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Hydrologic Mass Balance Of Pervious Concrete Pavement With Sandy Soils

Thomas Kunzen
University of Central Florida

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HYDROLOGIC MASS BALANCE
OF PERVIOUS CONCRETE PAVEMENT
WITH SANDY SOILS

by

THOMAS E. KUNZEN
B.S. University of Central Florida, 2004

A thesis submitted in partial fulfillment of the requirements
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ABSTRACT

Use of pervious concrete pavement as a method of stormwater management has shown great promise in previous studies. Reduction in runoff, water quality improvements, and long-term economic benefits are but a few of its many advantages. Regulatory agencies such as the St. Johns River Water Management District require further research into the performance of pervious concrete pavement before granting credits for its use as a best management practice in controlling stormwater. As a part of a larger series of studies by UCF's Stormwater Management Academy, this thesis studies the hydrologic mass balance of pervious concrete pavement in sandy soil common in Florida.

In order to conduct this study, a field experiment was constructed at the UCF Stormwater Field Lab. The experiment consisted of three 4-foot tall cylindrical polyethylene tanks with 30-inch diameters. All three tanks were placed into the side of a small embankment and fitted with outlet piping and piezometers. The test tanks were assembled by laying a 6-inch layer of gravel into the bottom of each tank, followed by a layer of Mirafi geofabric, followed by several feet of fine sand into which soil moisture probes were laid at varying depths. Two of the tanks were surfaced with 6-inch layers of portland cement pervious concrete, while the third tank was left with a bare sand surface. Mass balance was calculated by measuring moisture influx and storage in the soil mass.

Data collection was divided into three phases. The first phase ran from August to November 2005. Moisture input consisted of normal outdoor rainfall that was measured by a nearby rain gauge, and storage was calculated by dividing the soil mass into zones governed by soil moisture probes. The second phase ran for two weeks in March 2006. Moisture input consisted of water manually poured onto the top of each tank in controlled volumes, and storage was calculated by using probe readings to create regression trendlines for soil moisture profiles. The third phase followed the procedure identical to the second phase and was conducted in the middle of April 2006.

Data tabulation in this study faced several challenges, such as nonfunctional periods of time or complete malfunction of essential measuring equipment, flaws in the method of calculating storage in phase one of the experiment, and want of more data points to construct regression trendlines for soil moisture calculation in phases two and three of the experiment. However, the data in all phases of the experiment show that evaporation volume of the tanks with pervious concrete surfacing was nearly twice that of the tank with no concrete. Subsequent infiltration experiments showed that pervious concrete pavement is capable of retaining a portion of precipitation volume, reducing infiltration into the underlying soil and increasing total evaporation in the system.

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LIST OF ACRONYMS/ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing of Materials
EPA	Environmental Protection Agency (United States)
FCPA	Florida Concrete Products Association
PCA	Portland Cement Association
UCF	University of Central Florida

CHAPTER ONE: INTRODUCTION

1.1 Background

Portland cement pervious concrete is a concrete product that differs from traditional concrete in that no fines are added to the mix, utilizing only aggregate, cement, and water. The lack of fines creates a matrix of void spaces inside the concrete mass, allowing water to percolate from the surface down into the subgrade. The lack of fines in the concrete mix reduces its strength as opposed to traditional concrete, and therefore renders it unsuitable for most structural applications that require high compression strength. However, one application in which pervious concrete shows promise is in the use of permeable pavements.

Pervious concrete first came into widespread use in Europe during the post-World War II period when high demand for building materials created scarcity that necessitated the introduction of novel materials. During this time, pervious concrete was used for structural walls in single-family houses and multi-story housing projects. The first use of pervious concrete as pavement did not occur until the mid-1960s in England (FCPA).

Use of pervious concrete as a pavement material carries several advantages over traditional impervious pavement materials. Its permeable nature that allows passage of water through the concrete mass reduces runoff, which in turn can reduce the need for storm sewers and other storm water control structures. The lack of runoff or ponded water on the pavement surface creates a safer driving surface as glare and hydroplaning are reduced. Rainfall is allowed to percolate into the ground where it recharges the aquifer instead of wastefully being disposed of elsewhere, while pollutants are trapped in the concrete mass.

However, pervious concrete is not suitable for use in all conditions. Its lower strength makes it primarily ideal for low-traffic and low-load areas such as parking lots, sidewalks, and driveways. Pervious concrete pavements also have historically had a high failure rate of approximately 75 percent, primarily due to contractors' lack of experience installing pervious concrete, engineers' lack of experience designing it, and operators' lack of vigilance in maintaining it (EPA 1999).

Despite its disadvantages, pervious concrete pavement systems can be effective water quality and quantity control measures with adequate native conditions, design, construction, and maintenance. With this in mind, water management districts such as the Southwest Florida WMD and the St. Johns River WMD that are responsible for design standards of stormwater control systems are interested in the possibilities presented by pervious concrete pavement (Wanielista 2005). In addition, the EPA is also considering issuing credit points to projects utilizing pervious concrete to control runoff and pollution (Tennis 2004).

Before these regulatory agencies sign off on pervious concrete pavement and issue finalized design specifications and requirements, further research must first be conducted to their satisfaction. The faculty and students of the Stormwater Management Academy at the University of Central Florida is in the process of performing several studies on various pervious concrete pavement issues, such as infiltration rate, maintenance issues, and water quality performance. This thesis concerns the experiment conducted from the summer of 2005 to the spring of 2006 to develop an understanding of the hydrologic mass balance in pervious concrete pavement.

The published body of knowledge contains many studies on pervious concrete issues such as optimal mix parameters and compaction methods and water quality comparisons. However, the issue of hydrologic mass balance has largely been ignored. Japanese researchers have studied the mechanisms of heat transfer in urban environments using several types of ground surfacing, including pervious concrete pavement, but the issue of evaporation was only peripherally referenced as a cause for temperature variation among the different types of pavement, and was not measured as an end in itself (Asaeda 1997).

1.2 Research Objectives and Scope

The primary goal of this study is to develop an understanding of evaporation of water through pervious concrete pavement from the underlying soil medium. The work supports the conclusion that pervious concrete pavement increases the rate of evaporation.

In order to measure evaporation through pervious concrete, an experimentation setup was designed for use with the hydrologic mass balance equation, which was simplified by elimination of equation variables such as infiltration through control of the environment. The setup consisted of three polyethylene tanks filled with sandy soil similar to that found at the natural ground surface in many parts of Florida, two of which were surfaced with a layer of pervious concrete and one of which was left as bare soil. Rainfall was measured continuously using a tipping-bucket rain gauge sensor, and soil moisture content was measured on a regular basis using soil moisture probes buried in the soil during tank construction. Experimentation was separated into three phases. The first phase relied on natural rainfall for moisture inflow into the tanks, and moisture storage was calculated by dividing the soil inside the tanks into zones of influence governed by specific soil moisture probes. The second phase was conducted during a dry period of negligible rainfall, thus moisture inflow consisted almost entirely of controlled volumes of water poured on the tanks at sporadic intervals, while moisture storage was calculated by using the readings taken at the moisture probes to construct a curve using regression. The third phase was identical to the second phase with the exception that surface temperatures of the three tanks were recorded.

1.3 Research Approach

This document is comprised of five chapters. In Chapter One, pervious concrete and the immediate scope of the research in this study are introduced. In Chapter Two, the current body of knowledge regarding pervious concrete issues is summarized. In Chapter Three, the concepts behind the experimentation and the physical model for data collection are explained. In Chapter Four, the findings of the experimentation are presented, and in Chapter Five, some concluding remarks and recommendations for further study are offered. In the Appendices, data tables are provided for soil tests, moisture probe calibration, field readings during experimentation, and calculation of storage and other parameters.

CHAPTER TWO: LITERATURE REVIEW

2.1 Previous Studies

One of the well-known problems associated with land development is the conversion of natural watershed areas to impervious space, disrupting the hydrological balance in the vicinity by impeding infiltration of water into the soil and creating large amounts of runoff that cause erosion and degrade quality of receiving waters. The standard stormwater management solution in areas not serviced by a municipal storm sewer system is the excavation of retention ponds to collect runoff from impervious areas to facilitate infiltration and/or offsite release at a controlled rate, However, these ponds take up valuable land area to meet the required retention volume. In the state of Florida alone, 2500 acres of land are set aside for stormwater ponds in new developments each year (Ghafoori 1995c). Thus, the use of pervious concrete pavement has a multiple purpose; that is, to treat stormwater, thereby reducing the need for more expensive management options, while at the same time providing a stable and durable paved surface for regular use (FCPA).

Pervious concrete has numerous advantages over traditional pavements. If properly maintained, it has the ability to filter out pollutants found in runoff and trap them in the concrete mass, allowing treated water to percolate into the underlying soil where it can recharge the aquifer. With this infiltration capacity, less water is carried across the surface as runoff, resulting in less need for curbing and storm sewers to handle it. Another benefit of reduced or eliminated ponding of runoff is safer driving conditions, as skid resistance is improved and headlight glare is reduced (EPA 1999). Pervious concrete is also relatively unobtrusive, and can easily blend into a typical urban environment (Georgia 2001).

Pervious concrete, specifically Portland cement pervious concrete, is one of three specific varieties of porous concrete, the other two being cellular and lightweight aggregate concrete. Cellular concrete uses a chemical reaction to create gas bubbles inside the concrete mass, while lightweight aggregate concrete uses porous material as an aggregate, Of these three varieties of porous concrete, pervious concrete using a no-fines mix is the only one with the capability to absorb stormwater, as its porosity is the result of an interconnected matrix of void spaces (Ghafoori 1995a). These voids take up between 15 and 25 percent of the concrete mass by volume, allowing for infiltration rates of approximately 480 inches per hour (Tennis 2004).

Pervious concrete is well-suited for low traffic applications such as parking spaces in primary lots and as auxiliary parking lots, as pedestrian sidewalks and trails, and as residential driveways (Georgia 2001). Successful pavement applications also include patios, tennis courts, greenhouse floors, and roadside edge drains (Tennis 2004). However, some stormwater agencies have regulations in place governing its use. The Georgia Stormwater Management Manual requires the use of backup stormwater conveyance structures for larger storm events, such as storm inlets with inverts places slightly higher than the surface of the pavement. In this case, some ponding would be acceptable, but the inlets should exist to handle runoff volumes beyond the infiltration capability of the pavement, or in the event that the pavement clogs (2001). The Southwest Florida Water Management District similarly requires the treatment volume to be recovered in 72 hours, and that concrete curbing should be in place around the pervious pavement to prevent off-site discharge in the event of ponding due to pavement failure (Higginbotham 1996).

Pervious concrete is excellent for filtering pollutants out of stormwater runoff in typical concentrations, but it is not recommended in sites where there is a risk of a spill or similar event causing a contaminant to infiltrate into groundwater, Gas stations, industrial sites, liquid container storage areas, and hazardous waste facilities are all examples of this. Also unacceptable are sites with high concentrations of fertilizers or pesticides in runoff, such as golf courses or farmland (Smith 2003).

A typical section of pervious concrete pavement consists of several layers. The topmost layer is the actual Portland cement pervious concrete layer, with a variable thickness depending on anticipated loads, but usually ranging from 2 to 8 inches. Research by Ghafoori has shown that the two primary design procedures used to calculate required pavement thickness, the PCA method and the AASHTO method, are both acceptable for use in designing pervious concrete sections. The PCA procedure was more suited to thinner sections, while the AASHTO method was more suited to thicker sections (Ghafoori 1995c).

