>7.9-9ft: yellow-brown with some mottling CLAY, some SILT - moist, soft<br>9-10.5ft: gray CLAY with angular shale fragments - hard to stiff, softer at 9.5-10.5ft | Run 3<br>>100% |
| 11-<br>12- | ▒ | 10.5-12ft: gray CLAY with angular shale fragments - moist, hard<br>Refusal at 12ft | Run 4<br>93% |

Symbology

| | |
|---|---|
| ■ | A Horizon |
| ▒ | clay |
| ☰ | silt |
| ░ | sand |
| ▩ | gravel |
| ▤ | shale |



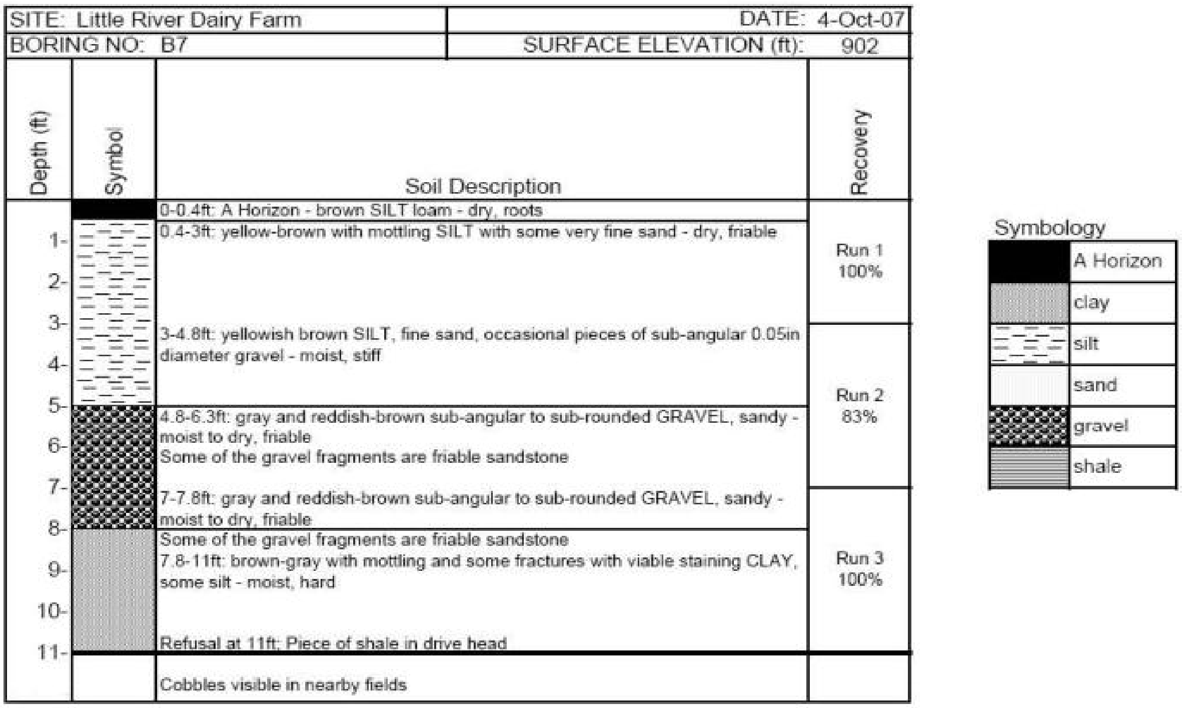
SITE: Little River Dairy Farm | DATE: 4-Oct-07
BORING NO: B6 | SURFACE ELEVATION (ft): 902

| Depth (ft) | Symbol | Soil Description | Recovery |
|---|---|---|---|
| | ■ | 0-0.4ft: A-Horizon - brown SILT - dry, friable, frequent roots | Run 1<br>71% |
| 1-<br>2-<br>3-<br>4- | ☰ | 0.4-2.5ft: yellow-brown with mottling SILT, trace sand - dry, friable<br>3.5-5.1ft: yellow-brown with mottling SILT, increasing sand with depth - dry, friable | |
| 5-<br>6-<br>7- | ░ | 5.1-6.2ft: gray with yellow mottling SAND with up to 0.1in diameter weathered gravel (some subrounded) - dry, compact<br>6.2-7.2ft: gray-brown SAND, minor gravel, some silt - moist, stiff, slightly cohesive | Run 2<br>93% |
| 8- | ▩ | 7.5-7.9ft: gray with yellow-brown mottling SAND & GRAVEL, trace silt - moist, compact | |
| 9-<br>10- | ▒ | 7.9-10.5ft: yellow-brown with reddish mottling (changes to brown with depth) CLAY, silty - moist, stiff to hard<br>10.5-10.6ft: gray SHALE - weakly cemented | Run 3<br>>100% |
| | | Refusal at 10.6ft | |

Symbology

| | |
|---|---|
| ■ | A Horizon |
| ▒ | clay |
| ☰ | silt |
| ░ | sand |
| ▩ | gravel |
| ▤ | shale |

Boring Log 7 & 8

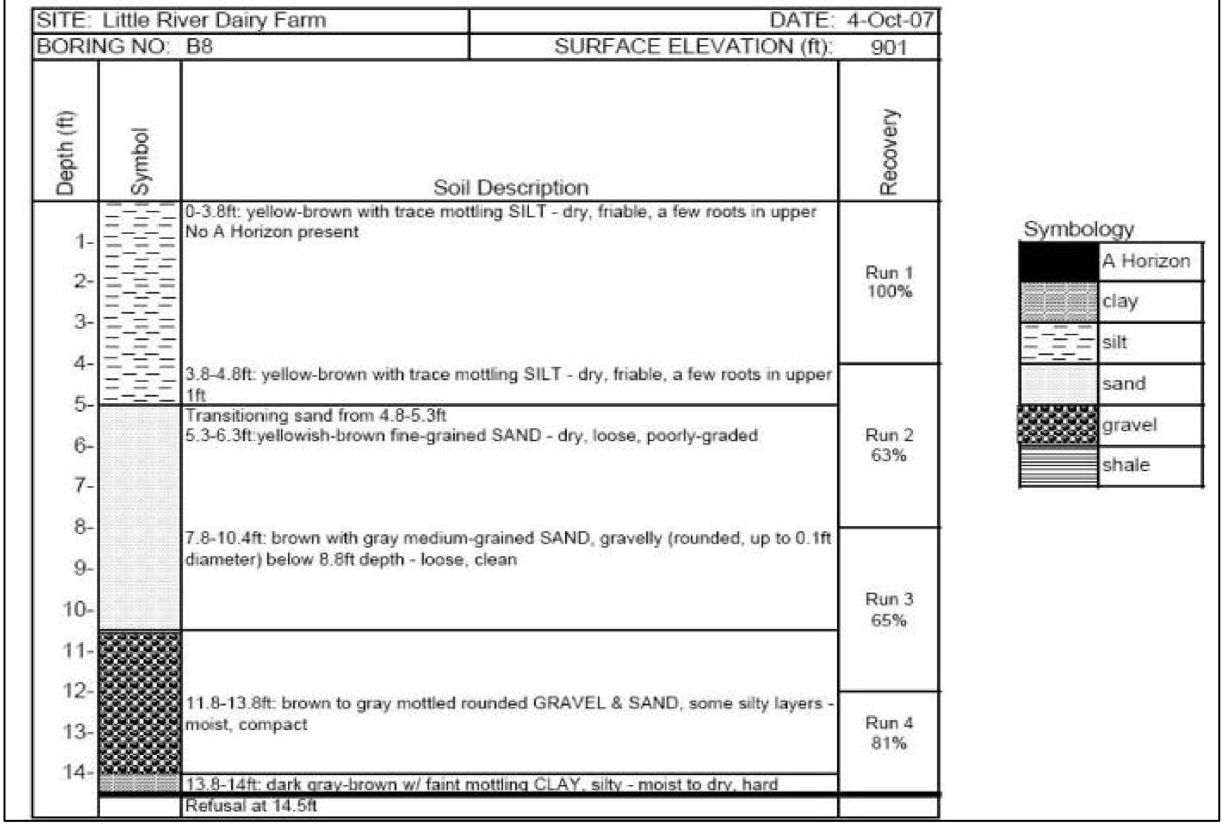


SITE: Little River Dairy Farm | DATE: 4-Oct-07
BORING NO: B7 | SURFACE ELEVATION (ft): 902

| Depth (ft) | Symbol | Soil Description | Recovery |
|---|---|---|---|
| | ■ | 0-0.4ft: A Horizon - brown SILT loam - dry, roots | Run 1<br>100% |
| 1-<br>2- | ┅ | 0.4-3ft: yellow-brown with mottling SILT with some very fine sand - dry, friable | |
| 3-<br>4- | ┅ | 3-4.8ft: yellowish brown SILT, fine sand, occasional pieces of sub-angular 0.05in diameter gravel - moist, stiff | Run 2<br>83% |
| 5-<br>6- | ▩ | 4.8-6.3ft: gray and reddish-brown sub-angular to sub-rounded GRAVEL, sandy - moist to dry, friable<br>Some of the gravel fragments are friable sandstone | |
| 7- | ▩ | 7-7.8ft: gray and reddish-brown sub-angular to sub-rounded GRAVEL, sandy - moist to dry, friable<br>Some of the gravel fragments are friable sandstone | Run 3<br>100% |
| 8-<br>9-<br>10-<br>11- | ▒ | 7.8-11ft: brown-gray with mottling and some fractures with viable staining CLAY, some silt - moist, hard<br>Refusal at 11ft: Piece of shale in drive head | |
| | | Cobbles visible in nearby fields | |

Symbology

| | |
|---|---|
| ■ | A Horizon |
| ▒ | clay |
| ┅ | silt |
| ░ | sand |
| ▩ | gravel |
| ▤ | shale |



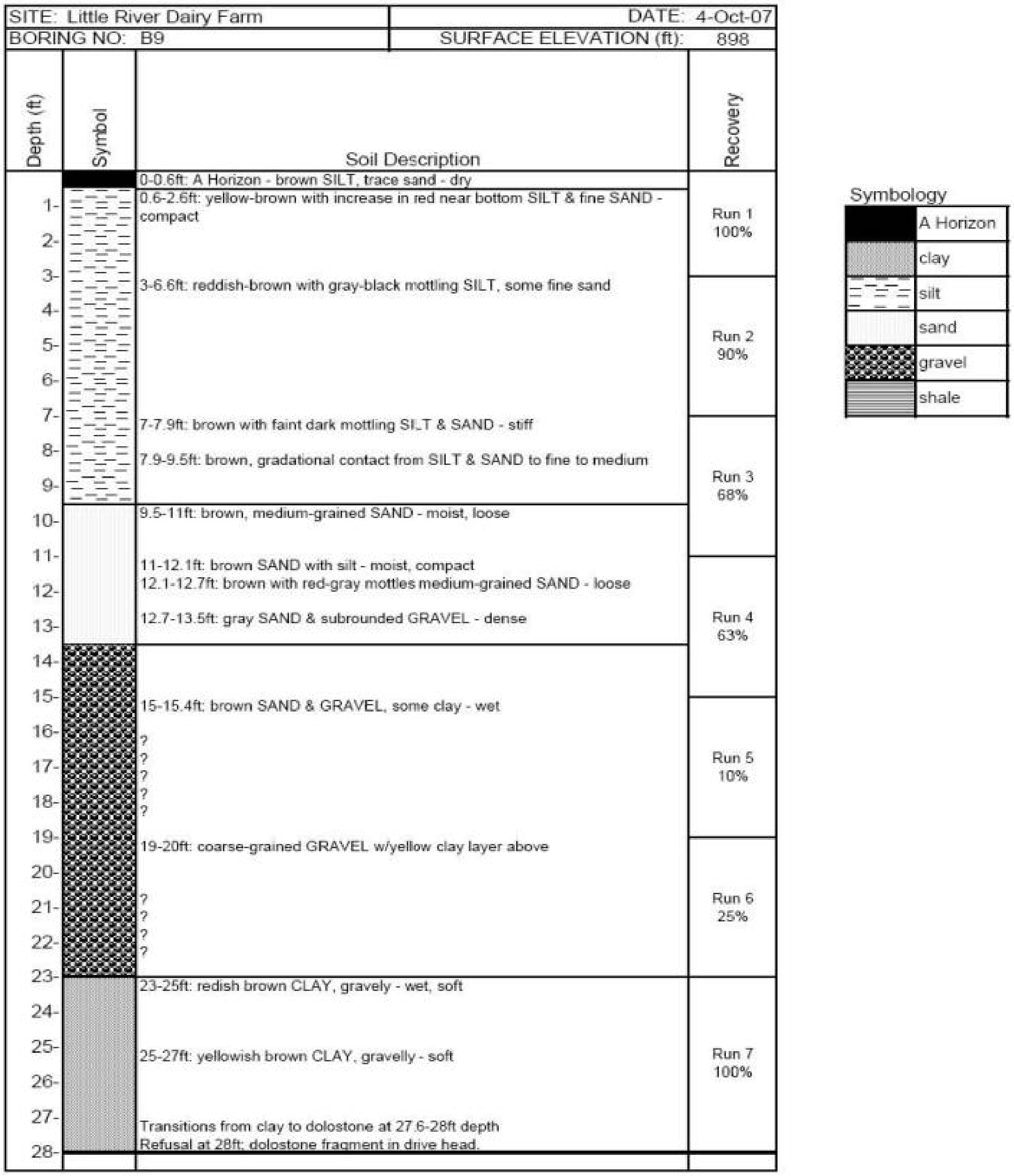
SITE: Little River Dairy Farm | DATE: 4-Oct-07
BORING NO: B8 | SURFACE ELEVATION (ft): 901

| Depth (ft) | Symbol | Soil Description | Recovery |
|---|---|---|---|
| 1-<br>2-<br>3- | ┅ | 0-3.8ft: yellow-brown with trace mottling SILT - dry, friable, a few roots in upper<br>No A Horizon present | Run 1<br>100% |
| 4- | ┅ | 3.8-4.8ft: yellow-brown with trace mottling SILT - dry, friable, a few roots in upper 1ft | Run 2<br>63% |
| 5-<br>6-<br>7- | ░ | Transitioning sand from 4.8-5.3ft<br>5.3-6.3ft:yellowish-brown fine-grained SAND - dry, loose, poorly-graded | |
| 8-<br>9-<br>10- | ░ | 7.8-10.4ft: brown with gray medium-grained SAND, gravelly (rounded, up to 0.1ft diameter) below 8.8ft depth - loose, clean | Run 3<br>65% |
| 11-<br>12-<br>13- | ▩ | 11.8-13.8ft: brown to gray mottled rounded GRAVEL & SAND, some silty layers - moist, compact | Run 4<br>81% |
| 14- | ▤ | 13.8-14ft: dark gray-brown w/ faint mottling CLAY, silty - moist to dry, hard | |
| | | Refusal at 14.5ft | |

Symbology

| | |
|---|---|
| ■ | A Horizon |
| ▒ | clay |
| ┅ | silt |
| ░ | sand |
| ▩ | gravel |
| ▤ | shale |

Boring Log 9



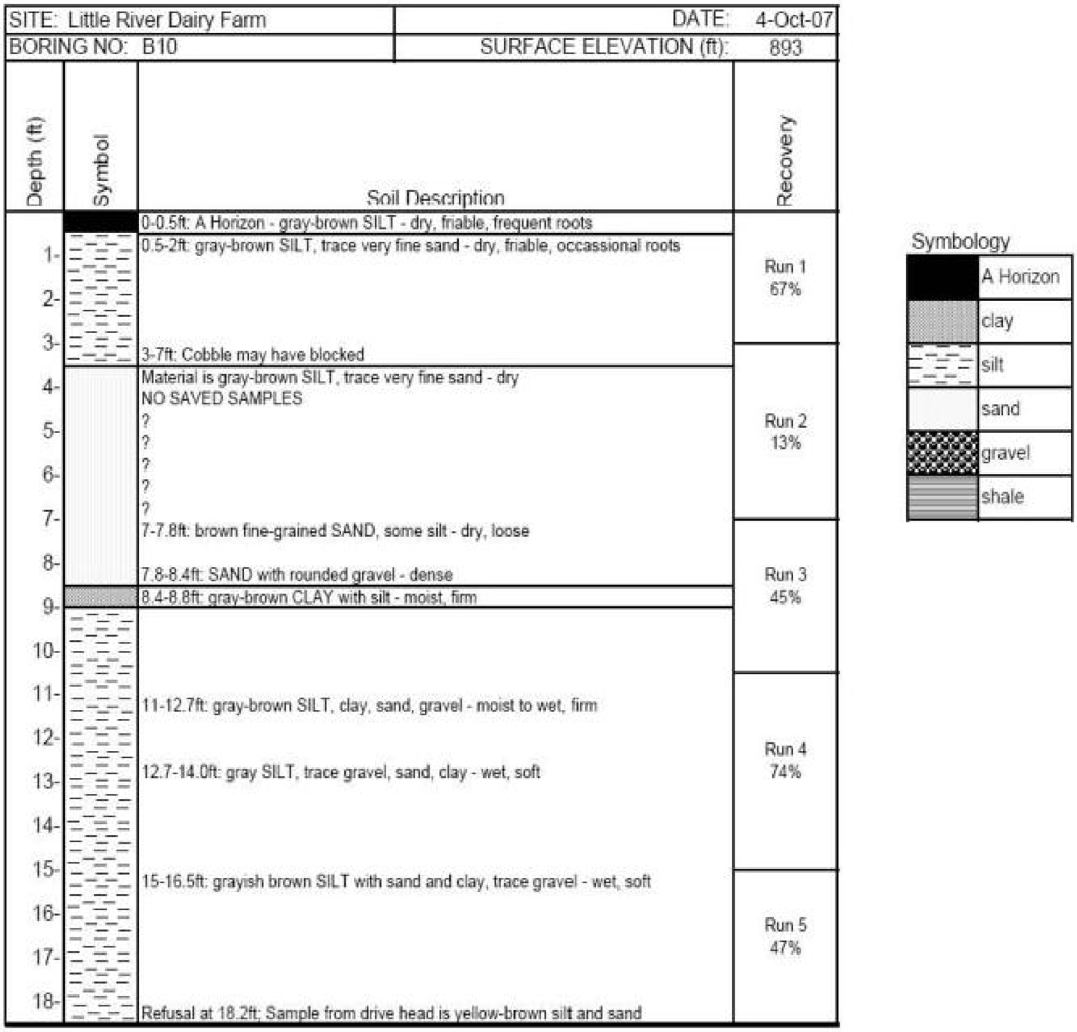
SITE: Little River Dairy Farm
DATE: 4-Oct-07
BORING NO: B9
SURFACE ELEVATION (ft): 898

| Depth (ft) | Symbol | Soil Description | Recovery |
|---|---|---|---|
| | | 0-0.6ft: A Horizon - brown SILT, trace sand - dry | |
| 1- | | 0.6-2.6ft: yellow-brown with increase in red near bottom SILT & fine SAND - compact | Run 1<br>100% |
| 3- | | 3-6.6ft: reddish-brown with gray-black mottling SILT, some fine sand | Run 2<br>90% |
| 7- | | 7-7.9ft: brown with faint dark mottling SILT & SAND - stiff | |
| 8- | | 7.9-9.5ft: brown, gradational contact from SILT & SAND to fine to medium | Run 3<br>68% |
| 10- | | 9.5-11ft: brown, medium-grained SAND - moist, loose | |
| 11- | | 11-12.1ft: brown SAND with silt - moist, compact | |
| 12- | | 12.1-12.7ft: brown with red-gray mottles medium-grained SAND - loose | |
| 13- | | 12.7-13.5ft: gray SAND & subrounded GRAVEL - dense | Run 4<br>63% |
| 15- | | 15-15.4ft: brown SAND & GRAVEL, some clay - wet | |
| 16-18- | | ?<br>?<br>?<br>?<br>? | Run 5<br>10% |
| 19- | | 19-20ft: coarse-grained GRAVEL w/yellow clay layer above | |
| 21-22- | | ?<br>?<br>?<br>? | Run 6<br>25% |
| 23- | | 23-25ft: redish brown CLAY, gravely - wet, soft | |
| 25- | | 25-27ft: yellowish brown CLAY, gravelly - soft | Run 7<br>100% |
| 27- | | Transitions from clay to dolostone at 27.6-28ft depth<br>Refusal at 28ft; dolostone fragment in drive head. | |
| 28- | | | |

Symbology

| | |
|---|---|
| ■ | A Horizon |
| ▒ | clay |
| ☰ | silt |
| ░ | sand |
| ▩ | gravel |
| ▤ | shale |

Boring Log 10



| | |
|---|---|
| SITE: Little River Dairy Farm | DATE: 4-Oct-07 |
| BORING NO: B10 | SURFACE ELEVATION (ft): 893 |

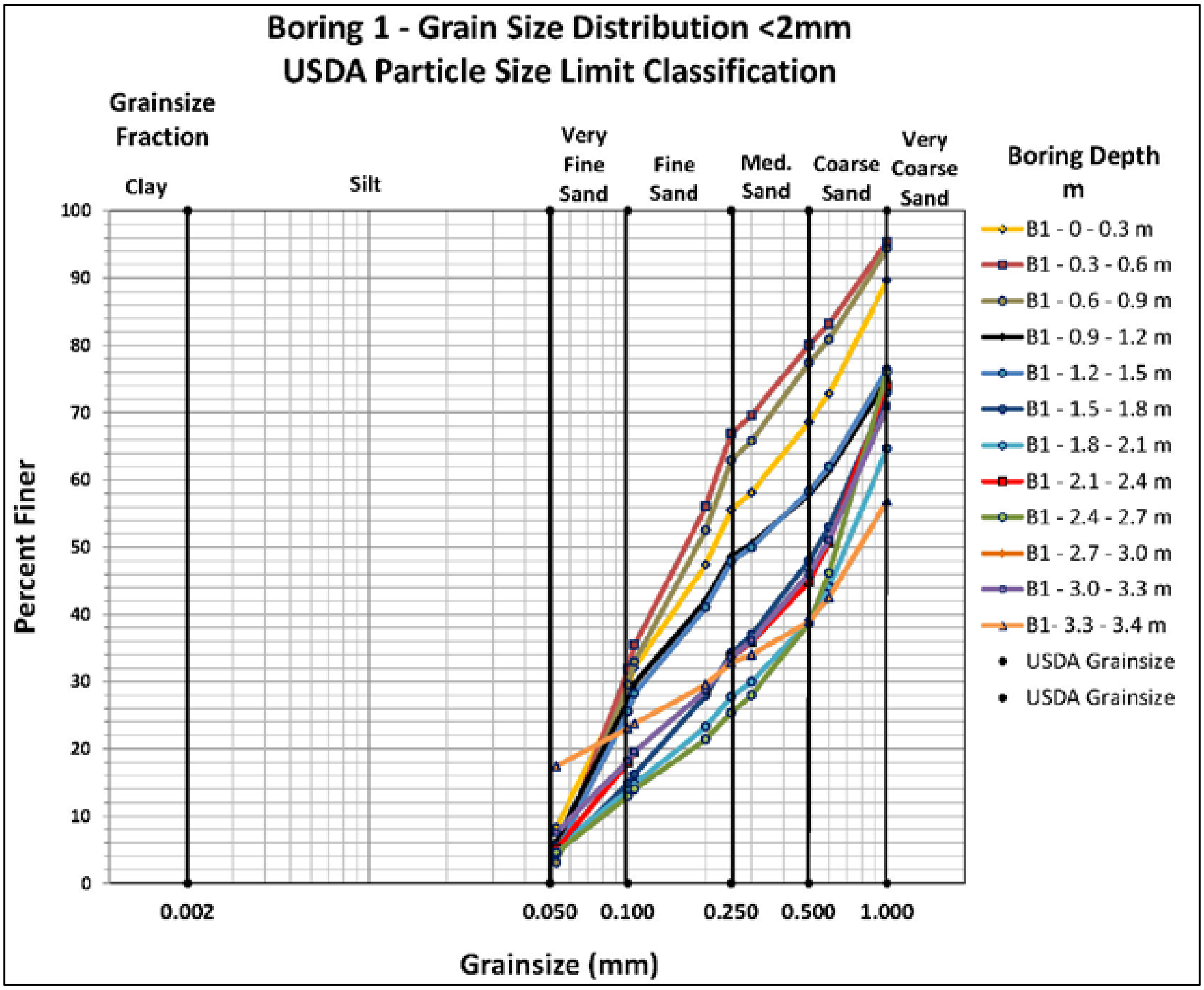
| Depth (ft) | Soil Description | Recovery |
|---|---|---|
| 0 | 0-0.5ft: A Horizon - gray-brown SILT - dry, friable, frequent roots | |
| 1 | 0.5-2ft: gray-brown SILT, trace very fine sand - dry, friable, occassional roots | Run 1<br>67% |
| 3 | 3-7ft: Cobble may have blocked | |
| 4 | Material is gray-brown SILT, trace very fine sand - dry<br>NO SAVED SAMPLES<br>?<br>?<br>?<br>?<br>? | Run 2<br>13% |
| 7 | 7-7.8ft: brown fine-grained SAND, some silt - dry, loose | |
| 8 | 7.8-8.4ft: SAND with rounded gravel - dense | Run 3<br>45% |
| 8.4 | 8.4-8.8ft: gray-brown CLAY with silt - moist, firm | |
| 11 | 11-12.7ft: gray-brown SILT, clay, sand, gravel - moist to wet, firm | Run 4<br>74% |
| 12.7 | 12.7-14.0ft: gray SILT, trace gravel, sand, clay - wet, soft | |
| 15 | 15-16.5ft: grayish brown SILT with sand and clay, trace gravel - wet, soft | Run 5<br>47% |
| 18 | Refusal at 18.2ft; Sample from drive head is yellow-brown silt and sand | |

