2007

Electronic instrumentation of coal slurry impoundments for real-time data collection to support automated monitoring

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Electronic Instrumentation of Coal Slurry Impoundments for Real-Time Data Collection to Support Automated Monitoring

James A. Altobello

**Thesis submitted to the
College of Engineering and Mineral Resources
at West Virginia University
in partial fulfillment of the requirements
for the degree of**

**Master of Science
In
Mechanical Engineering**

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**Morgantown, West Virginia
2007**

**Keywords: Coal Slurry Impoundment, Instrumentation, Data Acquisition
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ABSTRACT

Electronic Instrumentation of Coal Slurry Impoundments for Real-Time Data Collection to Support Automated Monitoring

James A. Altobello

Following the breakthrough and release of coal slurry from the Martin County Coal Corporation impoundment near Inez, Kentucky on October 11, 2000 the United States Congress requested the National Research Council (NRC) to examine ways to reduce these types of accidents. The NRC completed their study titled "Coal Waste Impoundments" which identified numerous areas of concern and the committee presented recommendations for improving the design, operation, and safety of coal slurry impoundments. This research addresses the National Research Council's findings for introducing state-of-practice electronic instrumentation for monitoring parameters within the embankment and slurry pool area of an impoundment. This research will improve impoundment stability, safety, and environmental compliance monitoring. Previous research performed by West Virginia University (WVU) in 2003 at nineteen coal impoundments within West Virginia indicated no occurrences of electronic instrumentation in use for the real-time collection and emergency warning annunciation of important safety and environmental related parameters. The research identified that coal company operators and their design engineers were not familiar with the new instrumentation equipment and systems.

This research project has been initiated by the National Technology Transfer Center (NTTC) Coal Slurry Impoundment Project which funded WVU for the development of a prototype wireless data collection system for monitoring impoundment performance, safety, and environmental indicators at Eastern Associated Coal Corporation's Rocklick Impoundment located in Greenwood, Boone County, West Virginia. The scientific accomplishments of this research as reported herein include the engineering design, instrument system fabrication, assembly, and field construction of a prototype automatic wireless data collection system for monitoring impoundment performance (weather data, piezometric water levels, pH, Specific Conductance, and Oxidation Reduction Potential).

ACKNOWLEDGMENTS

I would first like to thank the National Technology Transfer Center (NTTC) for funding the Coal Slurry Impoundment Project because without the support from them the scientific accomplishments made during this project could not have been fulfilled.

Second, I would like to thank Eastern Associated Coal Corporation (EAC) for allowing us to use their Rocklick Impoundment site as the location of our prototype system. I would especially like to thank EAC's Erman Moore and Mark Bailey for all their support and help with the visits to the impoundment. They provided invaluable information, in-kind support, and advice that helped this project advance.

Third, I would like to thank the West Virginia Water Research Institute (WVWRI) and the West Virginia University Mechanical Engineering Department for accepting me as a graduate research assistant and providing the tuition waiver that allowed me to continue my education.

Fourthly, I would like to thank my committee members Dr. Larry Banta, Dr. John Quaranta, and Dr. Mario Perhinschi for supporting me throughout the process of this project. I'm thankful for their guidance, patience, and input. I would especially like to thank Dr. Banta for keeping me focused, Dr. Quaranta for reassuring my progress was on track, and Dr. Perhinschi for taking on the role of one of my committee members with extremely short notice and without being able to visit the project site.

Finally, I would like to thank my parents Jerry and Beverly for instilling in me the ambition to continue learning and the willingness to work hard for what I want. I also would like to thank them for supporting me in my decision to earn a Masters Degree.

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LIST OF SYMBOLS, ABBREVIATIONS, OR NOMENCLATURE

1. VDC – Volts (Direct Current)
2. Wrap-Around Data Collection – When data capacity is reached in a datalogger, the system then begins to overwrite the oldest data points with new incoming points.
3. MHz – Mega-Hertz (1×10^6 Hertz) (a measure of frequency)
4. mW – milli-Watts (1×10^{-3} Watts) (a measure of power)
5. Kbps – Kilobits per second (a measure of data transfer rate)

CHAPTER 1: INTRODUCTION

“Coal impoundments hold wastewater and impurities that result from coal washing and processing. A bulkhead or embankment is made of coarse coal refuse and acts as a dam. Behind it lays a pond of coal slurry. Sediment settles out of this turbid mixture, filling the pond, while wastewater is recycled back into the coal washing process. The sizes of the ponds and bulkheads vary, but pond basins are often hundreds of feet deep and hold millions of gallons of slurry.”¹

The health and stability of a coal slurry impoundment facility can have a direct impact on the surrounding areas and environment. Under-monitored impoundments or unidentified problems could potentially result in a failure of the embankment and a release of millions of gallons of coal slurry and water. The release of this material can cause environmental impacts such as the death of fish, land animals, and vegetation, as well as property damage or human casualties, depending on the magnitude and location of the spill.

The benefits of using specific equipment designed to properly monitor and collect impoundment stability data in an automated environment could far exceed the costs and labor saved by installing such a system.² When implemented correctly, the automated monitoring system will provide a long-term record of the dam's performance through data acquisition and storage. By collecting data on a more frequent basis than is currently done and storing the data in a convenient digital format would facilitate more detailed analysis than is currently performed and would eventually lead to techniques for analyzing impoundment safety in real time. It could also be possible for any data collected, stored, and evaluated to be uploaded to the Internet. With this, it would be possible for any person with an Internet connection to view the material. The goal of this research is to design,

install, and test an automated data acquisition system on an operating coal slurry impoundment and demonstrate the feasibility of this technology.

1.1 BASIS FOR RESEARCH

From 1972 to 2004 there have been fifty-three recorded coal impoundment spills in West Virginia, Kentucky, and Virginia, according to the Coal Impoundment Location and Warning System website.³ These spills have ranged in magnitude from approximately one thousand gallons to nearly 309 million gallons spilled in Martin County, Kentucky in 2000.⁴ However, the most infamous coal impoundment failure occurred in February of 1972. An embankment that held back millions of gallons of coal slurry broke, releasing a “torrent” of the refuse into Buffalo Creek Hollow in Logan County, West Virginia.⁵ One hundred and twenty-five people were killed, more than 1,000 were injured and about 4,000 were left homeless. Nearly all the homes downstream were destroyed.⁶ Table 1 shows a few of the largest spills (in magnitude) to date from West Virginia, Kentucky, and Virginia.⁷ Also, Figure 1 is a timeline illustrating the number of reported spills, and classifying the type of failure that occurred.⁸

Table 1: Major Impoundment Spills

YEAR	SPILL VOLUME (gal)	COMPANY	COUNTY	STATE
1972	132,000,000	Pittston Coal Company	Logan	WV
1977	2,200,000	Island Creek Coal Company	Boone	WV
1981	25,000,000	Eastover Mining Company	Harlan	KY
1987	7,500,000	Unknown	Floyd	KY
1988	6,500,000	Tennessee Consolidated Coal Co.	Marion	TN
1991	10,000,000	Great Western Coal, Inc.	Harlan	KY
1994	112,000,000	Massey Energy Company	Martin	KY
1994	14,000,000	Cumberland Coal Company	Harlan	KY
1995	1,200,000	Consolidation Coal Company	Buchanan	VA
1996	6,000,000	Arch Coal, Inc.	Lee	VA
1996	4,000,000	Consolidation Coal Company	Buchanan	VA
2000	309,000,000	Massey Energy Company	Martin	KY
2002	10,000,000	Abandoned Mine Land	McDowell	WV

Figure 1: Number of Impoundment Spills Timeline

The impoundment failure that lead directly to this research was the failure in Martin County, Kentucky in 2000. After this failure, Congress instructed the National Research Council (NRC) to conduct an investigation. In 2001 the NRC published their findings reported that although mine operators are required to monitor and report regularly on the health of slurry impoundments, very few operators have automated this critically important, but time- and labor-intensive process. In West Virginia, nineteen coal impoundments were surveyed, and not a single one used automated, remote data acquisition and data analysis equipment. It was also found that most coal company executives and engineers were not familiar with modern, automated methods for monitoring slurry impoundments.⁹

The U.S. Mine Safety and Health Administration (MSHA) counts more than 1,000 coal waste dams across the nation. West Virginia has 232 of these dams, far more than any other state, while Kentucky has 155 and Pennsylvania is home to 132.¹⁰ With the help of better record keeping and better reporting it seems that, from information gathered from the Coal Impoundment Location and Warning System Website, impoundment spills have increased over the past two decades. It is hard to tell whether this increase is a result of the better record keeping or if the age of the impoundments is playing a role in the situation.¹¹ Not knowing the exact cause of all the failures and the desire to predict and possibly eliminate catastrophic events is the main basis for a study into remote monitoring of impoundments.

1.2 OBJECTIVES OF RESEARCH

- Research current instrumentation practices and determine adequacy
- Instrument one dam using existing boreholes and new ancillary equipment
- Develop remote, automated monitoring system to service sensors
- Install and demonstrate monitoring system
- Publish results of work

CHAPTER 2: REVIEW OF LITERATURE

Each coal company is solely responsible for its coarse refuse slurry impoundments. With this responsibility come many requirements. These include minimum monitoring requirements, reporting and tracking of the progress and conditions of the impoundment, and meeting standards set by MSHA. Abiding by these requirements and regulations is required to maintain a safe coal slurry impoundment for the employees and residents.

2.1 Soil Structure

To understand the reasoning behind the guidelines and requirements that will be discussed later in this chapter, the basics of soil structure must be examined.

Soil, whether it is in the ground or compacted in impoundment embankments is comprised of two simple structures. These two components are the solid particles (dirt, rock, coal refuse, etc.) and the open spaces referred to as voids or pores. These pores are typically filled with one of two fluids, air or water. When a soil is referred to as saturated, this means that “all the voids are filled with water”¹²; otherwise, the soil is considered unsaturated.

Using this basic information, soils can be classified into “two broad groups: cohesionless soil and cohesive soil.”¹³ “Cohesionless soils are soils that consist of particles of rocks or minerals having visibly individual grains.”¹⁴ This type of soil consists of sands, gravel, and coarse refuse, is granular and non-plastic, and has little strength when dried. “Cohesive soils such as clays consist of fine textured materials with microscopic and submicroscopic particles resulting from chemical decomposition of rocks.”¹⁵ These materials have some strength when

dry and retain plasticity or cohesion when water is introduced between the mineral grains.

The force per unit area within a soil is referred to as stress or pressure. In geotechnical engineering, these terms are used interchangeably. The stress or pressure that exists within a mass is usually represented with units of pounds per square inch (PSI) or Pascals (Pa). The total stress is the term used to describe the total force applied to a given area. In saturated soils, the total stress is comprised of the sum of two different forms of stresses. The relationship between the total stress and its two components is known as Terzaghi's principle of effective stress. The first component type is the effective stress which can be described as the stress that is carried and transmitted from grain to grain. The second type of stress is called the pore water pressure, and it can be described as the component of the total stress that is transferred through the pore water. In contrast, in unsaturated soils there is another form of stress that must be taken into account. This stress is known as the pore gas pressure, and it can be described as the "component of the total stress that is transmitted to the pore gas portion of the voids."¹⁶ Accordingly, "if pore gas pressure exists, then it will always be greater than the pore water pressure."¹⁷

2.2 Pore Water Pressure (Hydrostatic Pressure)

In a saturated soil, when an increase in the total stress occurs, the initial excess of pressure is carried by the pore water pressure. This increase in pore water pressure must be transferred to the effective stress by "squeezing out the water"¹⁸ through a process called consolidation. This action, with the applied total stress, causes deformation in the soil and results in the settlement of the particles. All soils tend to have an equilibrium pore pressure, and "the amount by which the actual pore pressure exceeds this equilibrium is referred to as excess pore water pressure."¹⁹ The term used to describe the "decrease of the excess pore pressure is dissipation, and it is a function of the permeability of the

material.”²⁰ The permeability is a property that describes the material’s ability to allow a fluid (liquid or gas) to flow through it, and it determines how fast settlement occurs.

The effective stress is also related to the ability of the soil to resist movement or sliding. The ability to resist sliding is known as the material’s shear strength. From this, the shear strength is a material property that can be monitored by monitoring the pore water pressure. Any decrease in pore water pressure will relate to an increase of shear strength, and exactly the opposite occurs with an increase in pore water pressure.

Groundwater level is another indicator of pore water pressure. In a permeable soil, the groundwater level in an open standpipe can be measured and related directly to the pore pressure at any given point below the water level. This is possible because of the equilibrium condition that occurs with the pore pressure and the atmospheric pressure. Normal behavior is exhibited when the “pore water pressure increases hydrostatically with the depth below the groundwater level.”²¹ Using this, the pore water pressure, or the hydrostatic pressure, can be calculated by multiplying the unit weight of water by the vertical distance from the point at which the measurement is needed. Coarse refuse can be considered a permeable material; therefore, the pore pressure can be calculated by finding the groundwater level in an open standpipe.

There are two types of pore water pressure; positive and negative. Positive pore water pressure occurs when the pressure is higher than atmospheric pressure. This can be caused by any increase in stress in a soil with low permeability. This induced pore water pressure can result in the loss of stability or shear strength of the impoundment. Examples of an increase of stress include applied “compressive force or applied shearing force that would decrease the overall volume of the structure.”²² Negative pore water pressure is exactly the opposite of positive pore water pressure. “Negative pore pressure

occurs when the pressure is less than atmospheric pressure. This situation can happen when an applied compressive load is removed or if a densely packed soil shears (or fails) and increases in volume.”²³

Figure 2: Groundwater Level and Pore Water Pressure when there is Flow of Groundwater²⁴

The pore water pressure in a system (impoundment, embankment, etc.) is rarely constant over time. A few variables that can affect the pore water pressure are “precipitation, evaporation, atmospheric pressure, and water seepage.”²⁵ Also, human variables can play a part, such as vehicle traffic and construction.

2.3 Groundwater Observation Time Lag

As with most any kind of measurements there will always be some time lag when observing groundwater levels and pore water pressure. The hydrostatic time lag can be described as “the time it takes for water to flow to or from a piezometer to create equalization between pore water pressure and

atmospheric pressure.”²⁶ This time lag is dependant on several different factors. These factors include “the permeability of the material, the type and dimensions of the piezometer and the change in pore water pressures.”²⁷ In a highly permeable material such as coarse refuse, the time lag is minimal, but can be affected by occurrences like the formation of gas bubbles, either natural or as a result of corrosion.

The determination of time lag can be estimated using the following equation²⁸:

$$t = 3.3 \times 10^{-6} \frac{d^2 \ln \left[\frac{L}{D} + \sqrt{1 + \left(\frac{L}{D} \right)^2} \right]}{kL}$$

Where: t = time required for 90% response, days

d = inside diameter of standpipe, centimeters (cm)

L = length of intake filter (or sand zone around filter), centimeters (cm)

D = diameter of intake filter (or sand zone), centimeters (cm)

k = permeability of soil, centimeters per second (cm/sec)

This equation is determined with respect to the 90% response since the 100% response is considered to be infinite. “It can often be more desirable to measure time lag in the field by comparing pool fluctuation with desired piezometer readings.”²⁹ This comparison is illustrated in Figure 3.

Figure 3: Time Lag Measurement from Time-History Plot of Reservoir Level and Piezometer³⁰

2.4 Controlling Conditions of Soil Behavior

Three types of mechanisms control the engineering behavior of soils. These three mechanisms include hydraulic, stress-deformation, or strength. In the presence of excess pore water pressures, resistance to flow and friction is created as water flows through the pore spaces. This resistance to flow is referred to as the soil's permeability. "The permeability of the soil is a function of the created friction and resistance to flow. The flow of water through the soil creates an exertion force on the soil particles in the direction of flow."³¹ Also, under a saturated soil condition, the water creates a buoyant force whether or not it is flowing. "Stress-deformation characteristics of cohesionless soils are caused by rearrangement of the relative positions of grains as shear deformation occurs. For cohesive soils, the stress-deformation characteristics are governed by the

time required for water to flow through the pore spaces in the soil and for subsequent volume changes to occur.”³² Shear strength of a soil is governed by several different factors. These factors include the nature, size, and shape of the soil grains. Also included is the packing density and effective stresses within the soil. “Shear failure occurs when the applied stresses increase beyond those that can be sustained by the soil.”³³

Embankments (earthen and rockfill) can experience several different types of failure. These mechanisms include: “overtopping, instability, and internal seepage.”³⁴ Overtopping occurs when the level of the reservoir or river exceeds the height of the embankment. “This mechanism may be a result of underestimation of water volumes or the result of another mechanism causing a large displacement of water.”³⁵

An embankment and its foundation is considered to be stable when “the available shearing resistance along a potential surface of sliding of an embankment slope is greater than the shear stress or driving force on that surface”.³⁶ The increase of the pore water pressure along any potential surface of sliding decreases the shearing resistance and the embankment’s sliding factor of safety. In the case where the foundation is stronger than the soil used in the embankment, “the slope will generally move within the embankment.”³⁷ If the foundation is softer than the soil in the embankment then the properties of the foundation material determine if the entire structure is stable. “The embankment loading could cause movement in the foundation or any weak layer in the foundation.”³⁸ An earthquake can also cause failure by liquefaction and sliding if the foundation consists of loose cohesionless materials.

Internal seepage is another form of a mechanism that could cause failure. “Seepage can cause piping when the velocity of the flowing water is sufficient enough to carry soil particles.”³⁹ Piping is a form of internal erosion. The onset of piping usually begins at the downstream, or “toe”, of the embankment. A small

tunnel or pipe is formed. This allows for less resistance to the flow of water, which in turn, increases the rate at which piping occurs. Silt and fine sand are the most prone to piping.

2.5 Geotechnical Instrumentation

Instrumentation of embankments is a necessary part of geotechnical design. It assists in the evaluation of the safety of the embankment as well as providing insight into the performance of the slope. "Field instrumentation is more vital to the practice of geotechnical engineering than to most other branches of engineering, in which designers have greater control over the materials utilized for construction."⁴⁰ Although extremely important, instrumentation is not a stand-alone operation. Instrumentation must be coupled with the knowledge needed to accurately locate the areas of concern within an embankment and the ability to understand what the data for evaluation means in regards to overall stability and safety.

"Instrumentation cannot guarantee good design, trouble-free construction, or long-term maintenance-free operation. The wrong type of instruments placed in inappropriate locations can provide information that may be confusing, or divert attention away from other signs of potential distress. It is not appropriate to mandate instrumentation at every dam or levee with the expectation that some unknown defect will be revealed during monitoring and provide a warning of impending failure. Instruments cannot indicate signs of pending deterioration or failure unless they happen to be placed at the right location. Geotechnical instrumentation is not intended to be sole basis for embankment evaluation; it is intended to provide data for evaluation within a comprehensive embankment safety inspection and surveillance program."⁴¹

2.6 Objectives of Geotechnical Instrumentation

Four objectives for geotechnical instrumentation can be identified: analytical assessment; prediction of future performance; legal evaluation; and development and verification of future designs. These objectives can be achieved by providing quantitative data to assess groundwater pressure, total stress, temperature, leakage, and water levels. A variety of instruments may be used in a monitoring program to ensure that all critical conditions for a given project are covered sufficiently. Examples of instruments used will be discussed later in this chapter.

Analysis of data obtained from instrumentation may be used to verify design parameters, verify design assumptions and construction techniques, analyze adverse events, and verify apparent satisfactory performance.

Verifying design parameters can be accomplished through observations of actual performance. This results in the engineers being able to determine the effectiveness of the design. These observations can also lead to improvements or refinements in the design of the structure. These changes or updates could result from a study of actual forces to which the structure is subjected, and must be based on conservative geotechnical assumptions concerning material characteristics and structural behavior.

Verification of design assumption and construction techniques is another useful objective of the geotechnical instrumentation. "Experience has shown that most new or modified designs and construction techniques are not readily accepted until proven satisfactory on the basis of actual performance. The data obtained from the instrumentation can aid in evaluating the suitability of new or modified techniques."⁴²

Geotechnical instrumentation can also help in the analysis of adverse events. According to the Army Corps of Engineers' (ACOE) Instrumentation manual, "When a failure, a partial failure, a severe distress condition, a visually noted non-severe change in shape, appearance, or seepage has occurred at a dam or levee project, the data from instrumentation can be extremely valuable in the determination of the specific cause or causes of the event."⁴³ Also, instrumentation is often installed before, or during, remedial work at a site to determine if the improvements being made are effective.