The Georgia Stormwater Management Manual specifies a 1- to 2-inch thick top filter layer consisting of ½-inch diameter crushed stone below the concrete for stabilization. Below this should be a 2- to 4-foot thick reservoir layer consisting of gravel with 40% void spaces. Thickness of this layer should be designed such that the void spaces can hold the required treatment volume and drain it in 48 hours. Below this should be a bottom filter layer consisting of 6 inches of sand or 2 inches of ½-inch diameter crushed stone. This layer is required to stabilize the reservoir layer and to protect the underlying soil from compaction. Between the bottom filter layer and the underlying soil, a liner of geofabric should be placed to prevent soil migration into the reservoir layer, which would occupy void space and reduce storage capacity. The underlying soil itself should have a permeability of 0.5 inches per hour or more and should not be excessively compacted during the construction process (2001). Variations to this specified cross-section are common, however. In Florida, native sandy soils can have naturally high permeability, and pervious concrete may be placed directly on top of the native soil once the site has been stripped and leveled without the need for a reservoir layer (Offenberg 2005).

Except for the omission of fines, portland cement pervious concrete consists of the same materials as traditional concrete. Either portland cement (ASTM C150) or blended cement (ASTM C595) is acceptable for use. Cement content may vary, but approximately 600 pounds per cubic yard is an average proportion. Ground granulated blast furnace slag or fly ash can be substituted for a portion of the cement, if desired. Commonly used aggregates are 3/8-inch to ¾-inch diameter gravel, which should be used in proportions of approximately 2000 to 2500 pounds per cubic yard. Both rounded and angular aggregates are suitable for use, although rounded aggregates tend to provide pavement with higher strength (Tennis 2004).

Water content in the mix must be carefully controlled, with an average water to cement ratio of 0.27 to 0.34. Correct water content can be verified during the mixing process when the mixture has a “wet-metallic sheen.” A correctly proportioned mixture, when lightly formed into a ball in the hands, should hold its shape without crumbling or reverting back to an amorphous mass, which would indicate either insufficient moisture or excessive moisture, respectively (Tennis 2004). Pervious concrete with a high water content will, when poured, cause the cementitious paste to flow down into the pavement, leaving insufficient bonding for the aggregate in the top layer and plugging the void spaces in the bottom. Low water content will result in insufficient bonding throughout the entire pavement mass. Both situations cause premature failure of the pavement (FCPA).

For placement of a pervious concrete pavement, the first step is proper preparation of the subgrade. Underlying soil should be smoothed and compacted to approximately 92 to 96% of the modified Proctor maximum density. Compaction past this point will negatively impact the infiltration ability of the soil and the performance of the entire pavement system. Subgrade soil should also be lightly moistened prior to concrete placement, as dry soil will leech moisture out of the concrete mixture (Offenberg 2005).

Because of the sensitivity of the water content, pervious concrete should be placed within an hour of batch mixing, although this time can be extended somewhat with the use of admixtures. High temperatures and wind will induce rapid drying of the concrete, and care should be taken in these conditions. After being placed, pervious concrete may be struck with a screed and consolidated with a steel roller. A hand-held tamper may be used to compact pervious concrete near edges and where inaccessible by rollers. Consolidation should be completed within 15 minutes of initial placement (Tennis 2004). The pavement should then be covered with plastic sheeting held in place with lumber or steel rebar for seven days to allow the concrete to cure. This covering should begin no more than 20 minutes after placement. Once the plastic has been removed after seven days, the pavement may be opened to traffic (Offenberg 2005).

The EPA encourages pervious concrete to be placed on as flat a surface as possible, and does not recommend its use on slopes greater than 5 percent (1999). Moisture tends to travel horizontally inside the pavement mass on slopes instead of percolating into the soil. This moisture then accumulates in low spots which are unable to handle the additional water volume (Field 1982). Pervious concrete has also been shown to be a source of failure in impervious pavement when placed adjacent to each other. Moisture that infiltrates into the subgrade through the pervious concrete results in a higher water table in the immediate locality. This additional moisture then causes increased deflection and cracking, thus traditional pavement placed next to pervious concrete should be designed accordingly (FCPA).

Compressive strength of pervious concrete can range from 500 to 4000 psi, depending on the mix, but an average value is 2500 psi. When it is desired to rest the compressive strength of a pervious concrete mixture, samples should be obtained by drilling a core out of pavement that has been placed and cured instead of casting a cylinder, as a cast sample is compacted differently and will therefore yield test results different from actual field conditions. Compaction and curing methods are also important in preventing surface raveling during the service life of the pavement. Even the best-placed pervious concrete will experience some initial raveling, though, as loosely-bound aggregate pieces at the pavement surface will be sheared off by vehicle traffic for a few weeks after entering regular service (Tennis 2004).

Meininger's research in 1988 studied the performance of several different pervious concrete mixes and compaction methods. It was found that a minimum air void content of 15 percent was necessary to create the network of interconnected void spaces essential to the permeability of water, and that heavy compaction methods consistently produced concrete with air void content lower than 15 percent. The research concluded that a water-to-cement ratio between 0.35 and 0.45 was necessary to create paste of the consistency needed to bond the aggregate without flowing off. Meininger also experimented with adding sand to the pervious concrete mixture. Sand has the effect of filling in the air voids, raising compressive strength but reducing air void content. In small amounts, however, appreciable strength benefits were obtained while maintaining the required void space. This experiment utilized a concrete mixture using ¾-inch aggregate, and aggregate-to-cement and water-to-cement ratios of 6 and 0.38, respectively. Sand was added to the mixture in proportions of 10 and 20 percent of aggregate mass. The baseline pervious concrete mixture with no fines had an air void content of 26 percent and a compressive strength of 1500 psi. The 10 and 20 percent fines mixes had air void contents of 22 and 17 percent and compressive strengths of 1800 and 2500 psi. A mix with 30 percent fines was also attempted but discarded because of insufficient air void content (1988).

In a similar study, Ghafoori concluded that porosity and unit weight of pervious concrete were inversely proportional, and devised a linear equation to describe the relationship between the two. This proportionality follows from the expectation that as unit weight increases from continued compaction, air voids are reduced as their volume is replaced by solids. This has the effect of preventing the creation of the void space network that gives pervious concrete its permeability (1995c).

Among the first studies on pervious concrete as a roadway pavement was Maynard's 1970 experiment. A 600-foot long roadway section was constructed in the rural north of England. The road consisted of a 2-inch thick pervious concrete layer over an 8-inch slab of traditional concrete. The pervious concrete was made with 3/8-inch diameter aggregate and an aggregate-to-cement ratio of 4. Compressive strength of 2000 psi and unit weight of 90 pounds per cubic foot were measured. The test road apparently was initially successful, but the road was extensively used by heavy farm machinery that tracked soil particles onto the pavement. The heavy loads and clogging of void spaces, combined with damage from freeze/thaw cycles, led to ponding of water and extensive raveling such that the road was declared a failure ten years later (Ghafoori 1995b).

The use of pervious concrete as a pavement for parking lots in Florida was explored in two studies in 1975 and 1981. The 1975 study by Medico concerned a pervious concrete mixture using a proprietary adhesive admixture, laid over two base layers of aggregate. The concrete was mixed and placed by hand. The 1981 study by Monahan involved a concrete mixture without admixtures or aggregate base, but prepared using a high-speed mixer and placed with a paving machine. The 1975 concrete showed a compressive strength of 3800 psi and a permeability of 3.68 inches per minute in tests, and the backers of the 1981 concrete claimed a permeability of 10 inches per minute (Ghafoori 1995b).

A study by Pratt published in 1995 investigated performance of permeable pavement consisting of concrete block pavers with square holes. The holes were filled with gravel, and below this surface layer, a reservoir layer of gravel was placed, separated from the pavers by a geotextile. The main focus of this study was water quality, but a side experiment was conducted in which evaporation losses through the pavement were measured. During periods of negligible rainfall, evaporation rates of less than 0.01 inches per day were recorded, although evaporation increased with rainfall. A week with 1.34 inches of rainfall resulted in 0.22 inches of evaporation per day. There was no further discernible pattern in evaporation that the researchers could establish, however (Pratt 1995). It must be noted, however, that these low evaporation rates are partially a result of lower temperature and lower incoming solar radiation due to Britain's climate and latitude, and that the depth of the groundwater table was not noted in the published study.

A study performed at Saitama University in Japan in 1994-1995 investigated thermal characteristics of various surfacing materials and their effects in impacting the ambient temperatures in urban environments. Included in these materials were natural grass, brick, porous ceramic pavement, and various porous and non-porous asphalt and concrete pavements. The researchers measured temperatures at the surface of the material and in the underlying soil at various depths. Due to the large amount of evapotranspiration, the natural grass had the lowest surface temperature. Similarly, because of the high absorption of solar radiation and the absence of any evaporation, the dark non-porous asphalt pavement had the highest temperature. Porous ceramic pavement had a surface temperature roughly equal to that of the natural grass due to the fact that its small pore size resulted in capillary action, which retained water in the pavement mass after rainfall and even drew moisture out of the underlying soil. However, porous concrete pavement had much larger pore spaces than the ceramic pavement, which resulted in rapid permeability and lack of moisture retention. As a result, evaporation was very low, and the surface temperature was nearly that of the dark asphalt pavement (Asaeda 1997).

CHAPTER THREE: METHODOLOGY

3.1 Experiment Design

In order to create a system in which evaporation could be measured, an experiment had to be designed to account for all terms of the mass balance equation:

$P + R + B - F - E - T = \Delta S$ (Equation 1)

Precipitation (P), runoff (R), and subsurface flow (B) are all inputs, while infiltration (F), evaporation (E), and transpiration (T) are all outputs, which, when added together, produce the change in storage(ΔS) (Wanielista 1997).

Previous studies performed by Stormwater Management Academy students to determine mass balance in a soil mass utilized test chambers installed outdoors. It was decided to use the same basic setup for this experiment. A test chamber enclosing the soil mass to be studied would eliminate horizontal subsurface flow and vertical infiltration out of the soil mass, while transpiration would be eliminated by the absence of vegetation. The test chamber would have to be installed into the ground to best replicate the subterranean thermal profile that would govern the evaporation this study wished to measure. Runoff would be controlled by preventing any precipitation that falls onto the area of the test chamber from flowing off its surface.

As this conceptualization process of the test chambers proceeded, it was realized that it may become necessary to allow water to flow out of the chambers. Therefore, some effluent system would have to be incorporated into the test chambers to allow for water withdrawal (W). It would also be necessary to measure precipitation and soil moisture storage.

A total of three test chambers were envisioned. Two test chambers would be surfaced with pervious concrete, and the third chamber would leave the soil mass directly exposed to the atmosphere. With runoff, infiltration, subsurface flow, and transpiration removed from consideration, the mass balance equation is reduced to:

$P - W - E = \Delta S$ (Equation 2)

In order to measure evaporation, therefore, known quantities for precipitation, moisture storage, and water withdrawal are necessary.

3.2 Selection of Materials

For the test chambers, three polyethylene cylindrical tanks were selected. These tanks, open on one end, have a diameter of 2.5 feet and a height of 4.0 feet with a wall thickness of 0.5 inch. Measurement of precipitation would be handled by a David Instruments Vantage Pro weather station located at the Stormwater Field Lab. The weather station incorporates a tipping-bucket rain gauge for continuous measurement of rainfall, along with temperature and other parameters, which are recorded every 30 minutes. This information was ported to a laptop computer and delivered via email at regular intervals.

Since two of the test tanks would incorporate pervious concrete surfacing, it was necessary to have a non-intrusive method of measuring soil moisture content that did not require disturbance of the concrete. EC-20 ECH2O soil moisture probes, manufactured by Decagon Devices, Inc., were selected. The probes, shown in Figure 1, could be buried in the soil while wires connected to the probes lead out of the soil mass out the top of the test tanks. The EC-20 probes work by measuring the dielectric constant of the soil to find volumetric moisture content (Decagon 2002). The wires end in a "stereo-plug" style connector that plugs into the ECH2O Check, a hand-held readout device that displays the moisture content on an LCD screen in inches of water per foot of soil, as shown in Figure 2.