Symbology

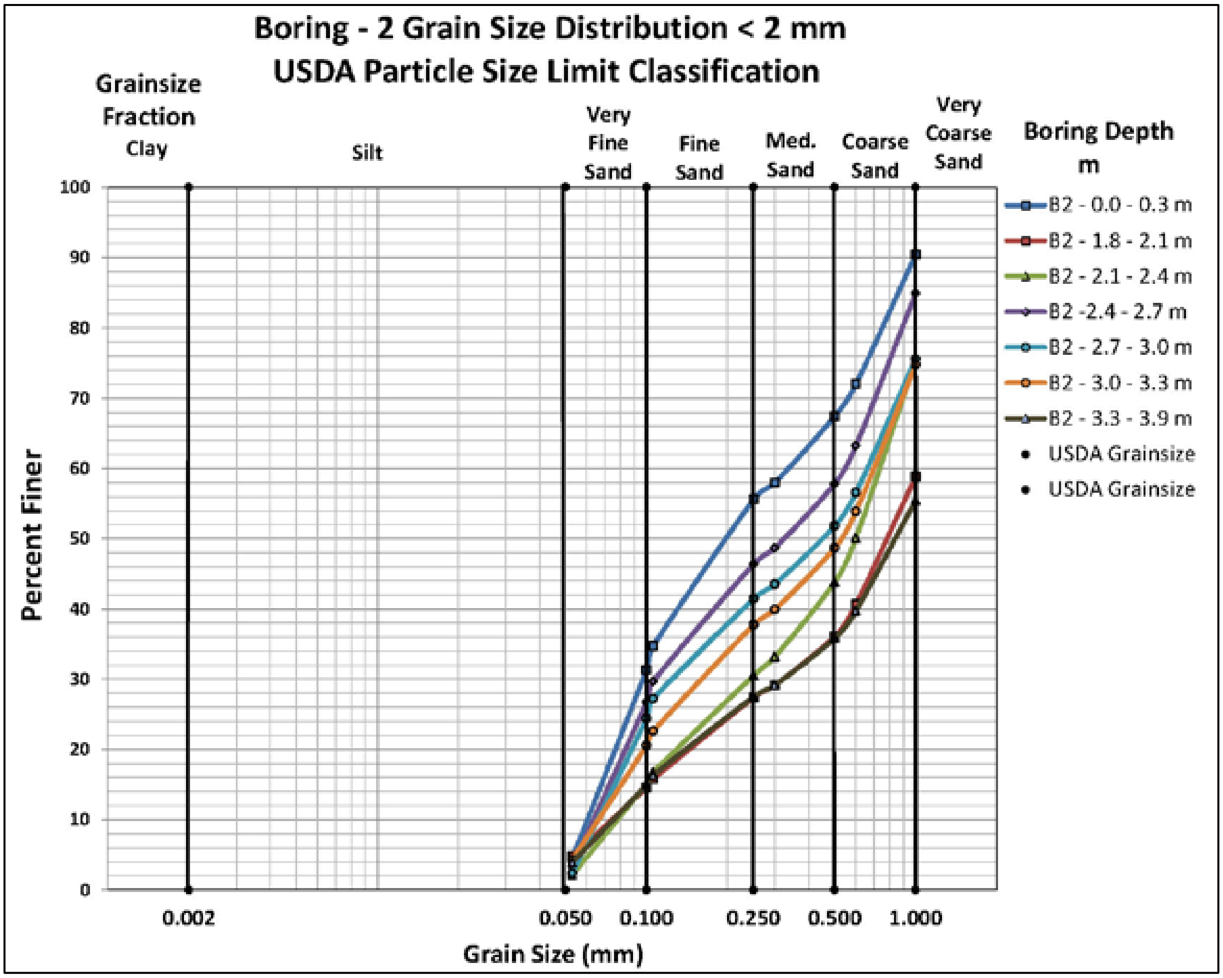
- A Horizon
- clay
- silt
- sand
- gravel
- shale

# Appendix B – Alluvium Grainsize and Hydrometer Analysis Tables and Figures

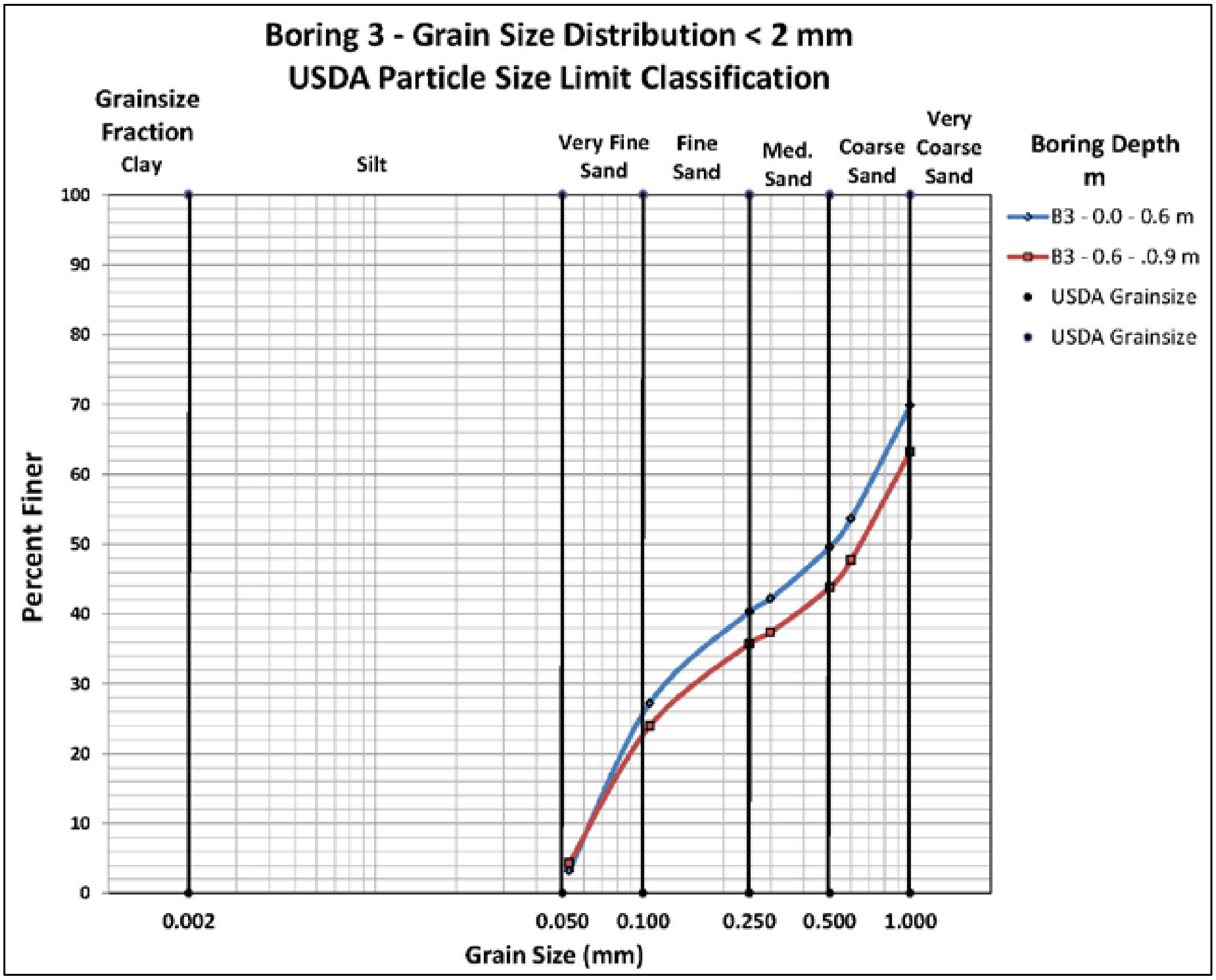
B1 - Dry Sieve Method - Grainsize Distribution Chart



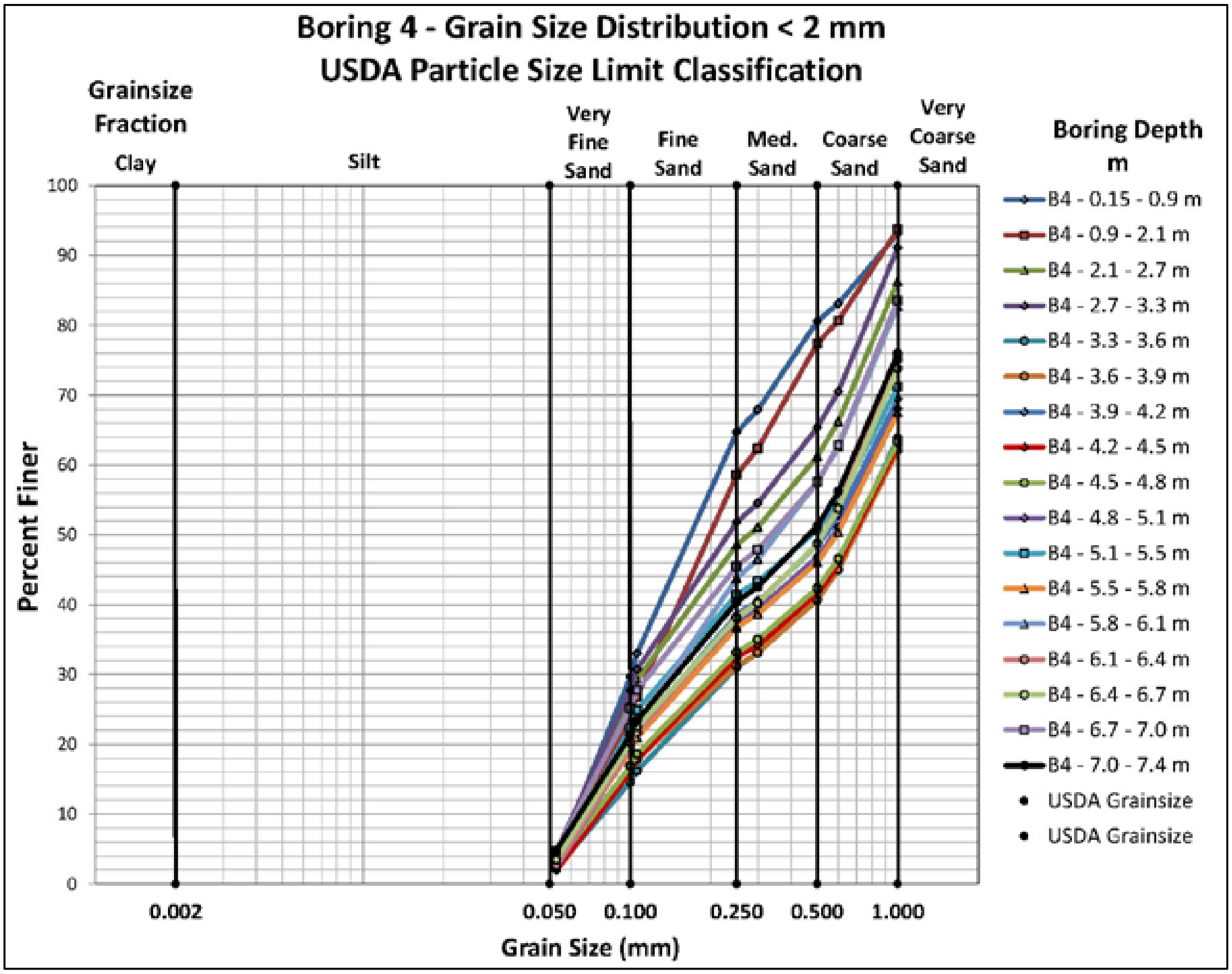
B2 - Dry Sieve Method - Grainsize Distribution Chart



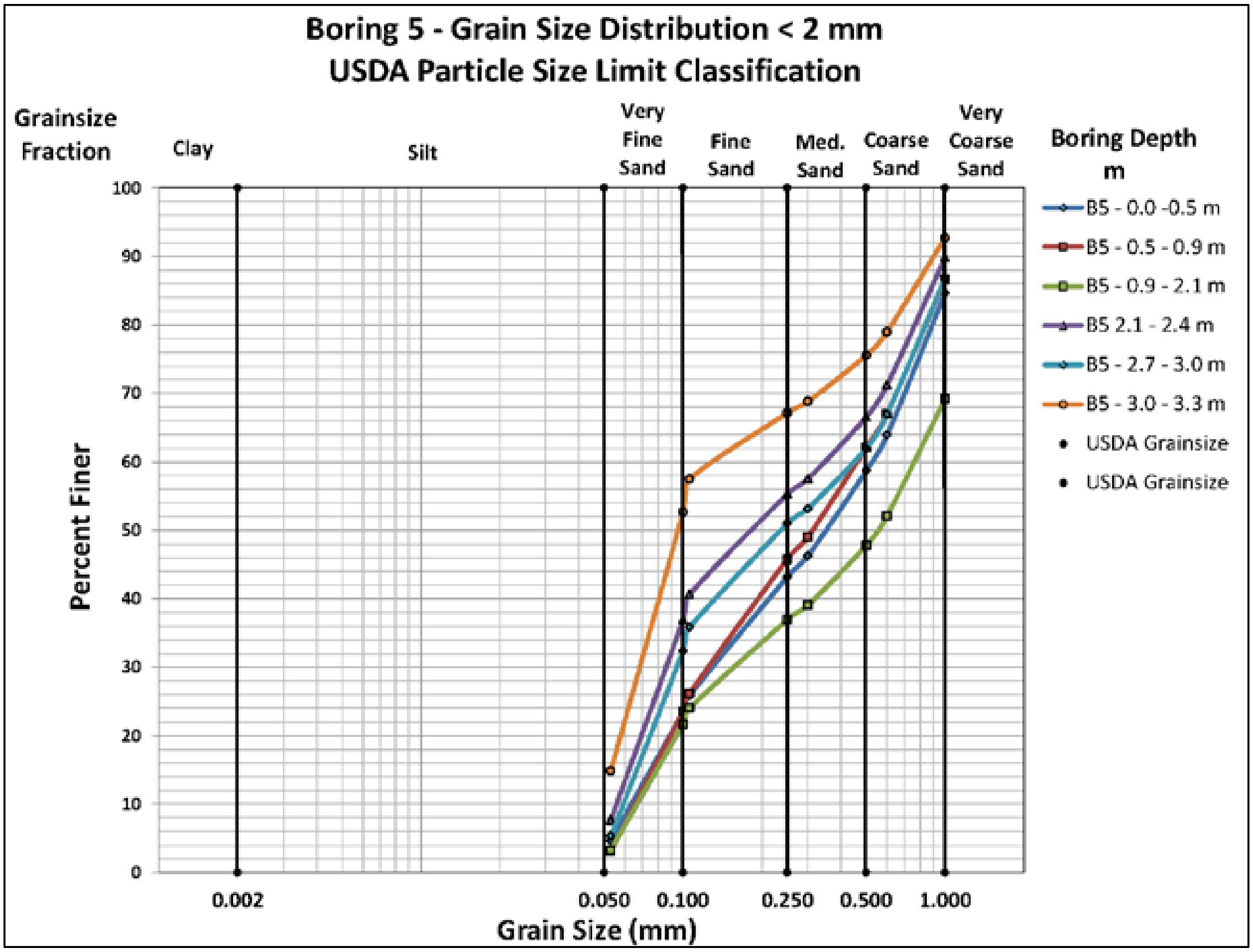
B3 - Dry Sieve Method - Grainsize Distribution Chart



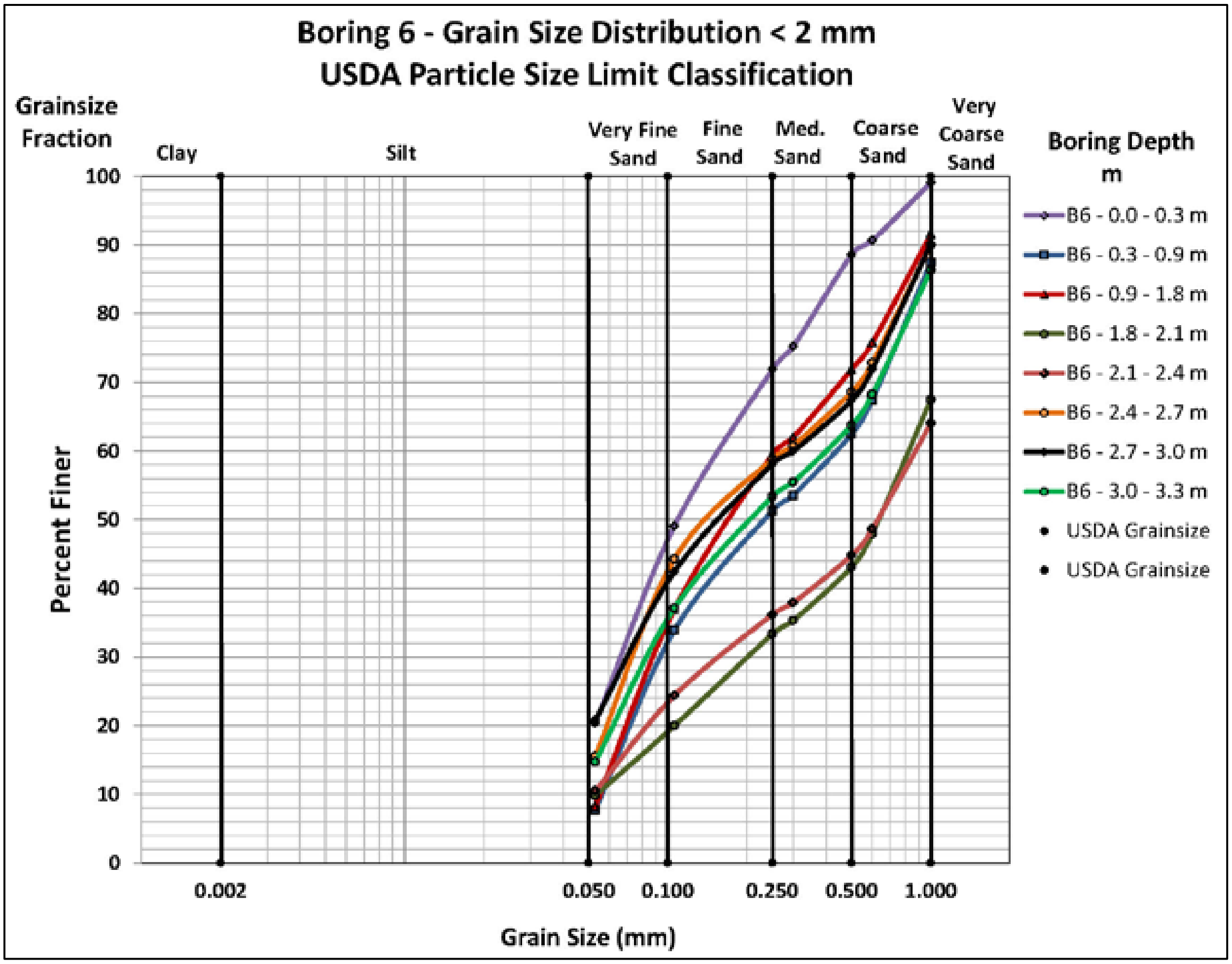
B4 - Dry Sieve Method - Grainsize Distribution Chart



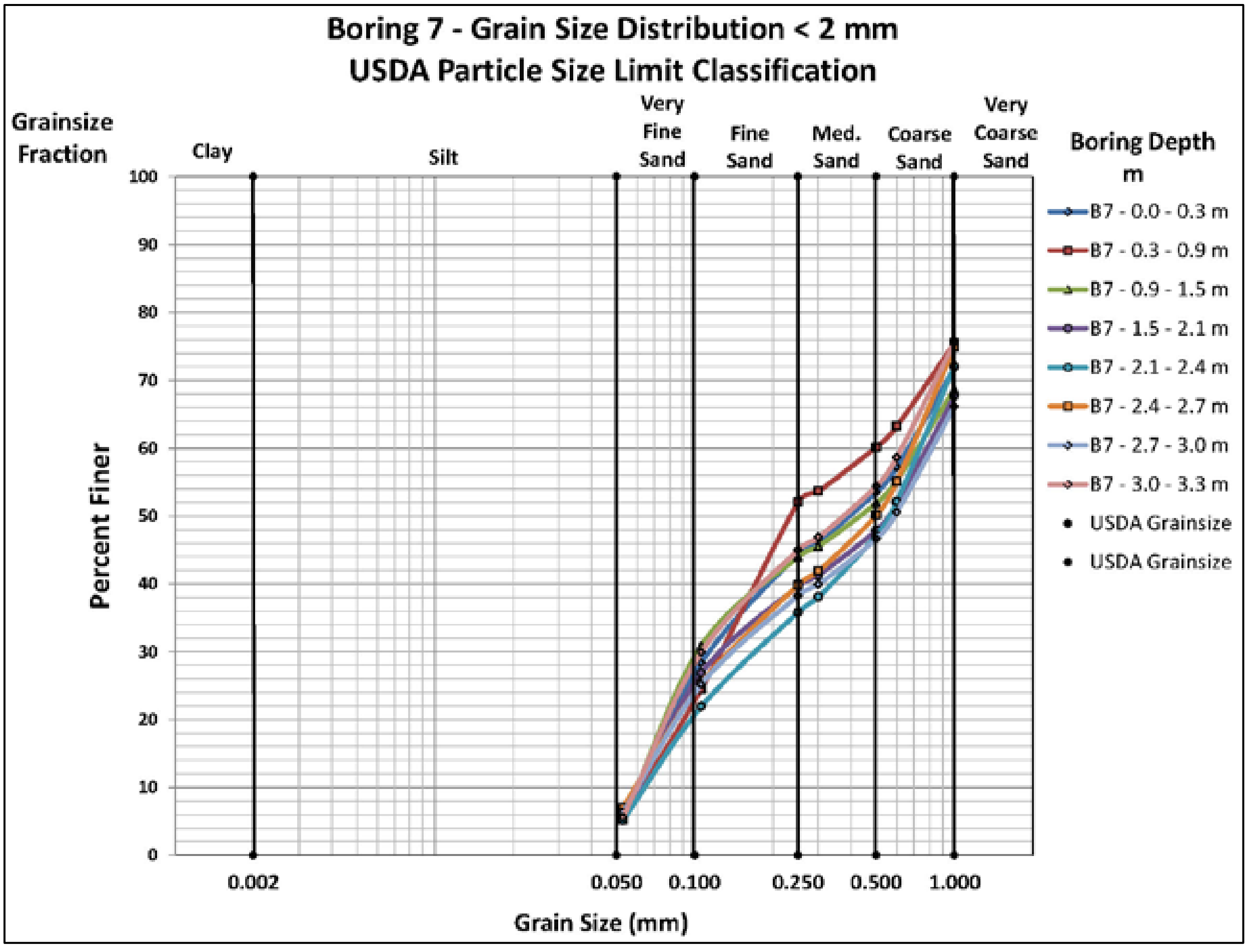
B5 - Dry Sieve Method - Grainsize Distribution Chart



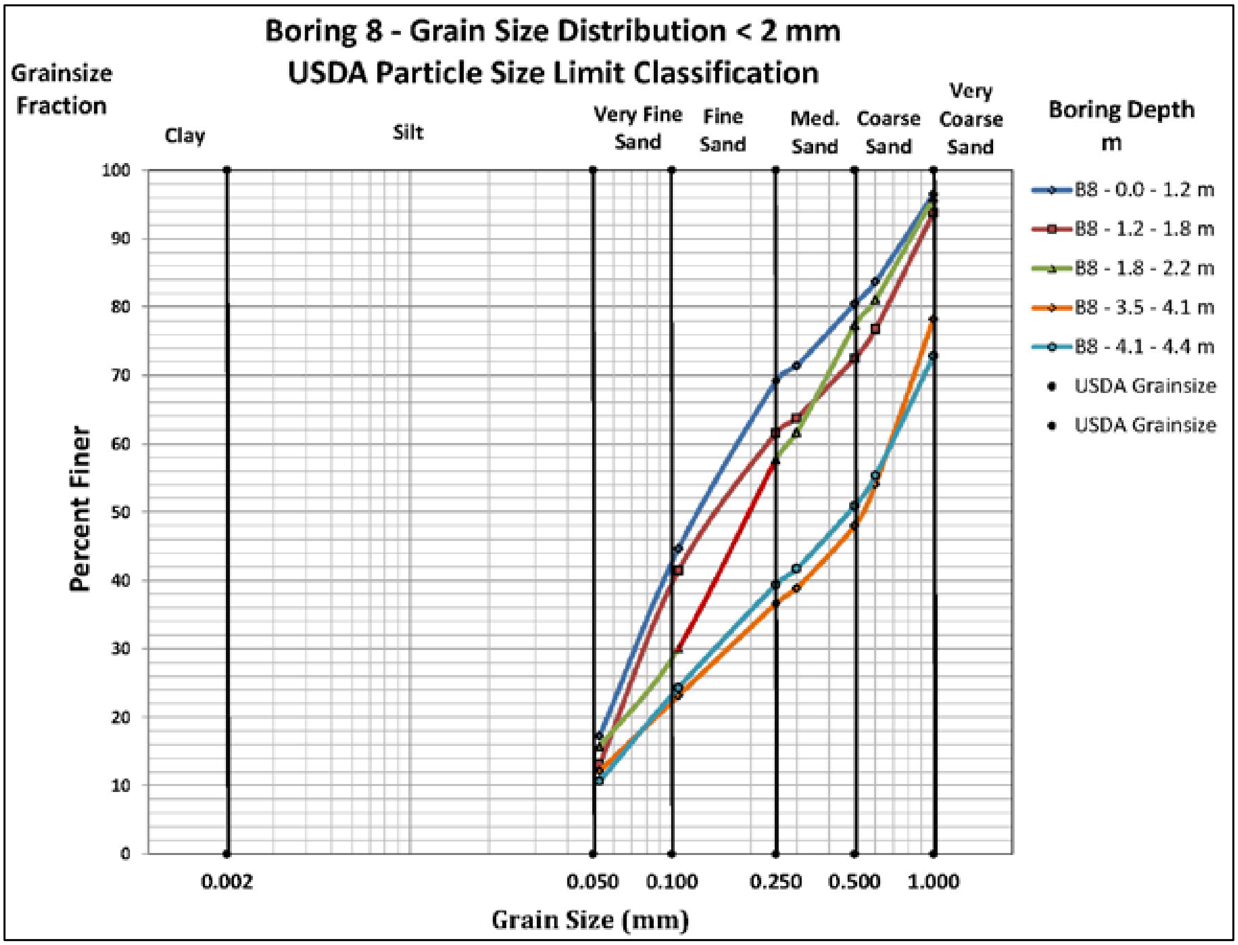
B6 - Dry Sieve Method - Grainsize Distribution Chart