The fourth use of data from impoundment instrumentation is the verification of apparent satisfactory performance. The data can provide reassurance to the engineers and operators of the embankment, and establishes a baseline of performance that serves as valuable reference, should some future variation in the data occur, signaling a potential problem. Also, gathering data that indicates satisfactory performance can aid in the designs of future projects.

The ACOE manual states that, "Instrumentation data should be used in such a manner that informed, validated predictions of future behavior of an embankment can be made. Such predictions may vary from indicating continued satisfactory performance under normal operating conditions to an indication of potential future distress which may become threatening to life or safety, and necessitate remedial action."⁴⁴

The majority of earth and rockfill embankments (not including coal slurry embankments) constructed for flood-control purposes remain dry, or are maintained only at very low levels, except during infrequent flood events. These embankments can exist for years without experiencing a major flooding event. In these cases, instrumentation data obtained during an intermediate flood event can be projected to predict performance during potential maximum flood events. For coal slurry impoundments under continuous construction, it is important to

maintain a water and slurry level that, under a major flooding event, would not exceed the height or capabilities of the embankment slope. Continuous instrumentation at these sites during a significant rainfall can provide insight as to how the embankment will perform in the case of a major event.

“Valid instrumentation data can be valuable for potential litigation relative to construction claims. It can also be valuable for evaluation of later claims relative to changed groundwater conditions downstream of a dam.”⁴⁵ The expense of an extensive instrumentation plan can be justified by just examining the high monetary value that many damage claims entail. The data that is collected with instrumentation can be “utilized as an aid in determining the causes or extent of adverse events so that various legal claims can be evaluated.”⁴⁶

Finally, geotechnical instrumentation can provide data that is crucial in the development and verification of future designs. “Analysis of the performance of existing dams and levees, and instrumentation data generated during operation, can be used to advance the state-of-the-art of design and construction.”⁴⁷ The instrumentation installed and the analysis of the data from existing projects can “promote safer and more economical design and construction of future earth and rockfill embankments.”⁴⁸

2.7 Instrumentation System Planning

“Planning an embankment instrumentation system requires the consideration of many factors, and a team effort of the designers and personnel having expertise in the application of geotechnical instrumentation.”⁴⁹ A series of logical steps should be followed when developing an instrumentation system after a system objective has been defined. A list of the steps that should be taken are shown in Table 2. For a complete description of the elements in the table, please refer to the listed reference.

Table 2: Steps for Developing an Instrumentation System (Dunnicliff 1990) ⁵⁰

Step	Element of Plan
A	Prediction of mechanisms that control behavior
B	Definition of purpose of instrumentation
C	Definition of geotechnical questions
D	Selection of parameters to monitor
E	Prediction of magnitudes of change
F	Selection of instrument locations
G	Selection of instruments
H	Determination of need for automation
I	Planning for recording of factors which influence measurements
J	Establishment of procedures for ensuring data validity
K	Determination of costs
L	Planning installation
M	Planning long-term protection
N	Planning regular calibration and maintenance
O	Planning data collection and management
P	Coordination of resources
Q	Determination of life cycle costs

For step C, “Every instrument on, in, or near an embankment should be selected and placed to assist in answering a specific concern.”⁵¹ Table 3, below, illustrates the type of questions that do, or should, arise during the design, construction, and operation of an embankment.

Table 3: Examples of Possible Geotechnical Questions (Dunnicliff 1990) ⁵²

Questions to Answer	Features to Assess	Parameters to Monitor
What are initial site conditions?	Foundation Abutments Drainage basin	Pore water pressure Hydrology Meteorology
How does the embankment perform during construction?	Foundation Embankment Abutments	Pore water pressure Horizontal/vertical movement
How does the embankment perform during first filling?	All features and adjacent terrain	Pore water pressure Horizontal/vertical movement Seepage Dissolved solids
How does the embankment perform during drawdown?	Upstream face Adjacent natural slopes	Pore water pressure Slope stability
How does the embankment perform during long-term operation?	All features	All parameters

To expand on step F, “Locations for instruments should be determined based on predicted behavior of the site. The locations should be compatible with the geotechnical concerns and the method of analysis that will be used when interpreting the data. A practical approach to selecting instrument locations includes: (1) identify zones of particular concern such as structurally weak areas that are most heavily loaded, and locate appropriate instrumentation, (2) select zones that can be represented by typical cross sections where predicted behavior is considered representative of behavior as a whole (typically, one cross section

will be at or near the maximum height of the dam, and one or two other sections will be at appropriate locations), (3) identify zones where there is discontinuity in the foundation or abutments, (4) install some additional instruments at other potentially critical secondary locations to serve as indices of comparable behavior, and (5) locate rows of survey monuments at intervals in the longitudinal direction at appropriate elevations.”⁵³

2.8 Measurement Methods

“Most electronic instrumentation measurement methods consist of three components: a transducer, a data acquisition system, and a linkage between these two components. A transducer is a component that converts a physical change into a corresponding electrical output signal. Data acquisition systems range from simple portable readout units to complex automatic systems.”⁵⁴

One of the main measurements taken at currently monitored impoundment sites is the pore water pressure (PWP) in the damming material. The pore water pressure is the pressure of the water in the void spaces between particles of saturated soil. Pore water pressure is important in all types of earthen structures because the shear strength of the soil decreases with increasing pressure. For structures subjected to shearing loads, such as dams, excessive pore water pressure can lead to failure. PWP is measured using sensitive pressure gauges called piezometers.

Three types of piezometers are in common use. These types include open pipe, pneumatic, and vibrating wire. The pneumatic type piezometers are slow and cumbersome to use. Typically, the open pipe piezometer is used at coal impoundment facilities for monitoring seepage water levels. The open pipe (standpipe) consists of a conventional screened pipe located at a set elevation

within the coarse waste. Measurement of the groundwater table within the impoundment is made by lowering a weighted tape into the standpipe and recording the elevation of the water. This technique is performed for each desired elevation reading. The process is inherently manual and requires access by a person to each piezometer location. In times of heavy rain or emergency conditions, the data collection from this piezometer must be performed at increasing frequencies in order to comply with Emergency Warning Plan procedures.

The relatively newer, Vibrating Wire (VW) Piezometers overcome these shortcomings at the expense of high cost and complexity. VW piezometers use water pressure to change the tension on a vibrating wire, causing its frequency to change. The piezometer's temperature is simultaneously measured. A special transducer measures the frequency of the vibrating wire and converts the frequency and temperature information into a measurement of the water pressure acting on the piezometer. VW piezometers provide an accurate reading within seconds and can be remotely monitored without human intervention. The involvement of humans can be restricted to the initial setup of the piezometers, the data acquisition system, and the monitoring software, as well as interpreting and analyzing the collected data. VW piezometers will be used in this research to allow the important data to be automatically monitored at intervals appropriate to the situation. Figure 4 depicts a schematic of a vibrating wire pressure sensor.

Accompanying the VW piezometers will be hydrostatic water level transducers. With very permeable coarse refuse, the water level sensors constitute a viable alternative to the vibrating wire piezometers because the phreatic water level changes quickly with changes in pore water pressure producing very similar resulting measurements from both types of sensors. The hydrostatic water level sensors have the advantage of being cheaper and simpler to purchase and interface to the data logging equipment. These sensors have the capability to be left permanently in standing water and measure its height.

The signal that is produced is a 0 to 5 VDC output that can be converted to measurements in feet. These submersible pressure transducers use isolated-diaphragm sensors that are specifically designed for use with hostile fluids and gases. These sensors utilize a silicon pressure cell that has been fitted into a stainless steel package with an integral, compliant stainless steel barrier diaphragm. The sensor assembly is housed in a rugged 316 stainless steel or titanium case which provides for a variety pressure inputs from 0-15000 PSI.⁵⁵

Figure 4: Schematic of Vibrating Wire Pressure Sensor (Dunnicliff 1988)⁵⁶

The most common type of device used for measuring piezometric levels is the piezometer. “Applications for piezometers fall into two general categories: first, for monitoring the pattern of water flow and second, to provide an index of soil strength.”⁵⁷ Some examples for the first category include “determining piezometric pressure conditions prior to construction, monitoring seepage, and effectiveness of drains, relief wells, and cutoffs.”⁵⁸ For the second category, “monitoring of pore water pressure allows an estimate of effective stress to be made, and thus an assessment of strength.”⁵⁹ “Examples include monitoring dissipation of pore water pressure during consolidation of foundation and fill material and the effect of rapid drawdown.”⁶⁰ Figure 5 and Figure 6 show two types of piezometers. The first is an observation well and the second is an open standpipe (or Casagrande piezometer), and their differences can be noted in their construction.

Figure 5: Schematic of Observation Well⁶¹

Figure 6: Schematic of Open Standpipe Piezometer Installed in a Borehole⁶²

There are several more different types of piezometers including twin-tube hydraulic, pneumatic (embedded), vibrating wire (embedded), and electrical resistance. Table 4 lists the advantages and limitations of each of these types of piezometers.

Table 4: Instruments for Measuring Piezometric Pressure⁶³

Instrument Type	Advantages	Limitations^a
Observation well	Easy installation Field readable	Provides vertical connection between strata and should only be used in continuously permeable strata
Open standpipe piezometer	Reliable Long successful performance record Self-de-airing if inside diameter of standpipe is adequate Integrity of seal can be checked after installation Can be used to determine permeability Readings can be made by installing pressure transducer or sonic sounder in standpipe	Time lag can be a factor Subject to damage by construction equipment and by vertical compression of soil around standpipe Extension of standpipe through embankment fill interrupts construction and may cause inferior compaction Possible freezing problems Porous filter can plug owing to repeated water inflow and outflow
Twin-tube hydraulic piezometer	Buried components have no moving parts Reliable when maintained Long successful performance record When installed in fill, integrity can be checked after installation Piezometer cavity can be flushed Can be used to determine permeability Short time lag Can be used to read negative pore water pressures	Application generally limited to long-term monitoring of pore water pressure in embankment dams Elaborate terminal arrangements needed Tubing must not be significantly above minimum piezometric elevation Periodic flushing is required Possible freezing problems Attention to many details is necessary

Instrument Type	Advantages	Limitations^a
Pneumatic piezometer (embedded)	Short time lag Calibrated part of system accessible Minimum interference to construction; level of tubes and readout independent of level of tip No freezing problems	Requires a gas supply Installation, calibration, and maintenance require care
Vibrating wire piezometer (embedded)	Easy to read Short time lag Minimum interference to construction; level of lead wires and readout independent of level of tip Lead wire effects minimal Can be used to read negative pore water pressures No freezing problems	Potential for zero drift (Special manufacturing techniques required to minimize zero drift) Need for lightning protection should be evaluated
Electrical resistance piezometer	Easy to read Short time lag Minimum interference to construction; level of lead wires and readout independent of level of tip Can be used to read negative pore water pressures No freezing problems	Potential lead wire effects unless converted to 4-20 milliamps Errors caused by moisture and corrosion are possible Need for lightning protection should be evaluated

^a Diaphragm piezometer readings indicate the head above the piezometer, and the elevation of the piezometer must be measured or estimated if piezometric elevation is required. All diaphragm piezometers, except those provided with a vent to the atmosphere, are sensitive to barometric pressure changes. If piezometer pipes, tubes, or cables are carried up through fill, there will be significant interruption to construction and the probability of inferior compaction.

In some cases, the measurement of groundwater temperature may need to be collected. A reason for measuring groundwater temperature includes monitoring the temperature to aid in the “attempt to detect seepage and to monitor changes in the seepage pattern in an embankment dam.”⁶⁴ Another reason for measuring the groundwater temperature is “When a transducer itself

is sensitive to temperature change, then a thermal correction to measured data may be required.”⁶⁵

“Three types of instruments are most frequently used for remote measurement of temperature: thermistors, thermocouples, and resistance temperature devices (RTD’s). The name *thermistor* is derived from thermally sensitive resistor. A thermistor is composed of semiconductor material that changes its resistance very markedly with temperature. A *thermocouple* is composed of two wires of dissimilar metals, with one end of each wire joined together to form a measuring junction. At any temperature above absolute zero, a small voltage is generated between the wires at the other end. This voltage is proportional to the difference in temperature of the measuring junction and the temperature of the cold junction. *Resistance temperature devices* depend on the principle that change in electrical resistance of a wire is proportional to temperature change. The wire is usually mounted on a postage-stamp-sized backing or wound on a small-diameter coil.”⁶⁶

Comparisons of the different types of instruments used for temperature measurement are listed in Table 5. “All three types have wide temperature range and rapid response to temperature changes.”⁶⁷

Table 5: Comparison of Instruments for Remote Measurement of Temperature⁶⁸

Feature	Thermistor	Thermocouple	Resistance Temperature Device (RTD)
Readout	Digital ohmmeter or multimeter	Thermocouple reader	Wheatstone bridge with millivolt scale
Sensitivity	Very high	Low	Moderate
Linearity	Very poor	Fair	Fair

Feature	Thermistor	Thermocouple	Resistance Temperature Device (RTD)
Accuracy	High	Moderate	Very High (but may be reduced by lead wire effects)
Stability	Excellent	Good	Excellent
Type of lead wire	Two-conductor	Special (bi-metal)	Three-conductor
Repairability of lead wire	Straightforward	Less straightforward (can cause errors)	Straightforward
Applicability for instrument temperature corrections	Preferred	Possible	Possible
Suitability for automatic data acquisition	Fair	Excellent	Good

2.9 Automation

“Automation of instrumentation can assist in the assessment of the safety of dams and levees. This is particularly true for monitoring that requires rapid and frequent data collection or for instruments that are inaccessible. In recent years, the technology of devices for measuring seepage, stresses, and movements in dams and levees has improved significantly with respect to accuracy, reliability, and economics. Although the initial installation of an Automated Data Acquisition System (ADAS) may appear to be more expensive than traditional instrumentation systems, the overall long-term cost, in many cases, is now economically competitive. Automation should receive consideration for all systems that are to be installed during

new dam construction, major rehabilitations, structural modifications, or any major effort that would support a major instrumentation system....The instrument automation concept generally includes an instrument or transducer that is linked to a datalogger or computer with communication capability that allows data retrieval locally or from a remote location.”⁶⁹

Figure 7 shows a generalized setup for an automated data collection system. There are several different options for data communication shown, including satellite, radio frequency, and telephone.

Figure 7: Automatic DAQ System with Geotechnical Instrumentation⁷⁰

There are many reasons to deploy an automated data acquisition system, but one specific application stands out when referring to implementation at a coal

slurry impoundment. This applicable situation is when “high hazard potential in the event of uncontrolled releases and timeliness of response to performance changes is critical to public safety.”⁷¹ This type of situation is usually the consequence of failure or partial failure. Many coal slurry impoundments under construction are ranked as a Class C, High Hazard Impoundment. “Class C dams are those dams located where failure may cause a loss of human life or serious damage to homes, industrial and commercial buildings, important public utilities, primary highways or main haul roads. This classification must be used if failure would cause possible loss of human life.”⁷²

There can be many advantages and limitations to an automated system. Table 6 describes some of the most common advantages and limitations. “The limitations can be minimized with appropriate attention to planning and use of the system.”⁷³

Table 6: Advantages and Limitations of an Automated DAQ System⁷⁴

Advantages	Limitations
• Increased accuracy-reduced human error • Increased frequency-more data, less system error • Increased data reliability and consistency • Replaces lost manpower • Timeliness of information-obtain data whenever needed • Data and system validity checks enhance data quality • Alarms for exceeding data thresholds and system health • Remote diagnostics, calibrations, and programming	• Produces large volumes of data; overtaxes storage medium • Installation could be expensive • Removes personal attention from the field • Lightning; variable voltage potential is destructive. • Excessive downtime with overly complex integrations • Sufficient computer and electronics expertise not available • Potentially higher maintenance costs • Requires a constant electrical power source • Requires use of electronic transducers which have least long-term reliability of any type used

2.10 Automation Configuration

There are generally three types of configurations of automated systems. These three types are datalogger, supervisory control and data acquisition (Scada), and distributed intelligence.

The datalogger configuration can be described as “an electronic component collects data from attached instruments upon command from a personal operator.”⁷⁵ “The system can include modems for remote communication, but generally requires that the intelligence and operation be external to the system.”⁷⁶ Figure 8 shows a stand-alone datalogger configuration.

Figure 8: Stand-Alone Datalogger Configuration⁷⁷

The Scada configuration is slightly different. “Scada is a host computer that controls remote monitoring units (RMUs) which are intelligent dataloggers. RMUs acquire data and report those data upon command from the host computer. The remote unit can carry out the acquisition of data and store the information until communication with the host computer is established. The host computer is the system intelligence. It is programmed for frequency and scheduling of data acquisition. Personal intervention is not typically required for this system to operate.”⁷⁸ This is the type of system that this research attempts to implement because of the distance the project site is from the university and

the unavailability of personnel to tend to the computer to collect the data from the dataloggers. Figure 9 shows a Scada configuration.

Figure 9: Scada Configuration⁷⁹

The third and final type of configuration is distributed intelligence. "Computers are located at each remote monitoring unit in the network. All are linked to a central computer; central network monitor (CNM) and communications can be established with the central computer as well as with each other. The remote units are fully responsible for the frequency and scheduling of data acquisition as well as initiating communications."⁸⁰ Figure 10 shows a distributed intelligence configuration.

Figure 10: Distributed Intelligence Configuration⁸¹

With each of these automation options come more options for communications and power supplies. “The most common local communication, linking the remote units to the host or central computer, is electrical cabling or radio transmission.”⁸² Typically, when communicating the data and information from the host computer to the district office one or several options can be employed. These options include telephone, microwave, radio, and satellite. However, “all modes of communication are not appropriate for any one application,”⁸³ so the required design of the system will aid in the determination of what mode of communication would be appropriate.

As far as power supplies are concerned, the type used will be determined best for each individual situation. The size of the project and the environment will play greater roles in determining the power supplies than any other variables. “Automated systems can be energized by alternating current, battery, or solar panels and are normally supplemented by uninterruptible power supplies or emergency generators.”⁸⁴ This research project uses both batteries and solar panels for power. This is due to the extensive range at which the sensor arrays are positioned. The batteries give direct current to the electronics that are used while the solar panels recharge the batteries as they lose power.

CHAPTER 3: TECHNICAL APPROACH

The approach followed in this project consisted of the following processes:

- Identify a site and survey the existing instrumentation and the specific requirements for an automated data acquisition system.
- Specify the types and number of additional sensors required to adequately instrument the site.
- Design the data communications, data storage, data analysis and operator interface systems for the installation.
- Purchase and assemble the system in the laboratory. Write the necessary software for system control. Test functionality.
- Install and commission the system at the impoundment.
- Monitor and analyze data, maintain system, refine and improve software.
- Report results in the open literature.

3.1 Objectives and General Considerations

The main objectives of this project are to design and demonstrate a cost effective data acquisition system that can function primarily without assistance to collect data that is relevant to coal slurry impoundment stability for analysis and interpretation. To meet these objectives, it is necessary to itemize the variables and their interactions in a coal slurry impoundment. Key variables include the pore water pressure, the pH and specific conductance of the water, and the seepage flow. Also, various weather parameters will be monitored, including temperature, barometric pressure, rainfall, and wind speed. The following section contains a discussion of various options for sensing these parameters and transmitting the data to a central repository for storage and analysis.

3.2 Site Survey and Overview

Eastern Associated Coal Corporation has agreed to participate in this project. The company is willing to provide access to its Rocklick Branch Coal Refuse Disposal Facility located in Boone County, West Virginia. A site visit was conducted on April 27, 2006 to determine the location of the instrumentation. Figure 11 shows an overview plot of the impoundment (Provided by: Alliance Consulting Inc.). Each of the circles indicates a piezometer location where sensor grids and data acquisition stations will be located. The weather station and repeater modem will be on an earthen bench above the right side of the crest of the impoundment. The data collection computer will be inside of a warehouse that is situated approximately 150 yards from the toe of the dam. This warehouse is not shown in the illustration. Additional instrumentation will include a water depth sensor located in the impoundment pond, opposite the dam, and a variety of sensors including a water flow meter, pH sensor, specific conductivity sensor, and redox potential sensor at the toe of the dam.

Figure 11: Site Overview and Equipment Locations ⁸⁵

It was decided that each available piezometer location would be used as a data collection site. At each of these sites, it is necessary to have the following sensors and equipment: 1) A sensor to measure water levels in the piezometer standpipe; 2) One or more water quality sensors; 3) A data acquisition “node”; 4) A radio modem with long range capabilities; and 5) A sealed enclosure and power source for all electrical components. The project requires a minimum of 5 to 6 piezometers, the equipment in the pond and at the toe, and the weather station link directly to the base computer; therefore, each piece of equipment will be purchased in those quantities with one to two additional pieces purchased for spares. The only exception to this will be the radio modems. They will be purchased with two to three additional units; one to serve as the base station collection modem and the others to serve as signal repeaters as necessary.