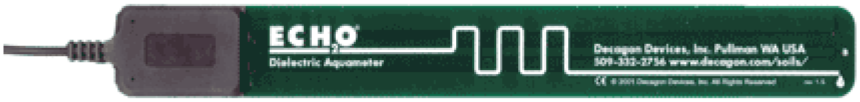

Figure 1: ECH2O EC-20 Soil Moisture Probe

Figure 2: ECH2O Check Display Device

Upon request, two tons of brown fine sand was delivered to the Stormwater Field Lab courtesy of Rinker Materials. This soil type was chosen because it is generally found at the natural ground surface in many parts of Florida and because of its widespread use as fill in construction areas where the native surface soil is unsuitable for development. Samples of the sand were taken to the UCF Geotechnical Laboratory for analysis. Tests run on the sand samples included sieve analysis, standard proctor compaction analysis, and falling head permeability analysis. The particle size distribution curve and the standard proctor compaction curve are shown in Figures 3 and 4, respectively. Soil properties ascertained during testing are summarized in Table 1.

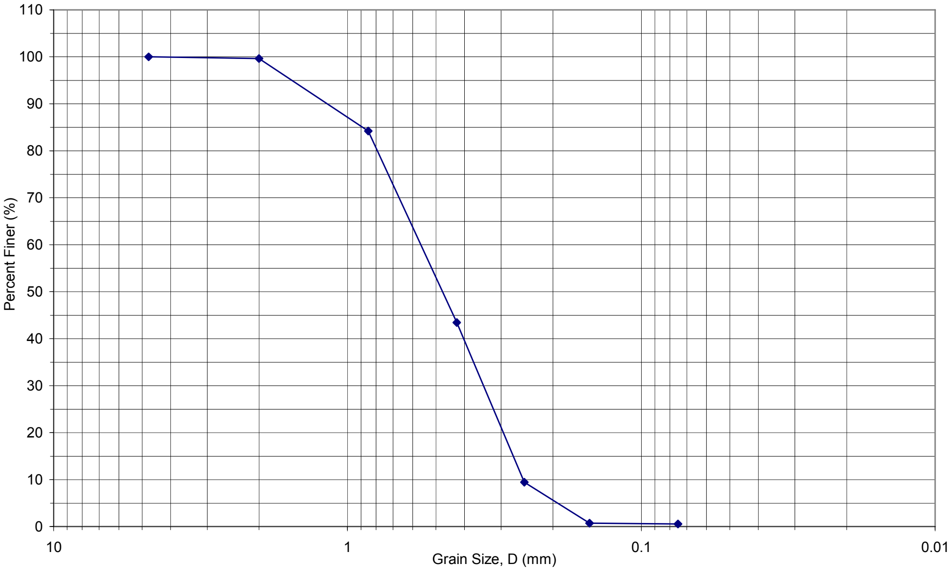

Figure 3: Sand Particle Size Distribution Curve

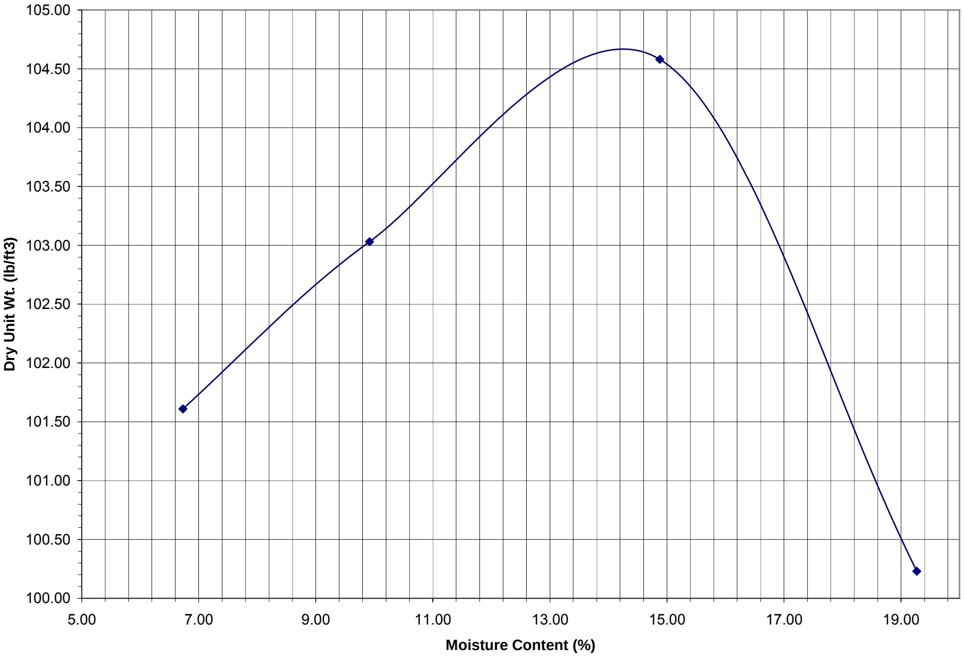

Figure 4: Sand Standard Proctor Compaction Curve

Table 1: Sand Properties

Soil type	Poorly-graded fine sand
Unified soil classification	SP
AASHTO soil classification	A-3
Maximum dry unit weight (lb/ft^3)	104.70
Optimum moisture content	14.30
92% dry unit weight (lb/ft^3)	96.32
Specific gravity	2.65
Void ratio	0.563
Porosity	0.36
Vertical permeability (in/hr)	69.12

The ECH2O Check device had to be re-calibrated for the sand, since the device was manufactured calibrated to soil types with greater fines content. The calibration followed the procedure detailed in Decagon’s publication entitled “Calibrating ECH2O Soil Moisture Probes,” and involved taking probe readings on a quantity of sand while continuously adding water to the sand. For each addition of water, the probe readout was recorded and samples were taken from the larger sand sample, then set aside for moisture content testing. These data were then used to create a calibration curve for the sand sample, followed by adjusting moisture content calculation parameters on the ECH2O device. Part of the calibration procedure is shown in Figures 5 and 6.

Figure 5: ECH2O Probe Calibration Materials

Figure 6: ECH2O Probe Calibration in Progress

3.3 Construction of Experiment

Construction of the test tanks at the UCF Stormwater Field Lab lasted from July to August, 2005. An existing embankment where several other projects of similar setup were located was chosen as the project site. A backhoe provided by UCF Physical Plant created a cut in the embankment where the ground was leveled before the tanks were placed in a row roughly 3 inches apart. ¾-inch diameter holes were drilled at the bottom of each tank, where threaded fittings were installed and sealed with plumbers' putty and silicone caulking. ¾-inch PVC pipe was connected to each fitting, and a valve was installed at the end of each pipe to control water outflow. Also installed near the valve at the end of each pipe was a nipple for subsequent installation of a piezometer tube. The tanks during this stage of construction are shown in Figures 7, 8, and 9. After the caulking was allowed to set for 24 hours, the tanks were filled with 3 inches of water and left overnight. No leakage was observed the next morning, thus verifying that the seals were watertight.

Figure 7: Test Tank Construction in Progress

Figure 8: Test Tank Construction in Progress

Figure 9: Valve Assembly Details

At the bottom of each tank, a 6-inch layer of gravel was poured to assist in drainage. A layer of Mirafi geofabric was placed on top of the gravel, so that water would be allowed to percolate into the gravel layer while keeping out sand particles.

Sand was then placed in the tanks in 3-inch lifts. Since a 3-inch thick tank section would have a volume of 1.23 cubic feet, and since the desired degree of compaction was 92% of the standard proctor maximum unit weight determined in soil testing, each lift required approximately 120 pounds of sand, along with 16 pounds of water to achieve the approximate optimum moisture content of 14.3 percent. Since 136 pounds of moist soil would have been impractical to mix and carry at once, each lift required two wheelbarrow trips, each transporting approximately 68 pounds of moist soil. After the required moist soil mass for each lift was placed in the tank, the soil was compacted using a hand tamper until a lift thickness of 3 inches was achieved, discernible by looking through the translucent tank walls.

The ECH2O probes were installed in the tanks as the lifts were being placed. Following the procedure outlined in the ECH2O User's Manual, soil was compacted slightly around the contact surface of each probe so as to eliminate the presence of large void spaces that would cause the probe to return false results. Probes were installed at depths of 1.5 and 2.5 feet in tank 1, and at depths of 1.0, 2.0, and 3.0 feet in tanks 2 and 3.

Sand lifts were placed in tanks 1 and 2 to a depth of 0.5 feet, at which time portland cement pervious concrete was mixed under the supervision of Craig Ballock and Josh Spence. The concrete was mixed using 40 pounds of 3/8-inch gravel as aggregate, 10 pounds of portland cement, and 12 pounds of water per batch, and was prepared by first mixing the gravel and cement. Water was added gradually and continually stirred, until such time as the aggregate was covered in a layer of cement that gave off a shiny, metallic sheen. The concrete mix was then poured on top of the sand and compacted using a hand tamper. Three batches of concrete prepared in this manner were required to lay down a 6-inch layer in each tank. Plastic sheeting, held down by lumber, was used to cover the concrete during the pouring process in between batches and for a subsequent seven days to allow for proper curing. A concrete surface was not specified for tank 3, so sand lifts were placed to a depth of 0.1 feet instead. A cut-away schematic of the final test tank construction is shown in Figure 10. .

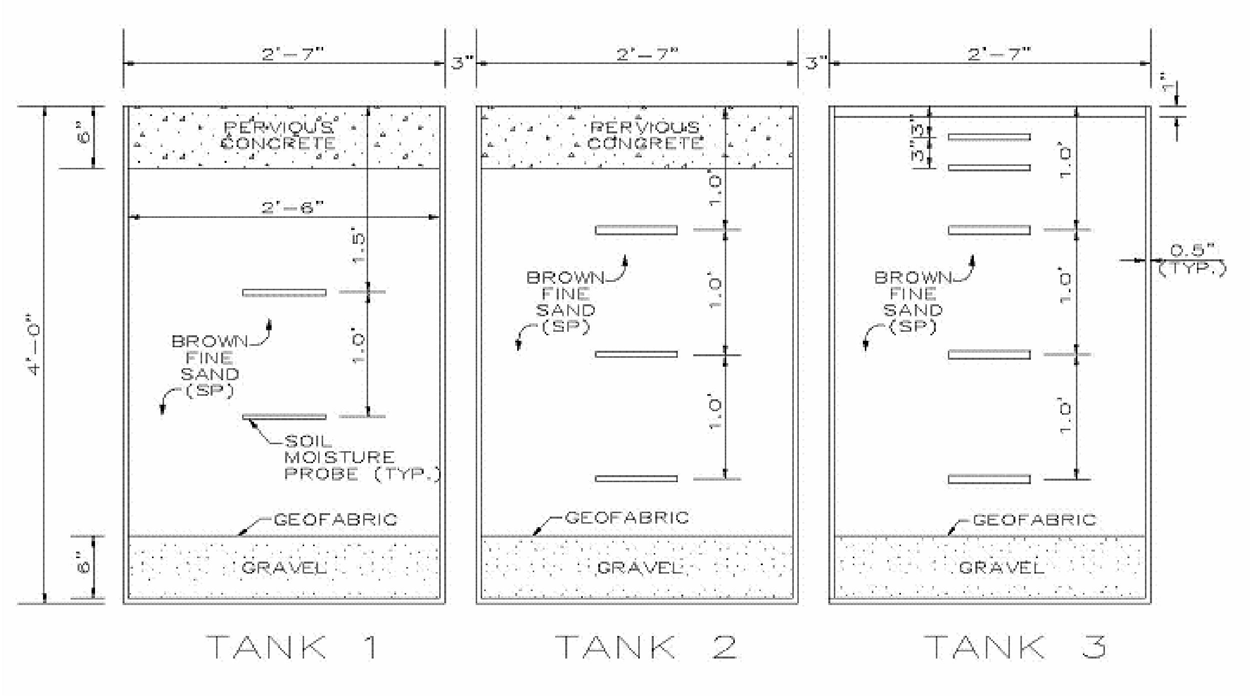

Figure 10: Test Tanks Cut-away Schematic

After the concrete curing was complete, 4-foot lengths of plastic tubing were attached to the outflow pipes and fastened to lumber posts to serve as piezometer tubes. Markings were made on the posts every six inches to assist in convenient depth readings of the groundwater level in each tank. The test tanks in their final completed form are shown in Figures 11 and 12.