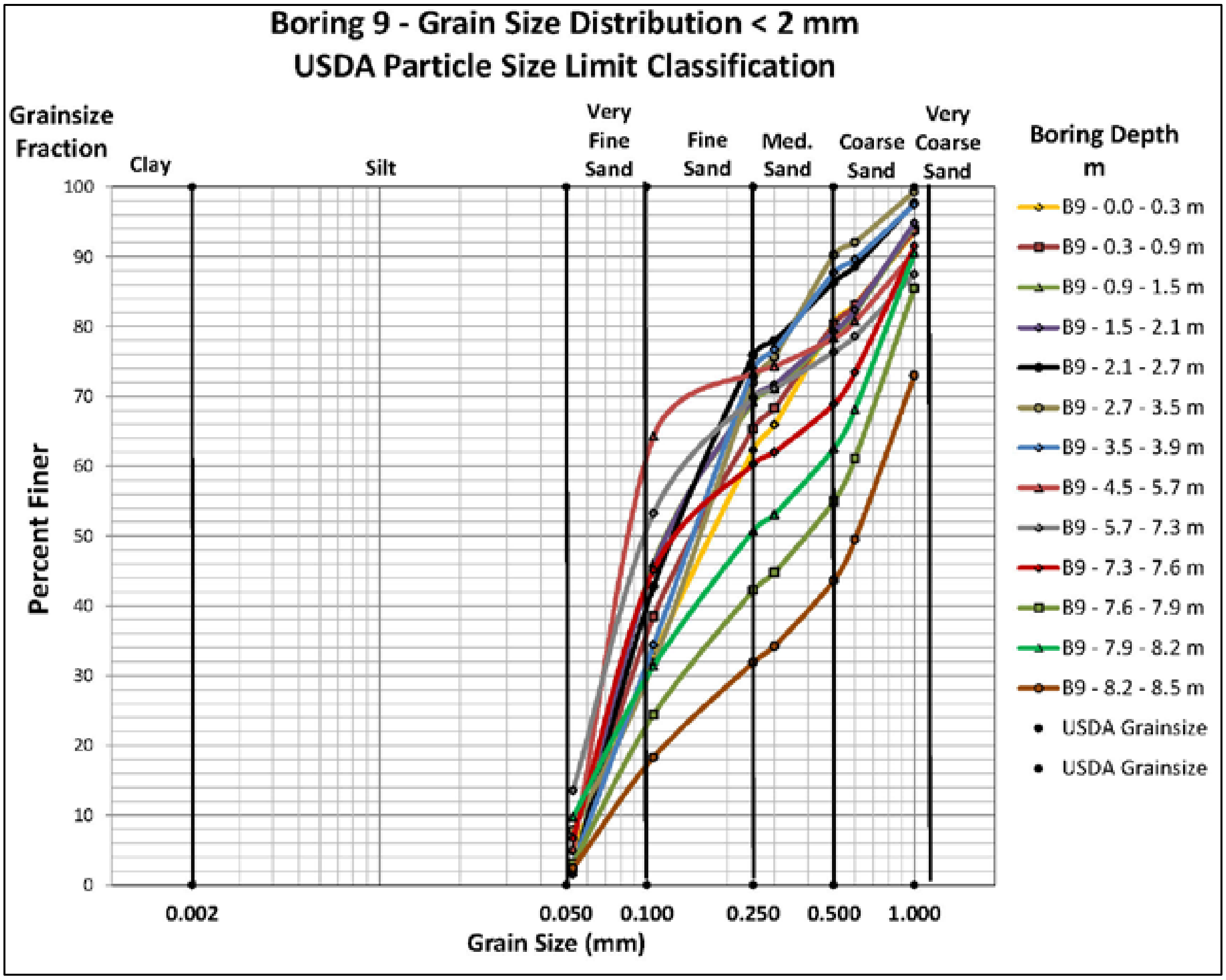
B7 - Dry Sieve Method - Grainsize Distribution Chart



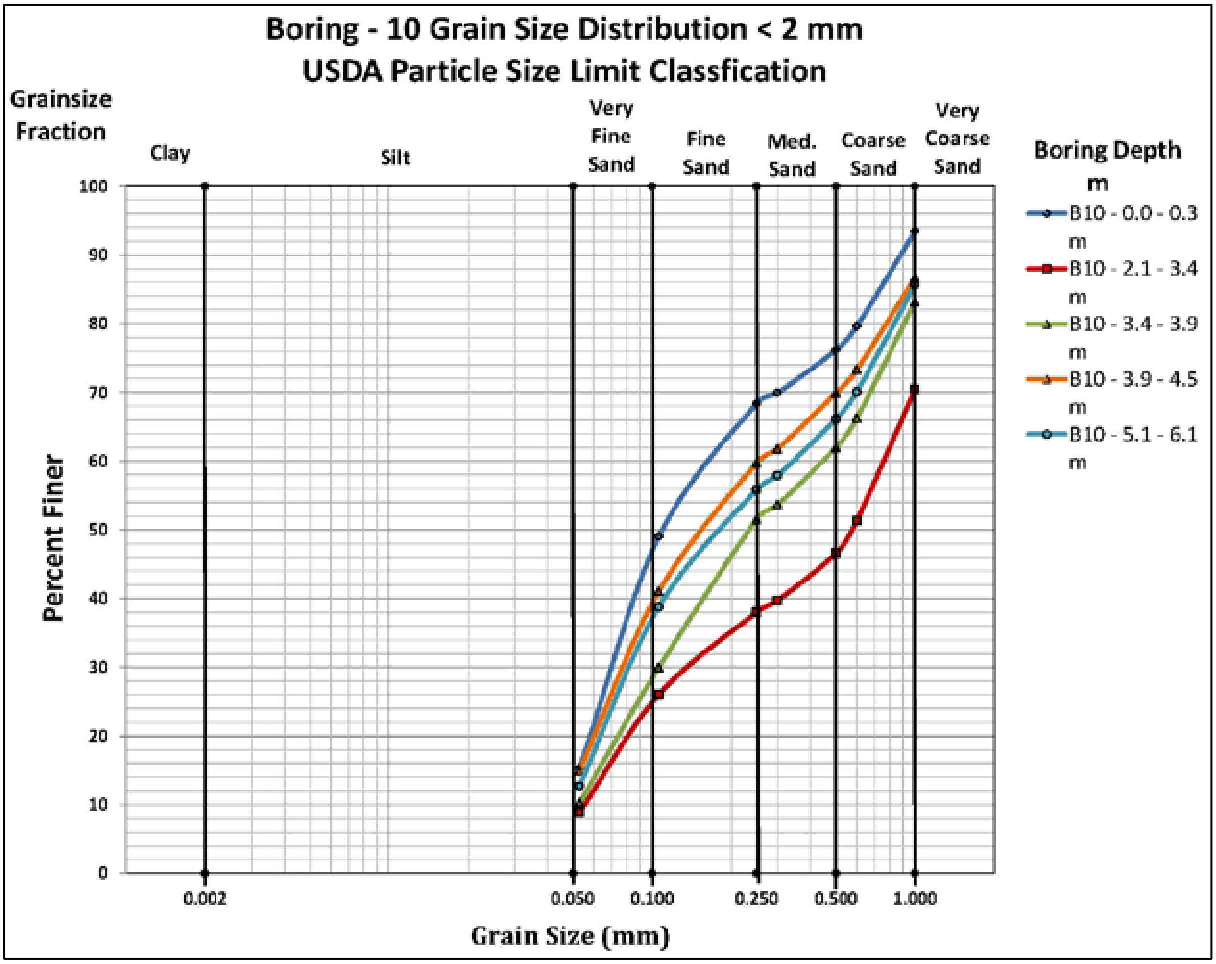
B8 - Dry Sieve Method - Grainsize Distribution Chart



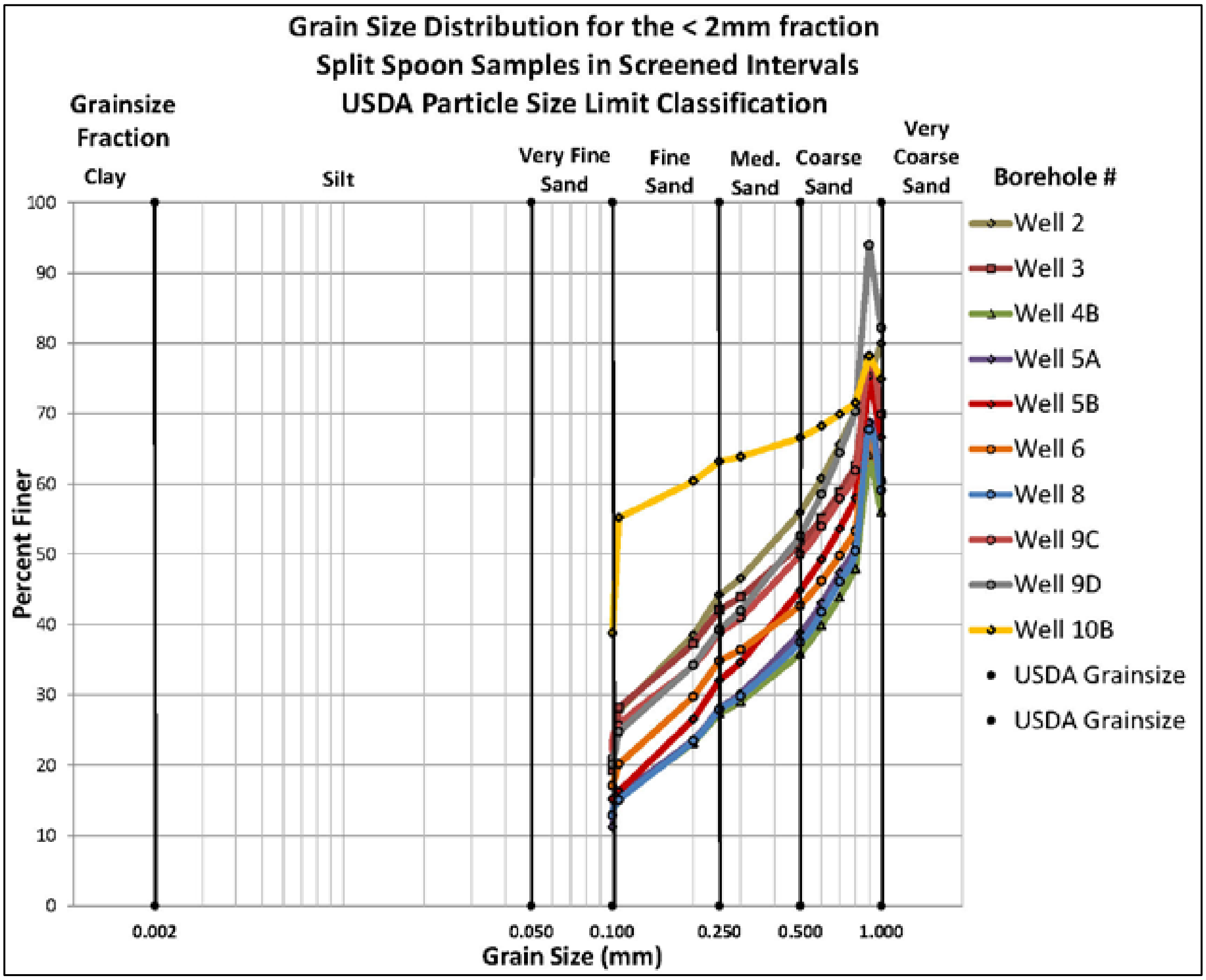
B9 - Dry Sieve Method - Grainsize Distribution Chart - B9



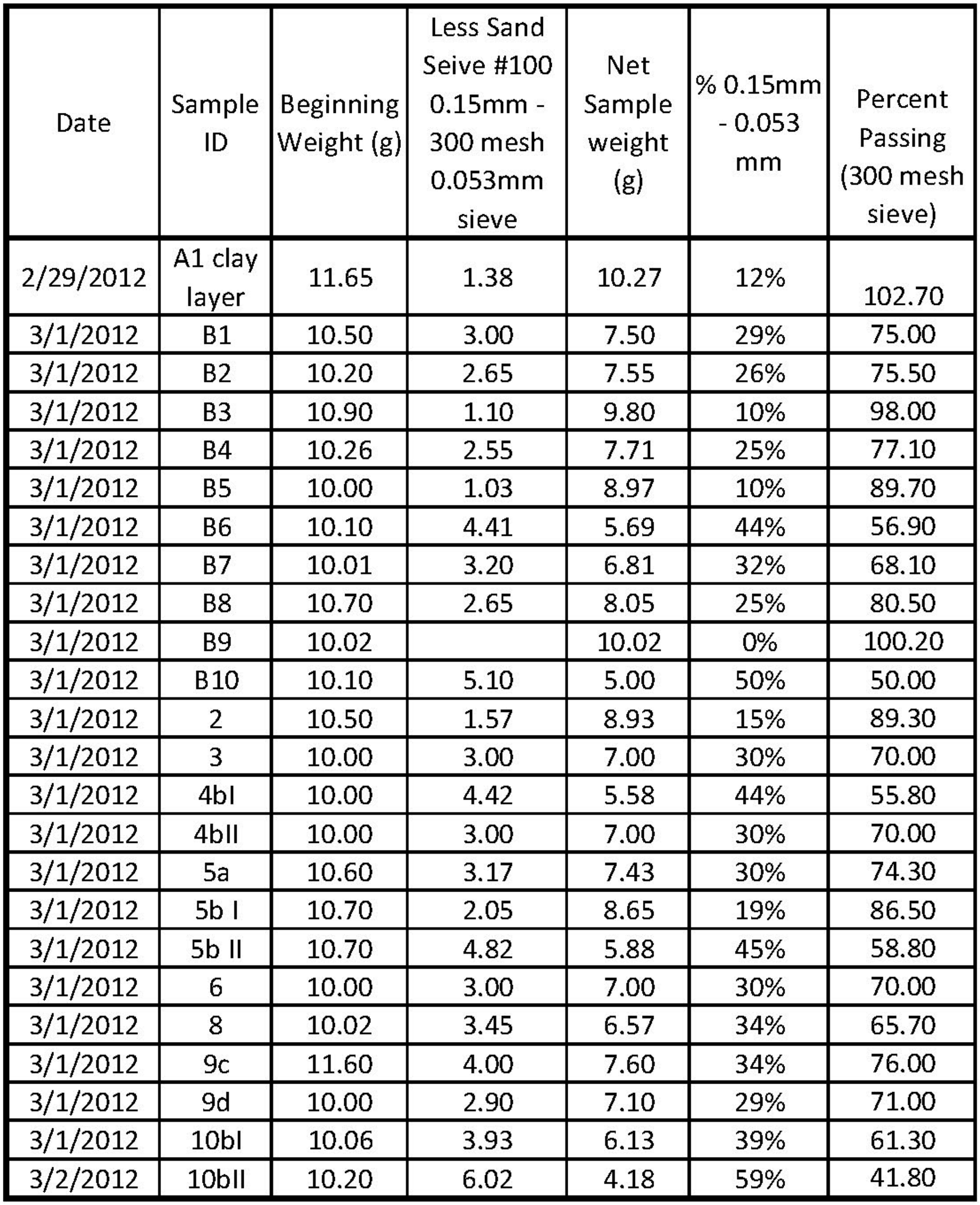
B10 - Dry Sieve Method - Grainsize Distribution Chart



All Wells - Dry Sieve Method - Grainsize Distribution Chart - Splitspoon Samples for the well screened interval.

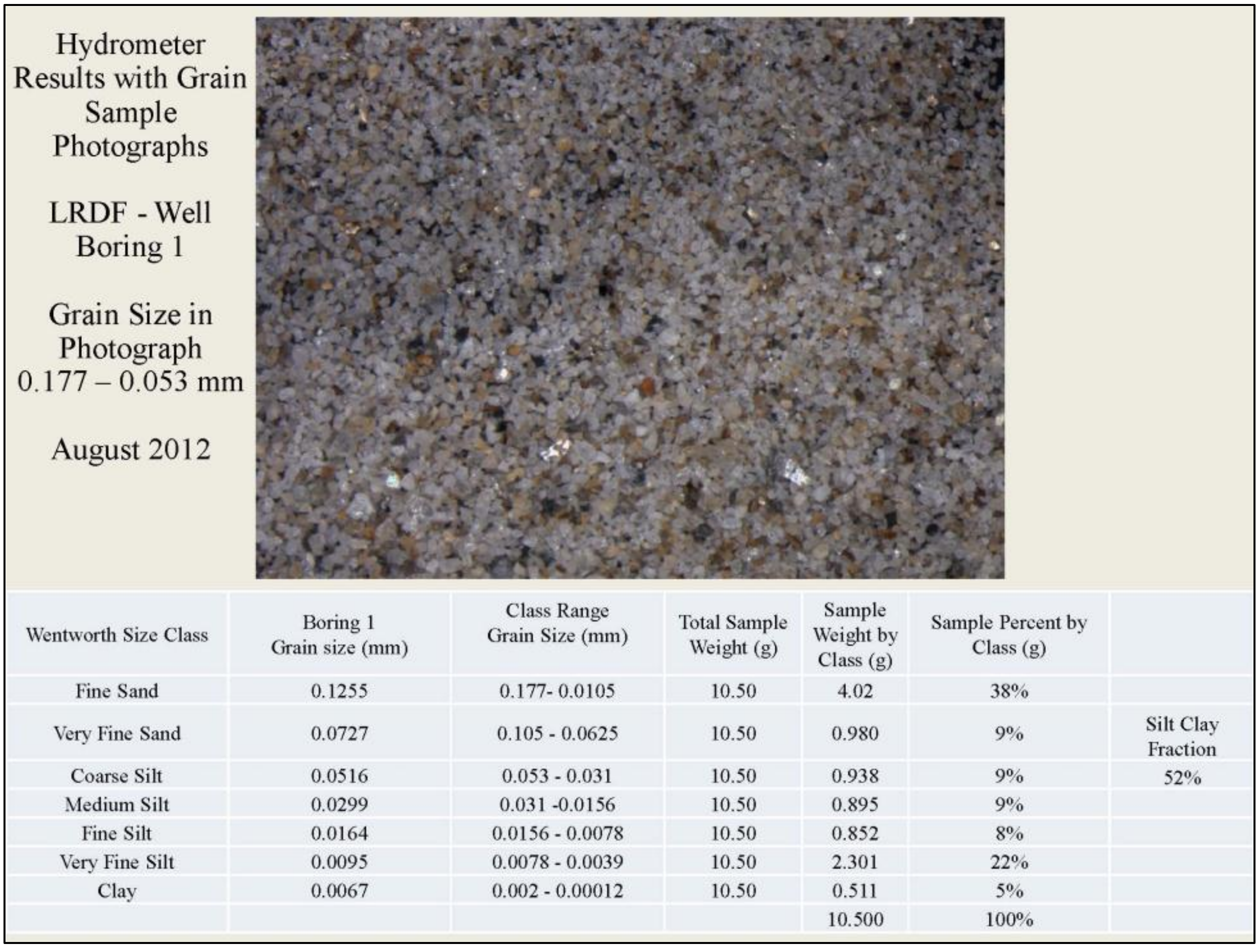


Hydrometer Test – Sample Summary – Boreholes and well splitspoon samples.



| Date | Sample ID | Beginning Weight (g) | Less Sand Seive #100 0.15mm - 300 mesh 0.053mm sieve | Net Sample weight (g) | % 0.15mm - 0.053 mm | Percent Passing (300 mesh sieve) |
|---|---|---|---|---|---|---|
| 2/29/2012 | A1 clay layer | 11.65 | 1.38 | 10.27 | 12% | 102.70 |
| 3/1/2012 | B1 | 10.50 | 3.00 | 7.50 | 29% | 75.00 |
| 3/1/2012 | B2 | 10.20 | 2.65 | 7.55 | 26% | 75.50 |
| 3/1/2012 | B3 | 10.90 | 1.10 | 9.80 | 10% | 98.00 |
| 3/1/2012 | B4 | 10.26 | 2.55 | 7.71 | 25% | 77.10 |
| 3/1/2012 | B5 | 10.00 | 1.03 | 8.97 | 10% | 89.70 |
| 3/1/2012 | B6 | 10.10 | 4.41 | 5.69 | 44% | 56.90 |
| 3/1/2012 | B7 | 10.01 | 3.20 | 6.81 | 32% | 68.10 |
| 3/1/2012 | B8 | 10.70 | 2.65 | 8.05 | 25% | 80.50 |
| 3/1/2012 | B9 | 10.02 |  | 10.02 | 0% | 100.20 |
| 3/1/2012 | B10 | 10.10 | 5.10 | 5.00 | 50% | 50.00 |
| 3/1/2012 | 2 | 10.50 | 1.57 | 8.93 | 15% | 89.30 |
| 3/1/2012 | 3 | 10.00 | 3.00 | 7.00 | 30% | 70.00 |
| 3/1/2012 | 4bI | 10.00 | 4.42 | 5.58 | 44% | 55.80 |
| 3/1/2012 | 4bII | 10.00 | 3.00 | 7.00 | 30% | 70.00 |
| 3/1/2012 | 5a | 10.60 | 3.17 | 7.43 | 30% | 74.30 |
| 3/1/2012 | 5b I | 10.70 | 2.05 | 8.65 | 19% | 86.50 |
| 3/1/2012 | 5b II | 10.70 | 4.82 | 5.88 | 45% | 58.80 |
| 3/1/2012 | 6 | 10.00 | 3.00 | 7.00 | 30% | 70.00 |
| 3/1/2012 | 8 | 10.02 | 3.45 | 6.57 | 34% | 65.70 |
| 3/1/2012 | 9c | 11.60 | 4.00 | 7.60 | 34% | 76.00 |
| 3/1/2012 | 9d | 10.00 | 2.90 | 7.10 | 29% | 71.00 |
| 3/1/2012 | 10bI | 10.06 | 3.93 | 6.13 | 39% | 61.30 |
| 3/2/2012 | 10bII | 10.20 | 6.02 | 4.18 | 59% | 41.80 |

Boring 1 - Hydrometer Results with Photograph



Hydrometer Results with Grain Sample Photographs

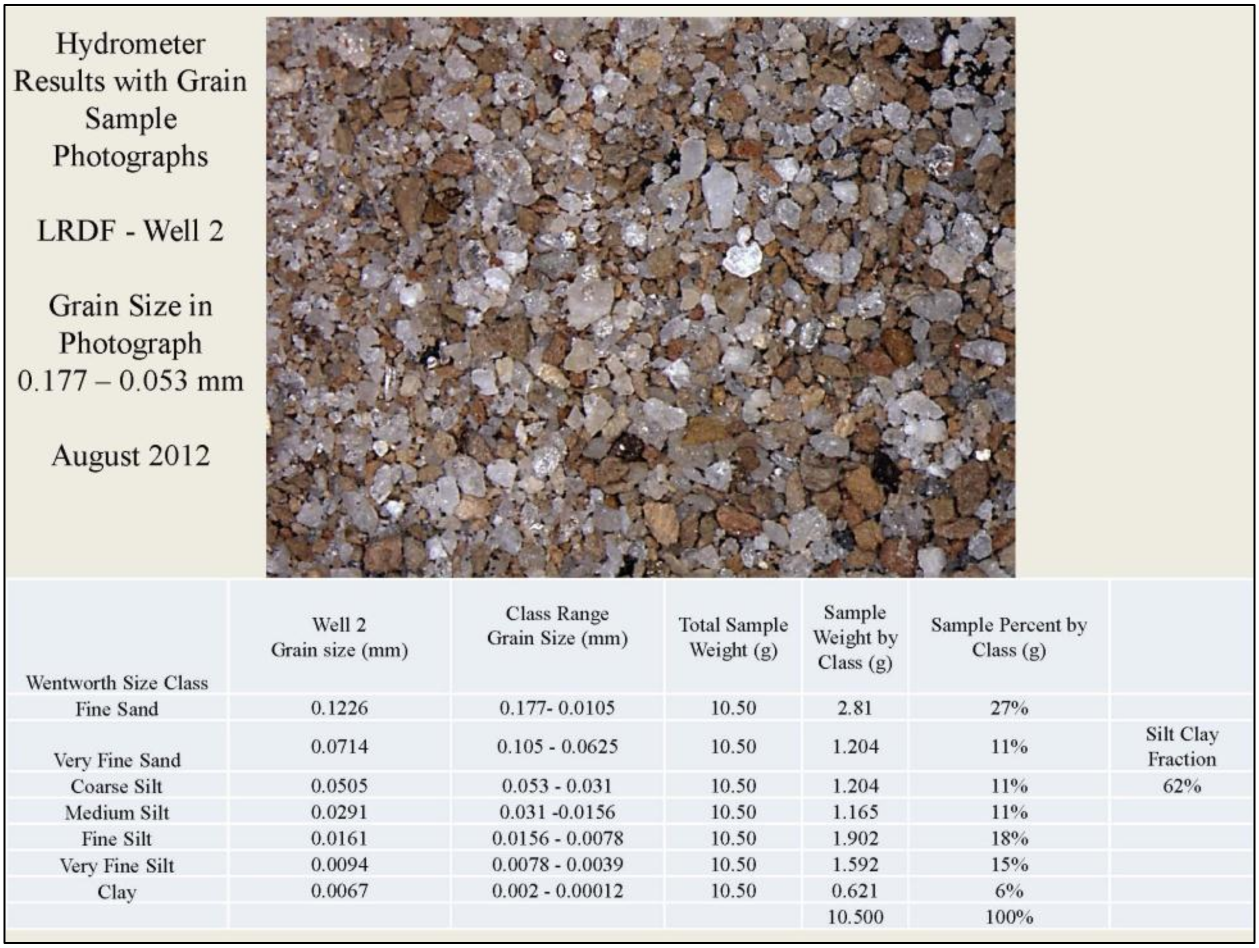
LRDF - Well Boring 1

Grain Size in Photograph
0.177 – 0.053 mm

August 2012

| Wentworth Size Class | Boring 1 Grain size (mm) | Class Range Grain Size (mm) | Total Sample Weight (g) | Sample Weight by Class (g) | Sample Percent by Class (g) | |
|---|---|---|---|---|---|---|
| Fine Sand | 0.1255 | 0.177- 0.0105 | 10.50 | 4.02 | 38% | |
| Very Fine Sand | 0.0727 | 0.105 - 0.0625 | 10.50 | 0.980 | 9% | Silt Clay Fraction |
| Coarse Silt | 0.0516 | 0.053 - 0.031 | 10.50 | 0.938 | 9% | 52% |
| Medium Silt | 0.0299 | 0.031 -0.0156 | 10.50 | 0.895 | 9% | |
| Fine Silt | 0.0164 | 0.0156 - 0.0078 | 10.50 | 0.852 | 8% | |
| Very Fine Silt | 0.0095 | 0.0078 - 0.0039 | 10.50 | 2.301 | 22% | |
| Clay | 0.0067 | 0.002 - 0.00012 | 10.50 | 0.511 | 5% | |
| | | | | 10.500 | 100% | |