3.3 Commercial Geotechnical Equipment Providers

It was found that the most effective way to develop a stand-alone data acquisition system was to use commercially available equipment. Numerous vendors and products were investigated to find an “off the shelf” package suitable for this application. However, no single company was found who provided a solution that completely met the needs of this project (Table 7). Appendix B provides a brief introduction to each of the companies researched for support and equipment for this project.

Table 7: Equipment Needs Specified for This Project

Project Requirements	
i.	Mountainous terrain and continual construction with large machinery requires that a wireless communications system be installed
ii.	Limited standpipe diameter requires that only a few sensors are installed at each location, thus a datalogger capable of handling only a few sensors is required
iii.	All sensors and communications devices must be compatible with datalogger

3.4 Company and Sensor Selection Reasoning

Commercially available geotechnical equipment is the most easily accessible product, but a drawback is the high cost in acquiring a simply integrated working system. Figure 12 is a relief map of the impoundment that was chosen for this project. The map illustrates the mountainous terrain and elevation changes that led to the decision to use a wireless communications system that is cost effective and provides a communications range that is sufficient for the data collection at a coal impoundment. It was found that wireless communications systems offered by the geotechnical companies were not competitively priced, nor were the distributors of the systems fully knowledgeable of their products' range capability and sensor compatibility. Other drawbacks to these wireless communications systems include proprietary software and the lack of flexibility in configuring the system.

Figure 12: Relief Map of Impoundment

The decision was made to use geotechnical sensors that could be integrated with general purpose data logging and communications equipment with a minimal amount of effort. This solution requires that the commercial data acquisition software be modified to suit the reporting requirements for the impoundment, but the level of effort for that task was judged to be modest in view of the potential cost savings. The modifications would have to apply to this specific impoundment monitoring situation.

3.5 Selected Equipment and Sensors

(Note: In-depth equipment descriptions and specifications can be found in Appendix A)

The instrumentation package includes a weather station to collect data on temperature, rainfall, barometric pressure, and wind speed. While several weather station companies could provide larger packages, one company in particular provided an option to only use sensors that were specific to the project's needs. This option cut back on the expense of purchasing a larger package with unnecessary sensors, and thus we chose to use the ONSET HOBO Weather stations.

Onset also offers a variety of data acquisition systems; two of which are the HOBO Weather Station Datalogger and the HOBO Microstation Datalogger. The HOBO Weather Station Datalogger can provide up to ten channels for 10 different sensors with a capacity of over 500,000 measurements and “wrap-around data collection”; whereas, the HOBO Microstation Datalogger provides up to four different channels with the same capacity. For this project, it has been determined that, at most, four sensors would be used at any given data collection point, so the HOBO Microstation Datalogger is the best choice, since it is \$200 cheaper than the HOBO Weather Station Datalogger.

ONSET does not manufacture radio modems for communications, but does partner with the MaxStream through the MicroDAQ Company to provide that capability. MaxStream offers several types of Radio Frequency (RF) modems that are compatible with Onset's HOBO Microstation Datalogger. These include MaxStream's 9XStream and 9XTend radio modems. The 9XStream radio modem uses a radio frequency of 900 MHz, a power output of 100 mW, a maximum range (with standard antennas) of 11.26 km (7 miles) line-of-sight (LOS), and a data transfer rate capability of 19.2 Kbps. The 9XTend radio modem also works on a radio frequency of 900 MHz but has a power

output of 1 Watt, a maximum range (with standard antennas) of 22.5 km (14 miles) LOS, and a data transfer rate capability of 115 Kbps. For this project, because some data collection locations (discussed later in this chapter) are not in the line-of-sight of the receiving radio modem, it is desired to use the 9XTend radio modem for its increased power and range capabilities.

Also available through MicroDAQ are Esterline Pressure Systems' Hydrostatic Water Level Transducers. These transducers, or sensors, will be used to determine and measure the water level in the open standpipes along the face and crest of the impoundment. As discussed in Chapter 2, the water level in an open standpipe can be used to calculate the pore water pressure since the coarse refuse material is highly permeable. Because the standpipe is open to the atmosphere the water level reading and determined pressure must be compensated for barometric pressure.

This project also uses Geo Durham's Slope Indicator Vibrating Wire Piezometers. These sensors can be used in an open standpipe to determine water level. A vibrating wire piezometer works on the principle that a small wire will change in length depending on the pressure applied to the sensor. This wire is then "plucked" with an electrical pulse. The wire then will vibrate at its natural frequency. This frequency is then interpreted by an adapter as a pressure. This pressure can then be converted to a water level when it is compensated for barometric pressure. Vibrating wire sensors are more sensitive and give faster response to pore water pressure changes in low-permeability soils. However, they are more expensive and more complex to interface to a Data Acquisition system (DAQ) than are the water level transducers. Vibrating wire piezometers will be used in conjunction with the Hydrostatic Water Level Transducers for data accuracy and response comparisons where low hydraulic conductivity (k) soils are present.

The three remaining sensors are the pH, the Oxidation Reduction Potential (ORP), and the Specific Conductance sensors (SpC). These sensors were all purchased directly from Campbell Scientific, Inc. The purpose of these sensors is to provide water quality data and investigate coal refuse deterioration.

This project will use a general constructed design for each of the data acquisition stations at the impoundment. Each station will consist first of a NEMA 4 enclosure that is mounted on a 1.905 centimeters (0.75 inch), 2.44 meters (8 feet) long piece of rebar that has a sharp tip at one end to be pounded into the ground. The brackets holding the NEMA enclosures are 30.48 cm x 5.08 cm x 63.5 cm (12"x2"x.25") pieces of strip steel with holes drilled for 1.905 cm (0.75") U-bolts to attach the enclosure to the rebar. Inside the enclosure is a single HOBO Microstation, a single 12 volt 18 amp-hour battery, and a single MaxStream 9X-Tend radio modem with a one foot antenna extension cable running through the wall of the enclosure to allow for the antenna to be attached to the outside of the box. The enclosure also has 0.95 cm (0.375") holes drilled in the upper right corner to allow for the mounting bracket for the 5 watt solar panel to be attached to it. Along with this general design will be sensors that are specific to the individual data collection station. The selected sensors and the individual data collection stations will be discussed in the next section.

Another important construction for this project is the weather station. The weather station that was constructed consists of a three meter (tall) tripod and mast, a 0.61 m (2') half cross arm, a solar radiation shield for the temperature sensor, and a set of guy wires to stabilize the structure. The complete assembly guide for the weather station can be downloaded from Onset's website.

3.6 Data Acquisition and Communications Setup

Data acquisition begins with Onset's Microstation datalogger. This datalogger is capable of handling four input signals from many types of sensors

that produce a 0 to 5V output. This includes most the sensors used in this project. A couple of sensors, including the pH, Oxidation Reduction Potential (ORP), and Specific Conductance (SpC) sensors, produce outputs that are bipolar. This means that the output will range from a negative voltage to a positive voltage. The input adapters for the datalogger are not capable of detecting negative voltages, so in order to compensate for negative voltages, ranging to -700 mV, a 1.5 volt alkaline battery was integrated in-line with the positive output signal of the sensor to boost the resulting readings.

Oxidation Reduction Potential (ORP) is a measure of how well water can oxidize contaminants or destroy harmful bacteria. Typical measurements for ORP are in millivolts, and the standard for drinking water is set at 650 millivolts.

“Specific Conductance (SpC) is a measure of how well water can conduct an electrical current. Conductivity increases with increasing amount and mobility of ions. These ions, which come from the breakdown of compounds, conduct electricity because they are negatively or positively charged when dissolved in water.”⁸⁶ A typical measurement for specific conductance is milli-Siemens per centimeter (mS/cm). This sensor outputs a measurement between 0 to 5 VDC. This is then converted linearly to the typical units for specific conductance.

The frequency at which data is collected by the dataloggers will be discussed in a later section, but as this implies, the data is collected at the individual dataloggers. To consolidate the raw data, it is necessary to establish a link to a host computer that will provide sufficient memory to store all the data from the various sensors. Because the coal impoundment is such a large structure and the terrain is so mountainous, it was decided that for this project it would be impractical to hardwire all the equipment together, so in order to store all the data on a computer the information has to be transmitted using radio frequency modems. As discussed previously, MaxStream's 9X-Tend radio modems are the choice products for this project.

MaxStream's 9X-Tend radio modems provide up to 64.4 km (40 miles) line-of-sight data transmission range with optional high-gain antennas. This is perfect for a situation as the one presented at the Rocklick Coal Refuse Facility. Line-of-sight can be difficult to come by considering the terrain that is present in southern West Virginia. The 1 watt power capabilities of these modems provide the ideal choice to circumvent the communication problems that the terrain presents. Figure 13 illustrates the region surrounding the impoundment and shows the steep ridges and mountains that cause the communications problems with the radio modems. The impoundment is located in the top left portion of the map.

These radio modems work on the 900 MHz frequency range which carries no permit requirements for use. Also, these modems interface well with Onset's Microstation dataloggers. The dataloggers have a computer communications port with a serial cable to connect it directly to a computer. In the case of this project, since a computer cannot be used to directly connect to the dataloggers, it is required to have a modem that has a serial connection. This is exactly what these modems provide along with different modes of operation that include stand-alone, repeater, and end-nodes. The versatility to function in different modes allows several different configurations to communicate the data. These configurations include direct links (line-of-sight), and indirect links (non-line-of-sight using a modem as a data repeater). The modems come with an easy to use software application that makes programming for different channels (up to 9), data transfer rates, and power consumption to be accomplished in a short period of time. This software will be discussed in more detail in a later section.

The final advantage that is provided by the 9X-Tend modems is that all programming is stored in non-volatile memory. This means that even in accidental or purposeful power outages, the modems' code will not be altered or

lost. This ensures that unless a modem's program is changed directly by a computer, the code will remain the same for accurate data transmission.

Figure 13: Regional Relief Map of Rocklick Impoundment

Figure 14, below illustrates the communication pathways that are being implemented in this project. Every station either communicates directly to the host computer or communicates via a radio repeater that relays information from one station to another.

Figure 15, below illustrates a profile view of the impoundment. The illustration shows the different stations being used for this project. This figure is a generalized profile drawing that is not to scale with the other site drawings. Figure 16 works in conjunction with Figure 15. It lists the specific equipment at

each of the stations shown in Figure 15. Also, Table 8 lists the elevations of each of the piezometers and their relative elevation to the radio base station.

Table 8: Piezometer Elevations

Piezometer #	Top Elevation	Tip Elevation	Top Elevation in Relation to Base Station
7	487.6 m (1599.7 ft)	438.9 m (1440 ft)	127.9 m (419.7 ft)
13	411.8 m (1351.2 ft)	377.6 m (1239 ft)	52.1 m (171.2 ft)
14	453.9 m (1489.3 ft)	411.8 m (1351 ft)	94.2 m (309.3 ft)

Figure 14: Communications Pathways⁸⁷

Figure 15: Site Profile and Station Locations

Piezometer Reference at Rocklick Impoundment Greenwood, Boone County, WV

NOTE 1	Piezometer -7 Depth: Approx. 165 ft. (Installed from 11/7/06 to 12/6/06)																															
		Station Components:	1)IIOBO Microstation Datalogger	2)MaxStream X-Tend 1 Watt Radio modem (2 ft. 5.1dBi antenna)	3)Power Patrol Rechargeable 12V, 7.5AH Battery	4)2x PowerUp 17.3V, 0.3A Solar Panel and mount	5)Pressure Systems 0-5V Hydrostatic Water Level Transducer	6)Wedgewood CSIM11 PII Sensor	7)2x IIOBO 0-5V Input Adapter																							
NOTE 2	Piezometer - 8A and Piezometer - 9A Elv. Approx. 1631 ft																															
	No equipment installed due to suspected obstructions in piezometer casing.																															
NOTE 3	Piezometer - 12A Elv. Approx. 1595 ft																															
	No equipment installed due to suspected obstructions in piezometer casing.																															
NOTE 4	Piezometer - 14 Depth: Approx. 135 ft.																															
		Station Components:	1)IIOBO Microstation Datalogger	2)MaxStream X-Tend 1 Watt Radio modem (6 inch antenna)	3)Power Patrol Rechargeable 12V, 7.5AH Battery	4)2x PowerUp 17.3V, 0.3A Solar Panel and mount	5)Pressure Systems 0-5V Hydrostatic Water Level Transducer	6)Campbell Scientific Water Conductance Sensor	7)2x IIOBO 0-5V Input Adapter																							
NOTE 5	Piezometer - 13 Depth: Approx. 113 ft.																															
		Station Components:	1)IIOBO Microstation Datalogger	2)MaxStream X-Tend 1 Watt Radio modem (3 ft. 5.1dBi antenna)	3)Power Patrol Rechargeable 12V, 7.5AH Battery	4)2x PowerUp 17.3V, 0.3A Solar Panel and mount	5)Pressure Systems 0-5V Hydrostatic Water Level Transducer	6)Wedgewood CSIM11 ORP Sensor	7)2x IIOBO 0-5V Input Adapter																							
NOTE 6		Toe Pumps																														
		Station Components:	1)IIOBO Microstation Datalogger	2)MaxStream X-Tend 1 Watt Radio modem (6 inch antenna)	3)Power Patrol Rechargeable 12V, 7.5AH Battery	4)2x PowerUp 17.3V, 0.3A Solar Panel and mount	5)Wedgewood CSIM11 PII Sensor	6)Wedgewood CSIM11 ORP Sensor	6)Campbell Scientific Water Conductance Sensor	7)3x IIOBO 0-5V Input Adapter																						
NOTE 7	Weather Station and Repeater																															

3.7 Sensor and Equipment Wiring

Each of the data collection stations is wired in a similar fashion. The wiring begins with the power sources (12 volt battery and two 5 watt solar panels). It then progresses to include the wiring for the radio modems and sensors. Finally, the communications wiring is completed with an RS-232 cable. A generalized illustration of the wiring is shown in Figure 17. Each of the sensors shown has more detailed wiring schematics shown below. For the “Smart Sensors” that Onset offers with their HOBO Microstations, the connections to the datalogger are very simple. Each sensor is equipped with a phone jack type connection that plugs directly into an input port in the datalogger. Each “Smart Sensor” is immediately recognized and identified by the system.

Figure 17: Generalized Wiring Schematic

Hydrostatic Water Level Transducer Wiring

The wiring schematic for the Hydrostatic Water Level Transducer is shown below in Figure 18. For this project the voltmeter shown in the schematic is considered to be the 0 to 5 volt input adapter for the HOBO Microstation. Also, the power supply is the 12 volt, 18 amp-hour battery used also for powering the radio modem. Finally, the drain wire shown in the schematic is attached to the “Shield” input terminal of the 0 to 5 volt adapter. The wiring into the 0 to 5 Volt adapter is shown in Figure 19.

Figure 18: Wiring Schematic for Hydrostatic Water Level Transducer⁸⁸

Figure 19: 0-5 Volt Wiring for Hydrostatic Water Level Transducer⁸⁹

ORP and pH Sensor Wiring

The wiring schematic for the Oxidation Reduction Potential (ORP) sensor and the pH Sensor is shown below in Figure 20. It is only necessary to show one schematic since both sensors are so similar (discussed in Appendix A). As discussed previously, the ORP and pH sensors have outputs that are bipolar. In order to create a signal that the 0 to 5 volt input adapters can interpret the output voltage of the sensors are “stepped up” using a 1.5 volt alkaline battery placed in line with the output signal wire.

Figure 20: 0-5 Volt Wiring for ORP/pH Sensors⁹⁰

Specific Conductance Sensor Wiring

The wiring schematic for the Specific Conductance Sensor is shown below in Figure 21. This sensor utilizes the 0 to 5 V input adapter's excitation terminal. This terminal, on command from the Microstation, will send out a 2.5V excitation to the attached sensor.

Figure 21: 0-5 Volt Wiring for Specific Conductance Sensor⁹¹

Vibrating Wire Sensor and Datalogger Wiring Schematics

As discussed previously, the vibrating wire piezometer operates by measuring the frequency at which a small wire vibrates when “plucked” electrically. The frequency measured varies with the applied pressure to the sensor. Onset’s HOBO Microstation is not capable of reading inputs that are frequency based as in the case of this sensor. For this reason, a completely separate datalogger was purchased from Geo Durham Slope Indicator that was designed to work directly with any vibrating wire sensor that the company offers. It is a single channel datalogger referred to as the VW Minilogger. A description of the Minilogger can be found in Appendix A.

The Minilogger will send the electrical excitation signal to the sensor every time a reading is to be taken. The datalogger then interprets the returned vibration frequency and converts to engineering units that can be specified by the user—in this case, feet of water. The Minilogger operates on two D-cell batteries and all the data is stored in non-volatile memory in an ASCII format for easy conversion to programs such as Excel.

The communication for downloading data is accomplished through an RS-232 cable directly connected to a laptop. Another option for communication is utilizing MaxStream's 9XStream radio modem lid that Slope Indicator offers, but for this project the VW sensor is being used to compare its accuracy with the hydrostatic water level transducer and due to budgetary constraints, the radio lid that Slope Indicator offers will not be purchased. It was decided that continuous storage of data collected will suffice with occasional downloads when visits to the project site are conducted. The wiring schematic for the vibrating wire piezometer and the VW Minilogger are shown below in Figure 22.

Figure 22: VW Minilogger and VW Piezometer Wiring Schematic⁹²

3.8 Interface and Analysis Software

To make this project successful, a good set of software packages is needed. The HOBO Microstation Dataloggers are supported with two pieces of software supplied directly from Onset. These two software packages are the

HOBOWare Pro Package and Onset's *Remote Site Manager Package* for managing remote systems such as ours. Also, software is needed to correctly address and identify the collection stations. For this, MaxStream's radio modems come with a separate software package called *X-CTU*. To discuss these software applications this report will discuss the steps necessary to work sequentially from data retrieval to data analysis and viewing.

The first step for collecting data for this project is the communication links for each of the data collection sites. This begins with setting the unique addresses and radio "hopping" frequency channels. This is accomplished through the *X-CTU* software. Figure 23 shows an example of the PC Settings tab for setting up computer communications with the radio modems. Figure 24 shows an example of the Modem Configuration tab used to set the commands and program for the X-Tend radio modems.

The PC Settings tab is used to establish the initial communications with the radio modems before programming takes place. The first step is to select the Baud Rate at which the computer communicates through its COM port. Initially, the modems are set up to communicate at 9800 bits per second (bps). The rest of the settings are defaults and should be left alone. Clicking the Test/Query button will indicate if a communication link can be made successfully. If so, a message box will appear displaying the radio modem's information.

Figure 23: PC Settings tab for X-CTU software

The Modem Configuration tab is the location in which the settings for the modem can be set. Before beginning the programming of each of the modems it is necessary to set the DIP switches on the modem to the correct ON/OFF position to all programming to be completed. This project requires that the settings be completely user defined so the 1, 5 and 6 DIP switches should be set to “ON” (up), and the 2, 3, and 4 switches should be “OFF” (down). The settings that this project uses to program the modems are the Hopping Channel (HP), the Destination Address (DT), the Source Address (MY), the Streaming Limit (TT),

the Polling/Repeater Mode (MD), and the Baud Rate (BD). These settings are available for firmware version 2020 for the radio modems. This is selectable in the drop-down menu in the upper right side of the window. Table 9 describes the definition of each of the settings while Table 10 lists the settings for each of the data collection stations. For more information on programming the X-Tend radio modems and the definitions of the programming commands refer to the following website: http://www.maxstream.net/products/xtend/product-manual_XTend_PKG-R_rs-232-rs-485-RF-Modem.pdf

Figure 24: Modem Configuration tab for X-CTU software

Table 9: Modem Settings Used for this Project⁹³

Setting	Definition
Hopping Channel	Channel/Frequency that the modem communicates over. (0-9)
Destination Address	Address of the modem receiving information from the modem being programmed. (0-infinity) These modems must use the same Hopping Channel.
Source Address	Address of the modem being programmed. (0-infinity)
Streaming Limit	Amount of bytes sent before a delay is inserted (0-infinity)
Polling/Repeater Mode	Transmission mode of modem
Baud Rate	Modem's communication rate

Table 10: Station Settings for this Project

Modem/Station	Settings/Configuration
Toe	HP-5, DT-10, MY-1, TT-FFFF, MD-0, BD-5
Piezometer 13	HP-1, DT-10, MY-1, TT-FFFF, MD-6, BD-5
Piezometer 14	HP-2, DT-10, MY-1, TT-FFFF, MD-0, BD-5
Weather Station	HP-3, DT-10, MY-1, TT-FFFF, MD-0, BD-5
Repeater Station	HP-1, DT-FFFF, MY-FFFF, TT-FFFF, MD-5, BD-5
Pond	HP-1, DT-10, MY-2, TT-FFFF, MD-6, BD-5
Host Modem	HP-Various, DT-Various, MY-10, TT-FFFF, MD-Various, BD-5

The next step after each of the radio modems has been programmed is to establish the remote communications and data downloading frequency. This project is based on the premise that remote data collection station will electronically store data from various sensors and then will transmit that data to a centralized host computer without the input from any person. This task is completed with the program *Remote Site Manager* that is available with the HOBO Microstation. *Remote Site Manager* makes downloading scheduling as

simple as possible through an easy-to-use, Windows-type application. Figure 25 shows an example of the startup screen for the program.