Figure 11: Test Tanks Front View

Figure 12: Test Tanks Top View

3.4 Experiment – Phase One

Phase one of the experiment involved recording soil probe readings and groundwater levels as indicated by the piezometers at least twice a week for an eight-week period. Moisture storage was calculated by dividing the soil mass in each tank into zones governed by a soil probe. For example, tank 1 was divided into two zones: zone 1 was from a depth of 0.5 to 2.0 feet and was governed by the probe at a depth of 1.5 feet, while zone 2 was from a depth of 2.0 to 3.5 feet and was governed by the probe at a depth of 3.0 feet. The soil moisture recorded at each probe was applied to the entire thickness of the zone to calculate moisture volume. Soil that was saturated, as shown by the height of water in the piezometer tubes, was also taken into account in determining moisture volume.

Approximately midway through the experiment, on September 29, 2005, two additional soil moisture probes were installed in tank 3 at depths of 3 and 6 inches. Shallower depths were chosen for the additional probe locations because soil moisture content increased with proximity to the ground surface, and it was hoped that the additional probes would provide more accurate volume information. Tank 3 was chosen for the additional probes because of the lack of a concrete layer.

3.5 Experiment – Phase Two

Phase two of the experiment attempted to rectify some of the shortcomings observed in phase one. Instead of relying on rainfall data from the weather station that was a previous source of error, all water loaded onto the test tanks was poured on manually in controlled amounts. Additionally, the method of dividing the soil mass into zones was eschewed in favor of using the probe readings to create a second-degree polynomial regression trendline. The trendline was plotted over the depth of the soil mass, with boundary conditions of zero moisture content at the surface and saturated conditions at the groundwater level height, as shown by the piezometers. The regression trendlines were then integrated to calculate moisture storage in the soil mass of the tanks.

3.6 Experiment – Phase Three

Phase three of the experiment was conducted to respond to the requests for further data by members of this thesis committee. The method of calculating soil moisture storage using regression trendlines remained the same, and this phase also happened to occur during a period of zero natural precipitation, necessitating manual loading of water onto the tanks.

In addition to continuing the calculation of evaporation, the temperature of the surface of each tank was measured on three separate midday occasions, as well as the ambient air temperature. The temperatures were measured using an Extech digital thermometer, model number 421502, as shown in Figure 13.

Figure 13: Extech Digital Thermometer

CHAPTER FOUR: FINDINGS

4.1 Experiment – Phase One

Data collection for phase one of the experiment began at 2:00 PM on September 2, 2005 upon the removal of plastic sheeting that covered the concrete-surfaced tanks during the curing process. At this time, no water had been added to the tanks in the form of precipitation; however, the piezometers indicated the presence of a small saturated zone at the bottom of the tanks, showing that some of the water that had been added to the sand during the tank construction had settled to the bottom.

The last data collection event took place at 12:30 PM on October 25, 2005. The day before, on October 24, 2005, Hurricane Wilma made landfall in Southwest Florida, with the outer bands dropping heavy rainfall on the Central Florida area. After the hurricane passed, the project site was inspected for damage. The site remained intact and did not experience any heavy washout, nor did the piezometer posts topple. However, water had ponded to the brim of all three tanks. Inspection of the soil around the tanks showed that there had been significant spillover. This spillover amounted to runoff that was not measured, making calculation of mass balance impossible. The decision was made to terminate phase one of the experiment at this time. To that end, the valves were opened to allow accumulated soil moisture to flow out of the tanks in preparation for the next phase of experimentation.

Rainfall data for phase one of the experiment are shown in Figure 14. A total of 11.69 inches of rainfall was recorded for this period, nearly half of which (5.01 inches) was a result of Hurricane Wilma. The other large rainfall event apparent in Figure 14 took place during the period from September 19 to 21, 2005, during which time Hurricane Rita passed south of the Florida Keys, dropping 2.76 inches of rain on Central Florida by way of the storm's outer bands. A total of two-thirds of the recorded rainfall during phase one was the direct product of hurricane events.

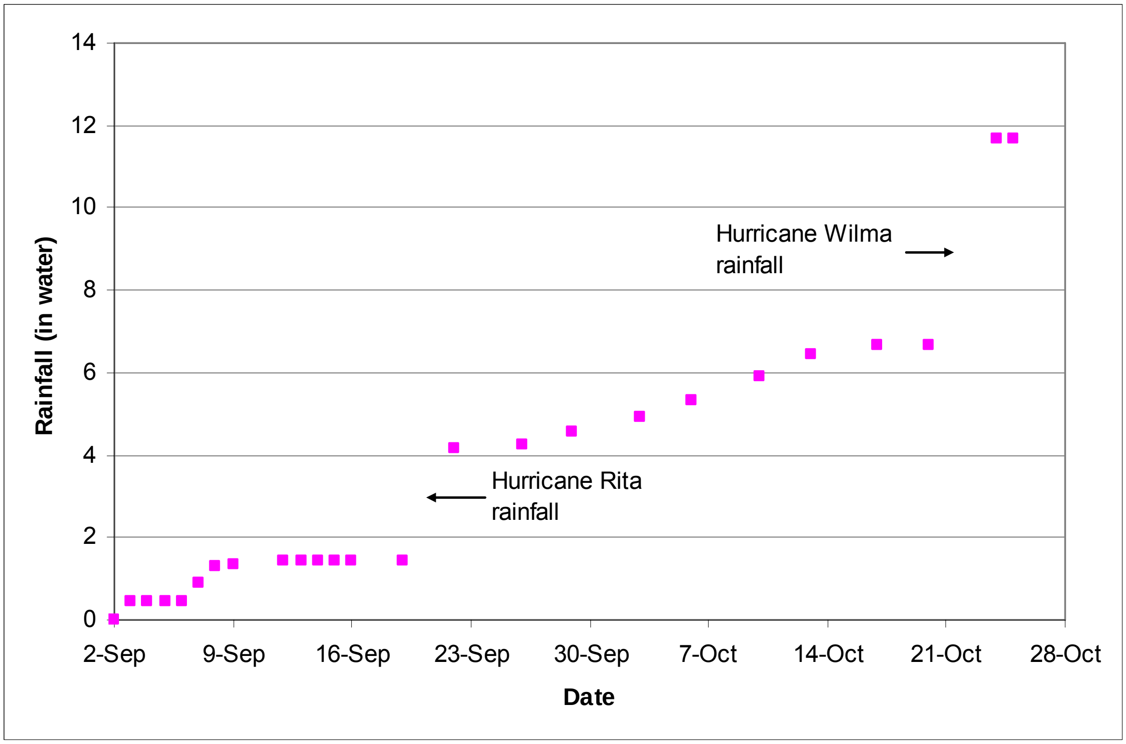

Figure 14: Phase 1 Experiment Cumulative Rainfall Volume

Apart from precipitation, water was manually added from time to time. On occasion, the water was added to test the rate of moisture infiltration into the soil. Readings from the moisture probes were taken before the simulated rainfall event and at regular five-minute intervals thereafter until no further change in probe readings was detected. These data are outside the scope of this research and are not included in this thesis, and are mentioned here only as an explanation for the addition of water to the test tanks.

Water was also collected from the tanks by way of the outlet valves at regular intervals. This withdrawal was conducted as part of another unrelated study on water quality in pervious concrete pavement systems, and was not immediately made known during the course of this experiment, which resulted in miscalculations that were later corrected.

One problem that became immediately apparent during the course of phase one of the experiment was the outcome of negative values for evaporation during many data collection events. For example, for the data collection period between September 4 and 5, 2005, no water was added to Tank 1 by way of precipitation or manual loading. Yet, through the moisture probe readings, an increase of 0.33 inches of water in storage was calculated, resulting in a value of –0.33 inches of precipitation for that period. Since negative evaporation is impossible, for graphing purposes the negative values were changed to zero but left intact on the calculation tables to show the extent of these errors.

Problems were also encountered with the rain gauge used to measure rainfall. Due to malfunction, no weather data were recorded on September 8 and 9, 2005. For this period, weather data were provided by the weather station monitoring the green roof research project, located at the UCF Student Union nearly 5000 feet from the Stormwater Field Lab. It was also discovered during the course of phase one of the experiment that bird droppings had periodically clogged the Vantage Pro rain gauge, producing rainfall data that were far lower than the actual values. To rectify this situation, rainfall data from the Vantage Pro gauge and a nearby Belfort weather gauge were compared, and data from the Belfort gauge were used whenever there was a discrepancy between the two values.

The moisture probes were also susceptible to malfunction. Probes located in soil that was indicated by the piezometers to be saturated would frequently give moisture readings greater than 4.32 inches of water per foot of soil, which was the laboratory-tested saturated moisture content of the brown fine sand used in the tanks. For these readings, a moisture value of 4.32 inches per foot was recorded in the field logs. However, the moisture probes also showed moisture values greater than 4.32 inches per foot even when the piezometers indicated that the soil around the probe was not saturated. This happened for several data collection events, mostly in tank 1.

Expected evaporation for all three tanks was calculated using the Blaney-Criddle equation using an assumed value of 0.65 for the consumptive use coefficient. The percentage of daylight hours was obtained from Table 4.6 in Wanielista et al., 1997. Average temperature was obtained by calculating the average of all temperature values recorded by the weather gauge for each month. Table 2 shows the calculated and measured evaporation volumes for each month, along with the percent difference between the two values. Generally, the evaporation in tank 3 was closest to the calculated values, remaining within 12% of the Blaney-Criddle value. Tanks 1 and 2 had much larger measured evaporation, although this could be due to need for a better assumption for the consumptive use coefficient.

Table 2: Phase 1 - Blaney-Criddle Evaporation Calculations

		September	**October**
Avg. Temp. (°F)		78.36	73.25
p (%)		8.32	8.02
k		0.65	0.65
Calc. E (in)		4.24	3.82
Meas. E (in)	Tank 1	8.34	4.80
	Tank 2	8.57	4.06
	Tank 3	4.19	4.31
Pct. difference	Tank 1	49.16%	20.42%
	Tank 2	50.53%	5.91%
	Tank 3	1.19%	11.37%

4.2 Experiment – Phase Two

Data collection for phase two of the experiment began on February 22, 2005, at 5:00 PM. The outlet valves that had been open since the termination of phase one were closed off, resulting in no visible water level in the piezometers. Moisture probe readings were taken and recorded for all three tanks, however both probes in tank 3 were malfunctioning, showing moisture readings around 6 to 8 inches per foot. Because of this, tank 1 was omitted from the scope of phase two and subsequent readings were taken only from tanks 2 and 3.

Data collection was performed daily or once every two days until March 12, 2005. During this data collection event, the moisture probe at a depth of 2.0 feet in tank 2 malfunctioned in the same manner as the tank 1 probes. Even though the probes in tank 3 remained functional, the decision was made to disregard the data from the March 12 event and terminate data collection with the March 11 collection. Since a comparison between evaporation in both tanks was no longer possible, it was considered unnecessary to continue data collection with only one tank providing reliable storage data.

No precipitation was measured during the entire duration of phase two. Loading of water was performed entirely by pouring 5-gallon buckets of water over tanks 2 and 3 over the span of approximately 10 minutes to simulate a significant rainfall event. Five gallons is equal to 1.64 inches of water over the area of the tanks, but a volume of 1.6 inches was used in calculations to compensate for possible spillage in transporting the buckets to the tank locations from the spigot. Figure 15 shows the cumulative volume of water loaded on the tanks over the course of phase two.