Well 2 - Hydrometer Results with Photograph



Hydrometer Results with Grain Sample Photographs

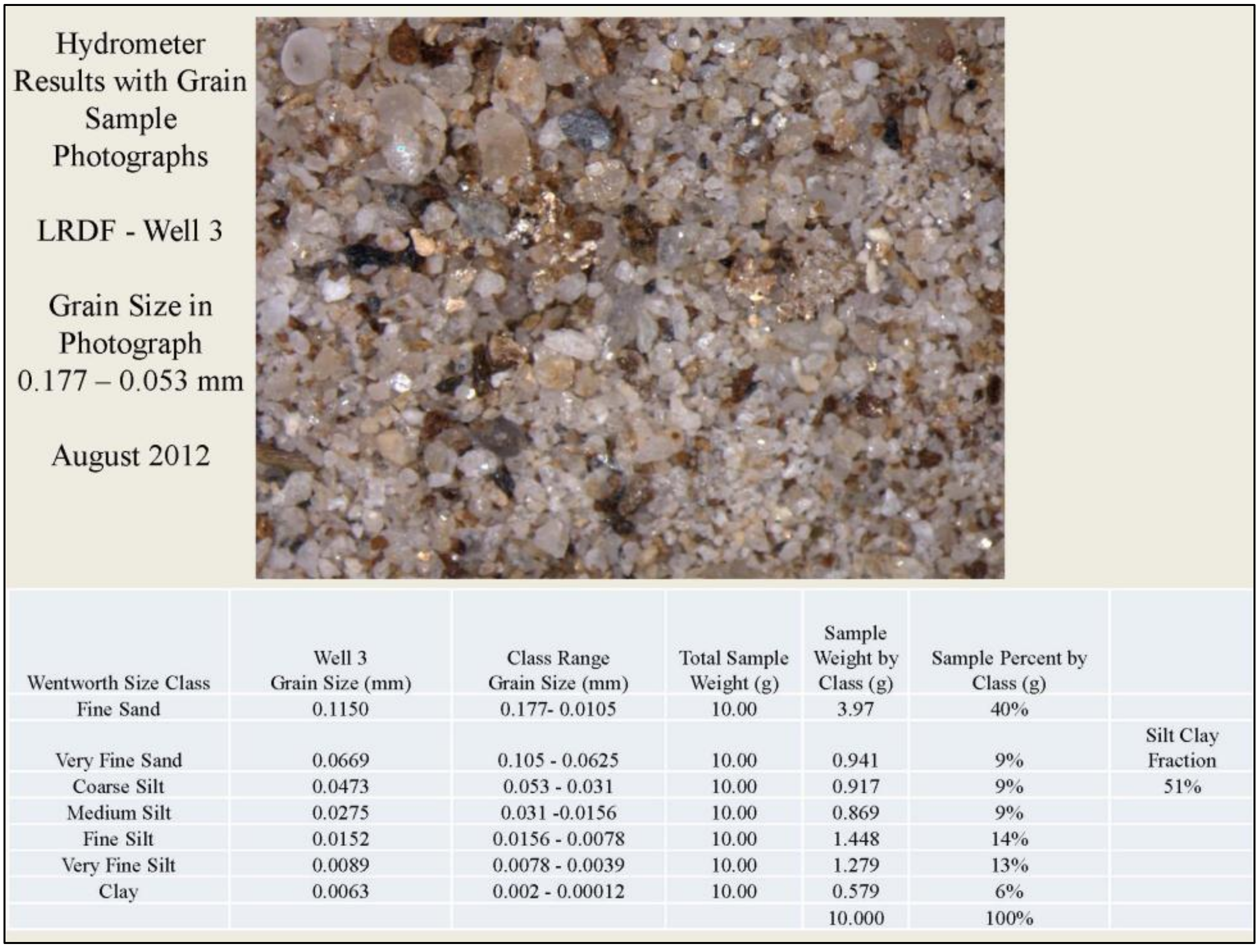
LRDF - Well 2

Grain Size in Photograph
0.177 – 0.053 mm

August 2012

| Wentworth Size Class | Well 2 Grain size (mm) | Class Range Grain Size (mm) | Total Sample Weight (g) | Sample Weight by Class (g) | Sample Percent by Class (g) | |
|---|---|---|---|---|---|---|
| Fine Sand | 0.1226 | 0.177- 0.0105 | 10.50 | 2.81 | 27% | |
| Very Fine Sand | 0.0714 | 0.105 - 0.0625 | 10.50 | 1.204 | 11% | Silt Clay Fraction |
| Coarse Silt | 0.0505 | 0.053 - 0.031 | 10.50 | 1.204 | 11% | 62% |
| Medium Silt | 0.0291 | 0.031 -0.0156 | 10.50 | 1.165 | 11% | |
| Fine Silt | 0.0161 | 0.0156 - 0.0078 | 10.50 | 1.902 | 18% | |
| Very Fine Silt | 0.0094 | 0.0078 - 0.0039 | 10.50 | 1.592 | 15% | |
| Clay | 0.0067 | 0.002 - 0.00012 | 10.50 | 0.621 | 6% | |
| | | | | 10.500 | 100% | |

Well 3 - Hydrometer Results with Photograph



Hydrometer Results with Grain Sample Photographs

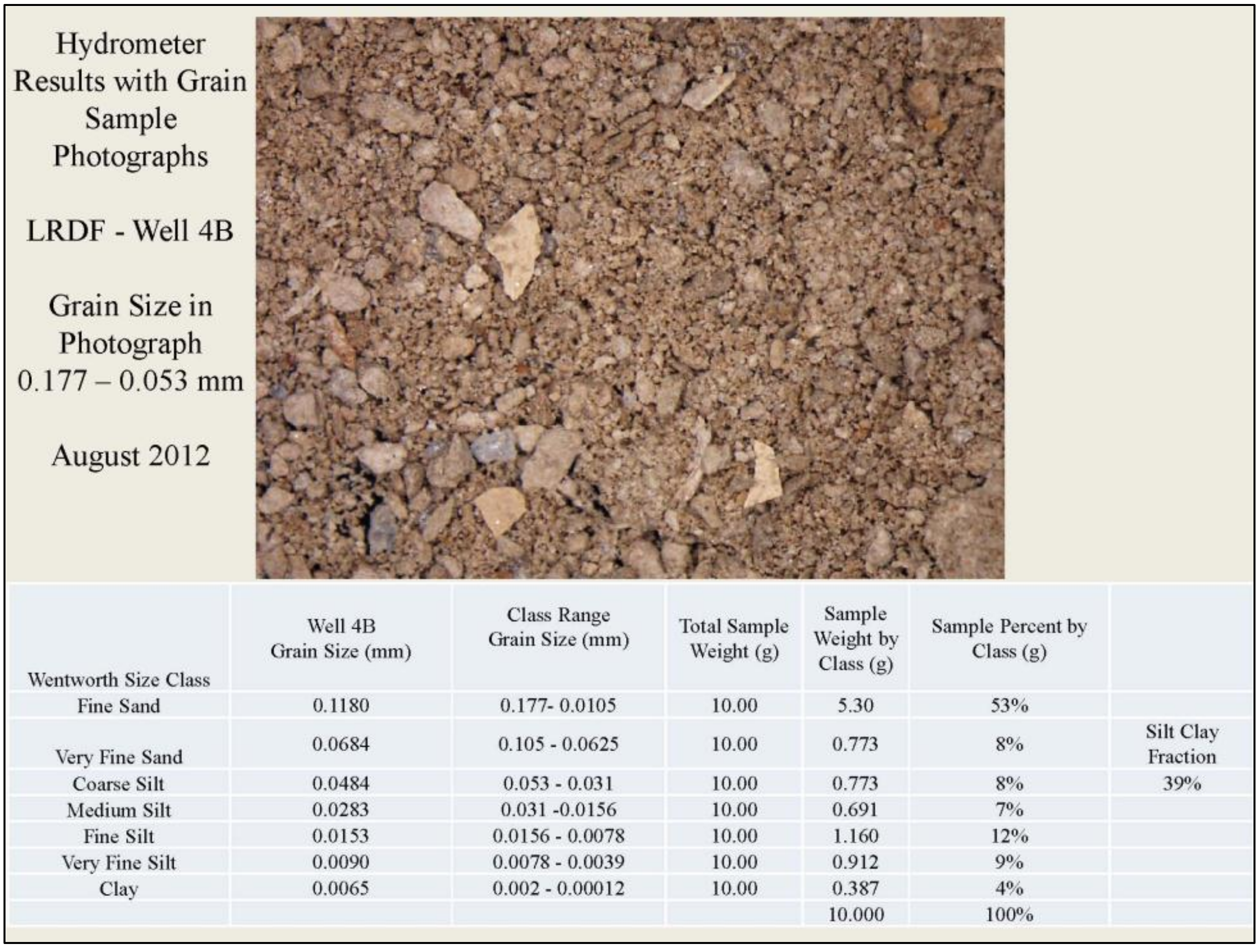
LRDF - Well 3

Grain Size in Photograph 0.177 – 0.053 mm

August 2012

| Wentworth Size Class | Well 3 Grain Size (mm) | Class Range Grain Size (mm) | Total Sample Weight (g) | Sample Weight by Class (g) | Sample Percent by Class (g) | |
|---|---|---|---|---|---|---|
| Fine Sand | 0.1150 | 0.177- 0.0105 | 10.00 | 3.97 | 40% | |
| Very Fine Sand | 0.0669 | 0.105 - 0.0625 | 10.00 | 0.941 | 9% | Silt Clay Fraction |
| Coarse Silt | 0.0473 | 0.053 - 0.031 | 10.00 | 0.917 | 9% | 51% |
| Medium Silt | 0.0275 | 0.031 -0.0156 | 10.00 | 0.869 | 9% | |
| Fine Silt | 0.0152 | 0.0156 - 0.0078 | 10.00 | 1.448 | 14% | |
| Very Fine Silt | 0.0089 | 0.0078 - 0.0039 | 10.00 | 1.279 | 13% | |
| Clay | 0.0063 | 0.002 - 0.00012 | 10.00 | 0.579 | 6% | |
| | | | | 10.000 | 100% | |

Well 4B - Hydrometer Results with Photograph



Hydrometer Results with Grain Sample Photographs

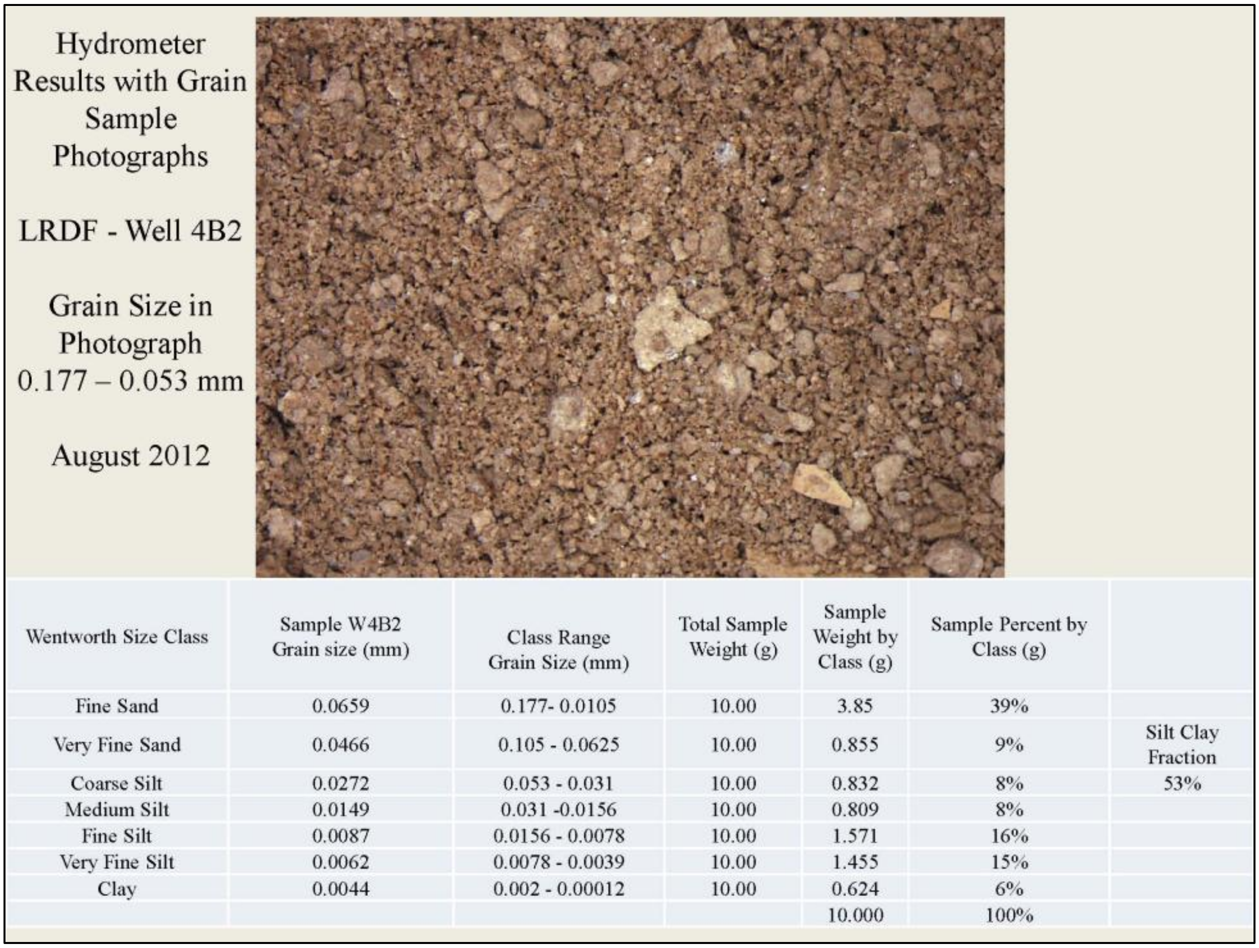
LRDF - Well 4B

Grain Size in Photograph
0.177 – 0.053 mm

August 2012

| Wentworth Size Class | Well 4B Grain Size (mm) | Class Range Grain Size (mm) | Total Sample Weight (g) | Sample Weight by Class (g) | Sample Percent by Class (g) | |
|---|---|---|---|---|---|---|
| Fine Sand | 0.1180 | 0.177- 0.0105 | 10.00 | 5.30 | 53% | |
| Very Fine Sand | 0.0684 | 0.105 - 0.0625 | 10.00 | 0.773 | 8% | Silt Clay Fraction |
| Coarse Silt | 0.0484 | 0.053 - 0.031 | 10.00 | 0.773 | 8% | 39% |
| Medium Silt | 0.0283 | 0.031 -0.0156 | 10.00 | 0.691 | 7% | |
| Fine Silt | 0.0153 | 0.0156 - 0.0078 | 10.00 | 1.160 | 12% | |
| Very Fine Silt | 0.0090 | 0.0078 - 0.0039 | 10.00 | 0.912 | 9% | |
| Clay | 0.0065 | 0.002 - 0.00012 | 10.00 | 0.387 | 4% | |
| | | | | 10.000 | 100% | |

Well 4B (2) - Hydrometer Results with Photograph



Hydrometer Results with Grain Sample Photographs

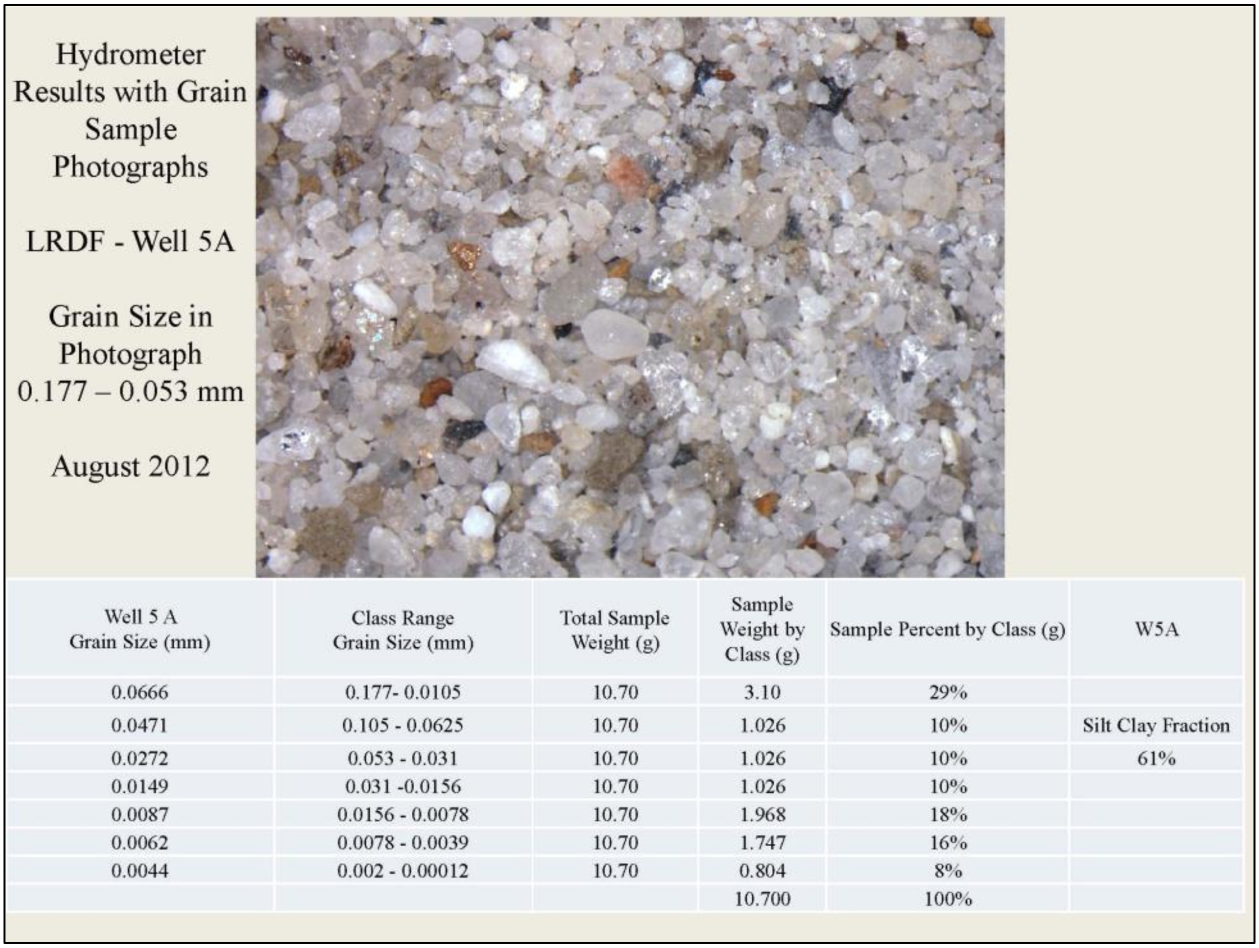
LRDF - Well 4B2

Grain Size in Photograph
0.177 – 0.053 mm

August 2012

| Wentworth Size Class | Sample W4B2 Grain size (mm) | Class Range Grain Size (mm) | Total Sample Weight (g) | Sample Weight by Class (g) | Sample Percent by Class (g) | |
|---|---|---|---|---|---|---|
| Fine Sand | 0.0659 | 0.177- 0.0105 | 10.00 | 3.85 | 39% | |
| Very Fine Sand | 0.0466 | 0.105 - 0.0625 | 10.00 | 0.855 | 9% | Silt Clay Fraction |
| Coarse Silt | 0.0272 | 0.053 - 0.031 | 10.00 | 0.832 | 8% | 53% |
| Medium Silt | 0.0149 | 0.031 -0.0156 | 10.00 | 0.809 | 8% | |
| Fine Silt | 0.0087 | 0.0156 - 0.0078 | 10.00 | 1.571 | 16% | |
| Very Fine Silt | 0.0062 | 0.0078 - 0.0039 | 10.00 | 1.455 | 15% | |
| Clay | 0.0044 | 0.002 - 0.00012 | 10.00 | 0.624 | 6% | |
| | | | | 10.000 | 100% | |

Well 5A - Hydrometer Results with Photograph



Hydrometer Results with Grain Sample Photographs

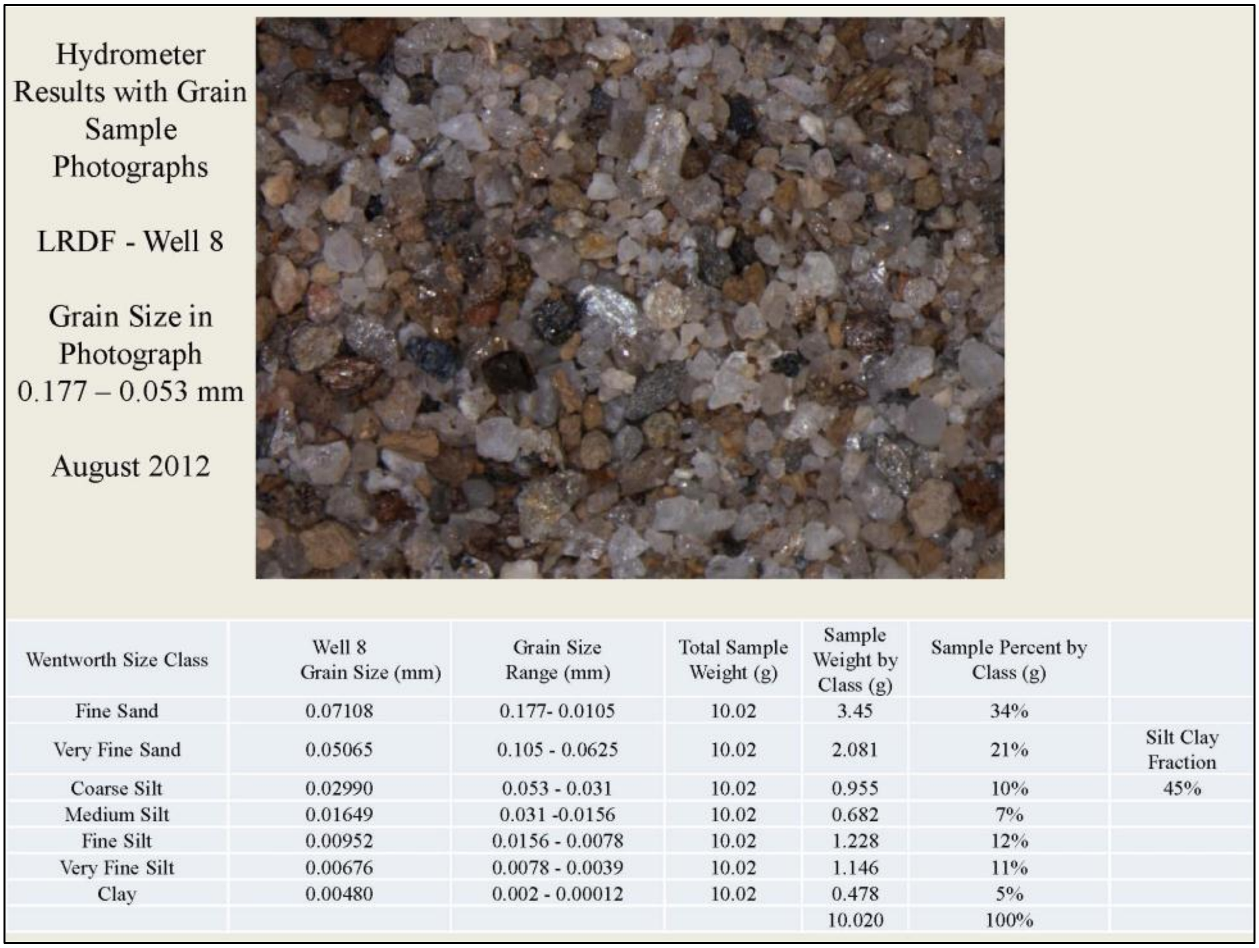
LRDF - Well 5A

Grain Size in Photograph 0.177 – 0.053 mm

August 2012

| Well 5 A Grain Size (mm) | Class Range Grain Size (mm) | Total Sample Weight (g) | Sample Weight by Class (g) | Sample Percent by Class (g) | W5A |
|---|---|---|---|---|---|
| 0.0666 | 0.177- 0.0105 | 10.70 | 3.10 | 29% | |
| 0.0471 | 0.105 - 0.0625 | 10.70 | 1.026 | 10% | Silt Clay Fraction |
| 0.0272 | 0.053 - 0.031 | 10.70 | 1.026 | 10% | 61% |
| 0.0149 | 0.031 -0.0156 | 10.70 | 1.026 | 10% | |
| 0.0087 | 0.0156 - 0.0078 | 10.70 | 1.968 | 18% | |
| 0.0062 | 0.0078 - 0.0039 | 10.70 | 1.747 | 16% | |
| 0.0044 | 0.002 - 0.00012 | 10.70 | 0.804 | 8% | |
| | | | 10.700 | 100% | |