Figure 25: Example Startup Screen for Remote Site Manager

To begin setting a schedule using *Remote Site Manager*, a basic understanding of the communication links to the remote stations is needed. To establish the first communication with each of the stations the host computer must have a radio modem connected to one of its COM ports. In the case of this project, it was necessary to attach an X-Tend modem to COM Port 1 of the host computer, run 9.1 meters (30 feet) of coaxial antenna cable outside the building, and attach a high-gain, 8 dBm antenna to an antenna mast in order to boost the outgoing and incoming signal from each of the stations. After programming the communication settings for the host modem to communicate with a single station by using the X-XTU program a link to that station can be made by clicking on the “Contact Remote Site” button in *Remote Site Manager*. A new window is displayed with connection settings. This is where the first software problem comes in.

For this project it was determined that a need for MaxStream’s X-Tend radio modems was necessary because of the distance and terrain at the

impoundment. This posed an initial problem with the software used to schedule the data downloads. *Remote Site Manager* was designed to operate with MaxStream's X-Stream radio modems. These modems' programming was slightly different from the X-Tend type. This difference was enough to not allow *Remote Site Manager* to access the X-Tend host modem's programming and change the settings for communications with each individual station. For this reason, a couple unique solutions for this project were created.

The first of these solutions for manual communications involves "tricking" the computer into believing that the remote stations are connected directly to it through the COM port. This is made possible initially through the "Remote Connections" tab in *Remote Site Manager*. Typically for remote communications the setting "Radio Modem" would be selected from the dropdown menu "Site Profile" found at the top of the window, but because the program cannot access the modem settings that option could not be used. When using the "Remote Connection" tab, for this project it is required to select "Local Port" from the dropdown menu. Next, after programming the host modem directly with X-CTU, a communication link can be established from the host modem and remote modem of choice by clicking the "Connect" button (looks like a telephone) found in the upper left corner of the "Remote Connection" window. The computer then searches for the HOB0 Microstation that it thinks is connected to its COM port. The host modem then relays that search to the remote modem that is connected to the Microstation by way of serial cable. When the Microstation is contacted the communications link is completed and scheduling for launching, data acquisition, and "readout" or downloading can be accomplished. Figure 26 displays an example of a successful communications link to a remote Microstation.

Figure 26: Example of Established Communications with Remote Microstation

From this new screen several options informational points arise. The first screen that is shown is the "Logger Status." This gives general information about which datalogger is contacted, the status of the scheduling, and the battery power remaining. The next tab, "Sensor Status," gives information about each of the sensors that are connected to the datalogger. This window is also where it is suggested that launching the datalogger take place. Figure 27 shows the launching options screen that is displayed after clicking the "Launch" button that is located at the top-center of the "Remote Connection" screen.

Figure 27: Example of Launch Screen

From the “Launch” screen the data logging interval and launch time can be set. The first step to launching a datalogger is to give it a short description (usually the location of the datalogger). This description will be used by the software to produce the data files when downloading. Next, selecting the type of AA batteries installed in the datalogger will help the program to determine the battery power remaining when the logger is contacted. The next step is to set the logging interval for the datalogger. It was determined that a four hour interval would be sufficient for this project. This interval allows for eight measurements in a day which is 56 times more data collected per week than by manual readings. The Sampling interval is used when several samples over a logging period are need. These samples would then be averaged to create the logged data point at the logging interval time. The final setting is the start time for logging. The Microstation will take it first reading at the beginning of the logging interval and at every interval from that point forward. The options for starting the logger include

immediate start, delayed start, and button start. The delayed start is used when it is sought that all remote stations take readings at similar times for easier data reduction and comparison. The button start option is used when it is not required to start logging until somebody can go out in the field and manually push the start button on the datalogger. Finally, by clicking on the “Start” (or “Delayed Start”) button found in the lower right corner of the screen a successful logging schedule has been made and communications with that Microstation can be ended by clicking the “Disconnect” button (X-out phone) on the “Remote Connection” screen.

After each of the remote stations has been programmed for launch; the next step is to set up the “Remote Profiles” for computer controlled data acquisition. From the startup screen of *Remote Site Manager*, clicking on the “Set Up Remote Site Profiles” will display the screen shown in Figure 29. This screen displays the current sites loaded in the program and has a tab for adding profiles. To add a profile for remote computer controlled data acquisition click the “Add Site” tab. This tab then displays the screen shown in Figure 30. This project, again, uses the COM port setting for communications. A short name for the profile is used to identify which remote station is being contacted for downloading, and the “Location” textbox is further used to identify which site is being connected. The “Auto-Readout” section of the “Add Site” tab is used to set the download, or “read-out,” schedule for each remote site that is added. The frequency at which the computer attempts to download data is set using the “Read out new data every...” drop-down menu. Also, the start time for the first download is selected on this screen. Typically the first reading should be set to at least one minute after the datalogger is scheduled to take a measurement. This allows time for the datalogger to complete its’ task before it is asked to send its data out. Finally, the file path is set so that the data files are sent to an easy-to-access folder on the computer. This process is completed for every remote site that is in use. Once all remote locations are added, making sure that all locations added are using the same COM port for reasons to be explained in

following text, the “Activate” check box must be selected on the startup page of the *Remote Site Profile* program. Once activated, all scheduled readouts will take place when they are programmed to, as long as communication with the datalogger can be established. Figure 28 is a flow chart of this process.

Figure 28: Flow Chart for Establishing Remote Profiles

Figure 29: Example of Remote Profiles Screen

Remote Profiles

Remote Sites   Add Site

Connection Route: Local Port

* Name (10 Char Max.): Officetest

* COM Port: COM 1

Location (10 Char Max.): office

Auto-Readout Schedule

☒ Utilize schedule

Read out new data every 2 Hours   DDD:HH:MM 000:02:00

Start Time IMMEDIATE   03/08/07 03:00 PM

* Datafile path: C:\Documents and Settings\James\Desktop\Office test of water lvl\water lvl test

Set Up Email and FTP Data Transfers

* Required field

OK   CANCEL

Figure 30: Example of Add Site Screen

This project attempted to use two different types of off-site remote access to the host computer. This remote access would allow for access to the host computer from any other computer that has internet access. The first attempted option was to create a “Remote Desktop” account in Windows on the host machine. Using the IP address of the host computer, a person could access the computer from anywhere, as long as they had a user name and password to the system. This option has been delayed due to server restrictions at the impoundment. Without access through the firewall of the on-site servers a “Remote Desktop” connection is impossible. The other option attempted was using the “E-mail and FTP Data Transfers” option in the “Remote Profiles” section of *Remote Site Manager*. This option allows for all the data that is collected to be e-mailed to as many different accounts that are specified. This option requires the outgoing “Simple Mail Transfer Protocol” (SMTP) server name for the host computer. This server name has been hard to come by, but promising steps forward are being made.

The final step in setting up the remote data acquisition is correctly programming the host modem to match the individual remote stations. Since the *Remote Site Manager* program is not capable of programming the X-Tend modems a different approach had to be taken. The solution to this was to write a separate program to change the host modem settings one minute before the *Remote Site Manager* program attempts to “readout” data from the dataloggers. Such a program was written by Josh Watts, and employee of MicroDAQ.com, Ltd. He was able to write the *AutoDialer* program that used the X-CTU engine to access the host modem and reconfigure the settings. He made it possible for the setting parameters for the program could be altered by a user so it would include all the data stations in use. An example of a running version of the *AutoDialer* program is shown in Figure 31, and an example of the settings file for the program can be found in Appendix C.

Figure 31: Example of AutoDialer Launch Screen

When, all the steps are followed correctly then a properly working remotely controlled data acquisition system is created. When working correctly, the *Remote Site Manager* software program will output three data files per remote site. These files will be a *HOBOWare Pro* file, a standard text file, and an .xml file for viewing in an internet browser. The *HOBOWare Pro* file is extremely useful because much of the reduction of data can be done automatically and charts can be made almost instantaneously with complete statistics. The

standard text file can be very useful because the data can be imported into a spreadsheet program such as Excel. This gives more freedom with arranging the data and allows for more different types of graphs to be created. Also, many types of equations can be used to further process the data.

The *HOBOWare Pro* software is a useful tool when quick graphs and general statistics are desired. Also, the software is capable of making multiple y-axis graphs using the same timeline. In addition, it can display several different graphs, tiled horizontally, at the same time. Figure 32 is the startup display for the *HOBOWare Pro* software.

Figure 32: HOBOWare Pro Startup Screen

To begin using the *HOBOWare Pro* software, at least one *HOBOWare* file must be available. Opening a file is as easy as doubling clicking the file itself or selecting the file from the “Open” menu under the “File” menu on the *HOBOWare Pro* software screen. When a file is opened the first screen that appears is the “Plot Setup” screen. Figure 31 shows the “Plot Setup” screen for weather data that was collected using the HOBO Microstation. The software has a built in routine that separates all the data into the measurements that were taken. Then it gives the option of allowing all, or just a few, of the data series that are available in the opened file to be displayed. Also, the program will automatically convert the units of the measurements to any user chosen units when a HOBO Smart Sensor is used. In the case of the weather example shown in Figure 33, the Wind Speed and Gust Speed measurements are deselected in order to produce the graph shown in Figure 34.

Figure 33: Example of Plot Setup for Weather Data

Figure 34: Example of Weather Data Plot

This graph illustrates the same timeline for all three plotted series and multiple y-axis are displayed on the right and left side. In addition to listing all the collected data in cell format in the top half of the screen the statistics and information for each of the series can be found on the left hand side of the screen. One drawback to this software is that it restricts the access to the data itself so removing groups of data to view smaller portions is impossible without changing the time axis. On the other hand, there is a function that allows for the data to be easily exported to Excel. This function is controlled by a button on the tool bar. All that is requested is a file name and location and the data will be immediately exported and separated into cells. The drawback to this is that no graphs are made.

For this project, third party sensors with 0 to 5 volt outputs were used with the HOBO 0 to 5 Volt Smart Sensors. When using these smart sensors, all the data collected is in volts. The *HOBOWare Pro* software has useful features called “Data Assistants” that are available when Smart Sensors such as these are used. Figure 35 shows the “Plot Setup” screen when two 0 to 5 volt smart sensors are being used. The “Data Assistants” are located at the bottom of the screen. The available “Data Assistant” that can be used with the 0 to 5 volt adapters is the “Linear Scaling Assistant.” To use it, first select the series in which linear scaling is to be applied then click the “Process...” button on the right hand side of the screen. The program then displays the “Linear Scaling Assistant” shown in Figure 36.

Figure 35: Example of Plot Setup for 0-5 Volt Inputs

Figure 36: Example of Linear Scaling for Voltage Input

The “Linear Scaling Assistant” is a simple tool to use. The tool shows the raw series units and allows for the upper and lower limit of the raw series to be input. Next, the program allows for any user defined series to be created by entering the units and the equivalent upper and lower limits for the series. The final steps are to enter the new series name, enter any notes, and click the “Create New Series” button. This will create a new series using the user defined units that is now visible on the “Plot Setup” screen. This processing can be done separately for each data series that uses “Data Assistants.”

A final useful feature that *HOBOWare Pro* has is that it allows for multiple graphs to be displayed simultaneously. This is possible when two or more data files have been opened. To make the program display more than one graph, simply click the “Tile Horizontally” or the “Tile Vertically” buttons in the lower left hand corner of the display screen. Figure 37 shows an example of graphs of

weather data and raw voltage data tiled horizontally at the same time. It can be seen that all the statistics and data can still be viewed for each of the data sets. A downfall of this software is that it cannot display data from remote sites in real-time. It would be possible if the HOBO Microstations were connected directly to the COM ports of the computer, but because *Remote Site Manager* must be used to connect to the remote stations real-time display is nearly impossible without someone writing a separate program to use *HOBOWare Pro's* engine to access the data files automatically. A program such as this would take a great deal of time and expense to create.

Complete software manuals for *Remote Site Manager* and *HOBOWare Pro* can be downloaded from Onset's website while a complete manual for the X-CTU software for specific radio modems can be downloaded from MaxStream's website.

Figure 37: Example of Simultaneous Horizontal Plots of Data

3.9 Equipment “Burn-In”

Initially, after all the software was reviewed, a “burn-in,” or testing, of the equipment was completed to demonstrate a working system and working sensors. There were several aspects of the system that were tested prior to installing any equipment at the impoundment. These aspects included testing the weather sensors, testing the water level sensors and water quality sensors, testing the dataloggers, and testing the radio modems.

To test the dataloggers and a few of the weather sensors, a data collection box was built and a datalogger was placed inside with the temperature sensor and the barometric pressure sensor attached. The box was then placed on the roof of the National Research Center for Coal and Energy (the location of the office at WVU). Temperature and barometric pressure data was collected over the course of a day. Figure 38 illustrates the temperature inside the box that was collected on August 21. This test demonstrated the working capabilities of the dataloggers and weather sensors.

To demonstrate the capability and accuracy of the hydrostatic water level transducers a short, in-office test was completed. The test consisted of placing a hydrostatic water level transducer in a bucket of water and collecting the water level data over the course of a week. To show the sensitivity of the sensor the water levels collected were compared to the actual water levels that were measured manually. To add a variety to the experiment the water level was increased or decreased at different times and by different levels during the test. Figure 39 illustrates the sensor measured and the manually measured water levels for the test period. Figure 39 shows that the sensor is accurate to a very small range, with some electrical noise, considering it is capable of measuring up to 35 meters (115 feet) of water.

Figure 38: Temperature Inside Data Collection Box on Aug. 21, 2006

Figure 39: Hydrostatic Water Level Test

Next, during the same water level test, the radio modems were tested for communication reliability. A modem was connected to the datalogger for the hydrostatic water level transducer and the entire setup was moved to a separate

room in the office. Next, a modem was connected to the host computer and it was set on a schedule to collect the data being measured. The computer and the sensor setup were separated by four concrete walls and several cubicles. Despite this separation the computer was able to communicate reliably for every scheduled transmission.

Finally, to test two of the water quality sensors, a short calibration was performed to determine their measurement reliability. To test the pH sensor, it was placed in two solutions. The first was a neutral solution, and the pH sensor should have an output of zero volts. The sensor's output was 0.002 volts. The second solution had a pH of 4 which should yield an output voltage of approximately 0.177 volts. The sensor's measurement was 0.183 volts. Both of these measurements were deemed acceptable. To test the Oxidation Reduction Potential (ORP) sensor, it was placed in normal tap water. The standard ORP reading for drinking water is 0.650 volts. The sensor's output was 0.785 volts. This measurement indicated that the water exceeded the acceptable standard for drinking water. Given the quality of the measurements for these two sensors it was determined that the readings that they would take in the field would be considered relatively acceptable.

CHAPTER 4: COLLECTED RAW DATA

This chapter illustrates all the raw data collected at each of the stations. Inconsistencies of the data are discussed as the data is presented.

4.1 Raw Weather Data

This section illustrates all the raw weather data collected from September 21, 2006 to February 20, 2007. The Microstation datalogger is set up to take a reading from the four attached sensors (barometric pressure, temperature, rainfall, and wind speed) every hour. Figure 40, below, shows the rainfall amounts per hour for the collection period. This graph gives basic results for rainfall, but a more meaningful graph would be the daily rainfall amounts for the collection period. A graph of the daily rainfall amounts is presented in Chapter 5.

Figure 40: Hourly Rainfall Amounts

It can also be noted that in Figure 38 the data shows no rainfall from September 21, 2006 to November 16, 2006. The reason for this was that the rain gauge was not functioning correctly, but after some thorough troubleshooting the problem was corrected.

Figure 41 illustrates the barometric readings for the same collection period as stated above. The barometric pressure data is extremely useful for compensating the water in the piezometers for atmospheric pressure. This compensation is presented and explained in Chapter 5. The gap in data between November 8, 2006 and November 18, 2006 is attributed to a communication error between one or more sensors and the datalogger. The type of error that was experienced resulted in lost data from several of the other sensors.

Figure 41: Barometric Pressure

Figure 42 illustrates the data collected for temperature over the above stated collection period. It can be noticed that a similar gap in data was created by the same communication error that caused the missing barometric pressure data. The missing temperature data is not quite as important as the missing barometric pressure data because the missing barometric pressure data means that water level readings during the gap cannot be compensated.

Figure 42: Temperature Trend

Finally, Figure 43 displays the wind speed readings that were collected during the collection period. The wind speed readings are not used for any specific compensations or results.

Figure 43: Wind Speed Readings

4.2 Raw Piezometer 14 Data

This section will describe and evaluate all the raw data collected at the remote data collection station located at Piezometer 14 (P14) (See Figure 14). First, Figure 44, below, illustrates the raw data collected for the water elevations. The output of the hydrostatic water level transducer is in volts. It can be noticed that there are quite a few steep drops in the raw data. It has been determined that these inconsistencies can be attributed to power drain on the 12 volt battery caused by the radio modem power consumption. The hydrostatic water level transducers require an input voltage between 9 and 36 VDC. In the instances where the reading drops off, the voltage of the batteries was well below 9 volts. It can be seen that there is a distinguishable gap in the collected data. This gap correlates to a two week period in when the datalogger was accidentally left

turned off after a data readout was performed. Table 11 lists the sensors that are installed at P14.

Table 11: Sensor Information for P14

Equipment Description
Hydrostatic Water Level Transducer: 0-5 VDC output
Specific Conductance (SpC): 0-5 VDC output

To process this data, a linear equation must be used to determine the amount of water above the sensor (in feet), and then an elevation can be computed by taking a single reading with the sensor and comparing it to the measured elevation by an engineer with a long tape that has a sensor lead at the end called an M-scope. Each hydrostatic water level transducer used in this project has its own calibrated equation. The equation for the sensor used at Piezometer 14, until February 6, 2007 was:

$$\text{Water Elevation} = 23.0343(\text{VDC} - 0.0520) + \text{Starting Elevation}$$

This equation is calibrated to give results in feet of elevation by using a starting elevation of 1351.66 feet (412 meters). To determine the amount of water located above the sensor, simply remove the “Starting Elevation” from the end of the equation. This raw data is processed in Chapter 5 and it will exclude the data collected when the 12 volt battery had an actual voltage below 9 volts.

Figure 44: Raw Voltage Readings for Water Elevation at P14

Figure 45, below, displays the raw data collected with a new hydrostatic water level transducer for water elevations between February 6, 2007 and February 20, 2007. The reason a new sensor was installed is because it was thought that the erratic readings (with a good input voltage) displayed by the sensor in Figure 44 were a result of a bad sensor. It has now been determined that the good readings taken with the original sensor were comparable to the actual field readings taken at the impoundment on a weekly basis. The explanation and comparison of sensor data and field data is discussed in Chapter 5. Once again, it is shown that there are two distinct drops in readings near the beginning of the collected data. These drops are associated with a battery voltage below 9 volts as described above. The equation for the new sensor, using a starting elevation of 1352.90 feet (412.4 meters), is:

$$\text{Water Elevation} = 22.9995(\text{VDC} - 0.0509) + \text{Starting Elevation}$$

Figure 45: Raw Voltage Readings for Water Elevation with New Sensor at P14

Figure 46, below illustrates the raw data collected for the specific conductance at Piezometer 14. This raw data is in volts and must be converted to the units typical of specific conductance, milli-Siemens per centimeter (mS/cm). The equation to do this for this sensor is:

$$\text{Specific Cond.} = 1.339(VDC) + 0.005$$

This information will be used to see how rainfall influences the specific conductance of the water flowing through the impoundment. This is discussed in Chapter 5.