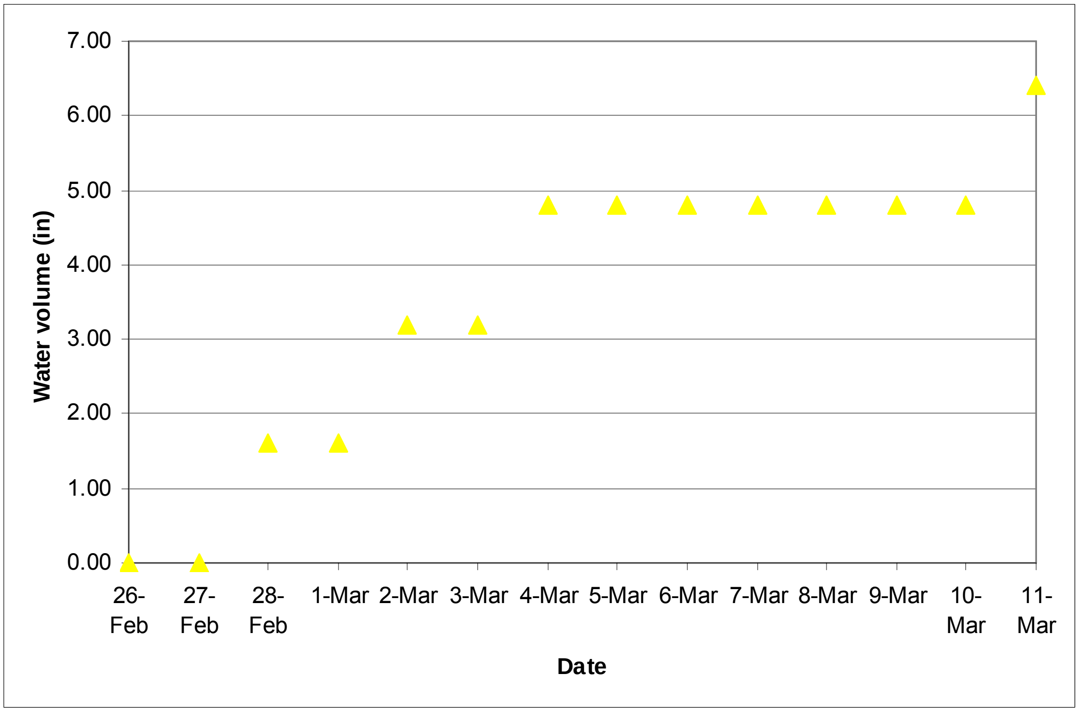

Figure 155: Phase 2 Experiment Cumulative Loading Volume

The problem of negative values for evaporation resurfaced in phase two. For example, between February 26 and 28, 2005, there was a calculated change in storage of approximately 2.6 inches, yet only 1.6 inches of water was loaded onto the tank during that time. Once again, negative values for evaporation were changed to zero for graphing purposes but were left as-is in the calculations.

Expected evaporation for all three tanks was again calculated using the Blaney-Criddle equation in the same manner as phase two. Table 3 shows the calculated and measured evaporation volumes for phase two, along with the percent difference between the two values. While the evaporation volume in tank 3 was closer to the calculated value, it was still nearly a third greater than the calculated value.

Table 3: Phase 2 Blaney-Criddle Evaporation Calculations

Avg. Temp. (°F)		66.10
p (%)		8.40
k		0.65
Calc. E (in)		1.81
Meas. E (in)	Tank 2	5.47
	Tank 3	2.52
Pct. difference	Tank 2	66.91%
	Tank 3	28.17%

4.3 Experiment – Phase Three

Data collection for phase three of the experiment began on April 11, 2006, at 1:00 PM. The outlet valves that had been open for two days prior were closed off, resulting in no visible water level in the piezometers. Moisture probe readings were taken and recorded for tanks 2 and 3. The moisture probe at a depth of 2.0 feet in tank 2 that had malfunctioned at the end of phase 2 resumed working, although the probe in tank 3 at the same depth did not work, returning values of 9.99 inches per foot of moisture. Data collection was performed daily or once every two days until April 17, 2006.

No precipitation was measured during the entire duration of phase three. Loading of water was again performed entirely by pouring 5-gallon buckets of water over tanks 2 and 3 over the span of approximately 10 minutes to simulate a significant rainfall event.

Five gallons is equal to 1.64 inches of water over the area of the tanks, but a volume of 1.6 inches was used in calculations to compensate for possible spillage in transporting the buckets to the tank locations from the spigot. Figure 16 shows the cumulative volume of water loaded on the tanks over the course of phase three.

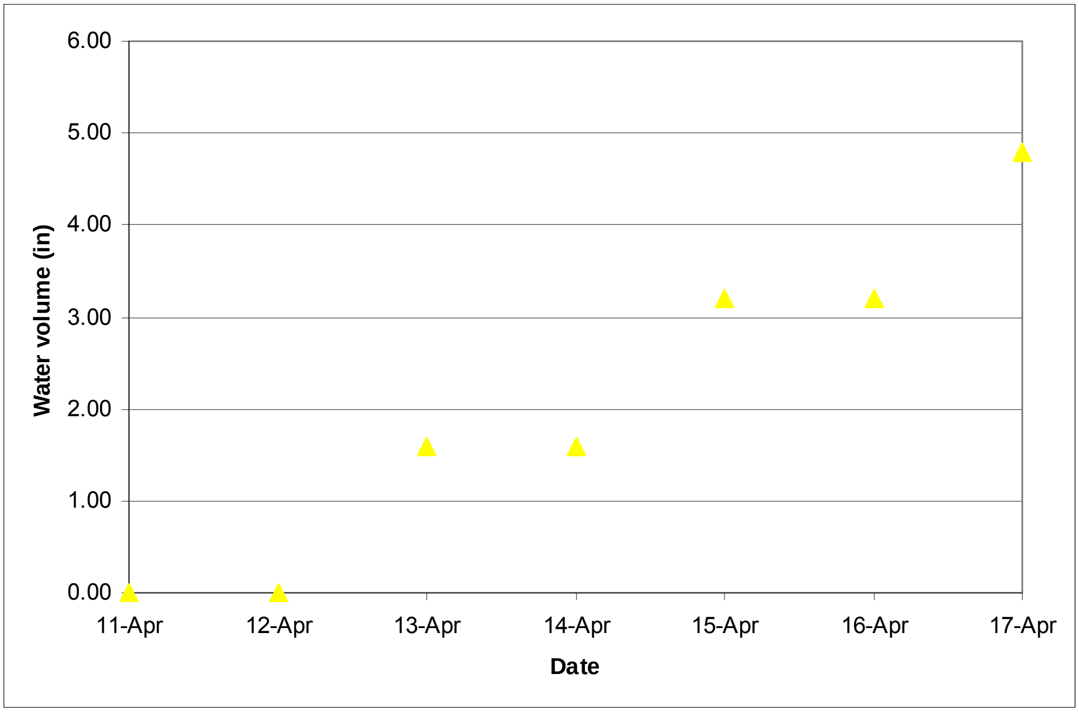

Figure 166: Phase 3 Experiment Cumulative Loading Volume

After one week of data collection, tank 2 showed an evaporation volume of 2.70 inches, approximately twice the 1.36 inches of evaporation registered in tank 3. In addition to evaporation, the surface temperature of all three tanks was measured and recorded on three separate occasions and weather conditions during the one week period of phase 3. The temperature at all three surfaces was higher than the ambient air temperature;

however, the concrete was much hotter than the bare sand surface. When subject to constant sunlight, the temperatures remained constant, but as shown on the data collection of April 17, 2006, the surface temperature of the concrete could change by as much as 5 degrees Fahrenheit when direct sunlight was obscured by cloud cover. Tank 1 was also found to have a hotter surface temperature than tank 2, which is most likely a result of tank 1's slightly darker color. This difference was immediately discernible by placing one's hand against both surfaces.

Table 4: Phase 3 Experiment Temperature Readings

	Temperature (°F)				cloud cover
	Ambient	Tank 1	Tank 2	Tank 3	
THURSDAY **4/13/2006** **1200h**	---	112	106	---	partly cloudy
MONDAY **4/17/2006** **1200h**	81	105-110	95-110	84-85	mostly cloudy
TUESDAY **4/18/2006** **1200h**	88	119	114	90	none

In response to the observation that evaporation rates in tanks 1 and 2 were much greater than that in tank 3, several hypotheses to explain this were formulated. The hypothesis that was considered the most likely at the time was that water was being retained in the pervious concrete pavement, where it evaporated before reaching the underlying soil. An experiment was devised to test this hypothesis.

Two 12-inch diameter pervious concrete core samples were selected from storage at the Stormwater Field Lab that were relatively identical in texture and appearance to the concrete used in the test tanks. These cores were placed over two 5-gallon buckets to catch water. 0.05 inch of water was drizzled over each core over 5 minutes, and 15 minutes were given for water to infiltrate through the concrete. 0.14 inch of water was then drizzled over each core over 5 minutes and given another 15 minutes to infiltrate. Finally, another 0.14 inch of water was drizzled over each core over 5 minutes and given another 15 minutes to infiltrate. Infiltrated water was collected in the buckets and was measured at the end of each 15-minute period and at one hour thereafter. No infiltrated water was measured in the first 15 minutes, and volumes of 0.06 inch of water were collected after each of the 15 minute periods for both cores. A negligible amount of water was collected one hour after the last 15-minute period.

This experiment was subsequently repeated using higher initial water loading after the cores were allowed to dry. First, 0.1 inch of water was drizzled over each core over 5 minutes, and 15 minutes were given for water to infiltrate through the concrete. Then 0.15 inch of water was then drizzled over each core over 5 minutes and given another 15 minutes to infiltrate. Infiltrated water was collected in the buckets and was measured at the end of each 15-minute period and at one hour thereafter. 0.02 inch of water was collected in the first 15 minutes from each core, and 0.11 inch of water was collected from each core in the second 15 minutes. A negligible amount of water was collected one hour after the second 15-minute period.

These experiments showed that pervious concrete pavement has substantial water retention properties. Precipitation that falls on pervious concrete pavement in relatively low amounts remains trapped in the concrete mass and never infiltrates into the underlying soil. While pervious concrete may have a permeability rate in the vicinity of 4 inches per minute, as found in the research, it appears that this infiltration rate is not achieved in the field, and is only applicable in testing when a larger volume of water is caused to flow through the concrete. These findings are also consistent with the observation during all three phases of the experimentation that showed slightly lower groundwater levels from the piezometer tubes in tanks 1 and 2 as compared to tank 3. The presence of pervious concrete pavement therefore does not increase the rate of evaporation from the underlying soil. Instead, a portion of the rainfall that would otherwise infiltrate into the soil is intercepted and retained in the concrete.

Empirical formulas have been developed that correlate evaporation rate from pans or natural bodies of water to conditions such as saturation vapor pressure at the water surface, atmospheric vapor pressure, and wind speed (Wanielista 1997). An increase in water temperature, therefore, should increase the saturation vapor pressure and the overall evaporation rate. Temperature readings taken at the surface of the test tanks showed a substantial heat difference between the concrete and the bare sand surfaces. Moisture in the concrete layer at temperature of 110 degrees Fahrenheit would have a saturation vapor pressure nearly twice that of moisture in the soil at a temperature of 90 degrees Fahrenheit (Finnemore 2002). While this does not mean that evaporation rate should also be twice as great with pervious concrete than with bare sand, it does demonstrate the general effect of increased moisture temperature.

CHAPTER FIVE: CONCLUSION

5.1 Review

Pervious concrete pavement represents a new way of thinking in stormwater management. Traditional engineering protocol concentrates on directing and collecting runoff via stormwater sewers for deposition in ponds, but use of permeable pavements reduces the overall runoff loading on a developed area while still achieving the desired amount of usable paved surface for pedestrian or vehicular traffic. Reduction of required stormwater pond size allows more property to be used for habitable development, resulting in obvious economic benefits. Runoff pollutants can safely be filtered out of stormwater by pervious concrete while allowing treated water to recharge groundwater supplies. With proper design, construction, and maintenance, previous concrete pavement can play an important role in stormwater best management practices. Governmental regulatory agencies whose approval will encourage more widespread use of pervious concrete require further research such as that being conducted at UCF's Stormwater Management Academy.