Well 8 - Hydrometer Results with Photograph



Hydrometer
Results with Grain
Sample
Photographs

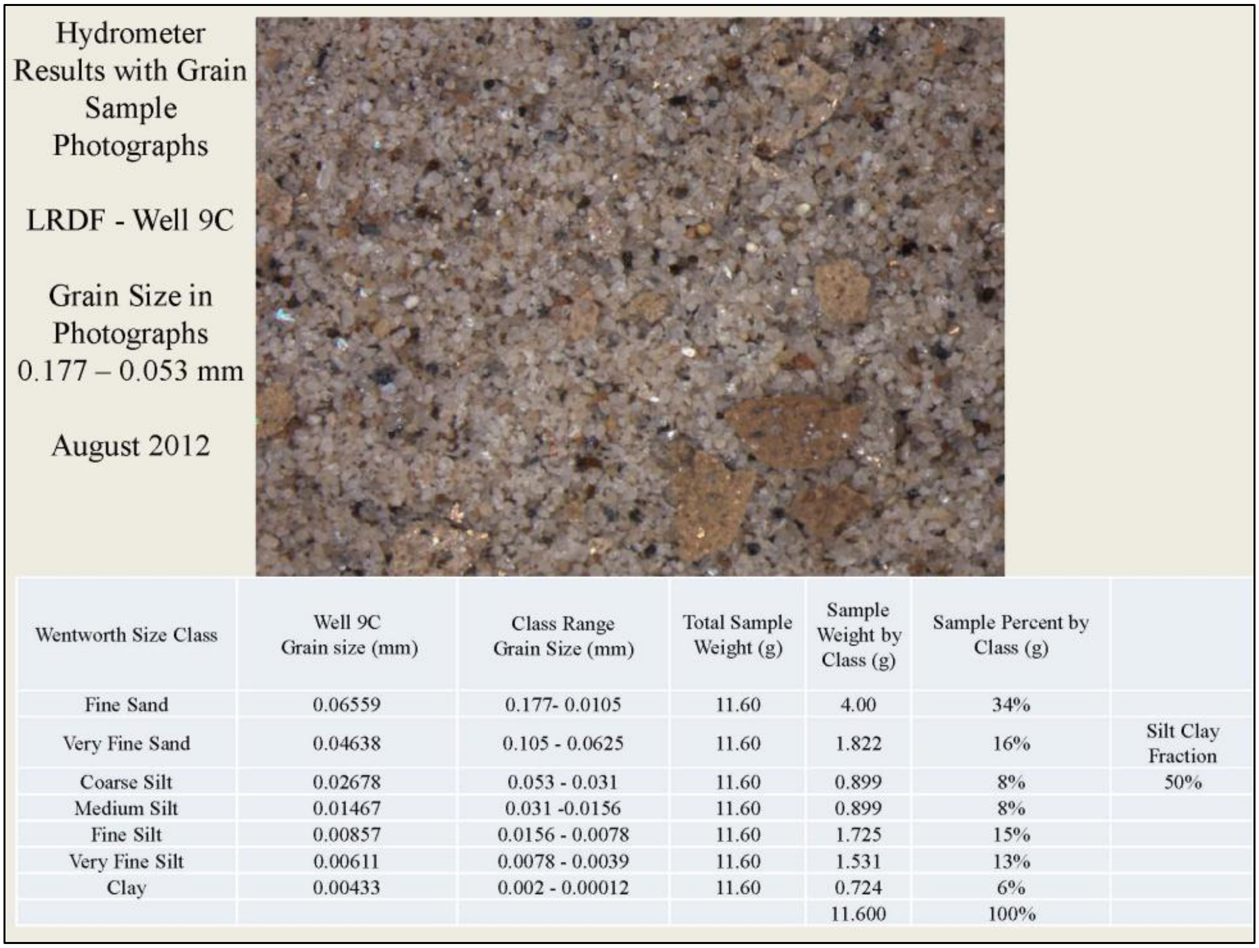
LRDF - Well 8

Grain Size in
Photograph
0.177 – 0.053 mm

August 2012

| Wentworth Size Class | Well 8 Grain Size (mm) | Grain Size Range (mm) | Total Sample Weight (g) | Sample Weight by Class (g) | Sample Percent by Class (g) | |
|---|---|---|---|---|---|---|
| Fine Sand | 0.07108 | 0.177- 0.0105 | 10.02 | 3.45 | 34% | |
| Very Fine Sand | 0.05065 | 0.105 - 0.0625 | 10.02 | 2.081 | 21% | Silt Clay Fraction |
| Coarse Silt | 0.02990 | 0.053 - 0.031 | 10.02 | 0.955 | 10% | 45% |
| Medium Silt | 0.01649 | 0.031 -0.0156 | 10.02 | 0.682 | 7% | |
| Fine Silt | 0.00952 | 0.0156 - 0.0078 | 10.02 | 1.228 | 12% | |
| Very Fine Silt | 0.00676 | 0.0078 - 0.0039 | 10.02 | 1.146 | 11% | |
| Clay | 0.00480 | 0.002 - 0.00012 | 10.02 | 0.478 | 5% | |
| | | | | 10.020 | 100% | |

Well 9C - Hydrometer Results with Photograph



Hydrometer Results with Grain Sample Photographs

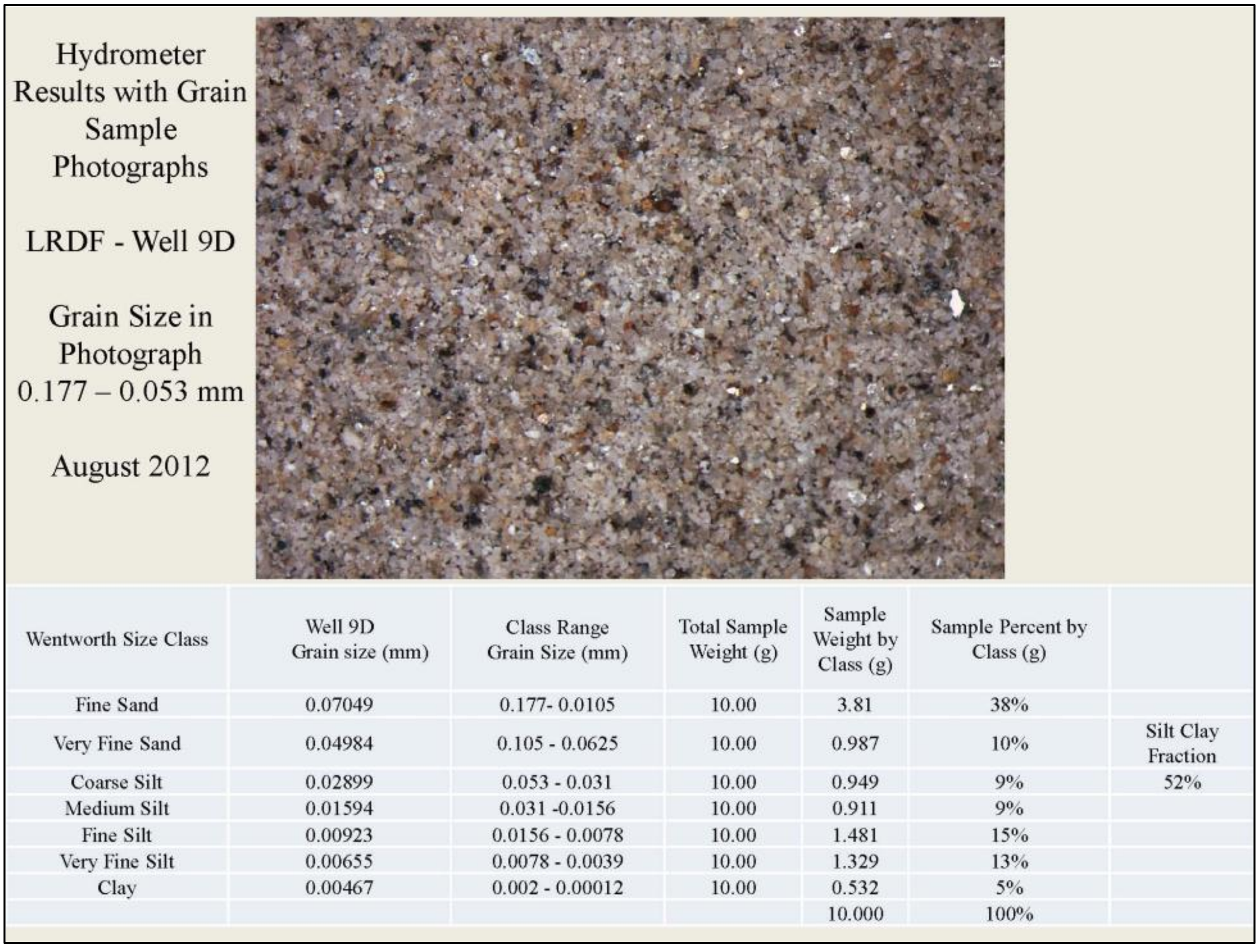
LRDF - Well 9C

Grain Size in Photographs 0.177 – 0.053 mm

August 2012

| Wentworth Size Class | Well 9C Grain size (mm) | Class Range Grain Size (mm) | Total Sample Weight (g) | Sample Weight by Class (g) | Sample Percent by Class (g) | |
|---|---|---|---|---|---|---|
| Fine Sand | 0.06559 | 0.177- 0.0105 | 11.60 | 4.00 | 34% | |
| Very Fine Sand | 0.04638 | 0.105 - 0.0625 | 11.60 | 1.822 | 16% | Silt Clay Fraction |
| Coarse Silt | 0.02678 | 0.053 - 0.031 | 11.60 | 0.899 | 8% | 50% |
| Medium Silt | 0.01467 | 0.031 -0.0156 | 11.60 | 0.899 | 8% | |
| Fine Silt | 0.00857 | 0.0156 - 0.0078 | 11.60 | 1.725 | 15% | |
| Very Fine Silt | 0.00611 | 0.0078 - 0.0039 | 11.60 | 1.531 | 13% | |
| Clay | 0.00433 | 0.002 - 0.00012 | 11.60 | 0.724 | 6% | |
| | | | | 11.600 | 100% | |

Hydrometer Results with Photograph



Hydrometer Results with Grain Sample Photographs

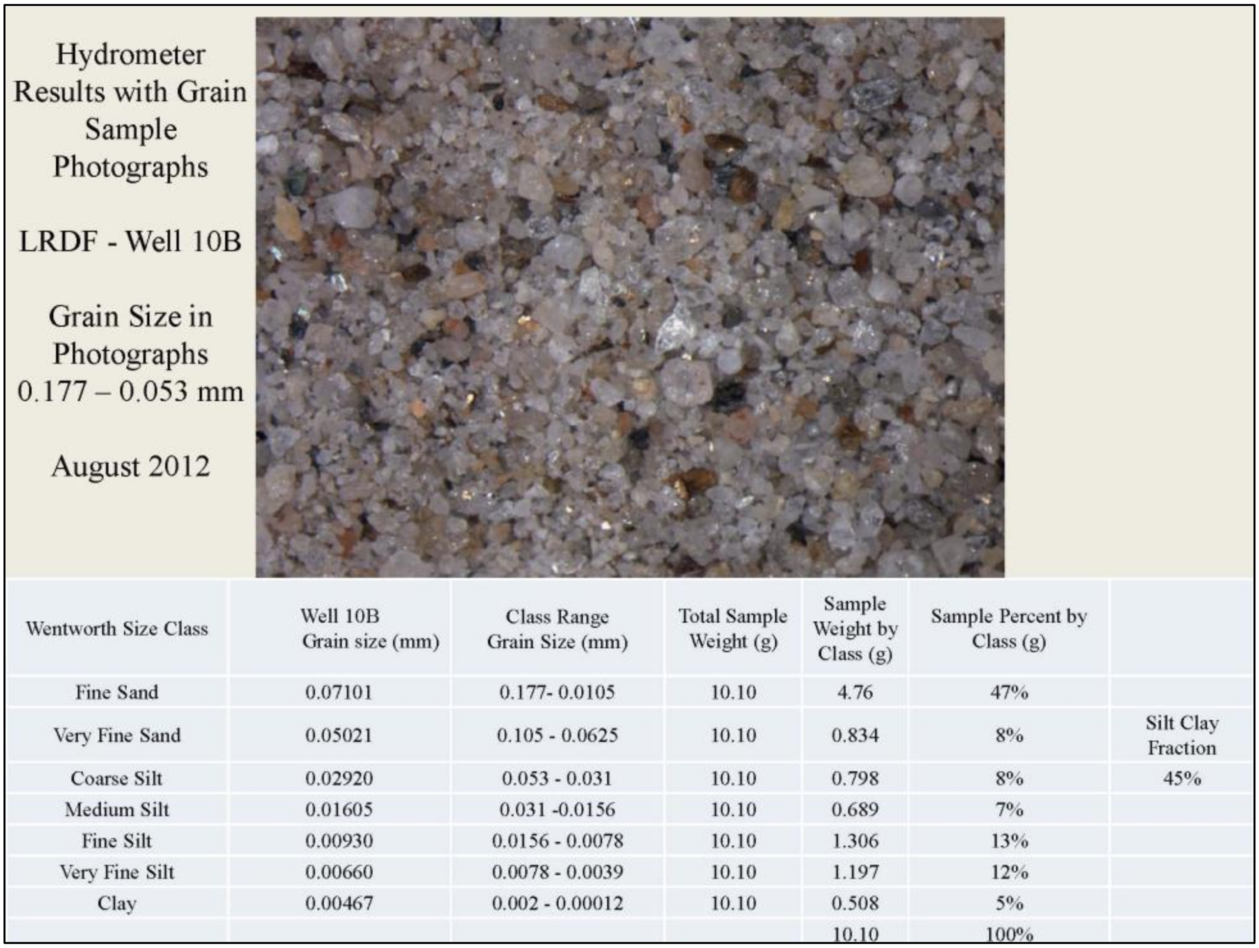
LRDF - Well 9D

Grain Size in Photograph
0.177 – 0.053 mm

August 2012

| Wentworth Size Class | Well 9D Grain size (mm) | Class Range Grain Size (mm) | Total Sample Weight (g) | Sample Weight by Class (g) | Sample Percent by Class (g) | |
|---|---|---|---|---|---|---|
| Fine Sand | 0.07049 | 0.177- 0.0105 | 10.00 | 3.81 | 38% | |
| Very Fine Sand | 0.04984 | 0.105 - 0.0625 | 10.00 | 0.987 | 10% | Silt Clay Fraction |
| Coarse Silt | 0.02899 | 0.053 - 0.031 | 10.00 | 0.949 | 9% | 52% |
| Medium Silt | 0.01594 | 0.031 -0.0156 | 10.00 | 0.911 | 9% | |
| Fine Silt | 0.00923 | 0.0156 - 0.0078 | 10.00 | 1.481 | 15% | |
| Very Fine Silt | 0.00655 | 0.0078 - 0.0039 | 10.00 | 1.329 | 13% | |
| Clay | 0.00467 | 0.002 - 0.00012 | 10.00 | 0.532 | 5% | |
| | | | | 10.000 | 100% | |

Well 10B - Hydrometer Results with Photograph



Hydrometer
Results with Grain
Sample
Photographs

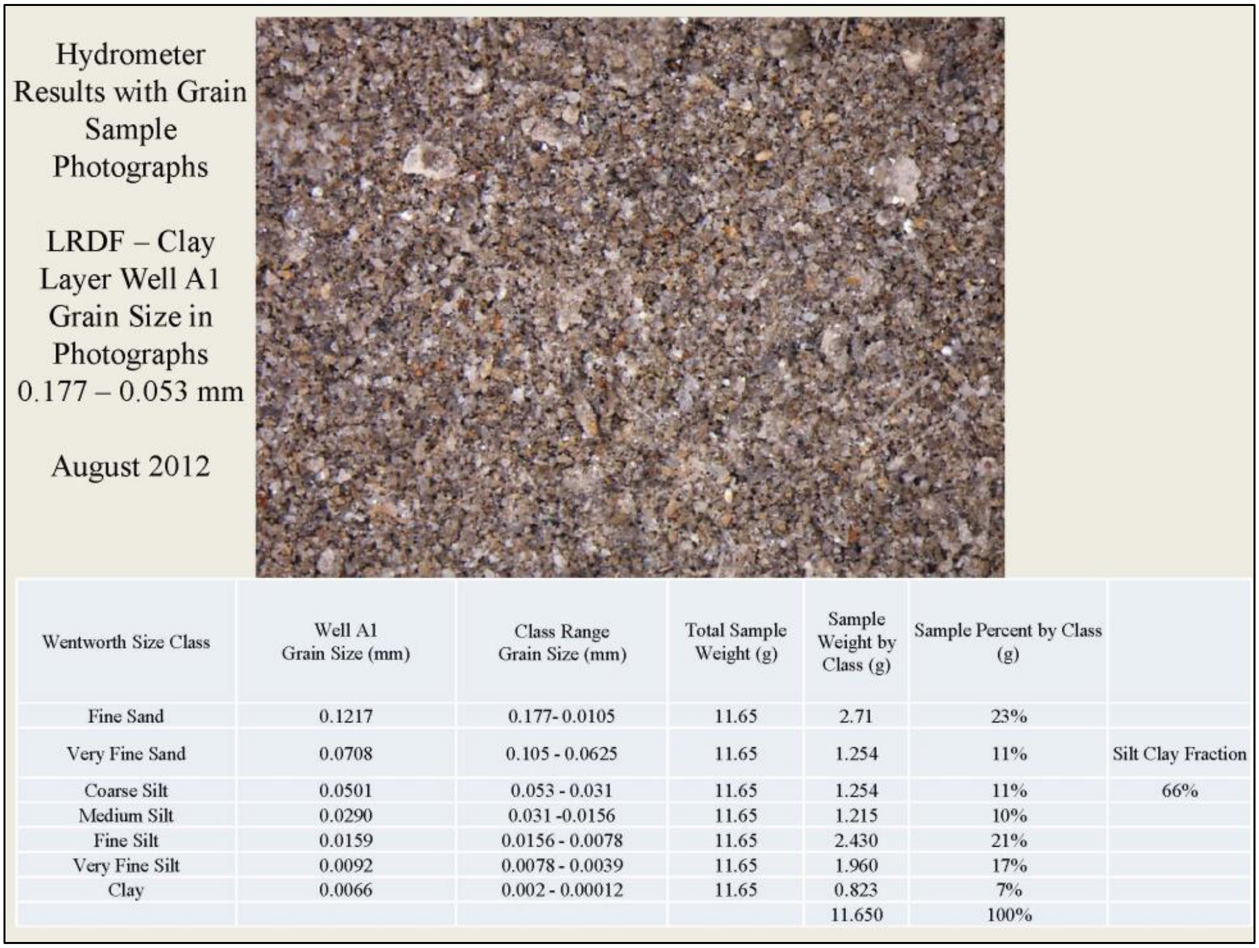
LRDF - Well 10B

Grain Size in
Photographs
0.177 – 0.053 mm

August 2012

| Wentworth Size Class | Well 10B Grain size (mm) | Class Range Grain Size (mm) | Total Sample Weight (g) | Sample Weight by Class (g) | Sample Percent by Class (g) | |
|---|---|---|---|---|---|---|
| Fine Sand | 0.07101 | 0.177- 0.0105 | 10.10 | 4.76 | 47% | |
| Very Fine Sand | 0.05021 | 0.105 - 0.0625 | 10.10 | 0.834 | 8% | Silt Clay Fraction |
| Coarse Silt | 0.02920 | 0.053 - 0.031 | 10.10 | 0.798 | 8% | 45% |
| Medium Silt | 0.01605 | 0.031 -0.0156 | 10.10 | 0.689 | 7% | |
| Fine Silt | 0.00930 | 0.0156 - 0.0078 | 10.10 | 1.306 | 13% | |
| Very Fine Silt | 0.00660 | 0.0078 - 0.0039 | 10.10 | 1.197 | 12% | |
| Clay | 0.00467 | 0.002 - 0.00012 | 10.10 | 0.508 | 5% | |
| | | | | 10.10 | 100% | |

Well A1 - Hydrometer Results with Photograph Clay layer



Hydrometer
Results with Grain
Sample
Photographs

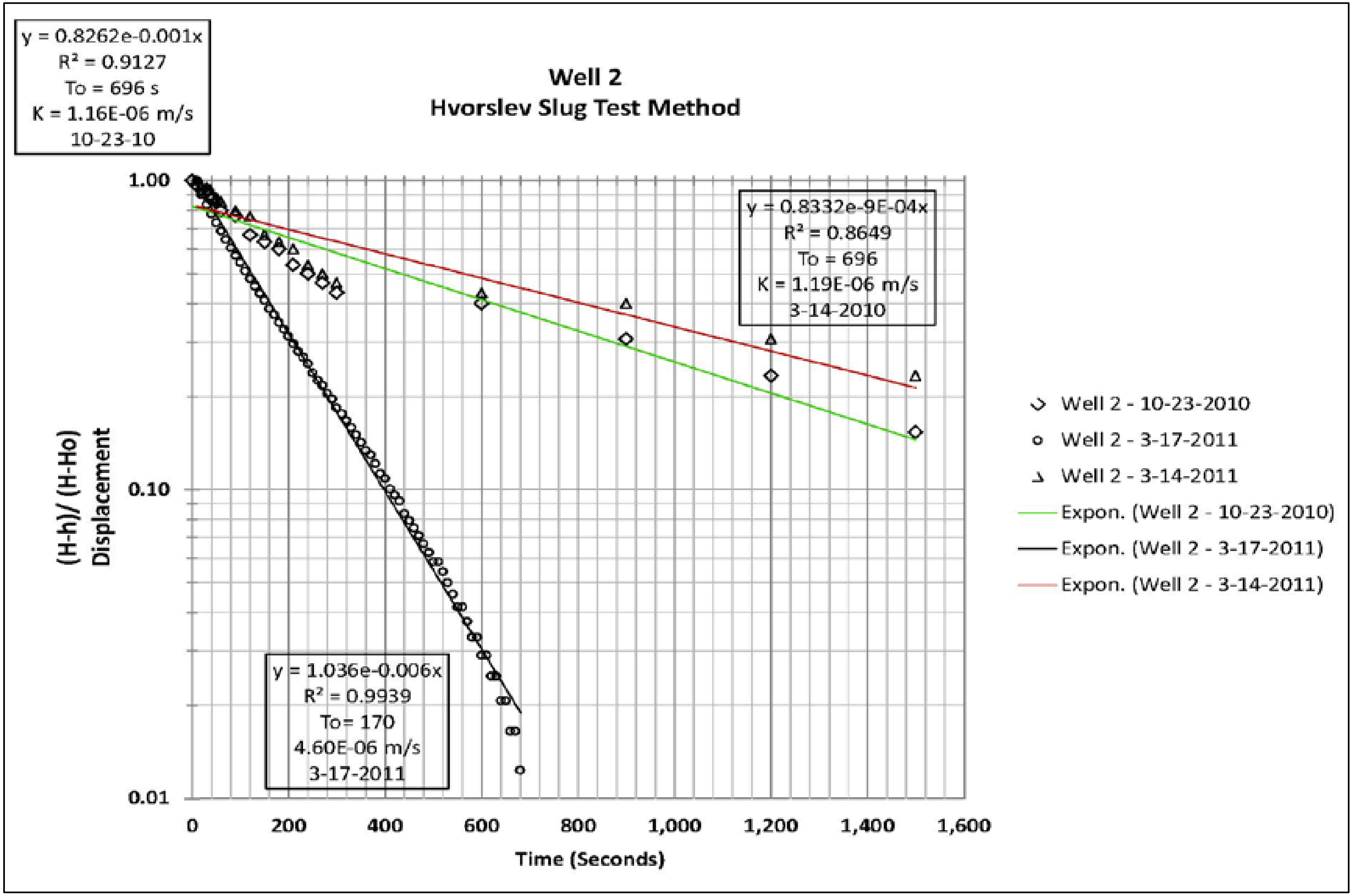
LRDF – Clay
Layer Well A1
Grain Size in
Photographs
0.177 – 0.053 mm

August 2012

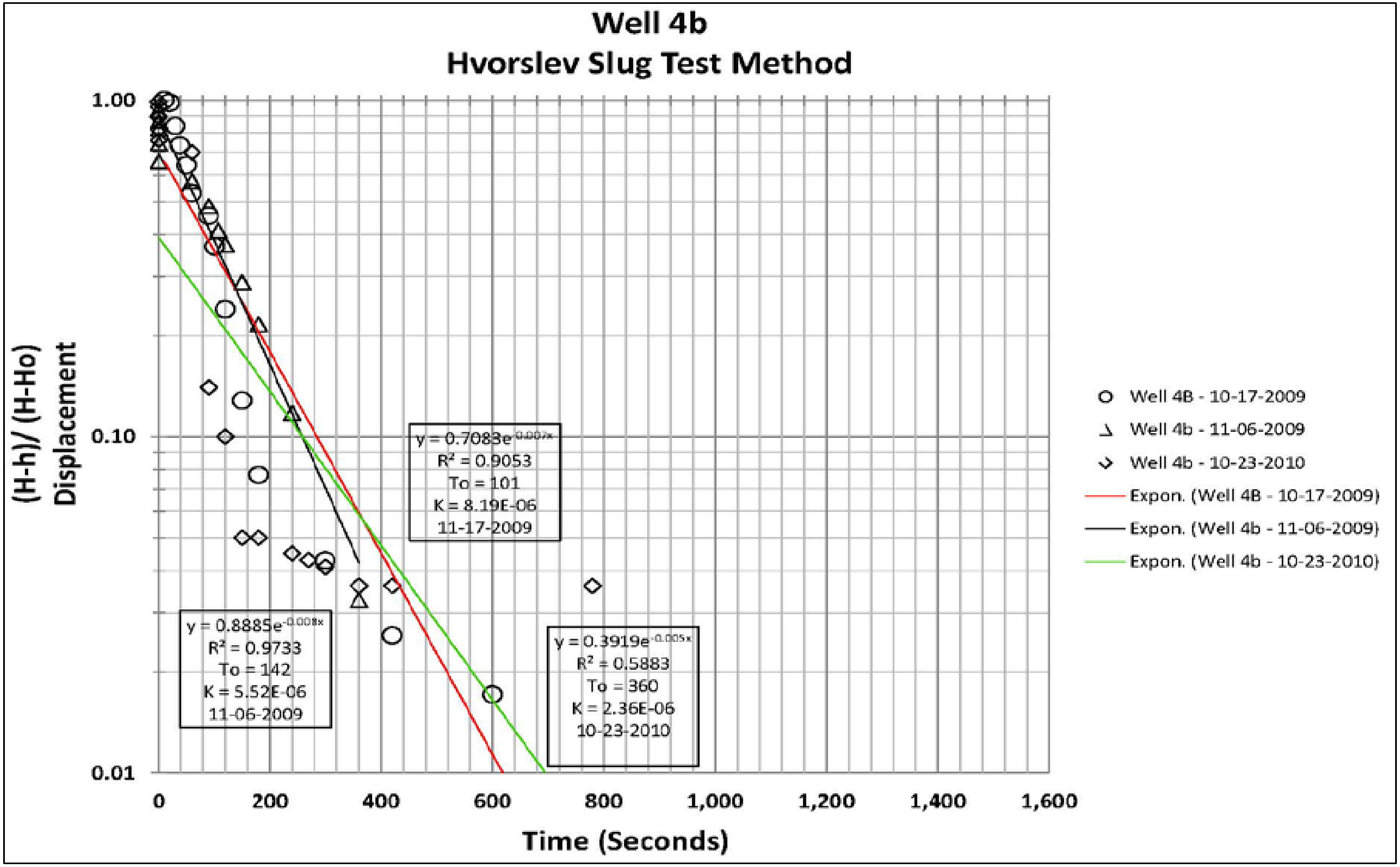
| Wentworth Size Class | Well A1 Grain Size (mm) | Class Range Grain Size (mm) | Total Sample Weight (g) | Sample Weight by Class (g) | Sample Percent by Class (g) | |
|---|---|---|---|---|---|---|
| Fine Sand | 0.1217 | 0.177- 0.0105 | 11.65 | 2.71 | 23% | |
| Very Fine Sand | 0.0708 | 0.105 - 0.0625 | 11.65 | 1.254 | 11% | Silt Clay Fraction |
| Coarse Silt | 0.0501 | 0.053 - 0.031 | 11.65 | 1.254 | 11% | 66% |
| Medium Silt | 0.0290 | 0.031 -0.0156 | 11.65 | 1.215 | 10% | |
| Fine Silt | 0.0159 | 0.0156 - 0.0078 | 11.65 | 2.430 | 21% | |
| Very Fine Silt | 0.0092 | 0.0078 - 0.0039 | 11.65 | 1.960 | 17% | |
| Clay | 0.0066 | 0.002 - 0.00012 | 11.65 | 0.823 | 7% | |
| | | | | 11.650 | 100% | |