Figure 46: Raw Voltage Readings for Specific Conductance at P14

4.3 Raw Piezometer 13 Data

Table 12: Sensor Information for P13

Equipment Description
Hydrostatic Water Level Transducer: 0-5 VDC output
Vibrating Wire Piezometer: 700-1400 Hz output

This section illustrates the raw data collected for the water elevations at Piezometer 13 (P13). Figure 47, below, shows the voltage readings produced by the sensor over a collection period from September 16, 2006 to February 20, 2007. It can be noticed that this sensor suffered from the same loss of input voltage as described in section 4.2. It can also be seen that on November 16, 2006 the sensor was removed and replaced back in the standpipe. This was done in order to add a new sensor to the remote station but it was found that the new sensor would not fit through the opening of the standpipe. When the

hydrostatic water level transducer was replaced it was not returned to its original depth, but placed a measurable distance above the first location. For this reason, two separate equations must be used when determining the water elevation. The two equations will use the same linear formula but will use two different y intercepts. The equation for pre-November 16, 2006, using a starting elevation of 1237.49 feet (377.2 meters), is:

$$\textit{Water Elevation} = 22.9883(\textit{VDC} - 0.0485) + \textit{Starting Elevation}$$

The equation for post-November 16, 2006, using a starting elevation of 1238.84 feet (377.6 meters), is:

$$\textit{Water Elevation} = 22.9883(\textit{VDC} - 0.0485) + \textit{Starting Elevation}$$

The processed data, along with a comparison to the actual field readings for the collection period is presented and discussed in Chapter 5. Once again, the processed data will exclude the data points in which the input voltage was below 9 volts.

Figure 47: Raw Voltage Readings for Water Elevation at P13

4.4 Raw Piezometer 7 Data

This section describes the raw data collected at Piezometer 7 (P7) over the collection period from November 16, 2006 to December 7, 2006. The reason that the collection period is so short is because the station had to be removed for further placement of course refuse on the upstream face.

Figure 48, below illustrates the water level readings at P7 for the collection period. It can be noticed that all the data points fall below 0.05 volts. The equation to determine the feet of water above the specific sensor used is:

$$\text{Water Elevation} = 23.0553(VDC - 0.0516) + 0.0000$$

It was found that when applying this equation the water level measurements were negative. This is indicative of readings from a sensor that is not submersed in water. For this, the water level measurements are erroneous and will not be processed and discussed in Chapter 5.

Figure 48: Water Elevation Readings at P7

Figure 49, below displays the voltage readings for the pH sensor located at P7. This sensor, being oriented below the hydrostatic water level transducer, was located in water and appreciable measurements were collected. This sensor is a bipolar sensor, meaning it produces an output signal that can be positive or negative by measure the difference between the two output leads. For this, a 1.5 volt AA battery was wired in-line with the output signal wire of the sensor to step the voltage up. The range of the pH sensor was 0 volts for a pH of 7 and ± 59 mV for every pH unit. To determine the actual pH of the water it is first required that 1.5 volts be subtracted from the collected reading then resultant is divided by 0.059 and subtracted from 7. This equation appears as follows:

$$pH = 7 - \left[\frac{(VDC - 1.5)}{0.059} \right]$$

This processing is completed and discussed in Chapter 5. Also, a discussion of how the construction and rainfall affected the pH readings will be presented.

Figure 49: pH Readings at P7

4.5 Raw Toe Pumps' Data

This section illustrates the raw data collected with the pH, Oxidation Reduction Potential (ORP), and Specific Conductance (SpC) sensors at the toe of the impoundment over the time period between October 27, 2006 and February 20, 2007. First, Figure 50 shows the raw voltage data collected from the oxidation reduction potential sensor. This sensor is similar to the pH sensor described in Section 4.4 in that it is a bipolar output sensor. For this same

reason a 1.5 volt AA battery was wired in-line with the output signal wire of the sensor. The typical measurement for oxidation reduction potential is volts so very little processing for this sensor's data is needed. The only processing needed is the subtraction of the 1.5 volts added by the AA battery. The ORP sensor used has a range of -700 mV to +1100 mV. This is a typical range for oxidation reduction potential. The raw data here shows very erratic readings from the sensor. This may be a result of the alkaline treatment of the seepage water leaving the impoundment. It can also be noticed that there is a gap in the data between November 9, 2006 to November 23, 2006 when the datalogger was accidentally turned off after a data readout. Also, a gap in the data appears around January 13, 2007. This break in data is attributed to a sensor communication error with the datalogger. Approximately 48 points of data were lost during the two day time period.

Figure 50: Oxidation Reduction Potential at Toe

Figure 51, below, shows the collected raw data for the pH sensor for October 27, 2006 to November 8, 2006. It is shown that the readings are a constant 0.006 volts. This measurement, after subtracting the 1.5 volts for the AA battery wired in-line with the output signal wire, is well below the lower range of the sensor of -0.035 volts at -1.494 volts. It was determined that the pH sensor must be faulty and that a replacement would be needed.

Figure 51: Raw Voltage for pH at Toe

At the time of the pH sensor removal a spare pH sensor was not available, so the pH sensor was replaced with a specific conductance sensor. Figure 52, below, displays the raw voltage data collected from the specific conductance sensor from November 16, 2006 to February 20, 2007. It can be seen that the raw readings for the specific conductance at the toe do not share the same drop in specific conductance as the readings at Piezometer 14. It is unclear as to why this may have occurred, but one factor influencing the readings is the alkaline treatment for the water seeping out of the impoundment. Also, it can be

assumed that the seepage flow through the impoundment is three-dimensional and the water that flows through P14 may be diverted to surface drains or seep underground. Then this water would never reach the treatment pond where the additional specific conductance sensor is located. This raw data, as stated before is in volts and must be converted to milli-Secants per centimeter (mS/cm). The equation for this sensor is the same as for the sensor at Piezometer 7.

Figure 52: Raw Voltage for Specific Conductance at Toe

All the above mentioned raw data in this chapter is processed and discussed, in detail, in Chapter 5. Most of the data is used to further examine the “health” of the impoundment as well as compare the measurements to the design criteria for the impoundment. The design criterion that is relevant to the data collected by this project is also presented in Chapter 5.

CHAPTER 5: DATA ANALYSIS

This chapter illustrates all the processed data collected and reduced, to date, at each of the stations. Analysis of data is discussed as the data is presented.

To collect the data that follows in this chapter, a complete, working data collection system was installed. To validate that the system functioned automatically, a few pre-operation procedures were completed. These procedures included:

- Perform a range test of radio modems and confirm their communications capabilities from each sensor station location.
  - Completed by using the X-CTU software to perform range test with loop-back modem connectors on the radio modems (See radio modem manual for details).
- Confirm that Auto-Dialer program completely and efficiently reprograms the host modem to communicate with remote stations.
  - Completed by running a short test case by using Auto-Dialer to change host modem configuration and then use Remote Site manager to connect to each of the remote stations.
- Finally, confirm that the entire system performed as intended by setting up the data acquisition to operate over night (after installation) and verifying that data was collected as scheduled during the next day's work.
  - The system operated as it was intended and collected data was appropriately logged. The system was then put into full operation.

5.1 Processed Weather Data

Rather than “flooding” the system with hourly rainfall data, we have reduced it to daily data, which correlate better with the piezometer plots. This is

useful in comparing the specific conductance, pH, oxidation reduction, and piezometric level changes with rain events. The impoundment itself is designed to handle up to 79 cm (31 inches) of runoff water in a 36 hour period.⁹⁴ With some effort, the rainfall data could be used to estimate the amount of runoff that enters the impoundment in a 36 hour period but is not performed here. Figure 53 below illustrates the daily rainfall data.

It can be noted that the time period in which no data was collected because the rain gauge was not in operation (discussed in Section 4.1) has been excluded from the processed graph. This is done to eliminate unused space on the graph and to give a clearer view of the credible data. On several occasions it was measured that over an inch of rain fell in a 24 hour period. For this impoundment, this is a situation where inspection personnel are notified and must show up to visually inspect the impoundment for physical signs of distress.

Figure 53: Processed Daily Rainfall Data

As far as processing the temperature, barometric pressure, and wind speed data is concerned, the raw data collected and presented in Chapter 4 is sufficient to explain the data since the raw data comes into the dataloggers already processed. However, the barometric pressure data will be used later in this chapter to compensate field data for piezometric levels. This pressure data will be introduced as it is needed.

5.2 Processed P14 Data

As stated in Chapter 4, the water elevation data collected by the hydrostatic water level transducers is important in determining the “health” of the impoundment. The readings are typically processed to show the actual elevations in the standpipes. This is the case because the actual levels are compared to the design criteria for maximum water levels. If the water level in a piezometer were to reach a maximum allowed level it could possibly be an indicator of a pore pressure problem with the impoundment that could lead to a failure. For Piezometer 14, the maximum allowable water elevation in the standpipe is 435.9 meters (1430 feet).⁹⁵ Figure 54 shows that the maximum water level reached for the collection period was approximately 415.3 meters (1362.60 feet)⁹⁶. This is well below the maximum allowable water level. Figure 54 also shows that all of the raw data points collected when the input voltage to the sensor was below 9 volts have been excluded.

Figure 54: Processed Water Elevation Data for Piezometer 14

The next step in processing the data taken by the sensor at Piezometer 14 is to compare the readings to the weekly measurements taken at the impoundment. This comparison gives insight into the operation, accuracy, and precision of the hydrostatic water level transducer. Figure 55, below illustrates the data taken by the sensor and the data collected by Mark Bailey of Eastern Associated Coal (EAC).

Figure 55: Processed Water Elevation Data Compared to EAC Data at P14

It has been suggested that for wells, or open standpipes in the case of this project, that when open to the atmosphere the “water levels in a well may not be at equilibrium with the aquifer, leading to inaccurate measurements”⁹⁷ of the water levels. This means that the measurement of the water levels in a well or open standpipe are not an indication of the true water table and pore pressure in the refuse surrounding the measurement area if the percentage of coal fines is high enough to produce a non-permeable soil. If the refuse and coal fines are distributed in a way that the impoundment has high permeability, then barometric changes will effect the water table and the measurements at the piezometers equally. For non-permeable soils, the only way to accurately measure the true water table level is to adjust the measurements for barometric pressure. Figure 56 illustrates how barometric pressure affects the water level measurements for permeable and non-permeable soils. For this project, the hydrostatic water level transducers used have a vent tube that is open to the atmosphere to perform an

automatic adjustment for the barometric pressure. Currently, the only sensor that would be affected by barometric changes is the vibrating wire piezometer (VWP).

The VWP is sealed with some “standard” pressure inside (P_o), presumably $P_o=39.37$ in Hg. The VWP measures $(P_{\text{water}}+P_{\infty})-P_o$; where P_{∞} can be either more or less than P_o . Thus, any deviation from P_o will look like a change in the height of the water elevation (Δh) to the VWP.

The issue of compensated versus uncompensated is mostly irrelevant, given how small ΔP_{∞} is, but if an accurate reading of pore water pressure is critical, the only way to get it is by using a VWP grouted into the piezometer or impoundment structure. Although the VWP has not been installed long enough to generate enough data to compare to EAC’s weekly data, it is still important to show how barometric pressure changes would effect the water elevation readings produced by the VWP.

It must be remembered, though, that compensating for barometric pressure when it is not needed introduces error into the measurements. That is why interpreting the data collected and compensating it for barometric pressure should be used to generally understand how changing pressure could affect the measurements.

Figure 56: Barometric Pressure Effects Illustration

To begin the compensation for barometric pressure for VWP data it is first necessary to determine what standard atmospheric pressure at 1700 feet is where the impoundment is located. Using the information that standard atmospheric pressure at sea level is 1 atm (29.92126 in Hg) and that atmospheric pressure at 518 meters (1700 feet) is 95.08% atm then it can be calculated that standard atmospheric pressure at 518 meters (1700 feet) is approximately 28.45 in Hg. Using this number as a reference point and

assuming the water level measurement at standard atmospheric pressure for 518 meters (1700 feet) is accurate then compensation can be determined using the barometric pressure measurements for each day. It has also been suggested that the barometric pressure over the course of a typical day would only vary by approximately +/- 1.5% of standard atmospheric pressure for a given altitude. In this case, the barometric pressure could conceivably range from approximately 28.023 in Hg to 28.877 in Hg. This range would affect the water level readings by approximately +/- 0.148 meters (+/- 0.484 feet).

The equation used to determine how the barometric pressure could affect the water column height is:

$$h_t = z + \frac{P - P_o}{\gamma_w} \quad 98$$

Where h_t is the height change of the water column, z is the elevation of the water column (taken as zero to determine only the effect of pressure on the water level), P is the measured pressure from the piezometer in lb/in^2 , P_o is the determined standard atmospheric pressure for 518 meters (1700 feet), and γ_w is the specific weight of water at 0.0361 lb/in^3 (1000 kg/m^3). Table 13, below, shows the barometric pressures taken on each day of field measurement and how they would have affected the water level. The effect has been converted to feet by dividing the resultant from the equation by twelve in order to match the units of elevation.

Table 13: Measured Barometric Pressure and Its Effect on Water Level

Date at 12:20	Pressure (in Hg)	Pressure Effect [cm (ft)]
9/27/2006 12:20	28.2262	7.62 (0.25)
10/4/2006 12:20	28.4329	0.61 (0.02)
10/11/2006 12:20	28.0491	13.7 (0.45)
10/18/2006 12:20	28.2056	8.53 (0.28)
10/25/2006 12:20	28.4743	-0.91 (-0.03)
11/1/2006 12:20	28.3266	4.26 (0.14)
11/8/2006 12:20	Communications Error	Communications Error
11/15/2006 12:20	Communications Error	Communications Error
11/22/2006 12:20	28.4595	-0.30 (-0.01)
11/29/2006 12:20	28.5186	-2.44 (-0.08)
12/6/2006 12:20	28.3857	2.13 (0.07)
12/14/2006 12:20	28.3207	4.57 (0.15)
12/20/2006 12:20	28.5629	-3.96 (-0.13)
12/27/2006 12:20	28.4123	1.22 (0.04)
1/3/2007 12:20	28.619	-5.79 (-0.19)
1/10/2007 12:20	28.616	-5.79 (-0.19)
1/17/2007 12:00	28.8641	-14.3 (-0.47)
1/24/2007 12:00	28.2942	5.49 (0.18)
1/31/2007 12:00	28.4536	0.00 (0.00)

Table 14, below, shows the actual field measurements taken by an m-scope for the water elevations at Piezometer 14. It should be assumed that the readings taken by the m-scope and the hydrostatic water level transducer would produce the same resulting elevations, and the vibrating wire piezometer would produce values that would have to be compensated for barometric pressure.

Table 14: EAC's Field Water Elevation Measurements at P14

Date	P-14 M-scope Field Readings [m (ft)]	
9/20/06 12:00 PM	414.74	1360.70
9/27/06 12:00 PM	413.40	1356.30
10/4/06 12:00 PM	413.98	1358.20
10/11/06 12:00 PM	414.06	1358.45
10/18/06 12:00 PM	414.01	1358.30
10/25/06 12:00 PM	413.93	1358.05
11/1/06 12:00 PM	414.31	1359.30
11/8/06 12:00 PM	414.77	1360.80
11/15/06 12:00 PM	414.65	1360.40
11/22/06 12:00 PM	414.46	1359.77
11/29/06 12:00 PM	414.68	1360.50
12/6/06 12:00 PM	414.59	1360.20
12/14/06 12:00 PM	414.86	1361.10
12/20/06 12:00 PM	414.54	1360.05
12/27/06 12:00 PM	414.96	1361.42
1/3/07 12:00 PM	415.05	1361.70
1/10/07 12:00 PM	414.24	1359.05
1/17/07 12:00 PM	415.05	1361.70
1/24/07 12:00 PM	415.17	1362.10
1/31/07 12:00 PM	415.11	1361.90

These elevations are displayed in Figure 55 (page 93). It is shown that the m-scope data tend to follow the same trend as the data collected by the hydrostatic water level transducer.

Table 15 is a reduction of the general statistics for the represented data. The missing data in the sensor reading column is a result of corrupt data due to a low input voltage to the sensor.

Table 15: General Comparison Statistic for Field and Sensor Data at P14

EAC Data	P-14 Field Readings (ft)	Sensor Reading (ft)	Difference Field vs. Sensor (ft)	% Error
9/20/06 12:00 PM	1360.70			
9/27/06 12:00 PM	1356.30	1357.53	-1.23	-0.09
10/4/06 12:00 PM	1358.20	1357.51	0.69	0.05
10/11/06 12:00 PM	1358.45	1357.93	0.52	0.04
10/18/06 12:00 PM	1358.30			
10/25/06 12:00 PM	1358.05			
11/1/06 12:00 PM	1359.30			
11/8/06 12:00 PM	1360.80			
11/15/06 12:00 PM	1360.40	1359.92	0.48	0.03
11/22/06 12:00 PM	1359.77	1359.28	0.49	0.04
11/29/06 12:00 PM	1360.50	1360.35	0.15	0.01
12/6/06 12:00 PM	1360.20	1360.85	-0.65	-0.05
12/14/06 12:00 PM	1361.10	1361.30	-0.20	-0.01
12/20/06 12:00 PM	1360.05	1359.78	0.27	0.02
12/27/06 12:00 PM	1361.42	1360.68	0.74	0.05
1/3/07 12:00 PM	1361.70	1359.22	2.48	0.18
1/10/07 12:00 PM	1359.05	1359.16	-0.11	-0.01
1/17/07 12:00 PM	1361.70	1360.80	0.90	0.07
1/24/07 12:00 PM	1362.10	1361.67	0.43	0.03
1/31/07 12:00 PM	1361.90	1361.42	0.48	0.04
MEAN =	1360.00	1359.83		

Sensor vs. Field (Ft)

MEAN DIFF. =	0.17
Avg. Diff. =	0.36
Max Diff. =	2.48
Min Diff. =	0.11

* MEAN DIFF. = The difference between the means of the measurements

** Avg. Diff. = The average of the differences between the measurements

The difference of the mean measurement with the sensor is approximately 0.05 m (0.17 feet). The average difference represents the average of the individual differences from one set of data to the other. The average difference is 0.11 m (0.36 feet). The final comparisons were of the maximum and minimum absolute difference from one data set to the other. It can be seen that the maximum was 0.76 m (2.48 feet), and the minimum was 0.03 m (0.11 feet). These statistics show that the hydrostatic sensor used in this project at Piezometer 14 contains electrical inconsistencies in its measurements, and/or the process in which field measurements was taken consists of human measurement error. But, if field measurements can be considered precise and

the sensor is accurate to within an average 0.12 m (0.4 feet) of an actual water level then this type of sensor is acceptable and would prove to be a useful, long-term device to implement with remote monitoring.

5.3 Processed P13 Data

The same process of reducing the water level measurements for Piezometer 14 was completed for Piezometer 13. For Piezometer 13, the maximum allowable water elevation in the standpipe is 384 meters (1260 feet).⁹⁹ This maximum water elevation can be assumed to produce a factor of safety (FS) of 1.5, where a FS of 1.0 is considered failure. It is shown in Figure 57 that the maximum water level reached for the collection period, measured by WVU, was approximately 378.6 meters (1242.15 feet). This is well below the maximum allowable water level by 6.4 meters (17.85 feet), and so the impoundment, at this location, is within design tolerances.

Figure 57: Processed Water Elevation Data for Piezometer 13

Figure 58 shows the graph comparing the data collected by the hydrostatic water level transducer and the field data collected by Mark Bailey of EAC. Table 16 shows the field data collected over several months time.

Figure 58: Processed Water Elevation Data Compared to EAC Data at P13

Table 16: EAC's Field Water Elevation Measurements at P13

EAC Data	P-13 M-Scope Readings [m (ft)]	
9/20/06 12:00 PM	378.41	1241.50
9/27/06 12:00 PM	378.42	1241.55
10/4/06 12:00 PM	378.45	1241.65
10/11/06 12:00 PM	378.38	1241.40
10/18/06 12:00 PM	378.41	1241.50
10/25/06 12:00 PM	378.42	1241.55
11/1/06 12:00 PM	378.42	1241.55
11/8/06 12:00 PM	378.42	1241.55
11/15/06 12:00 PM	378.50	1241.80
11/22/06 12:00 PM	378.43	1241.58
11/29/06 12:00 PM	378.42	1241.55
12/6/06 12:00 PM	378.41	1241.50
12/14/06 12:00 PM	378.45	1241.65
12/20/06 12:00 PM	378.54	1241.94
12/27/06 12:00 PM	378.46	1241.66
1/3/07 12:00 PM	378.56	1242.00
1/10/07 12:00 PM	378.52	1241.85
1/17/07 12:00 PM	378.56	1242.00
1/24/07 12:00 PM	378.50	1241.80
1/31/07 12:00 PM	378.45	1241.65

The elevations shown in Table 16 are displayed in Figure 58. The m-scope data tend to follow the same trend as the data collected by the hydrostatic water level transducer. Table 17 is a reduction of the general statistics for the data, with all elevation readings displayed in feet for simplification purposes. The missing data in the sensor reading column is a result of corrupt data due to a low input voltage to the sensor.