This thesis, which explored the hydrologic mass balance of pervious concrete, is one part of a battery of research being conducted by Stormwater Management Academy personnel to obtain the knowledge required by these agencies. Other studies being performed include those on pollutant filtration, development of an infiltration model, and infiltration rates with maintenance. This research is focused on native conditions in the state of Florida, which continues to see rapid growth and development. The introduction of pervious concrete pavement as a widely used material would make a positive contribution to the local economy and environment.

5.2 Future Work

Phase one of the experiment lasted for approximately three months in the late summer and early fall of 2005, and phase two lasted for approximately two weeks in the spring of 2006. Until further experiments can be performed for longer durations, this work should be considered preliminary in nature. The methodologies presented in this thesis should serve as a good foundation from which to base further studies of similar scope.

In addition to lengthening the duration of data collection, future studies should experiment with other types of ground cover for comparison to pervious pavement, such as St. Augustine grass, which is the dominant variety of grass in Central Florida for its hardiness in the native climate. Future studies should also refine the method of calculating water storage inside the test tanks. One possibility is to install a much greater number of moisture probes; for example, one probe every 3 inches in the upper 12 inches of soil and one probe every 6 inches beyond that. Such would increase the number of data points available for constructing regression trendlines, and would lessen the impact of the loss of a single probe due to malfunction. The new ECH2O-TE probe manufactured by Decagon Devices, Inc. appears suitable for this. The TE probes are more compact than the EC-20 models, and measure temperature in addition to moisture content. Temperature data could be very useful in examining the thermal effects on soil at different depths and their impact on evaporation trends.

APPENDIX A: SOIL TESTING DATA

Table 5: Sieve Analysis Data

Soil Description: Light Brown Fine Sand					
Location: Stormwater Field Lab via Rinker					
Test: Sieve Analysis					
Tested By: TEK				**Dry Mass:**	495.3

Sieve No.	**Sieve Opening (mm)**	**Mass Retained (g)**	**Percent Retained (%)**	**Cumulative Percent Retained (%)**	**Percent Finer (%)**
4	4.75	0.0	0.0	0.0	100.0
10	2	1.9	0.4	0.4	99.6
20	0.85	76.3	15.4	15.8	84.2
40	0.425	201.8	40.7	56.5	43.5
60	0.25	168.5	34.0	90.6	9.4
100	0.15	43.1	8.7	99.3	0.7
200	0.075	1.0	0.2	99.5	**0.5**
Pan	--	0.1	--	--	--

$\mathbf{D_{60}}$	0.55		
$\mathbf{D_{30}}$	0.35	$\mathbf{C_u}$	2.20
$\mathbf{D_{10}}$	0.25	$\mathbf{C_c}$	0.89

Table 6: Standard Proctor Compaction Test Data

Soil Description: Light Brown Fine Sand			
Location: Stormwater Field Lab via Rinker			
Test: Standard Proctor Compaction			
Mold Volume, ft^3:	0.033	**Hammer Wt.:** 5.5 lb.	
Blows/Layer:	25	**Layers:**	3
Tested By: TEK		**Date:** 7/13/2005	

Test	**1**	**2**	**3**	**4**	**5**	**6**
Weight of Mold (lb)	9.135	9.135	9.135	9.135	9.135	9.135
Weight of Mold + Moist Soil (lb)	12.815	12.925	12.995	13.415	13.435	13.520
Weight of Moist Soil (lb)	3.680	3.790	3.860	4.280	4.300	4.385
Moist Unit Weight (lb/ft3)	110.400	113.700	115.800	128.400	129.000	131.550

Moisture Can Number	13	2V	3	4	4+G	3K
Mass of can, (g)	11.00	11.00	12.00	11.00	11.00	11.00
Mass of can + moist soil (g)	43.00	41.00	41.00	42.00	43.00	41.00
Mass of can + dry soil (g)	43.00	40.00	38.00	38.00	38.00	36.00
Moisture Content (%)	**0.00**	**3.45**	**11.54**	**14.81**	**18.52**	**20.00**
Dry Unit Weight (lb/ft^3)	**110.40**	**109.91**	**103.82**	**111.83**	**108.84**	**109.63**
Maximum Dry Unit Weight (lb/ft^3)	**104.70**					
Optimum Moisture Content	**14.30**					
92% Dry Unit Weight (lb/ft^3)	**96.32**					

Table 7: Falling Head Permeability Test Data

Soil Description: Light Brown Fine Sand			
Location: Stormwater Field Lab via Rinker			
Tested By: TEK			
Length of specimen (cm)	13.18		
Diameter of specimen (cm)	6.3		
Area of specimen (cm^2)	31.17		
Volume of specimen (cm^3)	410.85		
Gs of soil solids	2.65		
Mass of tube and fittings (g)	2030.4		
Mass of tube/specimen (g)	2727.1		
Dry density (g/cm^3)	1.7		
Void ratio	0.563		
Porosity	0.36		
Test number	1	2	3
Volume water collected (cm^3)	590	490	390
Time of collection (s)	90	90	90
Water temperature (deg F)	70	70	70
Head difference (cm)	58	47	37
Coefficient of permeability k (cm/s)	0.0478	0.0490	0.0495
Average k (cm/s)	0.0488		
Average k (in/hr)	69.12		

APPENDIX B: PROBE CALIBRATION DATA

Table 8: Probe Calibration Data

Sample	**Can name**	**Wet soil wt.**	**Dry soil wt.**	**Can wt.**	**Water wt.**	**Soil wt.**	**Bulk density**	**Vol. w.c.**	**Avg. vol. w.c.**	**Probe read.**
		[g]	**[g]**	**[g]**	**[g]**	**[g]**	**[mg/m^3]**	**[m^3/m^3]**	**[m^3/m^3]**	**[mV]**
1.1	2V	72.9	72.6	10.9	0.3	61.7	1.37111	0.00667		
1.2	JAY2	72.0	71.6	10.8	0.4	60.8	1.35111	0.00889	0.00741	356
1.3	4G3	72.6	72.3	11.9	0.3	60.4	1.34222	0.00667		
2.1	MSJ2	74.0	72.3	11.6	1.7	60.7	1.34889	0.03778		
2.2	TMNT2	73.4	71.8	11.8	1.6	60.0	1.33333	0.03556	0.03481	407
2.3	JAY3	71.1	69.7	11.8	1.4	57.9	1.28667	0.03111		
3.1	MSJ1	81.2	75.6	11.8	5.6	63.8	1.41778	0.12444		
3.2	TNA1	75.6	70.1	11.7	5.5	58.4	1.29778	0.12222	0.12296	466
3.3	15	78.4	72.9	11.9	5.5	61.0	1.35556	0.12222		
4.1	MOM	83.8	75.9	11.5	7.9	64.4	1.43111	0.17556		
4.2	1	82.1	73.7	11.7	8.4	62.0	1.37778	0.18667	0.18370	514
4.3	4G1	83.6	75.1	11.1	8.5	64.0	1.42222	0.18889		

Table 9: Probe Calibration Results

Line Slope	**ECH2O value**
0.001	**100**

Intercept	**ECH2O value**
-0.35	**350**

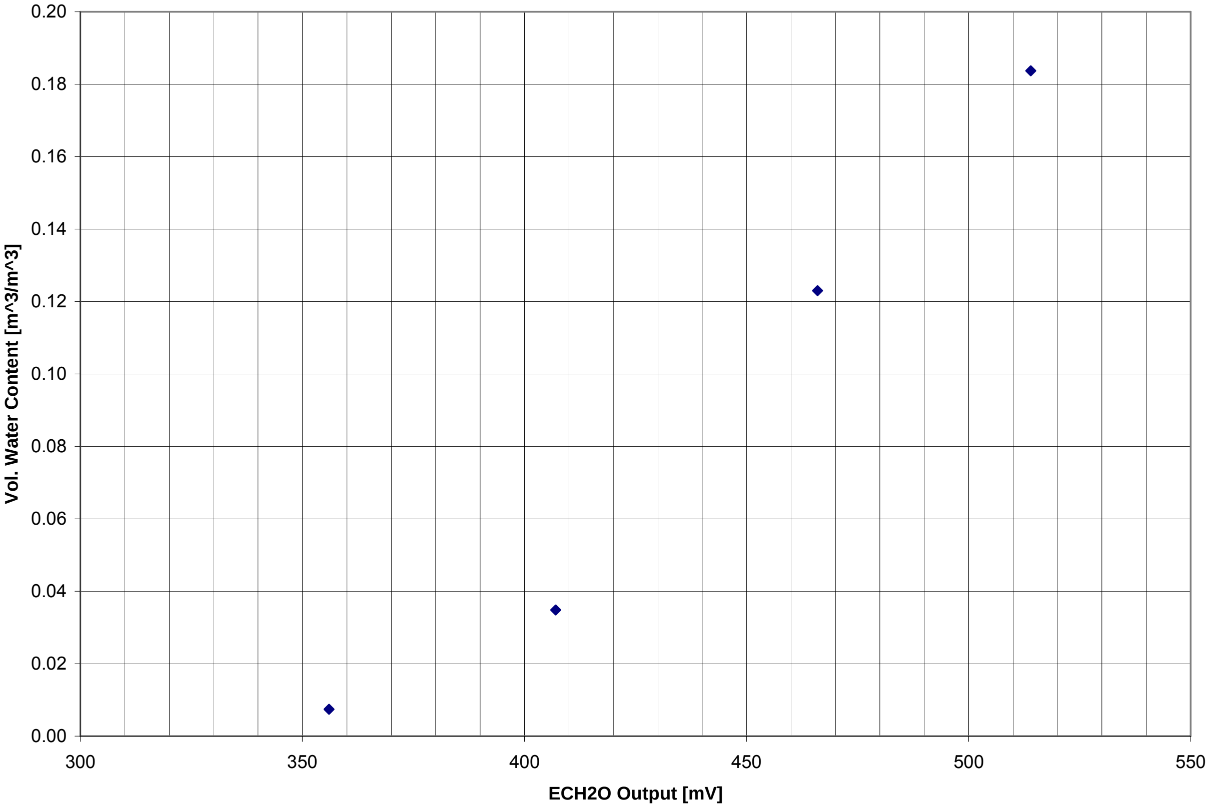

Figure 177: Probe Calibration Curve

APPENDIX C: PHASE 1 – FIELD READINGS

Table 10: Phase 1 - Field Readings

FRIDAY	rain (in)	**TANK 1**	Depth (ft)	GWT (ft)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
9/2/2005	na	moist. (in/ft)		3.25	moist. (in/ft)		3.50	moist. (in/ft)		3.60
1400h										
Probe A										
Probe B										
Probe 1		0.54	1.50		0.53	1.00		0.65	1.00	
Probe 2		1.28	2.50		0.65	2.00		0.76	2.00	
Probe 3					1.74	3.00		2.78	3.00	

SATURDAY	rain (in)	**TANK 1**	Depth (ft)	GWT (ft)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
9/3/2005	0.43	moist. (in/ft)		3.25	moist. (in/ft)		3.50	moist. (in/ft)		3.60
1200h										
Probe A										
Probe B										
Probe 1		0.70	1.50		0.64	1.00		0.81	1.00	
Probe 2		1.47	2.50		0.77	2.00		1.01	2.00	
Probe 3					1.74	3.00		2.69	3.00	

SUNDAY	rain (in)	**TANK 1**	Depth (ft)	GWT (ft)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
9/4/2005	0.01	moist. (in/ft)		3.10	moist. (in/ft)		3.50	moist. (in/ft)		3.50
1400h										
Probe A										
Probe B										
Probe 1		0.60	1.50		0.53	1.00		0.75	1.00	
Probe 2		1.78	2.50		0.75	2.00		0.85	2.00	
Probe 3					1.76	3.00		2.66	3.00	