# Appendix C – Alluvium Charts for Slug & Pumping Tests and Supplementary Tables, Figures.

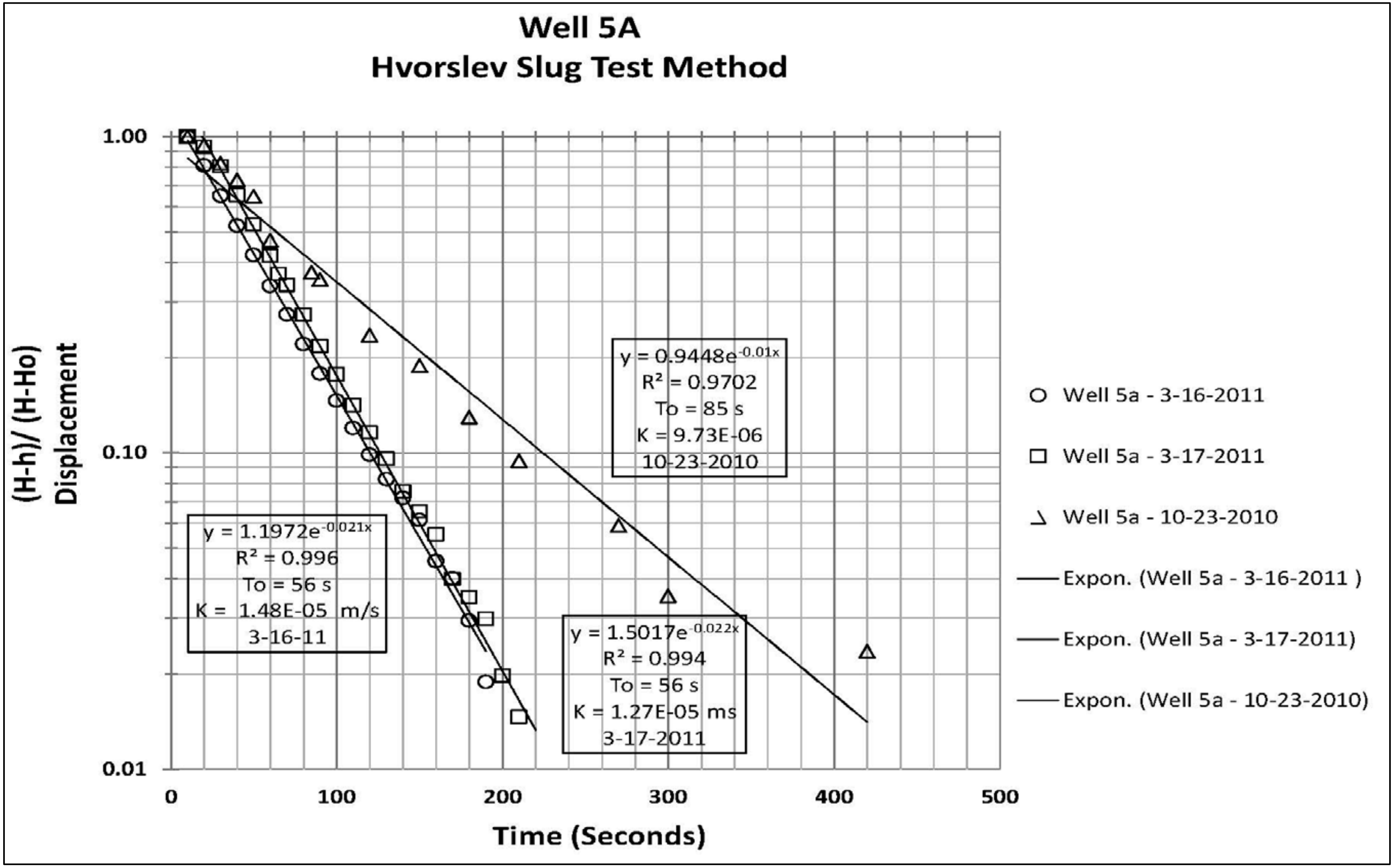
Hvorslev Method, Slug Test - Well 2 – Test Dates: 10-23-2010 – 3-14-2011 – 3-17-2011.



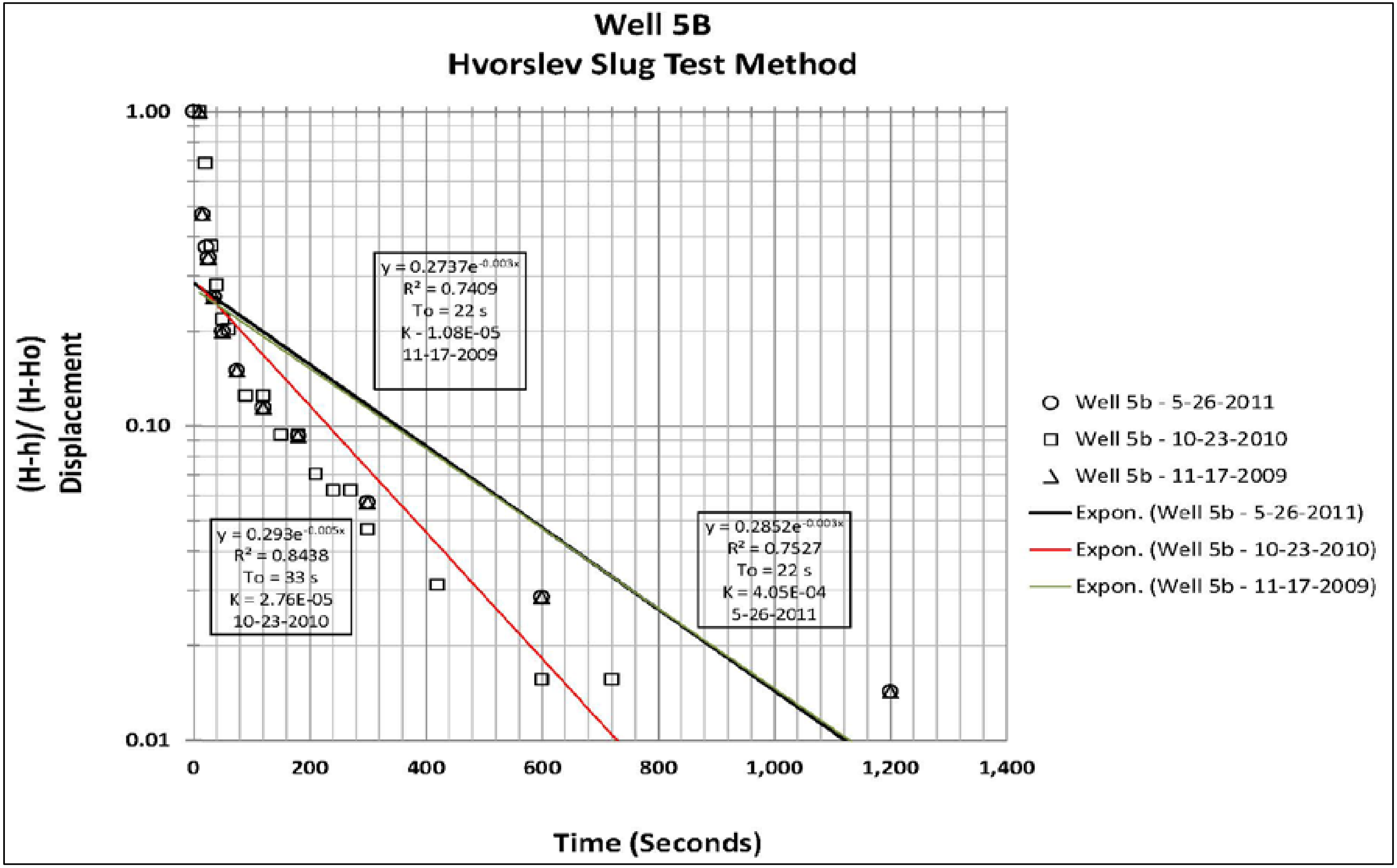
Hvorslev Method, Slug Test - Well 4b – Test Dates: 10-17-2009 – 11-06-2009 – 10-23-2010.



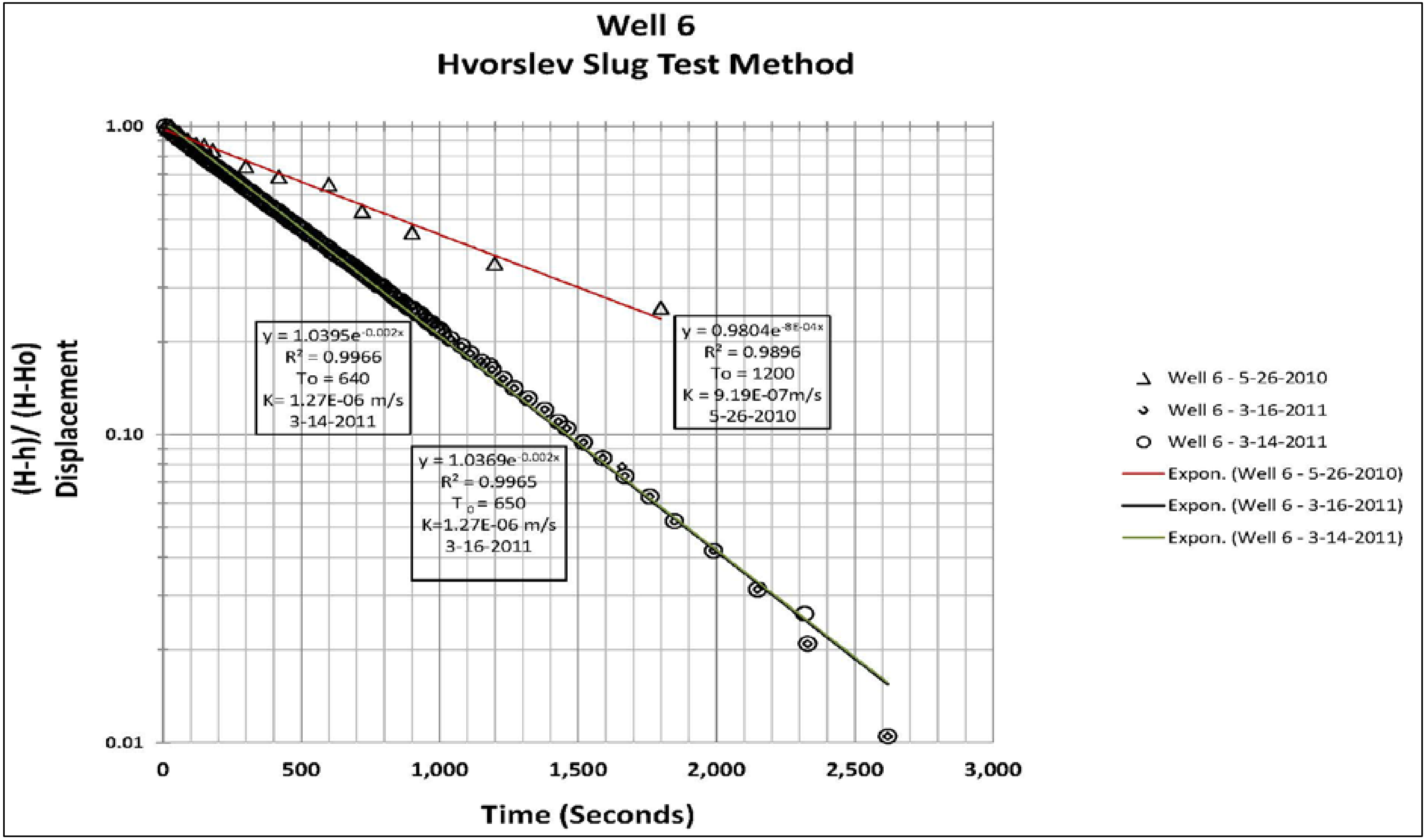
Hvorslev Method, Slug Test - Well 4b – Test Dates: 10-23-2010 – 3-16-2011 – 3-17-2011.



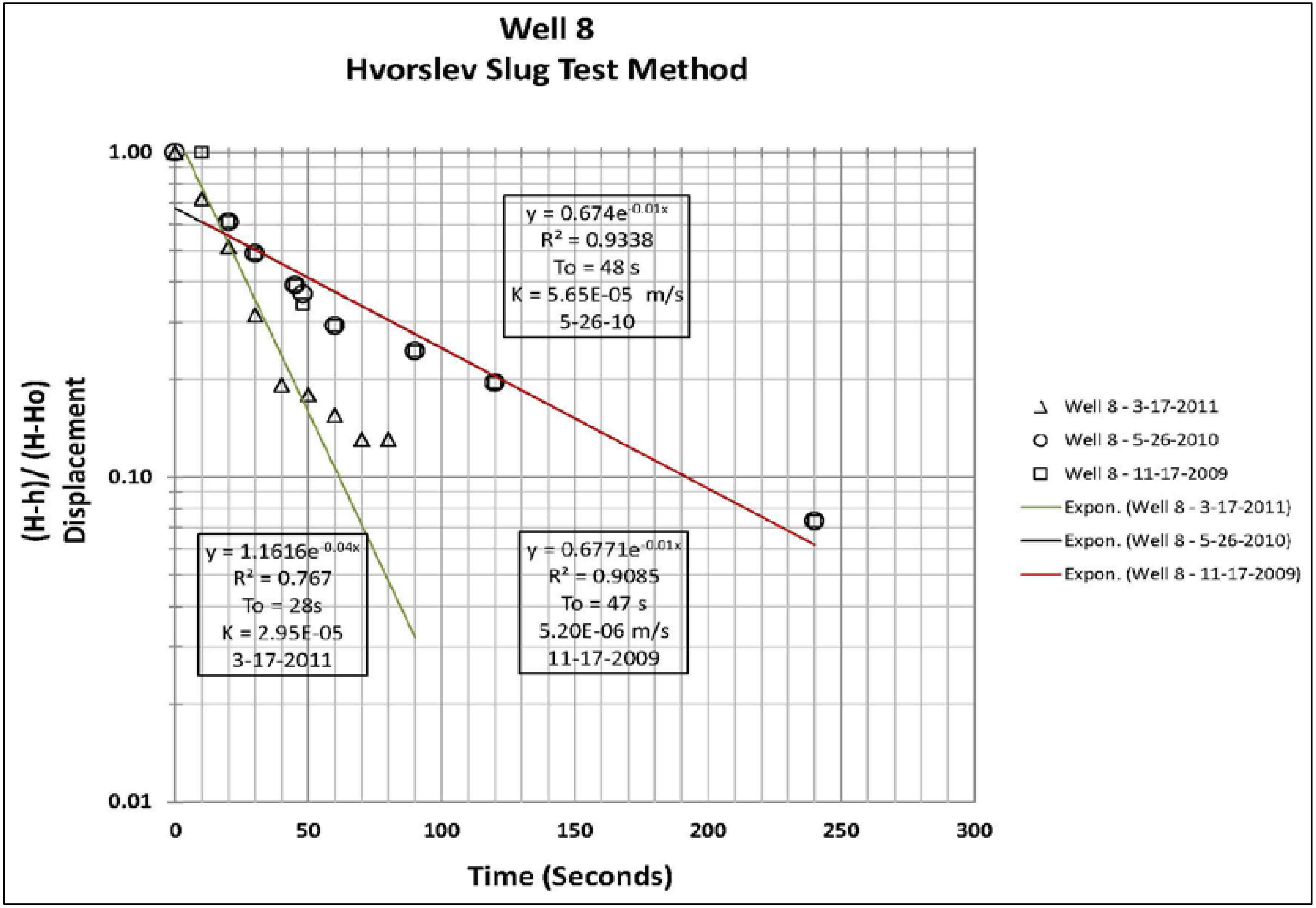
Hvorslev Method, Slug Test - Well 5b – Test Dates: 11-17-2009-10-23-2010 – 5-26-2011.



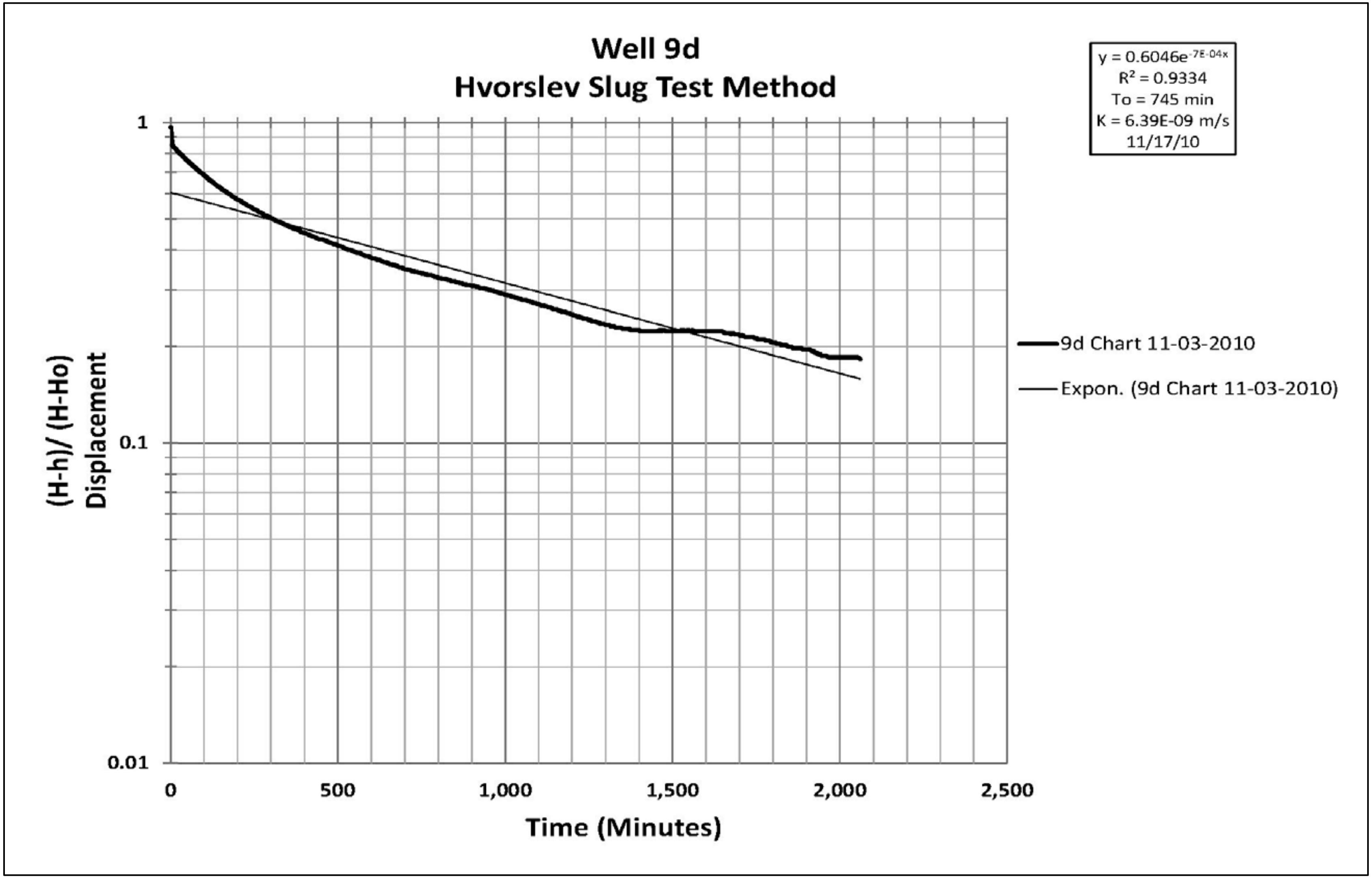
Hvorslev Method, Slug Test - Well 6 – Test Dates: 5-26-2010 – 3-14-2011 – 3-16-2011.



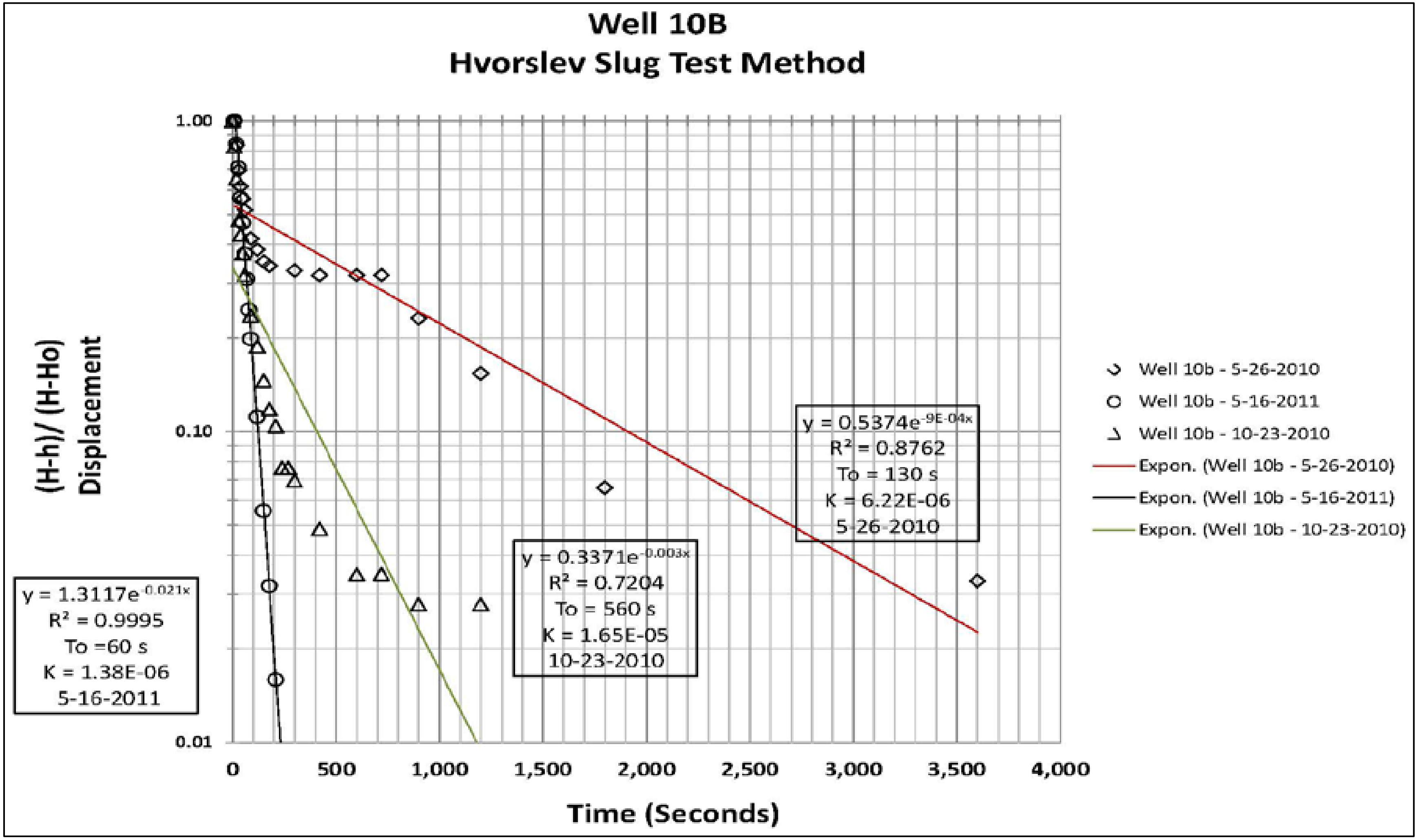
Hvorslev Method, Slug Test - Well 8 – Test Date: 11-17-2009 - 5-26-2010 – 3-17-2011



Hvorslev Method, Slug Test - Well 9d – Test Dates: 10-23-2010 – 11-03-2010.

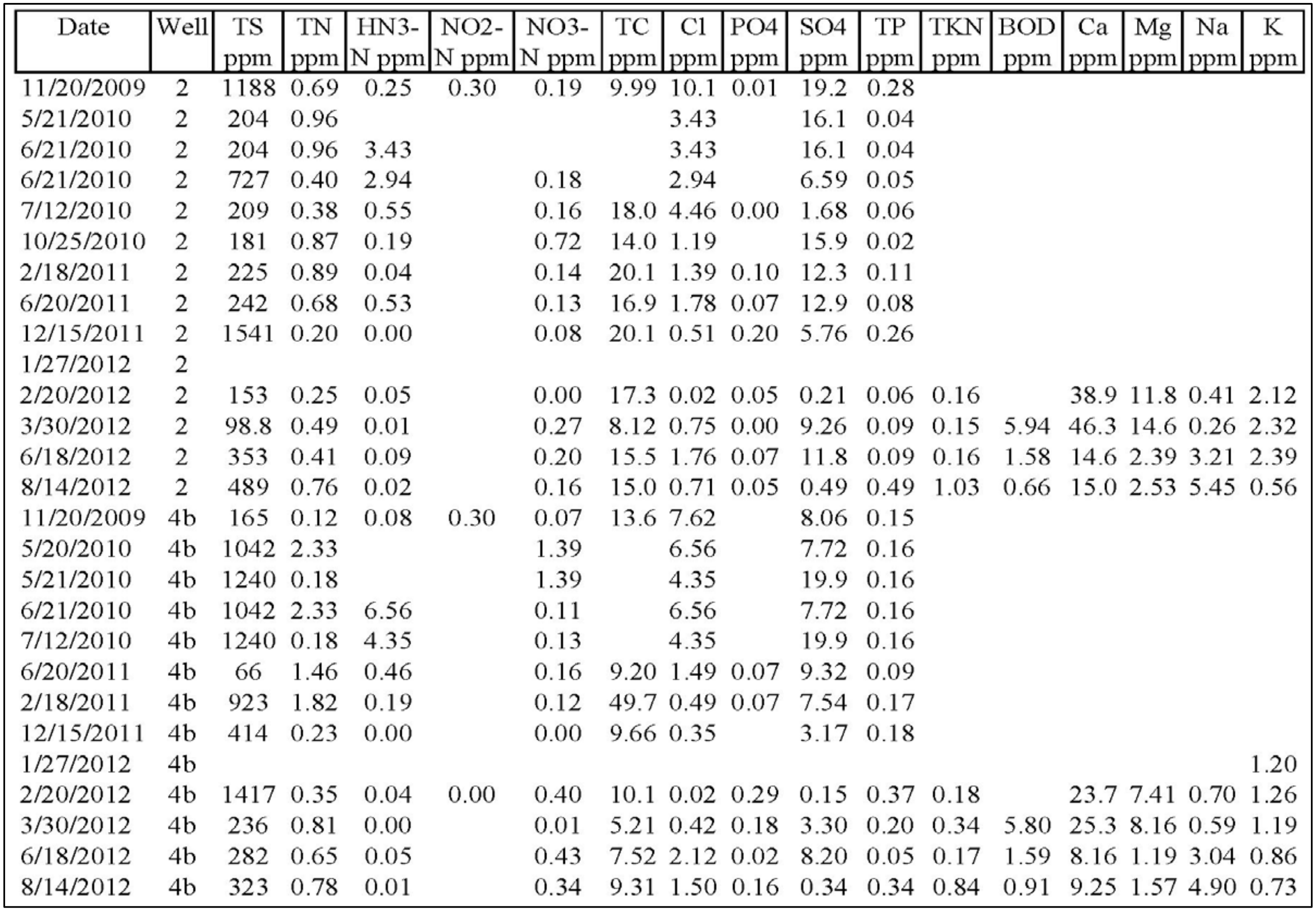


Hvorslev Method, Slug Test - Well 10b – Test Date: 5-26-2010 -5-18-2011 – 10-23-2010.