Table 17: General Comparison Statistic for Field and Sensor Data at P13

EAC Data	P-13 Field Readings (ft)	Sensor Reading (ft)	Difference Field vs. Sensor (ft)	% Error
9/20/06 12:00 PM	1241.50			
9/27/06 12:00 PM	1241.55	1241.55	0.00	0.00
10/4/06 12:00 PM	1241.65	1241.69	-0.04	0.00
10/11/06 12:00 PM	1241.40			
10/18/06 12:00 PM	1241.50	1241.64	-0.14	-0.01
10/25/06 12:00 PM	1241.55	1241.78	-0.23	-0.02
11/1/06 12:00 PM	1241.55			
11/8/06 12:00 PM	1241.55	1241.75	-0.20	-0.02
11/15/06 12:00 PM	1241.80			
11/22/06 12:00 PM	1241.58	1241.58	0.00	0.00
11/29/06 12:00 PM	1241.55	1241.58	-0.03	0.00
12/6/06 12:00 PM	1241.50	1241.67	-0.17	-0.01
12/14/06 12:00 PM	1241.65	1241.78	-0.13	-0.01
12/20/06 12:00 PM	1241.94	1241.87	0.07	0.01
12/27/06 12:00 PM	1241.66	1241.73	-0.07	-0.01
1/3/07 12:00 PM	1242.00	1242.01	-0.01	0.00
1/10/07 12:00 PM	1241.85	1241.89	-0.04	0.00
1/17/07 12:00 PM	1242.00	1242.06	-0.06	0.00
1/24/07 12:00 PM	1241.80	1241.84	-0.04	0.00
1/31/07 12:00 PM	1241.65	1241.73	-0.08	-0.01
MEAN =	1241.66	1241.76		

Sensor vs. Field (ft)

MEAN DIFF. =	0.10
Avg. Diff. =	-0.07
Max Diff. =	0.23
Min Diff. =	0.00

* MEAN DIFF. = The difference between the means of the measurements

** Avg. Diff. = The average of the differences between the measurements

The difference of the mean measurement with the sensor is approximately 0.03 m (0.10 feet). Next, the average difference is calculated. The average difference represents the average of the individual differences from one set of data to the other. The average difference is -0.021 m (-0.07 feet). The final comparisons were of the maximum and minimum absolute difference from one data set to the other. The maximum was 0.07 m (0.23 feet), and the minimum was 0.00 m (0.00 feet). These statistics show that the hydrostatic sensor used in this project at Piezometer 13 contains electrical inconsistencies in its measurements just as in the case of the sensor at P14; although, it can also be assumed that there are inconsistencies in the manually read data as well. The inconsistencies, or “noise,” in the manually read data can be attributed to

moisture or mud that has collected on the inside of the standpipe causing a false reading. If sensor measurements can be considered precise to within an average 0.04 m (0.14 feet) of an actual water level then this is completely capable of producing reliable data.

5.4 P13 and P14 Water Levels Compared to Rainfall

The graphs for the water elevations have already been presented, but are shown here in Figures 59 and 60 to illustrate how water seeps through the impoundment from one piezometer to the subsequent downstream piezometer (keep in mind that P14 is upstream from P13). Also, the rainfall data is shown again, in Figure 61) to illustrate how rain events affected the water levels in the piezometers.

Figure 59: Water Elevation Data for Piezometer 14

Figure 60: Water Elevation Data for Piezometer 13

Figure 61: Daily Rainfall Data

Figure 59 shows that the water level in Piezometer 14 steadily increases over the course of three months. This increase is on the magnitude of approximately four feet. The end of the increase seems to correspond to the increased rainfall in the area, but the rise early does not seem to correspond to any monitored data. The only occurrence at the impoundment that could contribute to this is the increased construction on the upstream face of the impoundment. The construction included filling in a portion of the impoundment directly behind the upstream face, and the compaction of the coal refuse could possibly contribute to the rise in water elevation at P14.

However, it can be seen that the increasing trend of water elevation at P14 is not followed on the same magnitude at P13 (Figure 60), although there is a slight increase of approximately one foot. One explanation for the fact that the water level at P13 does not follow the same trend as the water level at P14 could be that the seepage flow through the impoundment is not linear, in a directional sense. The seepage flow must be considered to be three dimensional, discharging to surface drains or going underground, and bypassing P13 to explain why the two piezometers do not follow the same trend. The increase in water elevation at P13 does appear to follow the same pattern as the increased activity of rainfall at the site. The water levels even start to drop off as the rainfall amounts decrease in February.

It was stated in Chapter Two that the 90% response time for different types of piezometers can be estimated by using equations derived by Penman (1960) using:

$$t = 3.3 \times 10^{-6} \frac{d^2 \ln \left[\frac{L}{D} + \sqrt{1 + \left(\frac{L}{D} \right)^2} \right]}{kL}$$

Where: t = time required for 90% response, days

d = inside diameter of standpipe, centimeters (cm)

L = length of intake filter (or sand zone around filter), centimeters (cm)

D = diameter of intake filter (or sand zone), centimeters (cm)

k = permeability of soil, centimeters per second (cm/sec)

It has been suggested that it would be more desirable to measure time lag in the field by comparing pool fluctuations with desired piezometers readings. At the time that this thesis was written a sensor array consisting of a hydrostatic water level transducer, a pH sensor, an oxidation reduction potential sensor, and a specific conductance sensor was scheduled to be installed in the pool of the impoundment. Once these sensors are installed it will easier to determine the time lag for the piezometers on the downstream face of the impoundment. The calculation technique is difficult because the length and the diameter of the intake filter are unknown by the author.

5.5 Seepage Flow Rate Calculations

One calculation that was performed was estimating the average seepage flow from P14 to P13. This calculation was performed using the following equations:

$$Q_{13-14} = k\bar{A} \frac{H_{14} - H_{13}}{L}$$

$$\bar{A} = \frac{1}{2}(A_{13} + A_{14})$$

$$A_{13} = \frac{1}{2}h_{13}T_{13}$$

$$A_{14} = \frac{1}{2}h_{14}T_{14}$$

Where Q is the flow between the two piezometers, k is the hydraulic conductivity of the coal refuse, H is the height of the water table above the datum, L is the distance between the two piezometers, A is the cross sectional area of the coal impoundment at the piezometers (assumed to be a triangle), h is the height of the water table above the tip of the piezometers, $\bar{A}$ is the average of the two areas, and T is the assumed width of the coal impoundment at the piezometers. Figure 62 illustrates these variables.

Figure 62: Illustration of Seepage Flow Variables

Using the information shown in Table 18 and the water elevation data collected between September 21, 2006 and October 1, 2006 an estimation of the average seepage flow can be calculated.

Table 18: Flow Calculation Variables

Width of pile at P-13 =	200.6 (658.04)	m (ft)
Width of pile at P-14 =	334.7 (1097.99)	m (ft)
Tip elevation for P-13 =	377.6 (1239.00)	m (ft)
Tip elevation for P-14 =	411.8 (1351.00)	m (ft)
Pile Hydraulic Conductivity =	8.3E-05 (2.72E-04)	m/s (ft/s)
Pile Hydraulic Conductivity =	4.96 (0.1219)	Lpm/m ² (gpm/ft ²)
Distance between P-13 and P14 =	167.1 (548.12)	m (ft)

Using these variables, the equations above, and the data from the specified collection period, the mean seepage flow can be estimated to be 215 liters/minute (56.78 gallons/minute). This seems to be a reasonable estimation and the newly installed flow meter at the toe of the impoundment can be used to compare to this estimation once a reasonable amount of data has been collected. The ultrasonic flow meter was installed on February 18, 2006, so a practical amount of data for comparison should be collected by mid-April.

5.6 Specific Conductance Changes with Rainfall

Another water quality measurement that typically changes with rainfall is the specific conductance of water. Rainfall can affect the measurement of dissolved solids in water, which is an indication of the specific conductance. Below, Figure 63 shows the measured specific conductance at P14 while Figure 64 illustrates the pH measured at P7. This data was processed using the equation presented in Chapter 4 for specific conductance.

Figure 63: Processed Specific Conductance Data at P14

For the specific conductance at P14, the drop in the readings coincides (with a 5 day lag) with the significant amount of rainfall experienced between December 20, 2006 and January 2, 2007. This indicates that the rainfall has affected the readings of the sensor. However, it does seem as though the readings are not climbing back to original values, but further examination of the data following February 20, 2007 is required to find a reason for this slow, “rebound” response.

Figure 64: Processed Specific Conductance Data at Toe

The specific conductance data collected by the sensor at the toe of the impoundment shows a more consistent trend that does not vary with the rainfall data. However, it can be seen that magnitude of the measurements is consistent with those measurements taken at P14. This demonstrates the effectiveness of the sensors to determine the specific conductance and may allow for a seepage rate calculation between the two locations to be completed once desired changes

are recorded at the toe when compared to changes at P14. Also, the difference in the readings at the toe may be attributed to the alkaline treatment or the bacterial iron that is heavily present at the outflow of the impoundment.

5.7 pH Changes at Piezometer 7

As discussed in Chapter 4, the pH sensor located at P7 was found to be located in water while installed, but the hydrostatic water level transducer was not. From this, only the pH data can be considered credible. The sensor was only installed for approximately 28 days due to expansive construction on the upstream face of the impoundment. Figure 65, below, illustrates the processed pH data from the sensor at P7 over a 28 day collection period. This processed data was calculated by subtracting the 1.5 volts that the AA battery contributed to the signal and realizing that the pH value changes from a value of 7 by a single pH unit for every 59 millivolts.

Figure 65: Processed pH Data at P7

Figure 65 shows a subtle increase in the pH during the 4.5 week collection period. The cause of the change is unknown, but some possibilities are:

- Change in the pH of incoming effluent
- Change in rainfall
- Upstream construction
- Other unknown mechanism

The pH data that is collected in the pond can be partnered with an additional pH sensor at the toe, and if pH changes can be shown to correlate with seepage conditions then the pH at the toe could represent a very “general” measurement of flow in the dam. As such, it may be a valuable supplement to the data supplied by the piezometers, which are more local measurements, are not always functional, and may not be optimally sited for measuring impoundment health.

Additional experiments are recommended for determining the causes of pH changes at the toe and to determine if the pH measurements could provide a source of information on the state of the impoundment. Some experimental solutions could involve placing a pH sensor near the incoming water discharge and coupling that information with rainfall and toe flow data to look for correlations.

CHAPTER 6: PROJECT SETBACKS AND SOLUTIONS

This chapter is intended to explain many of the setbacks and problems experienced during the operations of this project. While most of the problems had definite solutions, some problems were just temporarily solved or the recurring nature of those problems was lessened without eliminating the problem. For several of these types of problems, more permanent solutions or recommendations are presented.

6.1 Battery Power Loss

The first problem encountered in the operation of this project was the rapid loss of power from the 12 volt batteries used to power the radio modems. Initially, a 7.5 amp-hour (AH) battery was installed to supply the power while a single 5 watt solar panel was used to recharge the battery. It was found that the quiescent current draw and the transmitting current draw of the modem caused a power drain that was more rapid than the 5 watt solar panel could handle. The batteries were found to be below operational standards within approximately two weeks. The solar panel was originally designed with the assumption that there was approximately 6 hours of sunlight in a single day. This was thought to be enough to keep the batteries charged; however, it was found that over the course of a few cloudy days the power drawn from the battery was unrecoverable.

The first solution proposed for this problem was to add a second 5 watt solar panel, in parallel, to aid in the charging of the batteries. It was calculated that the modems would cause a loss of 2.64 Amp-hours (AH) over the course of 24 hours (assuming a current draw of 0.110 A). Assuming 6 hours of sunlight per day, one 5 watt solar panel (0.33 A) would provide 1.98 AH per day. This is a net of -0.66 AH per day. This would cause full discharge of the 7.5 AH batteries in 11 days. By adding an additional solar panel, the net would increase to +1.32 AH per day. This would theoretically ensure the batteries would never

fully discharge. However, 6 hours of sunlight per day seemed to be an overestimation, and the solution proved to only increase the power life of the batteries by approximately two to four days, so a second solution was proposed.

The second solution involved upgrading the batteries from 7.5 AH batteries to 18 AH batteries. With a single solar panel the 18 AH batteries would theoretically last 27 days assuming 6 hours of sunlight. With two solar panels, this solution has proved to be more reliable by allowing a wider range in days for the solar panels to perform their intended jobs. Now the batteries at most of the stations have proven to last approximately 4 to 5 weeks, with the battery at Piezometer 14 lasting as long as 9 weeks. This has been due, in most part, to the station at P14 receiving the most direct sunlight while the weather station receives the least due to the location below a hillside that blocks most of the winter sunlight. As spring and summer approach the ability of the solar panels to recharge the batteries should become more sufficient and should allow the 18 AH batteries to last well beyond 5 weeks. A proposed future resolution for this problem for any project similar in nature to this one would be to find some way to incorporate hard wiring of 110V AC power to the system, or replacing the radio modems with ones that would require less power.

Next, it was previously discussed that power loss in the batteries caused corrupt readings to be taken by the hydraulic water level transducers. These transducers require a minimum of a 9 volt input signal in order to output an accurate reading. As stated above, the modems applied enough stress on the power system that, early on, corrupt data points were collected on a regular basis. Upgrading the batteries to 18 AH and including an extra solar panel has alleviated most of this problem, but some situations still exist. A solution to this problem would include having a second battery dedicated to providing power solely for the sensor. This problem could also be avoided by finding a way to hard wire the system with a constant AC power source as stated above. This

would allow the batteries and solar panels to provide power directly to the sensor without the extra power loss attributed to the radio modem.

6.2 Sensor Communication Errors

Another problem encountered in this project was the occasional loss of data due to unknown reasons for sensor communication errors. These errors typically would cause the loss of several data points in succession but would resolve themselves without intervention. This occurred both at the toe of the impoundment with the ORP and specific conductance sensors as well as with the smart sensors located at the weather station. As for the communication errors at the toe, for unexplained reasons the loss of approximately ten data points was encountered, but with the “rebooting” of the datalogger no additional errors have been recorded.

The weather station was a different story. An unexplained communication error was encountered, and it resulted in the loss of approximately two days worth of data (48 points of data per sensor). After the datalogger was “rebooted” the problem was not resolved. The solution was to replace the datalogger with a new, unused unit. This has proven to be an effective solution, and no more communication errors have been experienced.

6.3 Separate Datalogger for VW Piezometer

This project attempts to compare the precision of a hydrostatic water level transducer to the precision of a vibrating wire (VW) piezometer. It was determined that the VW piezometer would not work, in any way, with the HOBO Microstation datalogger used in this project. A separate datalogger specifically designed for the VW piezometer was purchased from Slope Indicator. The new datalogger also required a “Radio Lid” that Slope Indicator provides.

The VW Piezometer (VWP) and the VW Minilogger have been installed in Piezometer 13 at the impoundment. Data can be downloaded directly from the unit using a laptop and an RS-232 cable. The datalogger stores the data that is collected from the sensor in an ASCII format, so transferring the data to a program such as Excel for analysis is fairly straightforward. Installation of the VWP was not completed until late March, so the comparison with the hydrostatic water level transducer must be done in the next phase of the project.

6.4 Frozen Wind Speed Sensor

A final setback that has not already been discussed in any part of this thesis is a minor problem. It was found during a visit to the impoundment during the winter that the wind speed sensor was frozen to the point in which it would not operate. This problem is completely irresolvable due to the fact that freezing rain and snow are uncontrollable during the winter. An attempt to loosen the sensor was futile due to the immense amount of ice that had built up on the working parts. The only solution is to allow the sensor to thaw normally with everything else. This problem will inevitably persist with lost wind data during the winter months, but nothing can be done to avoid the situation.

CHAPTER 7: PROJECT PICTURES

Figure 66: Impoundment Image

A good view of the slurry pond can be seen directly atop the impoundments crest. This impoundment is continuously under construction, so this view changes often.

Figure 67: Installation at P7 Image

Eastern Associated Coal's Mark Bailey (right) stands with WVU's Dr. Larry Banta (left) after finishing a sensor installation at Piezometer 14 at the Rocklick Impoundment.

Figure 68: Hydrostatic Water Level Transducer Image

A Hydrostatic Water Level Transducer is shown before it is lowered into an open standpipe. The transducer is approximately 0.75 inches in diameter.

Figure 69: Lowering Sensor into Piezometer Image

Dr. Larry Banta feeds a sensors cable to GRA James Altobello as he lowers the sensor down the standpipe. The datalogger and Radio Modem are housed in the NEMA 4 Enclosure to the right of the standpipe.

Figure 70: Electronics Image

A NEMA 4 Enclosure houses the electronics required to monitor the sensors installed in the impoundment. The enclosure contains a long-range radio modem (top right), a HOBO datalogger (center left), and a 12 V batter (bottom right). Also, mounted on the enclosure is a 5 watt solar panel to charge the battery and supply power to the radio modem.

Figure 71: Sensor and M-Scope Image

Mark Bailey's M-scope cable (right) is shown as his sensor is being lowered into the standpipe. This shows that there is ample room for this project's sensors and cables (left) to be permanently installed while leaving Mark enough room to continue taking his manual readings every week.

Figure 72: Checking Water Level in Field Image

James Altobello (left) and Dr. Larry Banta (middle) hold the cable for a Hydrostatic Water Level Transducer as Mark Bailey (right) lowers his M-scope sensor down the standpipe.

Figure 73: Installing Weather Station and Repeater Image

Dr. Larry Banta (left) works on a repeater radio modem used for data transmission to locations that are difficult to gain line-of-sight communication to the warehouse. James Altobello (right) works to finish the installation of the weather station that is located off the right corner of the crest of the impoundment.

Figure 74: Installation at Toe Image

James Altobello works on the electronics for the station located just above the pumps at the toe of the impoundment. This station incorporates a specific conductance sensor and an oxidation reduction potential sensor.

Figure 75: Replacing Battery at Weather Station Image

Dr. Larry Banta is diligent through a snow storm while he replaces a battery in the enclosure for the weather station. The weather station is located in an area where daily sunshine is limited. The battery here lasts up to one month during the winter and 2.5 months in the summer.

Figure 76: Flow Meter Controls Image

A recent addition to the impoundment project is an ultrasonic flow meter. The electronics to handle the sensors and readings is shown in a weatherproof enclosure.

Figure 77: Flow Meter Leads Image

The sensor heads for the ultrasonic flow meter are shown here circled. The spacing of the leads is extremely important in acquiring an accurate reading of flow.

Figure 78: Pond Monitoring Station Image

John Quaranta helps to install the pond monitoring station. This station will be temporarily installed until the water level of the impoundment threatens to overtake the frame structure.

CHAPTER 8: PROJECT CONCLUSIONS AND RECOMMENDATIONS

This project, funded by the National Technology Transfer Center, has produced positive and negative feedback throughout the research and the process implementation. It has provided a beginning step for the possibilities of installing and maintaining a standardized remote data acquisition system for the coal slurry impoundments located across West Virginia, as well as in other states.

This project has proved that it is possible to operate a remote data acquisition system in conjunction with a working field data collection plan, and the resulting data from each are comparable and reasonably accurate. This project has shown that remote data acquisition for performance monitoring of a coal slurry impoundment is a viable alternative to standard manual practices and offers a greater quantity of usable data.

This project is not without its setbacks, though. Some issues that arose with the implementation of the system include: 1) Reduced sunlight during winter months allows increased power drain on the batteries caused by the radio modems resulting in data transfer inconsistencies; 2) Line-of-sight issues provide increased problems for data communications; 3) Equipment from different manufactures prove to ensure more tedious setup for data acquisition; and 4) Data acquisition software cannot control all functions of modem configurations and cannot display graphs and data automatically.

Some solutions have been provided for these setbacks including additional solar panels and higher amp-hour batteries to prevent data loss and communication failures, larger antennas to overcome the line-of-sight difficulties, and additional software programs written to control radio modem functions. These, however, are not all permanent solutions, and power loss continues to be

an issue (although improvements in length of operation have been made). A more practical solution to decreasing power loss would be design a better power management system.