MONDAY	rain (in)	**TANK 1**	Depth (ft)	GWT (ft)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
9/5/2005	0.00	moist. (in/ft)		3.00	moist. (in/ft)		3.50	moist. (in/ft)		3.50
1400h										

Probe A										
Probe B										
Probe 1		0.56	1.50		0.51	1.00		0.69	1.00	
Probe 2		1.92	2.50		0.70	2.00		0.77	2.00	
Probe 3					1.76	3.00		2.59	3.00	
TUESDAY	rain (in)	**TANK 1**	Depth (ft)	GWT (ft)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
9/6/2005	0.00	moist. (in/ft)		3.00	moist. (in/ft)		3.50	moist. (in/ft)		3.50
1200h										
Probe A										
Probe B										
Probe 1		0.54	1.50		0.48	1.00		0.65	1.00	
Probe 2		2.01	2.50		0.67	2.00		0.72	2.00	
Probe 3					1.74	3.00		2.57	3.00	
WEDNESDAY	rain (in)	**TANK 1**	Depth (ft)	GWT (ft)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
9/7/2005	0.45	moist. (in/ft)		3.00	moist. (in/ft)		3.50	moist. (in/ft)		3.50
1200h										
Probe A										
Probe B										
Probe 1		1.53	1.50		0.97	1.00		1.30	1.00	
Probe 2		2.77	2.50		1.10	2.00		0.72	2.00	
Probe 3					1.83	3.00		2.61	3.00	
THURSDAY	rain (in)	**TANK 1**	Depth (ft)	GWT (ft)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
9/8/2005	0.40	moist. (in/ft)		3.00	moist. (in/ft)		3.40	moist. (in/ft)		3.30
1200h	(GR)									
Probe A										
Probe B										
Probe 1		0.77	1.50		0.56	1.00		0.91	1.00	
Probe 2		3.57	2.50		0.88	2.00		1.22	2.00	
Probe 3					1.89	3.00		2.88	3.00	
FRIDAY	rain (in)	**TANK 1**	Depth (ft)	GWT (ft)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)

9/9/2005	0.03	moist. (in/ft)		2.90	moist. (in/ft)		3.30	moist. (in/ft)		3.10
1200h	(GR)									
Probe A										
Probe B										
Probe 1		0.63	1.50		0.47	1.00		0.83	1.00	
Probe 2		3.84	2.50		0.81	2.00		0.90	2.00	
Probe 3					2.16	3.00		3.15	3.00	
MONDAY	rain (in)	**TANK 1**	Depth (ft)	GWT (ft)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
9/12/2005	0.10	moist. (in/ft)		2.70	moist. (in/ft)		3.10	moist. (in/ft)		3.00
1400h										
Probe A										
Probe B										
Probe 1		0.51	1.50		0.39	1.00		0.74	1.00	
Probe 2		4.19	2.50		0.65	2.00		0.80	2.00	
Probe 3					2.71	3.00		3.35	3.00	
TUESDAY	rain (in)	**TANK 1**	Depth (ft)	GWT (ft)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
9/13/2005	0.00	moist. (in/ft)		2.60	moist. (in/ft)		3.10	moist. (in/ft)		3.00
1030h										
Probe A										
Probe B										
Probe 1		0.50	1.50		0.38	1.00		0.72	1.00	
Probe 2		4.32	2.50		0.63	2.00		0.79	2.00	
Probe 3					2.78	3.00		3.36	3.00	
WEDNESDAY	rain (in)	**TANK 1**	Depth (ft)	GWT (ft)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
9/14/2005	0.00	moist. (in/ft)		2.40	moist. (in/ft)		3.10	moist. (in/ft)		3.00
1130h										
Probe A	1.64 in									
Probe B	5 gal									
Probe 1	tank 1	2.06	1.50		0.38	1.00		0.70	1.00	
Probe 2		4.32	2.50		0.61	2.00		0.79	2.00	
Probe 3					2.84	3.00		3.39	3.00	

THURSDAY	rain (in)	**TANK 1**	Depth (ft)	GWT (ft)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
9/15/2005	0.00	moist. (in/ft)		2.30	moist. (in/ft)		3.10	moist. (in/ft)		3.00
1430h										
Probe A										
Probe B										
Probe 1		1.93	1.50		0.38	1.00		0.67	1.00	
Probe 2		4.32	2.50		0.60	2.00		0.78	2.00	
Probe 3					2.88	3.00		3.42	3.00	

FRIDAY	rain (in)	**TANK 1**	Depth (ft)	GWT (ft)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
9/16/2005	0.00	moist. (in/ft)		2.60	moist. (in/ft)		3.50	moist. (in/ft)		3.50
1400h										
Probe A	-0.09 in									
Probe B	1 L									
Probe 1	all tanks	0.87	1.50		0.39	1.00		0.89	1.00	
Probe 2		4.32	2.50		0.60	2.00		1.00	2.00	
Probe 3					1.83	3.00		3.03	3.00	

MONDAY	rain (in)	**TANK 1**	Depth (ft)	GWT (ft)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
9/19/2005	0.00	moist. (in/ft)		2.40	moist. (in/ft)		3.20	moist. (in/ft)		3.20
1400h										
Probe A										
Probe B										
Probe 1		0.82	1.50		0.41	1.00		0.60	1.00	
Probe 2		4.32	2.50		0.64	2.00		0.67	2.00	
Probe 3					2.41	3.00		3.18	3.00	

THURSDAY	rain (in)	**TANK 1**	Depth (ft)	GWT (ft)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
9/22/2005	2.76	moist. (in/ft)		1.90	moist. (in/ft)		2.60	moist. (in/ft)		2.50
1200h										
Probe A										
Probe B										
Probe 1		4.32	1.50		1.52	1.00		1.04	1.00	
Probe 2		4.32	2.50		0.92	2.00		3.24	2.00	

Probe 3					4.32	3.00		4.32	3.00	
MONDAY	rain (in)	**TANK 1**	Depth (ft)	GWT (ft)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
9/26/2005	0.08	moist. (in/ft)		1.70	moist. (in/ft)		2.50	moist. (in/ft)		2.30
1400h										
Probe A	-0.09 in									
Probe B	1 L									
Probe 1	tanks 2-3	4.32	1.50		0.44	1.00		0.92	1.00	
Probe 2		4.32	2.50		1.03	2.00		3.49	2.00	
Probe 3					4.32	3.00		4.32	3.00	
THURSDAY	rain (in)	**TANK 1**	Depth (ft)	GWT (ft)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
9/29/2005	0.28	moist. (in/ft)		1.60	moist. (in/ft)		1.50	moist. (in/ft)		2.30
1400h										
Probe A	3.28 in							0.71	0.25	
Probe B	10 gal							0.72	0.50	
Probe 1	tank 2	4.32	1.50		1.05	1.00		0.96	1.00	
Probe 2		4.32	2.50		4.32	2.00		3.57	2.00	
Probe 3					4.32	3.00		4.32	3.00	
MONDAY	rain (in)	**TANK 1**	Depth (ft)	GWT (ft)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
10/3/2005	0.38	moist. (in/ft)		1.50	moist. (in/ft)		1.40	moist. (in/ft)		2.20
1600h										
Probe A								0.91	0.25	
Probe B								0.86	0.50	
Probe 1		4.32	1.50		1.47	1.00		0.99	1.00	
Probe 2		4.32	2.50		4.32	2.00		3.67	2.00	
Probe 3					4.32	3.00		4.32	3.00	
THURSDAY	rain (in)	**TANK 1**	Depth (ft)	GWT (ft)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
10/6/2005	0.42	moist. (in/ft)		0.10	moist. (in/ft)		1.00	moist. (in/ft)		1.80
1300h										

Probe A	2.62 in							0.82	0.25	
Probe B	8 gal							0.85	0.50	
Probe 1	tank 1	4.32	1.50		4.32	1.00		1.52	1.00	
Probe 2		4.32	2.50		4.32	2.00		4.32	2.00	
Probe 3					4.32	3.00		4.32	3.00	

MONDAY	rain (in)	**TANK 1**	Depth (ft)	GWT (ft)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
10/10/2005	0.56	moist. (in/ft)		0.20	moist. (in/ft)		0.20	moist. (in/ft)		1.30
1430h										
Probe A	-0.26 in							1.23	0.25	
Probe B	-3 L							1.54	0.50	
Probe 1	all tanks	4.32	1.50		4.32	1.00		3.86	1.00	
Probe 2		4.32	2.50		4.32	2.00		4.32	2.00	
Probe 3					4.32	3.00		4.32	3.00	

THURSDAY	rain (in)	**TANK 1**	Depth (ft)	GWT (ft)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
10/13/2005	0.52	moist. (in/ft)		0.40	moist. (in/ft)		0.40	moist. (in/ft)		1.30
1230h										
Probe A	-4L T1							1.24	0.25	
Probe B	-10L T2							1.63	0.50	
Probe 1	-4L T3	4.32	1.50		4.32	1.00		3.80	1.00	
Probe 2		4.32	2.50		4.32	2.00		4.32	2.00	
Probe 3					4.32	3.00		4.32	3.00	

MONDAY	rain (in)	**TANK 1**	Depth (ft)	GWT (ft)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
10/17/2005	0.26	moist. (in/ft)		0.26	moist. (in/ft)		1.30	moist. (in/ft)		1.70
1230h										
Probe A	-3L T1							0.64	0.25	
Probe B	-10L T2							0.86	0.50	
Probe 1	-10L T3	4.32	1.50		4.32	1.00		2.45	1.00	
Probe 2		4.32	2.50		4.32	2.00		3.68	2.00	
Probe 3					4.32	3.00		4.32	3.00	

THURSDAY	rain (in)	**TANK 1**	Depth (ft)	GWT (ft)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)

10/20/2005	0.00	moist. (in/ft)		0.50	moist. (in/ft)		1.30	moist. (in/ft)		1.70
1230h										
Probe A								0.60	0.25	
Probe B								0.79	0.50	
Probe 1		4.32	1.50		4.32	1.00		2.21	1.00	
Probe 2		4.32	2.50		4.32	2.00		3.57	2.00	
Probe 3					4.32	3.00		4.32	3.00	
MONDAY	rain (in)	**TANK 1**	Depth (ft)	GWT (ft)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
10/24/2005	5.01	moist. (in/ft)		0.00	moist. (in/ft)		0.00	moist. (in/ft)		0.00
1230h										
Probe A								4.32	0.25	
Probe B								4.32	0.50	
Probe 1		4.32	1.50		4.32	1.00		4.32	1.00	
Probe 2		4.32	2.50		4.32	2.00		4.32	2.00	
Probe 3					4.32	3.00		4.32	3.00	
THURSDAY	rain (in)	**TANK 1**	Depth (ft)	GWT (ft)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
10/25/2005	0.00	moist. (in/ft)		0.70	moist. (in/ft)		1.30	moist. (in/ft)		1.50
1230h										
Probe A	-10L T1							1.47	0.25	
Probe B	-20L T2							2.17	0.50	
Probe 1	-40L T3	4.32	1.50		4.32	1.00		4.32	1.00	
Probe 2		4.32	2.50		4.32	2.00		4.32	2.00	
Probe 3					4.32	3.00		4.32	3.00	

APPENDIX D: PHASE 1 – STORAGE CALCULATIONS

Table 11: Phase 1 - Storage Calculations

FRIDAY	**TANK 1**	Infl.Zone(ft)	GWT (ft)	**TANK 2**	Infl.Zone(ft)	GWT (ft)	**TANK 3**	Infl.Zone(ft)	GWT (ft)
9/2/2005	moist. (in/ft)		3.25	moist. (in/ft)		3.50	moist. (in/ft)		3.60
1400h									
Probe A									
Probe B									
Probe 1	0.54	1.50	0.81	0.53	1.00	0.53	0.65	1.40	0.91
Probe 2	1.28	1.25	1.60	0.65	1.00	0.65	0.76	1.00	0.76
Probe 3				1.74	1.00	1.74	2.78	0.90	2.50
Sat. zone	4.32	0.25	1.08	4.32	0.00	0.00	4.32	0.10	0.43
Storage			3.49			2.92			4.60