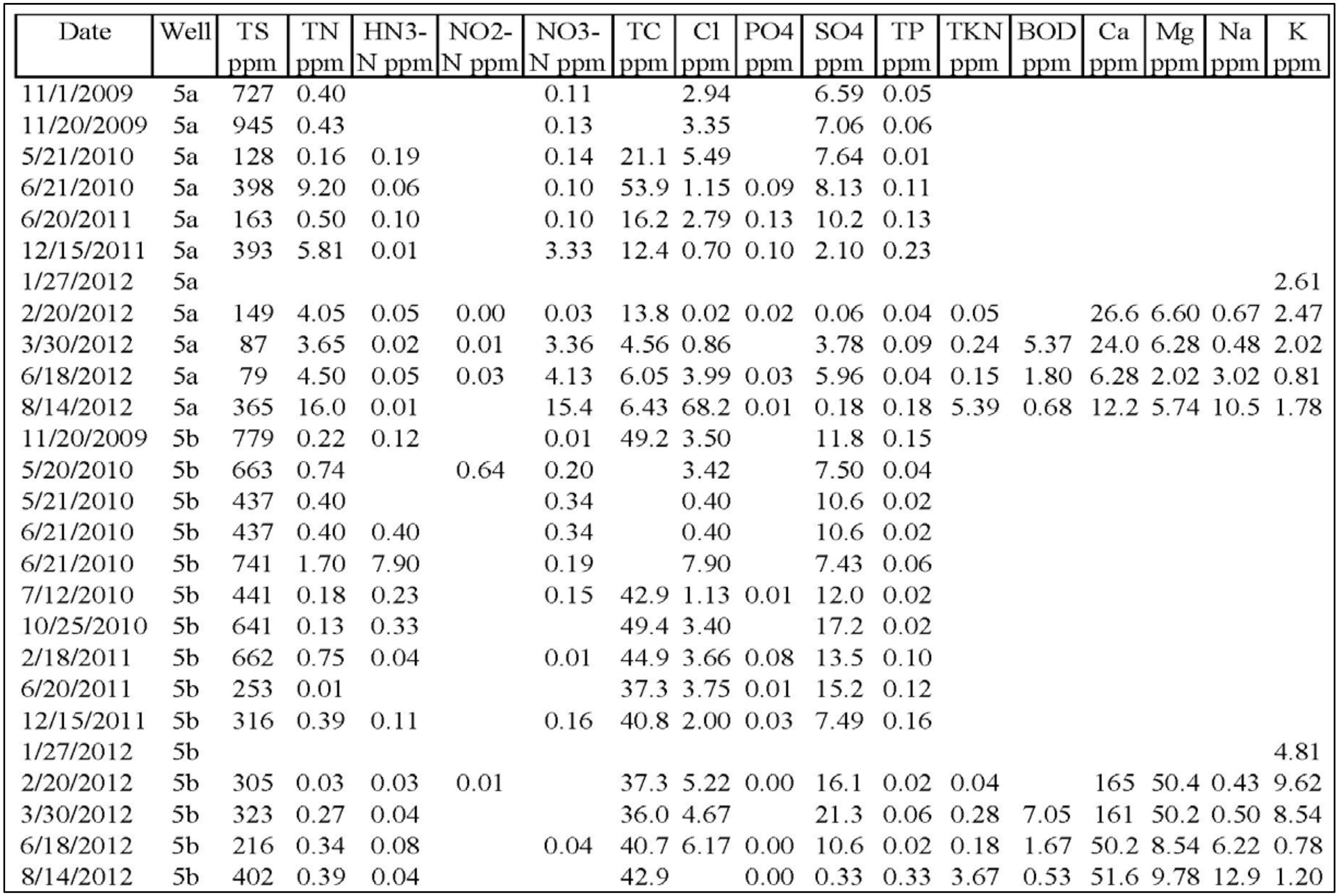
# Appendix D –Water Quality Data –Supplementary Tables, Figures and Charts

Geochemistry Data – Wells 2 & 4b



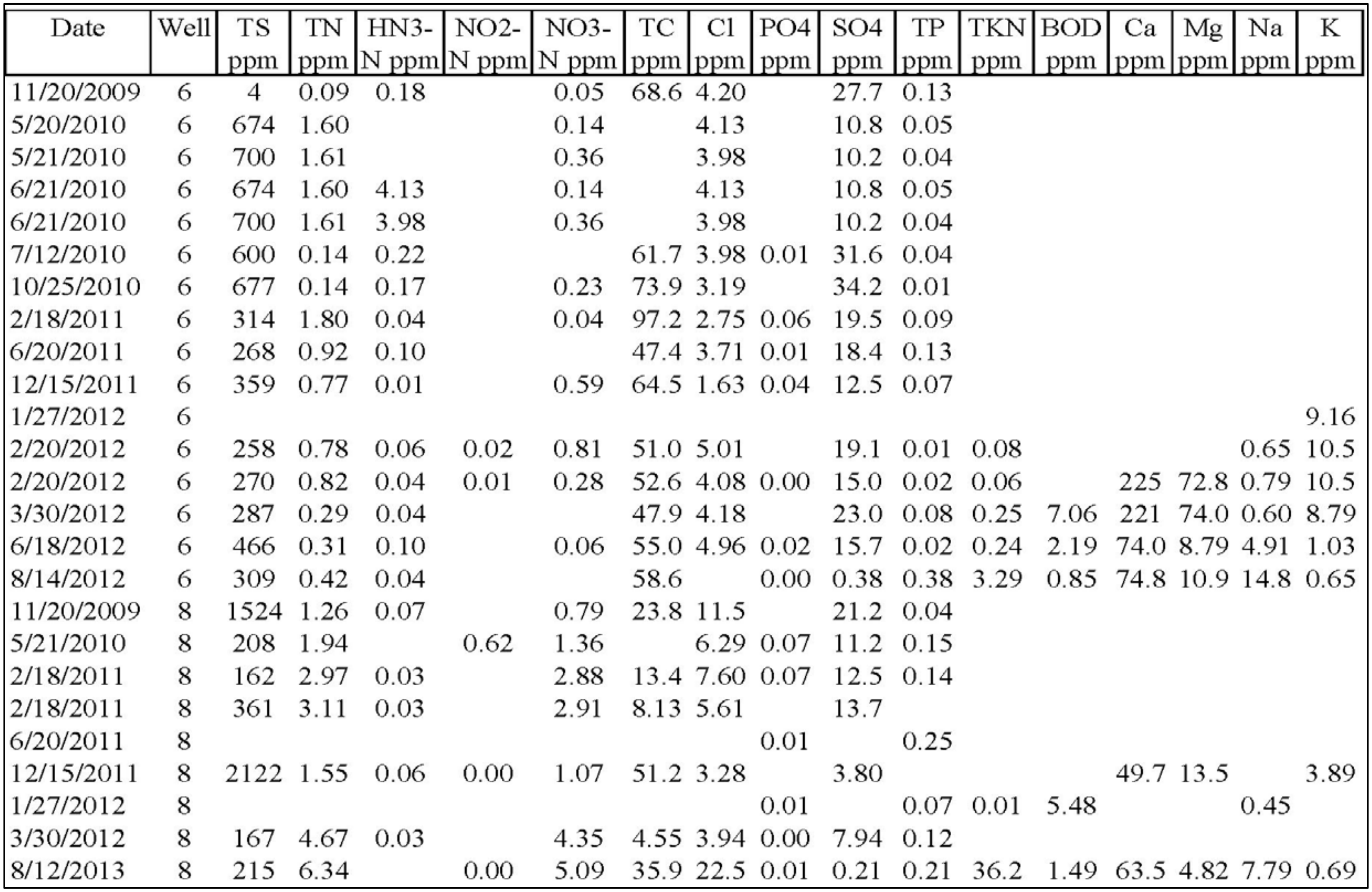
| Date | Well | TS ppm | TN ppm | HN3-N ppm | NO2-N ppm | NO3-N ppm | TC ppm | Cl ppm | PO4 ppm | SO4 ppm | TP ppm | TKN ppm | BOD ppm | Ca ppm | Mg ppm | Na ppm | K ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11/20/2009 | 2 | 1188 | 0.69 | 0.25 | 0.30 | 0.19 | 9.99 | 10.1 | 0.01 | 19.2 | 0.28 | | | | | | |
| 5/21/2010 | 2 | 204 | 0.96 | | | | | 3.43 | | 16.1 | 0.04 | | | | | | |
| 6/21/2010 | 2 | 204 | 0.96 | 3.43 | | | | 3.43 | | 16.1 | 0.04 | | | | | | |
| 6/21/2010 | 2 | 727 | 0.40 | 2.94 | | 0.18 | | 2.94 | | 6.59 | 0.05 | | | | | | |
| 7/12/2010 | 2 | 209 | 0.38 | 0.55 | | 0.16 | 18.0 | 4.46 | 0.00 | 1.68 | 0.06 | | | | | | |
| 10/25/2010 | 2 | 181 | 0.87 | 0.19 | | 0.72 | 14.0 | 1.19 | | 15.9 | 0.02 | | | | | | |
| 2/18/2011 | 2 | 225 | 0.89 | 0.04 | | 0.14 | 20.1 | 1.39 | 0.10 | 12.3 | 0.11 | | | | | | |
| 6/20/2011 | 2 | 242 | 0.68 | 0.53 | | 0.13 | 16.9 | 1.78 | 0.07 | 12.9 | 0.08 | | | | | | |
| 12/15/2011 | 2 | 1541 | 0.20 | 0.00 | | 0.08 | 20.1 | 0.51 | 0.20 | 5.76 | 0.26 | | | | | | |
| 1/27/2012 | 2 | | | | | | | | | | | | | | | | |
| 2/20/2012 | 2 | 153 | 0.25 | 0.05 | | 0.00 | 17.3 | 0.02 | 0.05 | 0.21 | 0.06 | 0.16 | | 38.9 | 11.8 | 0.41 | 2.12 |
| 3/30/2012 | 2 | 98.8 | 0.49 | 0.01 | | 0.27 | 8.12 | 0.75 | 0.00 | 9.26 | 0.09 | 0.15 | 5.94 | 46.3 | 14.6 | 0.26 | 2.32 |
| 6/18/2012 | 2 | 353 | 0.41 | 0.09 | | 0.20 | 15.5 | 1.76 | 0.07 | 11.8 | 0.09 | 0.16 | 1.58 | 14.6 | 2.39 | 3.21 | 2.39 |
| 8/14/2012 | 2 | 489 | 0.76 | 0.02 | | 0.16 | 15.0 | 0.71 | 0.05 | 0.49 | 0.49 | 1.03 | 0.66 | 15.0 | 2.53 | 5.45 | 0.56 |
| 11/20/2009 | 4b | 165 | 0.12 | 0.08 | 0.30 | 0.07 | 13.6 | 7.62 | | 8.06 | 0.15 | | | | | | |
| 5/20/2010 | 4b | 1042 | 2.33 | | | 1.39 | | 6.56 | | 7.72 | 0.16 | | | | | | |
| 5/21/2010 | 4b | 1240 | 0.18 | | | 1.39 | | 4.35 | | 19.9 | 0.16 | | | | | | |
| 6/21/2010 | 4b | 1042 | 2.33 | 6.56 | | 0.11 | | 6.56 | | 7.72 | 0.16 | | | | | | |
| 7/12/2010 | 4b | 1240 | 0.18 | 4.35 | | 0.13 | | 4.35 | | 19.9 | 0.16 | | | | | | |
| 6/20/2011 | 4b | 66 | 1.46 | 0.46 | | 0.16 | 9.20 | 1.49 | 0.07 | 9.32 | 0.09 | | | | | | |
| 2/18/2011 | 4b | 923 | 1.82 | 0.19 | | 0.12 | 49.7 | 0.49 | 0.07 | 7.54 | 0.17 | | | | | | |
| 12/15/2011 | 4b | 414 | 0.23 | 0.00 | | 0.00 | 9.66 | 0.35 | | 3.17 | 0.18 | | | | | | |
| 1/27/2012 | 4b | | | | | | | | | | | | | | | | 1.20 |
| 2/20/2012 | 4b | 1417 | 0.35 | 0.04 | 0.00 | 0.40 | 10.1 | 0.02 | 0.29 | 0.15 | 0.37 | 0.18 | | 23.7 | 7.41 | 0.70 | 1.26 |
| 3/30/2012 | 4b | 236 | 0.81 | 0.00 | | 0.01 | 5.21 | 0.42 | 0.18 | 3.30 | 0.20 | 0.34 | 5.80 | 25.3 | 8.16 | 0.59 | 1.19 |
| 6/18/2012 | 4b | 282 | 0.65 | 0.05 | | 0.43 | 7.52 | 2.12 | 0.02 | 8.20 | 0.05 | 0.17 | 1.59 | 8.16 | 1.19 | 3.04 | 0.86 |
| 8/14/2012 | 4b | 323 | 0.78 | 0.01 | | 0.34 | 9.31 | 1.50 | 0.16 | 0.34 | 0.34 | 0.84 | 0.91 | 9.25 | 1.57 | 4.90 | 0.73 |

Geochemistry Data – Wells 5a & 5b



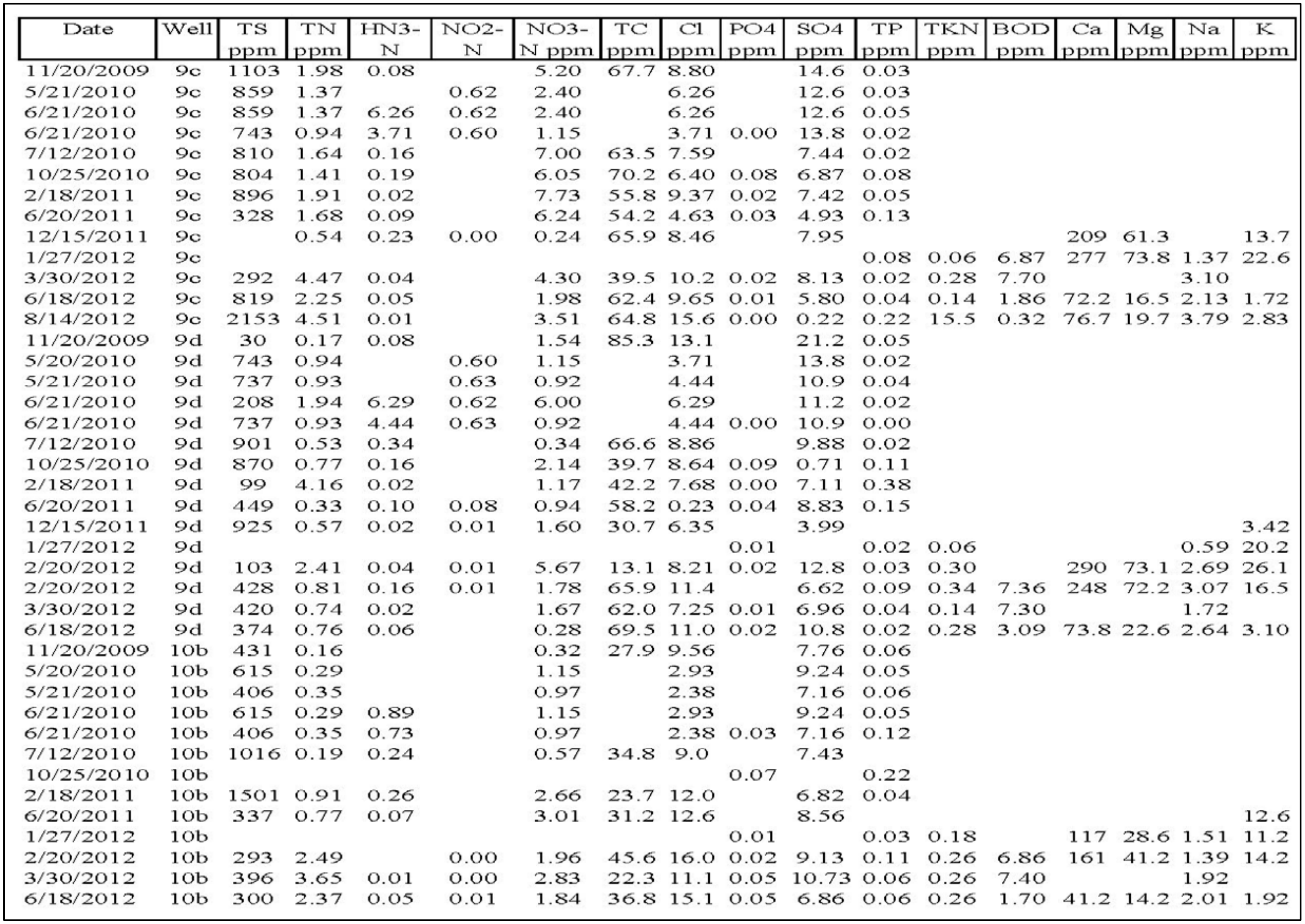
| Date | Well | TS ppm | TN ppm | HN3-N ppm | NO2-N ppm | NO3-N ppm | TC ppm | Cl ppm | PO4 ppm | SO4 ppm | TP ppm | TKN ppm | BOD ppm | Ca ppm | Mg ppm | Na ppm | K ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11/1/2009 | 5a | 727 | 0.40 | | | 0.11 | | 2.94 | | 6.59 | 0.05 | | | | | | |
| 11/20/2009 | 5a | 945 | 0.43 | | | 0.13 | | 3.35 | | 7.06 | 0.06 | | | | | | |
| 5/21/2010 | 5a | 128 | 0.16 | 0.19 | | 0.14 | 21.1 | 5.49 | | 7.64 | 0.01 | | | | | | |
| 6/21/2010 | 5a | 398 | 9.20 | 0.06 | | 0.10 | 53.9 | 1.15 | 0.09 | 8.13 | 0.11 | | | | | | |
| 6/20/2011 | 5a | 163 | 0.50 | 0.10 | | 0.10 | 16.2 | 2.79 | 0.13 | 10.2 | 0.13 | | | | | | |
| 12/15/2011 | 5a | 393 | 5.81 | 0.01 | | 3.33 | 12.4 | 0.70 | 0.10 | 2.10 | 0.23 | | | | | | |
| 1/27/2012 | 5a | | | | | | | | | | | | | | | | 2.61 |
| 2/20/2012 | 5a | 149 | 4.05 | 0.05 | 0.00 | 0.03 | 13.8 | 0.02 | 0.02 | 0.06 | 0.04 | 0.05 | | 26.6 | 6.60 | 0.67 | 2.47 |
| 3/30/2012 | 5a | 87 | 3.65 | 0.02 | 0.01 | 3.36 | 4.56 | 0.86 | | 3.78 | 0.09 | 0.24 | 5.37 | 24.0 | 6.28 | 0.48 | 2.02 |
| 6/18/2012 | 5a | 79 | 4.50 | 0.05 | 0.03 | 4.13 | 6.05 | 3.99 | 0.03 | 5.96 | 0.04 | 0.15 | 1.80 | 6.28 | 2.02 | 3.02 | 0.81 |
| 8/14/2012 | 5a | 365 | 16.0 | 0.01 | | 15.4 | 6.43 | 68.2 | 0.01 | 0.18 | 0.18 | 5.39 | 0.68 | 12.2 | 5.74 | 10.5 | 1.78 |
| 11/20/2009 | 5b | 779 | 0.22 | 0.12 | | 0.01 | 49.2 | 3.50 | | 11.8 | 0.15 | | | | | | |
| 5/20/2010 | 5b | 663 | 0.74 | | 0.64 | 0.20 | | 3.42 | | 7.50 | 0.04 | | | | | | |
| 5/21/2010 | 5b | 437 | 0.40 | | | 0.34 | | 0.40 | | 10.6 | 0.02 | | | | | | |
| 6/21/2010 | 5b | 437 | 0.40 | 0.40 | | 0.34 | | 0.40 | | 10.6 | 0.02 | | | | | | |
| 6/21/2010 | 5b | 741 | 1.70 | 7.90 | | 0.19 | | 7.90 | | 7.43 | 0.06 | | | | | | |
| 7/12/2010 | 5b | 441 | 0.18 | 0.23 | | 0.15 | 42.9 | 1.13 | 0.01 | 12.0 | 0.02 | | | | | | |
| 10/25/2010 | 5b | 641 | 0.13 | 0.33 | | | 49.4 | 3.40 | | 17.2 | 0.02 | | | | | | |
| 2/18/2011 | 5b | 662 | 0.75 | 0.04 | | 0.01 | 44.9 | 3.66 | 0.08 | 13.5 | 0.10 | | | | | | |
| 6/20/2011 | 5b | 253 | 0.01 | | | | 37.3 | 3.75 | 0.01 | 15.2 | 0.12 | | | | | | |
| 12/15/2011 | 5b | 316 | 0.39 | 0.11 | | 0.16 | 40.8 | 2.00 | 0.03 | 7.49 | 0.16 | | | | | | |
| 1/27/2012 | 5b | | | | | | | | | | | | | | | | 4.81 |
| 2/20/2012 | 5b | 305 | 0.03 | 0.03 | 0.01 | | 37.3 | 5.22 | 0.00 | 16.1 | 0.02 | 0.04 | | 165 | 50.4 | 0.43 | 9.62 |
| 3/30/2012 | 5b | 323 | 0.27 | 0.04 | | | 36.0 | 4.67 | | 21.3 | 0.06 | 0.28 | 7.05 | 161 | 50.2 | 0.50 | 8.54 |
| 6/18/2012 | 5b | 216 | 0.34 | 0.08 | | 0.04 | 40.7 | 6.17 | 0.00 | 10.6 | 0.02 | 0.18 | 1.67 | 50.2 | 8.54 | 6.22 | 0.78 |
| 8/14/2012 | 5b | 402 | 0.39 | 0.04 | | | 42.9 | | 0.00 | 0.33 | 0.33 | 3.67 | 0.53 | 51.6 | 9.78 | 12.9 | 1.20 |