This research may also lead to the implementation of a remote monitoring system with “watch-dog” capabilities. This means that the system would be able to automatically monitor the data that is retrieved and compare the readings to predetermined measurement thresholds. If any measured value were to be out of range then the system could automatically notify engineers and emergency response personnel via e-mail or phone. One such case in which this type of system would be effective is if drastic changes in water level were measured, indicating possible leaks or impending failure. Warning engineers and emergency response officials could possibly save lives.

Finally, the expenses to install the complete working system as it exists as of April 1, 2007 were approximately \$25,500. This can be considered to be a baseline cost for a system that was pieced together and built on site. Much of the construction of the data collection boxes was performed at WVU, not prefabricated. To employ a system that was provided entirely by a single supplier and prefabricated with minimal on-site construction, the costs could be considerably higher. Estimation for a system of this kind could eclipse \$40,000; however, the expenses could be justified over a long term implementation by reducing the number of man hours involved in manually taking measurements and improving the emergency response which could lead to less expenses for damage that might be caused by an impoundment failure. A list of the equipment purchased and installed can be found in Appendix D

This project will continue to grow and expand its data collection capabilities over the next year, and it will provide increased support and data to the impoundment design engineers and the West Virginia University Coal Impoundment Research program. So far, this project has provided key insight

into remote monitoring of coal slurry impoundments and may lead to the installation of commercialized monitoring packages, but it is not a replacement for visual inspections of the impoundments. This research has provided a greater quantity of data for analysis to be used in concurrence with practices already in place.

APPENDIX A: EQUIPMENT AND SENSOR DESCRIPTION AND SPECIFICATIONS

HOBO Microstation Datalogger

Designed to fit into tight spaces and even tighter budgets, the versatile four-input HOBO Micro Station Data Logger is an alternative to using the 10 channel HOBO Weather Station data logger. The Micro Station data logger is the perfect choice for applications requiring multi-channel monitoring of microclimates in one or more locations. The Micro Station can be user-configured with up to four plug-in smart sensors for research-grade measurements, and automatically recognizes each sensor without complicated wiring, programming, or calibration. Each Micro Station Logger can log over 500,000 measurements and will operate for up to one year using only four AA batteries.

Software Options:

- HOBOWare Software Kit (required) for system launch, data analysis, graphing and file export. (BoxcarPRO software is also compatible)
- Remote Site Manager software (optional) can be used for launch and readout via Radio Modem, Remote Phone Modem or local serial port connection
- HandCar EX software (optional) provides users with the option for logger launch and data offload to a Palm™ handheld while in the field.

Flexible, Reliable, Easy To Use:

- Small size and low price make multi-channel micro-climate monitoring easy.

- Select only the measurements you need from Onset's research-grade smart sensors.
- Scalable system size and flexible sensor mounting allow users to position the logger and sensors optimally.
- Smart sensors offer plug and play logging simplicity.
- Runs for one year on four user-replaceable AA batteries (typical).
- 512K memory can store over one-half million measurements.
- Non-volatile EEPROM memory retains data even if batteries fail.

Specifications:

- Operating Range: -20° to 50°C (-4° to 122°F) with alkaline batteries; -40° to 70°C (-40° to 158°F) with optional lithium batteries
- Sensor Inputs: Up to 4 smart sensors (can include multiple-parameter sensors that require more than one data channel)
- Communication: 38.4 K baud RS-232; 6 minutes for full 512 K offload with BoxCar Pro 4.3
- Dimensions: 8.9 cm x 11.4 cm x 5.4 cm (3.5" wide x 4.5" height x 2.125" depth)
- Weight: 0.5 kg (1 lb) approximate
- Memory: 512 kilobytes nonvolatile data storage (number of measurements depends on sensors used; sensors require from 8- to 12-bits per measurement)
- Memory Modes: Stop when full, Wrap around when full
- Operational Indicators: LEDs provide logging and network status
- Logging Interval: 1 second to 9 hours, user-specified interval
- Battery Life: 1 year typical use (up to 4 sensors with 10 min or longer logging interval)
- Battery Type: Four standard AA alkaline batteries included (for operating conditions of 20° to 50°C [-4° to 122°F]); optional AA lithium batteries available (for operating conditions of -40° to 70°C [-40° to 158°F])
- Time Accuracy: 0 to 2 seconds for the first data point and ± 3 seconds per week at 25°C (77°F)
- Data Type: Supports measurement averaging based upon availability of supporting data from sensor
- Logger Start Modes: Immediate, push-button, or delayed start options
- Data Communication: Current reading while logging, offload while logging, or when stopped
- Environmental Rating: Weatherproof
- Mounting: Mount on flat surface 3.5" or wider; optional mast mounting kit for use on 4.1 cm (1 5/8") diameter masts
- Enclosure Access: Cover secured by four screws
- Sensor network cable length: 100 meters (328 ft) maximum

HOBO 8 Bit Temperature Smart Sensor

Part Number: S-TMA-M002

The 8 Bit temperature smart sensor is designed to work with the HOBO Micro Station Data Logger or HOBO Weather Station Data Logger. The smart sensor has a plug-in modular connector that allows it to be easily connected to the data logger.

Features:

- Measurement range: -40° to +75°C (-40° to +167°F)
- Accuracy: $\pm 0.7^{\circ}\text{C}$ @ +25°C ($\pm 1.3^{\circ}\text{F}$ @ +77°F)
- Resolution: 0.4°C @ +25°C (0.7°F at +77°F)
- Drift: $< 0.1^{\circ}\text{C}$ (0.2°F) per year
- Response time: < 2.5 minutes typical in 2 meter/second airflow
- Housing: Stainless steel sensor tip
- Dimensions: 1/4" x 1 1/4" (0.6 cm x 3.2 cm)
- Approximate Weight: 1 oz (30 g), 4 oz (110 g), 12 oz (340 g); weight varies with cable length
- Cable Lengths: 2 meter, 6 meter, 17 meter (6.5', 20', 56')
- Number of Data Channels Used: 1

NOTE: Sensor tip and cable immersion in fresh water up to 50°C for one year; Radiation Shield strongly recommended for use in sunlight

Rain Gauge Smart Sensor

The Rain Gauge smart sensor is designed to work with the HOBO Micro Station data logger or HOBO Weather Station data logger. The smart sensor has a plug-in modular connector that allows it to be easily connected to the data logger.

Features:

- Mechanism: Tipping bucket, stainless steel shaft with brass bearings
- Resolution: 0.2 mm and 0.01" models
- Measurement Range: 10 cm or 0" to 5" per hour; maximum 4000 tips per interval
- Operating Range: 0° to 50°C (32° to 122°F); survival -40° to 75°C (-40° to +167°)
- Calibration Accuracy: $\pm 1.0\%$ at up to 20 mm or 1" per hour
- Calibration: Requires annual calibration; can be field calibrated by user or returned to factory
- Housing: Aluminum housing and collector
- Dimensions: 22.8 cm height x 15.4 cm diameter (9" height x 6" diameter), 154 mm receiving orifice (6.06")
- Approximate Weight: 1 Kg (2 lbs)
- Cable Lengths: 2 meter, 6 meter (6.5', 20')
- Number of Data Channels Used: 1

NOTE: Comes with side brackets for post or tripod mount and feet for surface mount. If mounting separate from main tripod, order with 6m cable and an additional 1.5m mast. If mounting on main tripod, order with guy wire kit.

Barometric Pressure Smart Sensor

The Barometric Pressure smart sensor is designed to work with the HOBO Micro Station data logger or HOBO Weather Station data logger. The smart sensor has a plug-in modular connector that allows it to be easily connected to the data logger.

Features:

- Measurement Range: 660 mb to 1070 mb (19.47 to 31.55 inHg)
- Operating Range: -10° to 60°C (14° to 140°F); survival range: -20° to +70°C (-4° to +158°F)
- Accuracy: ± 1.5 mbar (0.044 inHg) over full pressure range at +25°C (+77°F); additional temperature induced error of ± 2.5 mbar over -10° to +60°C (+14°F to +140°F)
- Resolution: 0.1 mbar (0.003 inHg)
- Drift: Typical ± 0.6 mb (0.018 inHg) per year, maximum <2.5 mb (0.074 inHg) per six months
- Dimensions: 4.5 cm x 4.8 cm x 1.6 cm (1 3/4" x 1 7/8" x 5/8")
- Approximate Weight: 30 g (1 oz)
- Cable Lengths: 10 cm (4")
- Number of data channels used: 1
- Measurement: Average over logging interval, user-defined sampling interval from 1 second

NOTE: Must be used inside logger enclosure to assure protection from direct exposure to the weather

Wind Speed Smart Sensor

The Wind Speed smart sensor is designed to work with the HOBO Micro Station Data Logger or HOBO Weather Station Data Logger. The smart sensor has a plug-in modular connector that allows it to be easily connected to the weather data logger.

Features:

- Measurement Range: 0 to 45 m/s (0 to 100 mph)
- Operating Range: -40° to 75°C (-40° to 167°F)
- Accuracy: ± 1.1 m/s (2.4 mph) or $\pm 4\%$ of reading whichever is greater
- Resolution 0.38 m/s (0.85 mph)
- Service Life: > 5 year life typical
- Distance Constant: 3 meters
- Housing: 3 cup anemometer with TEFLON bearings and hardened beryllium shaft
- Dimensions: 190 cm x 51 cm (7.5" x 3.2")
- Approximate Weight: 300 g (10 oz)
- Cable Lengths: 3 meter (10')
- Number of Data Channels Used: 2 total (only 1 port required)
- Measurement: Average wind speed and highest 2 second gust in logging interval
- Survival to 120 mph; starting threshold is 1 m/s (2.2 mph)
- Cross arm recommended or pole mount (2 hose clamps required for pole mount)
- A wind speed and direction sensor is also available

0-5VDC Input Adapter Smart Sensor

Input adapters make it easy to use third-party sensors with the HOBO Weather Station Logger or the HOBO Micro Station Logger. The 12-bit Voltage Input Adapter interfaces with sensors providing 0 to 5 VDC signals. The adapters provide a trigger signal for controlling power to external sensors.

Features:

- 12-bit resolution
- Digital filtering improves measurement accuracy with 32 readings/sample; 4-20 mA adapter has 60 Hz noise rejection
- Measurement averaging over logging interval further enhances accuracy
- Plug-in modular connector for easy interface with HOBO Weather Station or HOBO Micro Station data loggers
- Screw terminal for connecting to sensors
- Uses one data input channel
- Cable length: 14 cm (5.5 inch)

Specifications:

- 12-bit Voltage Input Adapter (S-VIA-CM14)
- Measurement Range: 0-5 V DC
- Measurement Accuracy: ± 10 mV $\pm 0.3\%$ of reading
- Resolution: ± 1.221 millivolts
- Input impedance: 1 Megohms
- Ground connection: same for adapters and PC interface
- Trigger Open Collector: Maximum sink current: 115 mA; 30 V max.
- Trigger Source: Voltage: 2.5 V $\pm 2.4\%$; maximum current: 1 mA
- Trigger Timing:
  - Warm-up Time: 10.3 ms $\pm 3\%$ (fixed)
  - Measurement Time: 2.4 ms $\pm 3\%$
- Operating Temperature Range: -40° to 75°C (-40° to 167°F)

NOTE: Shielded sensor cables are recommended. Sensor cables for the Micro Station logger should be 0.125" to 0.150" diameter (3.2mm-3.8mm). Diameter is not critical for the Weather Station logger.

MaxStream 9XTend Radio Modem

The 9XTend RS-232/485 RF Modem provides outstanding range (up to 40 miles) and security in a low-cost wireless solution. The modem is coupled with a DIP switchable RS-232 / RS-422 / RS-485 interface board and mounted in an anodized aluminum enclosure.

No configuration is necessary for out-of-box RF communications. The modem's default configuration supports a wide range of data system applications. Advanced configurations can be implemented using simple AT or binary commands.

Specifications:

Performance

Power Output:	1 mW - 1 Watt (0 - 30 dBm), software selectable
Indoor/Urban Range:	up to 3000' (900m)
Outdoor/RF Line-of-sight Range:	up to 40 miles (64 km)
RF Data Rate:	9.6 or 115.2 Kbps
Interface Data Rate:	up to 230.4 Kbps
Receiver Sensitivity:	-110 dBm (@ 9600 bps)

Networking

Spread Spectrum Type:	FHSS (Frequency Hopping Spread Spectrum)
Networking Topology:	Peer-to-peer, point-to-point, point-to-multipoint & repeater
Error Handling:	Retries & acknowledgements, multiple transmissions
Filtration Options:	VID (Vendor ID Number), channels and addressing
Channel Capacity:	10 hop sequences share 50 frequencies
Addressing:	65,000 network addresses available for each channel
Encryption:	256-bit AES

Power

Supply Voltage:	7 - 28 V
Transmit Current:	900 mA (@ 1W TX Power Output)
Receive Current:	110 mA
Power-down Sleep Current:	17 mA

General

Frequency Band:	902 - 928 MHz
Data Connection:	Female DB-9

Physical Properties

Size:	2.750" x 5.500" x 1.125" (6.99cm x 13.97cm x 2.86cm)
Weight:	6.1 oz. (200g)
Antenna Options:	RPSMA (Reverse Polarity SMA)
Operating Temperature:	-40 to 85° C (industrial)

Slope Indicator VW MiniLogger

VW MiniLogger

- **Sensor Compatibility:** Reads VW sensors operating in the range of 450 to 6000 Hz. Also reads temperature sensors (RTD and thermistor).
- **Data Storage:** Stores 8,000 records in secure, non-volatile memory. Each record includes a VW reading, a temperature reading, and the time and date. When memory is full, recording either stops or continues by overwriting the earliest readings, according to user preference.
- **Logger Settings:** Assign a logger ID; specify whether to stop when memory is full or to overwrite earliest readings.
- **Sensor Settings:** Assign a sensor ID, set sweep range for excitation, store calibration factors, and set temperature sensor to RTD or thermistor.
- **Reading schedule** starts recording immediately on power up or at specified date and time. The datalogger records readings at intervals from one reading every two seconds to one reading per week.
- **Logging schedule:** set logger to start recording on power up or at a specific date and time (to synchronize readings with other MiniLoggers or data loggers). Set reading intervals to day, hour, minute, and second.
- **Power:** Two D-cell batteries provide power for approximately six months at temperatures from -20 to +50°C, assuming readings are taken every half-hour.
- **Weatherproofing:** MiniLogger electronics are completely encapsulated in waterproof resin. Polycarbonate box has O-ring seal and cable gland for signal cable.
- **Dimensions:** 100 x 100 x 90 mm high (4 x 4 x 3.5").
- **Data Retrieval:** Readings are retrieved via RS-232 serial connection or by wireless link to computer running MiniLogger Manager Program.

Slope Indicator Vibrating Wire Piezometer

The VW piezometer is used to monitor pore-water pressure. Typical applications include:

- Monitoring pore water pressures to determine safe rates of fill or excavation.
- Monitoring pore water pressures to determine slope stability.
- Monitoring the effects of dewatering systems used for excavations.
- Monitoring the effects of ground improvement systems such as vertical drains and sand drains.
- Monitoring pore pressures to check the performance of earth fill dams and embankments.
- Monitoring pore pressures to check containment systems at land fills and tailings dams.
- **Sensor Type:** Pluck-type vibrating wire sensor with built-in thermistor or RTD.
- **Range:** 3.5, 7, 17, 35 bar (50, 100, 250, 500 psi). Other ranges can be quoted on request.
- **Resolution:** 0.025%FS.
- **Accuracy:** $\pm 0.1\%$ FS for 3.5 and 7 bar piezometers, $\pm 0.3\%$ FS for 17 and 35 bar piezometers.
- **Maximum Pressure:** 1.5 x rated range.
- **Filter:** 50-micron sintered stainless steel.
- **Temperature Coefficient:** $< 0.04\%$ FS per $^{\circ}\text{C}$.
- **Materials:** Stainless steel.
- **Dimensions:** 19 x 195 mm (0.75 x 7.75").
- **Weight:** 0.16 kg (0.3 lb).

Pressure Systems Hydrostatic Water Level Transducer

The Series 705 transducer is an economically-sized non-fouling level transducer featuring a 0.90" non-stick sensing area. It is designed to provide reliable depth measurement in highly viscous wastewater applications. It's welded 316 Stainless Steel or Titanium housing carries an IP 68/NEMA 6P rating and accommodates advanced electronics. The Series 705 Transducer is available in 4 different Outputs and various electrical connection options.

Specifications:

- Full Scale Level Range: 6-115 ft H₂O
- Proof Pressure: 1.5xFS
- Burst Pressure: 2.0xFS
- Static Accuracy $\pm 0.25\%$ FSO
- Resolution: Infinitesimal
- Wetted Materials: 316 SS
- Compensated Temp Range: 0 to 50 °C
- Thermal Error: $\pm 0.10\%$ FSO/°C
- Operating Temp. Range: -20 to 60 °C
- Protection Rating: IP 68, MEMA 6P
- Excitation: 9-30VDC
- Input Current 3.5 mA (max)
- Output: 0-5VDC
- Zero Offset: <0.1VDC
- Output Impedance: <10 ohms
- Insulation Resistance: 100 Mohm
- Approximate Weight: 0.5 lbs
- Cable: Jacket Material: Polyurethane
  - Pull Strength: 200 lbs
  - Number of Conductors: 4
  - Conductor size: 22 AWG

Innovative Sensors CSIM11 pH Probe

The CSIM11 is a versatile sensor that measures the full pH range. The sensor is designed for submersion or insertion into tanks, pipelines, and open channels. The sensor features a plunger-style pH glass electrode allowing it to be mounted at any angle. The porous Teflon® liquid junction is less susceptible to clogging as compared to conventional reference junctions. A titanium ground rod runs inside the PPS outer body to eliminate ground loop errors. An internal amplifier boosts the signal, decreasing signal interference.

Features

- 0 to 14 pH measurement range; accuracy is ± 0.1 pH unit
- Operable environments are 0° to +70°C; pressure 0 to 30 psig
- Requires 107 probe for temperature measurement and compensation
- Manufactured by Innovative Sensors

Specifications

- Temperature Range: 0° to +70°C
- Pressure Range: 0 to 30 psig
- Accuracy: $\pm 0.1\%$ over full range
- pH Range: 0 to 14
- Weight: 1 lb (0.5 kg)
- Sensor length: 7.0" (17.8 cm)
- Sensor diameter: 1.2" (3.0 cm)

Innovative Sensors CSIM11-ORP Probe

The CSIM11-ORP is a versatile sensor that measures oxidation reduction potential (ORP). The sensor is designed for submersion or insertion into tanks, pipelines, and open channels. The CSIM11-ORP is similar to the CSIM11-pH, but includes a 0.2 inch platinum band wrapped around the glass electrode. This allows the CSIM11-ORP to respond to the electron density in the fluid. A titanium ground rod runs inside the PPS outer body to eliminate ground loop errors. An internal amplifier boosts the signal, decreasing signal interference.

Features

- -700 to +1100 mV measurement range
- Operable environments are 0° to +70°C; pressure 0 to 30 psig
- Requires 107 probe for temperature measurement and compensation
- Manufactured by Innovative Sensors

Specifications

- Temperature Range: 0° to +70°C
- Pressure Range: 0 to 30 psig
- Accuracy: $\pm 0.1\%$ over full range
- ORP Range: -700 to +1100 mV

Innovative Sensors CSIM11-ORP Probe

Campbell Scientific's CS547A conductivity sensor measures the electrical conductivity (EC), total dissolved solids, and temperature of water. The CS547A is suitable in most surface water, laboratory, and industrial applications.

EC is measured with three cylindrical stainless steel electrodes mounted in an epoxy housing. The electrode configuration eliminates ground loop problems associated with sensors in electrical contact with earth ground. To reduce electrochemical reactions, minimize corrosion, and extend the probe's life, the electrodes are ac coupled, and a bipolar excitation is applied. Temperature is sensed with a thermistor.

The CS547A is easy to clean and resistant to corrosion. It has rounded ends to facilitate installation and removal. For groundwater applications, a weighted option is available to facilitate stand-alone submersion.

Features

- Conductivity measurement range is optimized for fresh water
- Temperature measurement made with thermistor

Specifications

- Conductivity range: 0.005 to 7.0 mS/cm
- Depth rating: Maximum 1000 ft (305 m)
- Lead length: Up to 1000 ft (305 m)
- pH range: survives 3.0 to 9.0
- Temperature measurement range: 0° to 50°C
- Temperature accuracy: Polynomial linearization error typically <0.1°C over 0° to 48°C
- Thermistor interchangeability: typically <0.2°C over 0° to 50°C
- Minimum pipe ID in which CS547A fits: 1.1" (2.79 cm)
- Dimensions: 1" x 0.75" x 3.5" (2.54 x 1.91 x 8.89 cm)
- Weight: 4.2 oz (120 g) w/4 ft lead

Sundance Solar 5 Watt OEM Solar Panel

The rugged 5 Watt outdoor solar panel comes complete with a built-in blocking diode and a ten foot UV resistant output cable. Aluminum framed glass.

Typical Electrical Characteristics

- Maximum Power (P_{max}) 5W
- Voltage at P_{max} (V_{mp}) 17.0V
- Current at P_{max} (I_{mp}) 0.30A
- Short-circuit current (I_{sc}) 0.33A
- Open-circuit voltage (V_{oc}) 21.0V

Mechanical Characteristics

- Dimensions 9.75" x 9.5" x 1.5"
- Weight 1.88 lbs

Model 205 Innova-Sonic™ Transit-Time Ultrasonic Flow Meter

Innova-Sonic ultrasonic flowmeter is a state-of-the-art universal transit-time flowmeter incorporating the latest developments in digital signal processing. Sophisticated electronics coupled with powerful ultrasonic transducers deliver highly accurate flow measurement for liquids in full pipes. While principally designed for clean liquid applications, the instrument is tolerant of liquids with a small quantity of air bubbles or suspended solids common in most industrial applications.

Innova-Sonic offers low power consumption, high reliability, and outstanding applicability at an economical price. An easy to read display and clear, user-friendly menu selections make using the instrument simple and convenient. The instrument can be configured via keypad without any additional programming devices, is packaged in a die cast NEMA 4X (IP65) housing, and is available in your choice of non-invasive clamp-on or insertion transducer configurations.

Innova-Sonic features a self-contained 4-20 mA current loop signal output for instantaneous flow, as well as two independent temperature inputs for thermal energy monitoring. The instrument also features a 7 digit alpha-numeric display, parallel operation of positive, negative and net flow totalizers (with user-selectable scale factors) and configurable pulse and frequency outputs (transmitted via relay and open collector) for totalized flow.

- Accuracy better than +/-1%
- Wide operating temperature range -40F to +300F (-40C to 150C)
- One meter for a wide range of pipe sizes 1-200" (25mm-5000mm)
- Clamp-on sensors are simple to install
- Clamp-on sensors mean no pipe cutting or process interruption
- Hygienic measurement, no risk of contamination
- Wide bi-directional Flow range of 1.5 to 40 fps
- Daily, monthly and yearly totalized flow
- Internally configured batch controller makes batch control convenient
- Measurement is independent of fluid conductivity

APPENDIX B: COMPANY OVERVIEWS

Slope Indicator

Slope Indicator manufactures a full range of geotechnical and structural sensors for monitoring tilt, displacement, pressure, and strain. The company also supplies data acquisition systems and web-based monitoring software for automated processing and distribution of data.¹⁰⁰ However, their “package” systems were much more expensive than the final design.

Campbell Scientific

Campbell Scientific manufactures dataloggers, data acquisition systems, and measurement and control products used worldwide in research and industry. Their instrumentation is known for its flexibility, precision measurements, and dependability—even in harsh, remote environments.¹⁰¹

Geokon

Over the years, Geokon has emerged as one of the leading designers and manufacturers of a broad range of high quality geotechnical instrumentation. In particular, Geokon, has developed a line of vibrating wire sensors unsurpassed anywhere in the world. These highly reliable devices have contributed in no small way to the growing worldwide acceptance of vibrating wire technology.¹⁰²

Heron Instruments

Heron Instruments provide some of the most reliable water level meters, interface meters, and groundwater level dataloggers available. The sensors and tapes are supplied as multi-use tools for determining water levels in many

applications. These sensors are generally made to be used at the time of measurements, and are not recommended for long term or permanent applications.¹⁰³

RST Instruments, LTD

RST entered the environmental sector to manufacture and distribute a line of groundwater monitoring instrumentation that geotechnical and hydrogeological consultants use. Products include borehole packers, water level meters, water level data loggers, hydrocarbon interface sensors and groundwater samplers. Engineers worldwide have installed RST's inclinometer casings for accurate slope stability monitoring.¹⁰⁴

Esterline: Pressure Systems

Pressure Systems, Inc. (PSI) is the leading supplier of innovative electronic pressure scanners, pressure measurement systems, and precision pressure transducers for aerospace vehicle and propulsion research. PSI is the manufacturer of industry recognized KPSI™ Level and Pressure Transducers including hydrostatic level sensors, submersible level transducers, pressure transducers, and instrumentation for environmental and municipal water management as well as other industrial process applications.¹⁰⁵

Onset (HOBO)

Onset manufactures small, battery-powered HOBO data loggers, weather stations, and Tattletale data logger/controllers for use in indoor, outdoor, and underwater monitoring applications. Innovative product design and high-volume, in-house manufacturing assure affordable, accurate, and reliable data logger performance. Onset products are used by more than 50,000 customers in a

broad range of environmental research, industrial, and energy/HVAC applications.¹⁰⁶

MicroDAQ

MicroDAQ is an authorized distributor of over 25 manufacturers of data logging, data acquisition, and weather station products. They address the data recording needs of the transportation, pharmaceutical, HVAC/R, environmental, educational, scientific and industrial communities.¹⁰⁷ One of their main providers is Onset, as well as Esterline Pressure Systems.

MaxStream

MaxStream supplies OEM (Original Equipment Manufacturer) products and integrators with reliable radio modems and radio modules that meet the unique needs of industry and commerce. The wireless modems are easy-to-use and provide reliable delivery of critical data between devices.¹⁰⁸

Crossbow Technologies

Crossbow Technology is a leading supplier of inertial sensor systems for aviation, land, and marine applications and other instrumentation sensors as well as the leading full solutions supplier in the wireless sensor networking arena. Crossbow has for years been at the forefront of creating and deploying smaller, smarter, wireless sensing devices and mesh networking platforms for large scale defense, environmental, agricultural, industrial monitoring and control, building automation, security and asset tracking applications.¹⁰⁹

APPENDIX C: MicroDAQ *AutoDialer* SETTINGS EXAMPLE CODE

```

<!-- This is the beginning of the example settings file. ALL nodes
listed bellow MUST be present. A missing node will cause the software
to throw an exception and quit.
    Also, all node names are CASE SENSITIVE. The software WILL fault
and throw an exception if "CommPort" is written "commport". -->
<AutoDialer>

    <!-- The serial port to use -->
    <CommPort>1</CommPort>

    <!-- data rate to communicate at -->
    <BaudRate>38400</BaudRate>

    <!-- Silence time to wait before trying to enter command mode
(Format: milliseconds) -->
    <GuardTime>1000</GuardTime>

    <!-- Each remote location must have one of these Location entries
    If Enabled is False, the software will ignore this location
when loading this settings file -->
    <Location Enabled="True">
        <!-- A short name for the location -->
        <Name>Remote location #1</Name>

        <!-- A short description for the location. -->
        <Description>Located in a tree 6mi NE from
base</Description>

        <!-- This is the interval with which the software will wait
between readings. (Format: hours:minutes:seconds) -->
        <SampleInterval>01:00:00</SampleInterval>

        <!-- This setting causes the software to start the process
of dialing slightly before the actual SampleInterval.
        (Format: hours:minutes:seconds) -->
        <SampleOffset>00:01:00</SampleOffset>

        <!-- This setting is used to help determine what time of
the day to sample.
        If this value is in the future, the software will
wait until this date/time to sample.
        (Format: mm/dd/yyyy hh:mm:ss) -->
        <SampleFrom>1/1/2000 00:00:00 </SampleFrom>

        <!-- This is the actual information used for programming
the local modem.
        If UseDialString is True, then the software will only
look at the DialString setting
        If not, then it will derive the dial string from
Address, Channel and SleepTime -->
        <Config UseDialString="True">

```

```

        <!-- Directly specifies the exact dial string for
this location.
        Use this to add custom settings to the dialing
process. -->
        <DialString>DT1,HP0</DialString>

        <!-- This is the address of the remote modem for this
location. (Format: Integer 0 to 65534) -->
        <Address>1</Address>

        <!-- This is the hopping channel (piece of frequency)
of the remote modem. (Format: Integer 0 to 9 (see modem user-guide to
be certain)) -->
        <Channel>0</Channel>

        <!-- This is amount of time the local modem should
wait while the remote modem wakes up.
        MUST be longer than the cyclic sleep time used
by remote modem.
        Recommended value: (Cyclic sleep time in
seconds) * 10 + 5
        Format: Integer from 0 to 255 (This value is
multiplied by 100ms internally)
        For more documentation, please see the LH
setting in your user-guide -->
        <SleepTime>0</SleepTime>
        </Config>
    </Location>

    <!-- Use the above Location node as a template and create new
ones bellow this line -->

    <!-- Finally, make sure that EVERY node has a matching end node -
->
</AutoDialer>

```

APPENDIX D: EQUIPMENT COSTS AND PROJECT EXPENSES

IMPOUNDMENT EQUIPMENT

Campbell Scientific www.campbellsci.com Phone: 1-435-750-1739				
Product #	Product Description	Unit Cost	Units	Total
AVW1-ST-SW Part: 4290-1	VW Interface	\$158.40	3	\$475.20
CS547A-L100-CW Part: 16725-59	Water Conductivity Probe + 100 ft of cable	\$384.80	3	\$1,154.40
A547 Part: 12323	Specific Conductance Interface	\$100.80	3	\$302.40
CSIM11-L100 Part: 16509-50	PH Sensor + 100 ft of cable	\$374.20	3	\$1,122.60
CSIM11-ORP-L100 Part: 16508-20	ORP Sensor + 100 ft of cable	\$393.40	3	\$1,180.20
IM11REFILL Part: 16349	PH/ORP Probe Refill Solution	\$8.64	1	\$8.64
107-L100 Part: 10755-158	Temperature Probe (-35 to +50C)	\$100.00	3	\$300.00
TOTAL:				\$4,543.44

Durham Geo Slope Indicator www.slopeindicator.com Phone: 1-800-331-0703				
Product # and Cost	Product Description	Unit Cost	Units	Total
56313310	VW Minilogger	\$540.00	1	\$540.00
52611040	Vibrating Wire Piezometer	\$350.00	3	\$1,050.00
50613524	400 feet of cable (attached to two sensors)	\$0.65/ft	1	\$260.00
TOTAL:				\$1,850.00

MaxStream www.maxstream.net Toll Free Phone: 1-866-765-9885				
Product #	Product Description	Unit Cost	Units	Total
A09-F8NF-M	8.1 dBi - 65" Omni-Directional High Gain Antenna	\$180.00	2	\$360.00
A09-F5NF-M	5.1 dBi fiberglass Omnidirectional Antenna	\$135.00	4	\$540.00
JR2N1-CL1-6F	6 foot, RPSMA male to N-male connector	\$42.00	4	\$168.00
TOTAL:				\$1,068.00

McMaster Carr www.mcmaster.com				
Product #	Product Description	Unit Cost	Units	Total
7865K47	14" x 12" x 6" NEMA 4 Enclosure	\$107.02	10	\$1,070.20
7871K67	12 3/4" x 10 7/8" Insert Panel	\$10.04	10	\$100.40
3043T52	U-Bolts for 3/4 inch mounts (10 pk)	\$6.35	2	\$12.70
9307K21	3/8" ID, 1/16" th rubber grommet - 50pk	\$5.00	2	\$10.00
TOTAL:				\$1,193.30

Sundance Solar Contact at 1-603-456-2020					
Product #	Product Description	Unit Cost	Units	Total	
201-10024-00	5 Watt OEM Solar Panel	\$77.50	15	\$1,162.50	
201-10027-00	20 Watt Solar Panel - 12V Framed	\$189.00	1	\$189.00	
700-11403-00	12 Volt 18 Amp Hour Sealed Lead Acid Battery	\$34.95	8	\$279.60	
201-10056-00	Mounting Bracket for 5 Watt OEM	\$11.95	15	\$179.25	
TOTAL:				\$1,810.35	

Interstate Batteries www.interstatebatteries.com					
Product #	Product Description	Unit Cost	Units	Unit Total	
SLA1075	12 V, 7.5 AH, sealed lead acid battery	\$26.99	17	\$458.83	
TOTAL:				\$458.83	

Miscellaneous Parts Various Hardware Stores					
Product #	Product Description	Unit Cost	Units	Unit Total	
-----	3/4 inch rebar (10 ft. sections)	7.5	8	\$60.00	
-----	Miscellaneous small parts (nuts, bolts, etc.)	-----	-----	\$300.00	
TOTAL:				\$360.00	

MicroDAQ (HOB0)				
www.microdaq.com Toll Free Phone: 1-877-275-9606				
Product #	Product Description	Unit Cost	Units	Total
H21-002	HOB0 Micro Station Data Logger	\$189.00	10	\$1,890.00
S-TMA-M002	Temperature Sensor with 2m cable	\$75.00	1	\$75.00
S-RGA-M002	Rain Gauge (0.1") with 2m cable	\$385.00	1	\$385.00
S-BPA-CM10	Barometric Pressure Sensor with 10cm cable	\$119.00	1	\$119.00
S-WSA-M003	Wind Speed Sensor with 3m cable	\$199.00	1	\$199.00
705-13H-0	Submersible Hydrostatic Level Transducer (<i>Slurry Application</i>)	\$595.00	7	\$4,165.00
26-03-0424ER	Cable for submersible hydrostatic level transducers	\$1.45	1250	\$1,812.50
S-VIA-CM14	0-5 VDC Input Adapter for Level Transducer	\$66.00	19	\$1,254.00
CABLE-HWS-G	HOB0 Micro Station Grounding Wire (required for use with Wind Speed/Direction sensor or when mounting on a metal mast or tripod)	\$19.00	1	\$19.00
BHW-PC	HOB0ware Software and User Manual for Windows	\$95.00	1	\$95.00
Cable-PC-3.5	Adapter cable to run HOB0ware Software	\$9.00	1	\$9.00
RSM	Remote Site Manager Software CD	\$10.00	1	\$10.00
XT09-PKI-RA-NA	MaxStream Xtend 1 Watt, 900 MHz Wireless Modem, RS232/485	\$273.00	11	\$3,003.00
2N-400-30F	30 Ft. RPSMA male to N-male connector for high gain antenna	\$65.00	1	\$65.00
Cable-HWS-F	Micro Station Adapter Cable	\$43.00	11	\$473.00
M-TPB-Kit	Complete 2m Tripod Kit (see below for included parts)	\$155.00	1	\$155.00
M-CAB	Half Cross Arm to Mount the Wind Speed Sensor	\$30.00	1	\$30.00
M-RSA	Solar Radiation and Rain Shield for Temperature Sensor	\$90.00	1	\$90.00
TOTAL:				\$13,848.50
Complete 2-Meter Tripod Kit Includes				
(1) M-TPB, 2 meter tripod				
(1) M-GKA, Grounding Kit				
(1) M-GWA, Guy wire kit				
(1) M-SKA, 1/2" Stake Kit (for guy wires)				
(1) M-SKB, 1/4" Stake Kit (for tripod)				
(1) M-MLA, Mast Level				
GRAND TOTAL =				\$25,132.42

ENDNOTES

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- ² U.S. Army Corps of Engineers, "Engineering and Design – Instrumentation of Embankment Dams and Levees," EM 1110-2-1908, 30 June 1995, National Technical Information Service, pg. 4-1
- ³ <http://coalimpoundment.com>
- ⁴ Ibid.
- ⁵ <http://www.geotimes.org/dec01/NNcoal.html>
- ⁶ <http://www.geotimes.org/dec01/NNcoal.html>
- ⁷ <http://coalimpoundment.com>
- ⁸ <http://coalimpoundment.com>
- ⁹ National Research Council, "Responses to Recommendations," 2001
- ¹⁰ Ward Jr., Ken, "Coal dams still loom over W.Va.," West Virginia Gazette,
<http://wvgazette.com/static/series/buffalocreek/BUF302B.html>
- ¹¹ <http://coalimpoundment.com>
- ¹² EM 1110-2-1908, pg. 2-1 – 2-2
- ¹³ Ibid., pg. 2-1
- ¹⁴ Ibid., pg. 2-1
- ¹⁵ Ibid., pg. 2-1
- ¹⁶ Ibid., pg. 2-1
- ¹⁷ Ibid., pg. 2-1
- ¹⁸ Ibid., pg. 2-1
- ¹⁹ Ibid., pg. 2-1
- ²⁰ Ibid., pg. 2-1
- ²¹ Ibid., pg. 2-3
- ²² Ibid., pg. 2-4
- ²³ Ibid., pg. 2-4
- ²⁴ Ibid., pg. 2-3
- ²⁵ Ibid., pg. 2-4
- ²⁶ Ibid., pg. 2-4
- ²⁷ Ibid., pg. 2-4
- ²⁸ Ibid., pg. 2-4
- ²⁹ Ibid., pg. 2-5
- ³⁰ Ibid., pg. 2-5
- ³¹ Ibid., pg. 2-5
- ³² Ibid., pg. 2-5
- ³³ Ibid., pg. 2-5
- ³⁴ Ibid., pg. 2-5
- ³⁵ Ibid., pg. 2-5
- ³⁶ Ibid., pg. 2-5
- ³⁷ Ibid., pg. 2-5
- ³⁸ Ibid., pg. 2-6
- ³⁹ Ibid., pg. 2-6

⁴⁰ Ibid., pg. 3-1

⁴¹ Ibid., pg. 3-1

⁴² Ibid., pg. 3-2

⁴³ Ibid., pg. 3-2

⁴⁴ Ibid., pg. 3-2

⁴⁵ Ibid., pg. 3-2

⁴⁶ Ibid., pg. 3-2

⁴⁷ Ibid., pg. 3-2

⁴⁸ Ibid., pg. 3-2

⁴⁹ Ibid., pg. 3-3

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⁵² Ibid., pg. 3-4

⁵³ Ibid., pg. 3-4

⁵⁴ Ibid., pg. 4-1

⁵⁵ Esterline Pressure Systems, “KPSI™ Level and Pressure Transducers User’s Manual,” 12th Edition, January 2006, pg. 2

⁵⁶ Ibid., pg. 4-2

⁵⁷ Ibid., pg. 4-4

⁵⁸ Ibid., pg. 4-4

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⁶⁰ Ibid., pg. 4-4

⁶¹ Ibid., pg. 4-5

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⁶⁴ Ibid., pg. 4-18

⁶⁵ Ibid., pg. 4-18

⁶⁶ Ibid., pg. 4-18 – 4-19

⁶⁷ Ibid., pg. 4-19

⁶⁸ Ibid., pg. 4-19

⁶⁹ Ibid., pg. 5-1

⁷⁰ Ibid., pg. 5-2

⁷¹ Ibid., pg. 5-1

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⁷³ EM 1110-2-1908, pg. 5-1

⁷⁴ Ibid., pg. 5-1 – 5-2

⁷⁵ Ibid., pg. 5-3

⁷⁶ Ibid., pg. 5-3

⁷⁷ Ibid., pg. 5-3

⁷⁸ Ibid., pg. 5-3

⁷⁹ Ibid., pg. 5-4

⁸⁰ Ibid., pg. 5-3

⁸¹ Ibid., pg. 5-4

⁸² Ibid., pg. 5-3

⁸³ Ibid., pg. 5-3

⁸⁴ Ibid., pg. 5-3

⁸⁵ Alliance Consulting, Inc., Drawing No. B02-222-E7

⁸⁶ "General Information on Specific Conductance,"
<http://bcn.boulder.co.us/basin/data/BACT/info/SC.htm>

⁸⁷ Ibid.

⁸⁸ Esterline Pressure Systems, "KPSI™ Level and Pressure Transducers User's Manual," 12th Edition, January 2006, pg. A-2

⁸⁹ Onset Computer Corporation, "12-Bit 0-5 Volt Input Adapter (Part # S-VIA-CM14)," Doc #: 7554-A, pg. 3

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⁹⁴ WVDEP, "Engineering Design Report," s-5020-86, pg. 40

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⁹⁶ Ibid., Proj. # B89-91-23, Table 1

⁹⁷ Hubbell, J.M.; Sisson, J.B.; Nicholl, M.J.; Taylor, R.G., "Well Design to Reduce Barometric Pressure effects on Water Level Data in Unconfined Aquifers," Vadose Zone Journal 3, 2004, pg. 183-189,

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