## Geochemistry Data – Wells 6 & 8



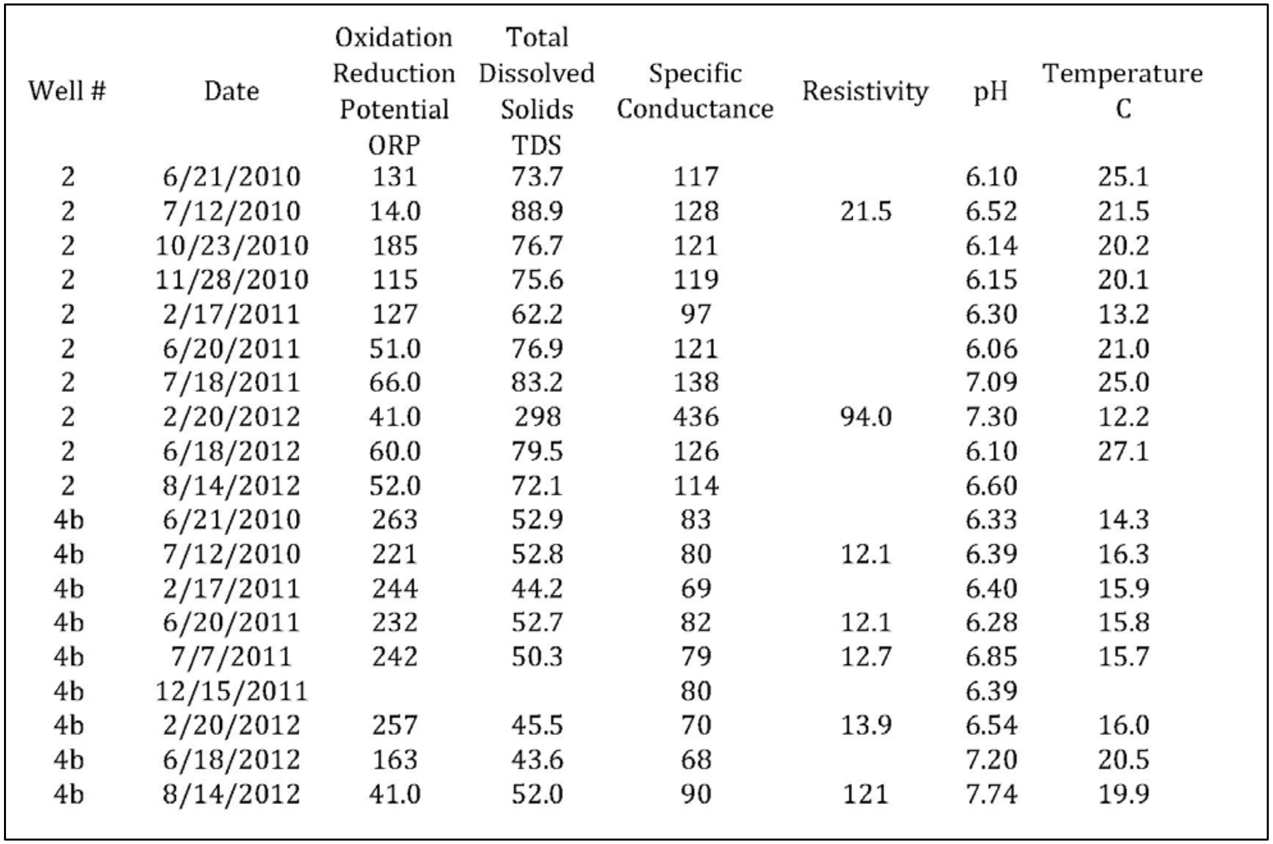
| Date | Well | TS ppm | TN ppm | HN3- N ppm | NO2- N ppm | NO3- N ppm | TC ppm | Cl ppm | PO4 ppm | SO4 ppm | TP ppm | TKN ppm | BOD ppm | Ca ppm | Mg ppm | Na ppm | K ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11/20/2009 | 6 | 4 | 0.09 | 0.18 |  | 0.05 | 68.6 | 4.20 |  | 27.7 | 0.13 |  |  |  |  |  |  |
| 5/20/2010 | 6 | 674 | 1.60 |  |  | 0.14 |  | 4.13 |  | 10.8 | 0.05 |  |  |  |  |  |  |
| 5/21/2010 | 6 | 700 | 1.61 |  |  | 0.36 |  | 3.98 |  | 10.2 | 0.04 |  |  |  |  |  |  |
| 6/21/2010 | 6 | 674 | 1.60 | 4.13 |  | 0.14 |  | 4.13 |  | 10.8 | 0.05 |  |  |  |  |  |  |
| 6/21/2010 | 6 | 700 | 1.61 | 3.98 |  | 0.36 |  | 3.98 |  | 10.2 | 0.04 |  |  |  |  |  |  |
| 7/12/2010 | 6 | 600 | 0.14 | 0.22 |  |  | 61.7 | 3.98 | 0.01 | 31.6 | 0.04 |  |  |  |  |  |  |
| 10/25/2010 | 6 | 677 | 0.14 | 0.17 |  | 0.23 | 73.9 | 3.19 |  | 34.2 | 0.01 |  |  |  |  |  |  |
| 2/18/2011 | 6 | 314 | 1.80 | 0.04 |  | 0.04 | 97.2 | 2.75 | 0.06 | 19.5 | 0.09 |  |  |  |  |  |  |
| 6/20/2011 | 6 | 268 | 0.92 | 0.10 |  |  | 47.4 | 3.71 | 0.01 | 18.4 | 0.13 |  |  |  |  |  |  |
| 12/15/2011 | 6 | 359 | 0.77 | 0.01 |  | 0.59 | 64.5 | 1.63 | 0.04 | 12.5 | 0.07 |  |  |  |  |  |  |
| 1/27/2012 | 6 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 9.16 |
| 2/20/2012 | 6 | 258 | 0.78 | 0.06 | 0.02 | 0.81 | 51.0 | 5.01 |  | 19.1 | 0.01 | 0.08 |  |  |  | 0.65 | 10.5 |
| 2/20/2012 | 6 | 270 | 0.82 | 0.04 | 0.01 | 0.28 | 52.6 | 4.08 | 0.00 | 15.0 | 0.02 | 0.06 |  | 225 | 72.8 | 0.79 | 10.5 |
| 3/30/2012 | 6 | 287 | 0.29 | 0.04 |  |  | 47.9 | 4.18 |  | 23.0 | 0.08 | 0.25 | 7.06 | 221 | 74.0 | 0.60 | 8.79 |
| 6/18/2012 | 6 | 466 | 0.31 | 0.10 |  | 0.06 | 55.0 | 4.96 | 0.02 | 15.7 | 0.02 | 0.24 | 2.19 | 74.0 | 8.79 | 4.91 | 1.03 |
| 8/14/2012 | 6 | 309 | 0.42 | 0.04 |  |  | 58.6 |  | 0.00 | 0.38 | 0.38 | 3.29 | 0.85 | 74.8 | 10.9 | 14.8 | 0.65 |
| 11/20/2009 | 8 | 1524 | 1.26 | 0.07 |  | 0.79 | 23.8 | 11.5 |  | 21.2 | 0.04 |  |  |  |  |  |  |
| 5/21/2010 | 8 | 208 | 1.94 |  | 0.62 | 1.36 |  | 6.29 | 0.07 | 11.2 | 0.15 |  |  |  |  |  |  |
| 2/18/2011 | 8 | 162 | 2.97 | 0.03 |  | 2.88 | 13.4 | 7.60 | 0.07 | 12.5 | 0.14 |  |  |  |  |  |  |
| 2/18/2011 | 8 | 361 | 3.11 | 0.03 |  | 2.91 | 8.13 | 5.61 |  | 13.7 |  |  |  |  |  |  |  |
| 6/20/2011 | 8 |  |  |  |  |  |  |  | 0.01 |  | 0.25 |  |  |  |  |  |  |
| 12/15/2011 | 8 | 2122 | 1.55 | 0.06 | 0.00 | 1.07 | 51.2 | 3.28 |  | 3.80 |  |  |  | 49.7 | 13.5 |  | 3.89 |
| 1/27/2012 | 8 |  |  |  |  |  |  |  | 0.01 |  | 0.07 | 0.01 | 5.48 |  |  | 0.45 |  |
| 3/30/2012 | 8 | 167 | 4.67 | 0.03 |  | 4.35 | 4.55 | 3.94 | 0.00 | 7.94 | 0.12 |  |  |  |  |  |  |
| 8/12/2013 | 8 | 215 | 6.34 |  | 0.00 | 5.09 | 35.9 | 22.5 | 0.01 | 0.21 | 0.21 | 36.2 | 1.49 | 63.5 | 4.82 | 7.79 | 0.69 |

Geochemistry Data – Wells 9cd & 10b



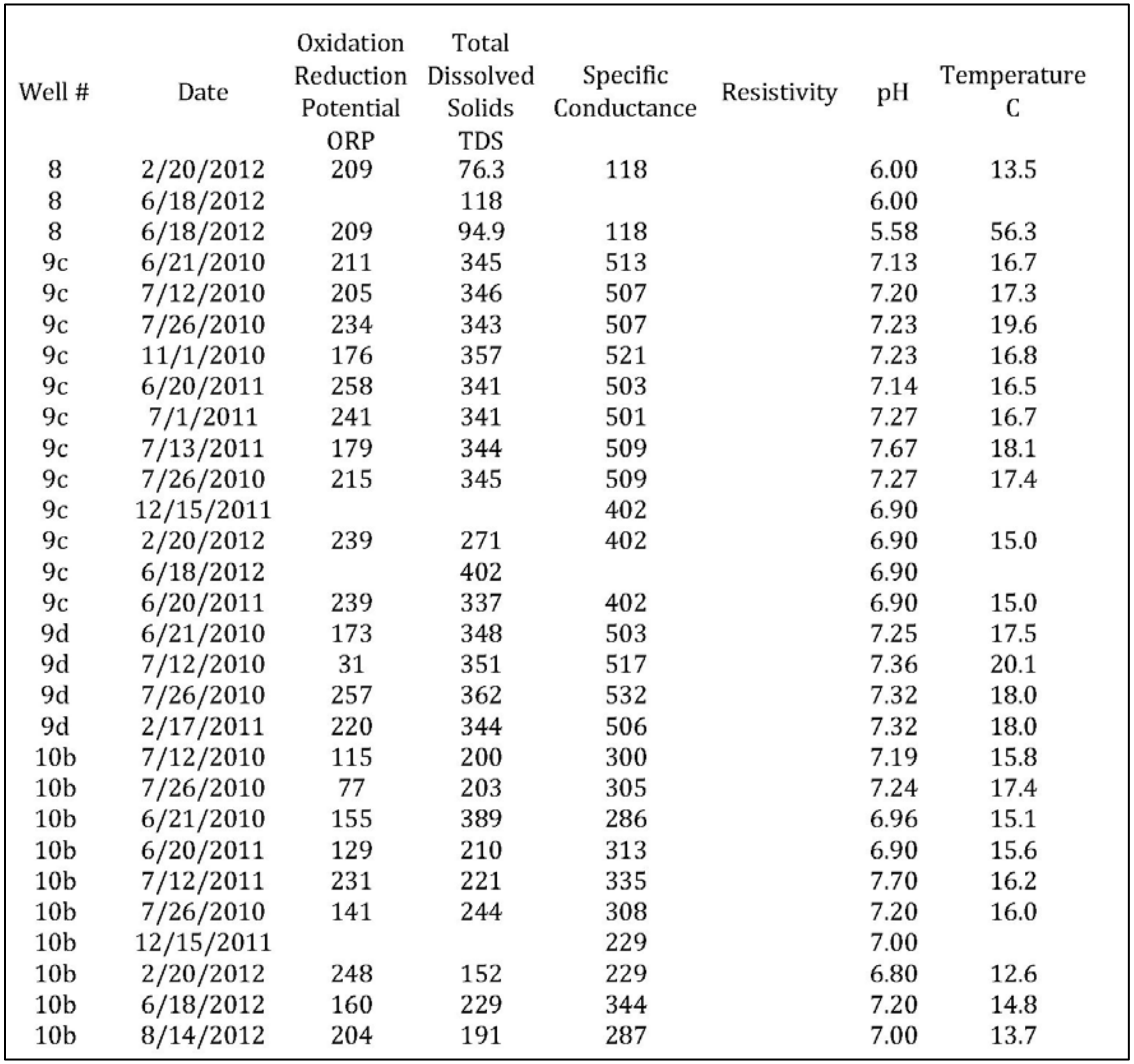
| Date | Well | TS ppm | TN ppm | HN3-N | NO2-N | NO3-N ppm | TC ppm | Cl ppm | PO4 ppm | SO4 ppm | TP ppm | TKN ppm | BOD ppm | Ca ppm | Mg ppm | Na ppm | K ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11/20/2009 | 9c | 1103 | 1.98 | 0.08 |  | 5.20 | 67.7 | 8.80 |  | 14.6 | 0.03 |  |  |  |  |  |  |
| 5/21/2010 | 9c | 859 | 1.37 |  | 0.62 | 2.40 |  | 6.26 |  | 12.6 | 0.03 |  |  |  |  |  |  |
| 6/21/2010 | 9c | 859 | 1.37 | 6.26 | 0.62 | 2.40 |  | 6.26 |  | 12.6 | 0.05 |  |  |  |  |  |  |
| 6/21/2010 | 9c | 743 | 0.94 | 3.71 | 0.60 | 1.15 |  | 3.71 | 0.00 | 13.8 | 0.02 |  |  |  |  |  |  |
| 7/12/2010 | 9c | 810 | 1.64 | 0.16 |  | 7.00 | 63.5 | 7.59 |  | 7.44 | 0.02 |  |  |  |  |  |  |
| 10/25/2010 | 9c | 804 | 1.41 | 0.19 |  | 6.05 | 70.2 | 6.40 | 0.08 | 6.87 | 0.08 |  |  |  |  |  |  |
| 2/18/2011 | 9c | 896 | 1.91 | 0.02 |  | 7.73 | 55.8 | 9.37 | 0.02 | 7.42 | 0.05 |  |  |  |  |  |  |
| 6/20/2011 | 9c | 328 | 1.68 | 0.09 |  | 6.24 | 54.2 | 4.63 | 0.03 | 4.93 | 0.13 |  |  |  |  |  |  |
| 12/15/2011 | 9c |  | 0.54 | 0.23 | 0.00 | 0.24 | 65.9 | 8.46 |  | 7.95 |  |  |  | 209 | 61.3 |  | 13.7 |
| 1/27/2012 | 9c |  |  |  |  |  |  |  |  |  | 0.08 | 0.06 | 6.87 | 277 | 73.8 | 1.37 | 22.6 |
| 3/30/2012 | 9c | 292 | 4.47 | 0.04 |  | 4.30 | 39.5 | 10.2 | 0.02 | 8.13 | 0.02 | 0.28 | 7.70 |  |  | 3.10 |  |
| 6/18/2012 | 9c | 819 | 2.25 | 0.05 |  | 1.98 | 62.4 | 9.65 | 0.01 | 5.80 | 0.04 | 0.14 | 1.86 | 72.2 | 16.5 | 2.13 | 1.72 |
| 8/14/2012 | 9c | 2153 | 4.51 | 0.01 |  | 3.51 | 64.8 | 15.6 | 0.00 | 0.22 | 0.22 | 15.5 | 0.32 | 76.7 | 19.7 | 3.79 | 2.83 |
| 11/20/2009 | 9d | 30 | 0.17 | 0.08 |  | 1.54 | 85.3 | 13.1 |  | 21.2 | 0.05 |  |  |  |  |  |  |
| 5/20/2010 | 9d | 743 | 0.94 |  | 0.60 | 1.15 |  | 3.71 |  | 13.8 | 0.02 |  |  |  |  |  |  |
| 5/21/2010 | 9d | 737 | 0.93 |  | 0.63 | 0.92 |  | 4.44 |  | 10.9 | 0.04 |  |  |  |  |  |  |
| 6/21/2010 | 9d | 208 | 1.94 | 6.29 | 0.62 | 6.00 |  | 6.29 |  | 11.2 | 0.02 |  |  |  |  |  |  |
| 6/21/2010 | 9d | 737 | 0.93 | 4.44 | 0.63 | 0.92 |  | 4.44 | 0.00 | 10.9 | 0.00 |  |  |  |  |  |  |
| 7/12/2010 | 9d | 901 | 0.53 | 0.34 |  | 0.34 | 66.6 | 8.86 |  | 9.88 | 0.02 |  |  |  |  |  |  |
| 10/25/2010 | 9d | 870 | 0.77 | 0.16 |  | 2.14 | 39.7 | 8.64 | 0.09 | 0.71 | 0.11 |  |  |  |  |  |  |
| 2/18/2011 | 9d | 99 | 4.16 | 0.02 |  | 1.17 | 42.2 | 7.68 | 0.00 | 7.11 | 0.38 |  |  |  |  |  |  |
| 6/20/2011 | 9d | 449 | 0.33 | 0.10 | 0.08 | 0.94 | 58.2 | 0.23 | 0.04 | 8.83 | 0.15 |  |  |  |  |  |  |
| 12/15/2011 | 9d | 925 | 0.57 | 0.02 | 0.01 | 1.60 | 30.7 | 6.35 |  | 3.99 |  |  |  |  |  |  | 3.42 |
| 1/27/2012 | 9d |  |  |  |  |  |  |  | 0.01 |  | 0.02 | 0.06 |  |  |  | 0.59 | 20.2 |
| 2/20/2012 | 9d | 103 | 2.41 | 0.04 | 0.01 | 5.67 | 13.1 | 8.21 | 0.02 | 12.8 | 0.03 | 0.30 |  | 290 | 73.1 | 2.69 | 26.1 |
| 2/20/2012 | 9d | 428 | 0.81 | 0.16 | 0.01 | 1.78 | 65.9 | 11.4 |  | 6.62 | 0.09 | 0.34 | 7.36 | 248 | 72.2 | 3.07 | 16.5 |
| 3/30/2012 | 9d | 420 | 0.74 | 0.02 |  | 1.67 | 62.0 | 7.25 | 0.01 | 6.96 | 0.04 | 0.14 | 7.30 |  |  | 1.72 |  |
| 6/18/2012 | 9d | 374 | 0.76 | 0.06 |  | 0.28 | 69.5 | 11.0 | 0.02 | 10.8 | 0.02 | 0.28 | 3.09 | 73.8 | 22.6 | 2.64 | 3.10 |
| 11/20/2009 | 10b | 431 | 0.16 |  |  | 0.32 | 27.9 | 9.56 |  | 7.76 | 0.06 |  |  |  |  |  |  |
| 5/20/2010 | 10b | 615 | 0.29 |  |  | 1.15 |  | 2.93 |  | 9.24 | 0.05 |  |  |  |  |  |  |
| 5/21/2010 | 10b | 406 | 0.35 |  |  | 0.97 |  | 2.38 |  | 7.16 | 0.06 |  |  |  |  |  |  |
| 6/21/2010 | 10b | 615 | 0.29 | 0.89 |  | 1.15 |  | 2.93 |  | 9.24 | 0.05 |  |  |  |  |  |  |
| 6/21/2010 | 10b | 406 | 0.35 | 0.73 |  | 0.97 |  | 2.38 | 0.03 | 7.16 | 0.12 |  |  |  |  |  |  |
| 7/12/2010 | 10b | 1016 | 0.19 | 0.24 |  | 0.57 | 34.8 | 9.0 |  | 7.43 |  |  |  |  |  |  |  |
| 10/25/2010 | 10b |  |  |  |  |  |  |  | 0.07 |  | 0.22 |  |  |  |  |  |  |
| 2/18/2011 | 10b | 1501 | 0.91 | 0.26 |  | 2.66 | 23.7 | 12.0 |  | 6.82 | 0.04 |  |  |  |  |  |  |
| 6/20/2011 | 10b | 337 | 0.77 | 0.07 |  | 3.01 | 31.2 | 12.6 |  | 8.56 |  |  |  |  |  |  | 12.6 |
| 1/27/2012 | 10b |  |  |  |  |  |  |  | 0.01 |  | 0.03 | 0.18 |  | 117 | 28.6 | 1.51 | 11.2 |
| 2/20/2012 | 10b | 293 | 2.49 |  | 0.00 | 1.96 | 45.6 | 16.0 | 0.02 | 9.13 | 0.11 | 0.26 | 6.86 | 161 | 41.2 | 1.39 | 14.2 |
| 3/30/2012 | 10b | 396 | 3.65 | 0.01 | 0.00 | 2.83 | 22.3 | 11.1 | 0.05 | 10.73 | 0.06 | 0.26 | 7.40 |  |  | 1.92 |  |
| 6/18/2012 | 10b | 300 | 2.37 | 0.05 | 0.01 | 1.84 | 36.8 | 15.1 | 0.05 | 6.86 | 0.06 | 0.26 | 1.70 | 41.2 | 14.2 | 2.01 | 1.92 |

Alluvium Analyte Data



| Well # | Date | Oxidation Reduction Potential ORP | Total Dissolved Solids TDS | Specific Conductance | Resistivity | pH | Temperature C |
|---|---|---|---|---|---|---|---|
| 2 | 6/21/2010 | 131 | 73.7 | 117 | | 6.10 | 25.1 |
| 2 | 7/12/2010 | 14.0 | 88.9 | 128 | 21.5 | 6.52 | 21.5 |
| 2 | 10/23/2010 | 185 | 76.7 | 121 | | 6.14 | 20.2 |
| 2 | 11/28/2010 | 115 | 75.6 | 119 | | 6.15 | 20.1 |
| 2 | 2/17/2011 | 127 | 62.2 | 97 | | 6.30 | 13.2 |
| 2 | 6/20/2011 | 51.0 | 76.9 | 121 | | 6.06 | 21.0 |
| 2 | 7/18/2011 | 66.0 | 83.2 | 138 | | 7.09 | 25.0 |
| 2 | 2/20/2012 | 41.0 | 298 | 436 | 94.0 | 7.30 | 12.2 |
| 2 | 6/18/2012 | 60.0 | 79.5 | 126 | | 6.10 | 27.1 |
| 2 | 8/14/2012 | 52.0 | 72.1 | 114 | | 6.60 | |
| 4b | 6/21/2010 | 263 | 52.9 | 83 | | 6.33 | 14.3 |
| 4b | 7/12/2010 | 221 | 52.8 | 80 | 12.1 | 6.39 | 16.3 |
| 4b | 2/17/2011 | 244 | 44.2 | 69 | | 6.40 | 15.9 |
| 4b | 6/20/2011 | 232 | 52.7 | 82 | 12.1 | 6.28 | 15.8 |
| 4b | 7/7/2011 | 242 | 50.3 | 79 | 12.7 | 6.85 | 15.7 |
| 4b | 12/15/2011 | | | 80 | | 6.39 | |
| 4b | 2/20/2012 | 257 | 45.5 | 70 | 13.9 | 6.54 | 16.0 |
| 4b | 6/18/2012 | 163 | 43.6 | 68 | | 7.20 | 20.5 |
| 4b | 8/14/2012 | 41.0 | 52.0 | 90 | 121 | 7.74 | 19.9 |

| Well # | Date | Oxidation Reduction Potential ORP | Total Dissolved Solids TDS | Specific Conductance | Resistivity | pH | Temperature C |
|---|---|---|---|---|---|---|---|
| 5a | 10/23/2010 | 97.8 | 53.1 | 84 | 11.9 | 5.83 | 19.2 |
| 5a | 11/28/2010 | 112 | 51.4 | 81 |  | 5.80 | 19.2 |
| 5a | 2/17/2011 | 83.0 | 43.5 | 69 |  | 6.30 | 15.8 |
| 5a | 6/18/2012 | 52.7 | 52.6 | 83 | 12.0 | 5.70 | 25.0 |
| 5a | 6/18/2012 | 58.7 | 231 | 351 |  | 7.00 | 20.0 |
| 5a | 8/14/2012 | 176 | 118 | 185 |  | 6.30 |  |
| 5b | 6/21/2010 | -83.0 | 241 | 363 |  | 7.70 | 16.7 |
| 5b | 7/12/2010 | -78.0 | 234 | 352 |  | 7.27 | 17.6 |
| 5b | 7/26/2010 | -110 | 244 | 369 |  | 7.23 | 21.3 |
| 5b | 10/23/2010 | -108 | 262 | 403 |  | 7.19 | 18.9 |
| 5b | 11/1/2010 | -104 | 271 | 403 |  | 7.31 | 18.9 |
| 5b | 2/17/2011 | -65.0 | 247 | 365 |  | 7.30 | 13.7 |
| 5b | 6/20/2011 | -94.0 | 251 | 375 |  | 7.22 | 19.3 |
| 5b | 7/8/2011 | -93.0 | 262 | 389 |  | 7.43 | 16.7 |
| 5b | 7/12/2011 | -82.0 | 255 | 379 |  | 7.44 | 16.8 |
| 5b | 12/15/2011 | -82.0 |  | 373 |  | 7.22 |  |
| 5b | 2/20/2012 | 100 | 64 | 95 |  | 6.45 | 17.3 |
| 5b | 8/14/2012 | -33.0 | 255 | 380 |  | 6.60 | 20.0 |
| 6 | 6/21/2010 | 2.00 | 324 | 485 |  | 7.29 | 18.4 |
| 6 | 7/12/2010 | 43.0 | 391 | 496 |  | 7.30 | 21.0 |
| 6 | 7/26/2010 | -28.0 | 318 | 485 |  | 7.24 | 22.9 |
| 6 | 10/23/2010 | -108 | 262 | 562 |  | 7.14 | 19.5 |
| 6 | 11/28/2010 | 56.0 | 373 | 549 |  | 7.14 | 19.3 |
| 6 | 6/20/2011 | 55.0 | 313 | 463 |  | 7.10 | 20.1 |
| 6 | 12/15/2011 |  |  | 422 |  | 7.08 |  |
| 6 | 2/20/2012 | 39.0 | 301 | 439 |  | 7.30 | 12.2 |
| 6 | 6/18/2012 | 86.0 | 307 | 465 |  | 7.00 | 27.0 |



| Well # | Date | Oxidation Reduction Potential ORP | Total Dissolved Solids TDS | Specific Conductance | Resistivity | pH | Temperature C |
|---|---|---|---|---|---|---|---|
| 8 | 2/20/2012 | 209 | 76.3 | 118 | | 6.00 | 13.5 |
| 8 | 6/18/2012 | | 118 | | | 6.00 | |
| 8 | 6/18/2012 | 209 | 94.9 | 118 | | 5.58 | 56.3 |
| 9c | 6/21/2010 | 211 | 345 | 513 | | 7.13 | 16.7 |
| 9c | 7/12/2010 | 205 | 346 | 507 | | 7.20 | 17.3 |
| 9c | 7/26/2010 | 234 | 343 | 507 | | 7.23 | 19.6 |
| 9c | 11/1/2010 | 176 | 357 | 521 | | 7.23 | 16.8 |
| 9c | 6/20/2011 | 258 | 341 | 503 | | 7.14 | 16.5 |
| 9c | 7/1/2011 | 241 | 341 | 501 | | 7.27 | 16.7 |
| 9c | 7/13/2011 | 179 | 344 | 509 | | 7.67 | 18.1 |
| 9c | 7/26/2010 | 215 | 345 | 509 | | 7.27 | 17.4 |
| 9c | 12/15/2011 | | | 402 | | 6.90 | |
| 9c | 2/20/2012 | 239 | 271 | 402 | | 6.90 | 15.0 |
| 9c | 6/18/2012 | | 402 | | | 6.90 | |
| 9c | 6/20/2011 | 239 | 337 | 402 | | 6.90 | 15.0 |
| 9d | 6/21/2010 | 173 | 348 | 503 | | 7.25 | 17.5 |
| 9d | 7/12/2010 | 31 | 351 | 517 | | 7.36 | 20.1 |
| 9d | 7/26/2010 | 257 | 362 | 532 | | 7.32 | 18.0 |
| 9d | 2/17/2011 | 220 | 344 | 506 | | 7.32 | 18.0 |
| 10b | 7/12/2010 | 115 | 200 | 300 | | 7.19 | 15.8 |
| 10b | 7/26/2010 | 77 | 203 | 305 | | 7.24 | 17.4 |
| 10b | 6/21/2010 | 155 | 389 | 286 | | 6.96 | 15.1 |
| 10b | 6/20/2011 | 129 | 210 | 313 | | 6.90 | 15.6 |
| 10b | 7/12/2011 | 231 | 221 | 335 | | 7.70 | 16.2 |
| 10b | 7/26/2010 | 141 | 244 | 308 | | 7.20 | 16.0 |
| 10b | 12/15/2011 | | | 229 | | 7.00 | |
| 10b | 2/20/2012 | 248 | 152 | 229 | | 6.80 | 12.6 |
| 10b | 6/18/2012 | 160 | 229 | 344 | | 7.20 | 14.8 |
| 10b | 8/14/2012 | 204 | 191 | 287 | | 7.00 | 13.7 |

# Vita

Robert W. Hunter, Jr. graduated from the University of Tennessee, Martin with a Bachelor of Science in Geosciences in May of 1985. In the subsequent 25 years, he worked in the corporate commercial real estate and development business, first in Washington, D.C. and later in Chattanooga, TN. While in Chattanooga, he owned and operated a commercial real estate brokerage and development practice. He began his graduate studies in the fall of 2010 in the Earth and Planetary Science Department at the University of Tennessee, where he focused in Hydrogeology, completing his Master of Science in Geology in August of 2013.