SATURDAY	**TANK 1**	Infl.Zone(ft)	GWT (ft)	**TANK 2**	Infl.Zone(ft)	GWT (ft)	**TANK 3**	Infl.Zone(ft)	GWT (ft)
9/3/2005	moist. (in/ft)		3.25	moist. (in/ft)		3.50	moist. (in/ft)		3.60
1200h									
Probe A									
Probe B									
Probe 1	0.70	1.50	1.05	0.64	1.00	0.64	0.81	1.40	1.13
Probe 2	1.47	1.25	1.84	0.77	1.00	0.77	1.01	1.00	1.01
Probe 3				1.74	1.00	1.74	2.69	0.90	2.42
Sat. zone	4.32	0.25	1.08	4.32	0.00	0.00	4.32	0.10	0.43
Storage			3.97			3.15			5.00

SUNDAY	**TANK 1**	Infl.Zone(ft)	GWT (ft)	**TANK 2**	Infl.Zone(ft)	GWT (ft)	**TANK 3**	Infl.Zone(ft)	GWT (ft)
9/4/2005	moist. (in/ft)		3.10	moist. (in/ft)		3.50	moist. (in/ft)		3.50
1400h									
Probe A									
Probe B									
Probe 1	0.60	1.50	0.90	0.53	1.00	0.53	0.75	1.40	1.05
Probe 2	1.78	1.10	1.96	0.75	1.00	0.75	0.85	1.00	0.85
Probe 3				1.76	1.00	1.76	2.66	0.90	2.39
Sat. zone	4.32	0.40	1.73	4.32	0.00	0.00	4.32	0.10	0.43
Storage			4.59			3.04			4.73

MONDAY	**TANK 1**	Infl.Zone(ft)	GWT (ft)	**TANK 2**	Infl.Zone(ft)	GWT (ft)	**TANK 3**	Infl.Zone(ft)	GWT (ft)
9/5/2005	moist. (in/ft)		3.00	moist. (in/ft)		3.50	moist. (in/ft)		3.50
1400h									

Probe A									
Probe B									
Probe 1	0.56	1.50	0.84	0.51	1.00	0.51	0.69	1.40	0.97
Probe 2	1.92	1.00	1.92	0.70	1.00	0.70	0.77	1.00	0.77
Probe 3				1.76	1.00	1.76	2.59	0.90	2.33
Sat. zone	4.32	0.50	2.16	4.32	0.00	0.00	4.32	0.10	0.43
Storage			4.92			2.97			4.50

TUESDAY	**TANK 1**	Infl.Zone(ft)	GWT (ft)	**TANK 2**	Infl.Zone(ft)	GWT (ft)	**TANK 3**	Infl.Zone(ft)	GWT (ft)
9/6/2005	moist. (in/ft)		3.00	moist. (in/ft)		3.50	moist. (in/ft)		3.50
1200h									
Probe A									
Probe B									
Probe 1	0.54	1.50	0.81	0.48	1.00	0.48	0.65	1.40	0.91
Probe 2	2.01	1.00	2.01	0.67	1.00	0.67	0.72	1.00	0.72
Probe 3				1.74	1.00	1.74	2.57	0.90	2.31
Sat. zone	4.32	0.50	2.16	4.32	0.00	0.00	4.32	0.10	0.43
Storage			4.98			2.89			4.38

WEDNESDAY	**TANK 1**	Infl.Zone(ft)	GWT (ft)	**TANK 2**	Infl.Zone(ft)	GWT (ft)	**TANK 3**	Infl.Zone(ft)	GWT (ft)
9/7/2005	moist. (in/ft)		3.00	moist. (in/ft)		3.50	moist. (in/ft)		3.50
1200h									
Probe A									
Probe B									
Probe 1	1.53	1.50	2.30	0.97	1.00	0.97	1.30	1.40	1.82
Probe 2	2.77	1.00	2.77	1.10	1.00	1.10	0.72	1.00	0.72
Probe 3				1.83	1.00	1.83	2.61	0.90	2.35
Sat. zone	4.32	0.50	2.16	4.32	0.00	0.00	4.32	0.10	0.43
Storage			7.23			3.90			5.32

THURSDAY	**TANK 1**	Infl.Zone(ft)	GWT (ft)	**TANK 2**	Infl.Zone(ft)	GWT (ft)	**TANK 3**	Infl.Zone(ft)	GWT (ft)
9/8/2005	moist. (in/ft)		3.00	moist. (in/ft)		3.40	moist. (in/ft)		3.30
1200h									
Probe A									
Probe B									
Probe 1	0.77	1.50	1.16	0.56	1.00	0.56	0.91	1.40	1.27
Probe 2	3.57	1.00	3.57	0.88	1.00	0.88	1.22	1.00	1.22
Probe 3				1.89	0.90	1.70	2.88	0.90	2.59
Sat. zone	4.32	0.50	2.16	4.32	0.10	0.43	4.32	0.10	0.43
Storage			6.89			3.57			5.52

FRIDAY	**TANK 1**	Infl.Zone(ft)	GWT (ft)	**TANK 2**	Infl.Zone(ft)	GWT (ft)	**TANK 3**	Infl.Zone(ft)	GWT (ft)

9/9/2005	moist. (in/ft)		2.90	moist. (in/ft)		3.30	moist. (in/ft)		3.10
1200h									
Probe A									
Probe B									
Probe 1	0.63	1.50	0.95	0.47	1.00	0.47	0.83	1.40	1.16
Probe 2	3.84	0.90	3.46	0.81	1.00	0.81	0.90	1.00	0.90
Probe 3				2.16	0.80	1.73	3.15	0.90	2.84
Sat. zone	4.32	0.60	2.59	4.32	0.20	0.86	4.32	0.10	0.43
Storage			6.99			3.87			5.33

MONDAY	**TANK 1**	Infl.Zone(ft)	GWT (ft)	**TANK 2**	Infl.Zone(ft)	GWT (ft)	**TANK 3**	Infl.Zone(ft)	GWT (ft)
9/12/2005	moist. (in/ft)		2.70	moist. (in/ft)		3.10	moist. (in/ft)		3.00
1400h									
Probe A									
Probe B									
Probe 1	0.51	1.50	0.77	0.39	1.00	0.39	0.74	1.40	1.04
Probe 2	4.19	0.70	2.93	0.65	1.00	0.65	0.80	1.00	0.80
Probe 3				2.71	0.60	1.63	3.35	0.90	3.02
Sat. zone	4.32	0.80	3.46	4.32	0.40	1.73	4.32	0.10	0.43
Storage			7.15			4.39			5.28

TUESDAY	**TANK 1**	Infl.Zone(ft)	GWT (ft)	**TANK 2**	Infl.Zone(ft)	GWT (ft)	**TANK 3**	Infl.Zone(ft)	GWT (ft)
9/13/2005	moist. (in/ft)		2.60	moist. (in/ft)		3.10	moist. (in/ft)		3.00
1030h									
Probe A									
Probe B									
Probe 1	0.50	1.50	0.75	0.38	1.00	0.38	0.72	1.40	1.01
Probe 2	4.32	0.60	2.59	0.63	1.00	0.63	0.79	1.00	0.79
Probe 3				2.78	0.60	1.67	3.36	0.90	3.02
Sat. zone	4.32	0.90	3.89	4.32	0.40	1.73	4.32	0.10	0.43
Storage			7.23			4.41			5.25

WEDNESDAY	**TANK 1**	Infl.Zone(ft)	GWT (ft)	**TANK 2**	Infl.Zone(ft)	GWT (ft)	**TANK 3**	Infl.Zone(ft)	GWT (ft)
9/14/2005	moist. (in/ft)		2.40	moist. (in/ft)		3.10	moist. (in/ft)		3.00
1130h									
Probe A									
Probe B									
Probe 1	2.06	1.90	3.91	0.38	1.00	0.38	0.70	1.40	0.98
Probe 2	4.32	0.00	0.00	0.61	1.00	0.61	0.79	1.00	0.79
Probe 3				2.84	0.60	1.70	3.39	0.90	3.05
Sat. zone	4.32	1.10	4.75	4.32	0.40	1.73	4.32	0.10	0.43
Storage			8.67			4.42			5.25

THURSDAY	**TANK 1**	Infl.Zone(ft)	GWT (ft)	**TANK 2**	Infl.Zone(ft)	GWT (ft)	**TANK 3**	Infl.Zone(ft)	GWT (ft)
9/15/2005	moist. (in/ft)		2.30	moist. (in/ft)		3.10	moist. (in/ft)		3.00
1430h									
Probe A									
Probe B									
Probe 1	1.93	1.80	3.47	0.38	1.00	0.38	0.67	1.40	0.94
Probe 2	4.32	0.00	0.00	0.60	1.00	0.60	0.78	1.00	0.78
Probe 3				2.88	0.60	1.73	3.42	0.90	3.08
Sat. zone	4.32	1.20	5.18	4.32	0.40	1.73	4.32	0.10	0.43
Storage			8.66			4.44			5.23

FRIDAY	**TANK 1**	Infl.Zone(ft)	GWT (ft)	**TANK 2**	Infl.Zone(ft)	GWT (ft)	**TANK 3**	Infl.Zone(ft)	GWT (ft)
9/16/2005	moist. (in/ft)		2.60	moist. (in/ft)		3.50	moist. (in/ft)		3.50
1400h									
Probe A									
Probe B									
Probe 1	0.87	1.50	1.31	0.39	1.00	0.39	0.89	1.40	1.25
Probe 2	4.32	0.60	2.59	0.60	1.00	0.60	1.00	1.00	1.00
Probe 3				1.83	1.00	1.83	3.03	0.90	2.73
Sat. zone	4.32	0.90	3.89	4.32	0.00	0.00	4.32	0.10	0.43
Storage			7.79			2.82			5.41

MONDAY	**TANK 1**	Infl.Zone(ft)	GWT (ft)	**TANK 2**	Infl.Zone(ft)	GWT (ft)	**TANK 3**	Infl.Zone(ft)	GWT (ft)
9/19/2005	moist. (in/ft)		2.40	moist. (in/ft)		3.20	moist. (in/ft)		3.20
1400h									
Probe A									
Probe B									
Probe 1	0.82	1.90	1.56	0.41	1.00	0.41	0.60	1.40	0.84
Probe 2	4.32	0.00	0.00	0.64	1.00	0.64	0.67	1.00	0.67
Probe 3				2.41	0.70	1.69	3.18	0.90	2.86
Sat. zone	4.32	1.10	4.75	4.32	0.30	1.30	4.32	0.10	0.43
Storage			6.31			4.03			4.80

THURSDAY	**TANK 1**	Infl.Zone(ft)	GWT (ft)	**TANK 2**	Infl.Zone(ft)	GWT (ft)	**TANK 3**	Infl.Zone(ft)	GWT (ft)
9/22/2005	moist. (in/ft)		1.90	moist. (in/ft)		2.60	moist. (in/ft)		2.50
1200h									
Probe A									
Probe B									
Probe 1	4.32	1.40	6.05	1.52	1.00	1.52	1.04	1.40	1.46
Probe 2	4.32	0.00	0.00	0.92	1.10	1.01	3.24	1.00	3.24

Probe 3				4.32	0.00	0.00	4.32	0.90	3.89
Sat. zone	4.32	1.60	6.91	4.32	0.90	3.89	4.32	0.10	0.43
Storage			12.96			6.42			9.02

MONDAY	**TANK 1**	Infl.Zone(ft)	GWT (ft)	**TANK 2**	Infl.Zone(ft)	GWT (ft)	**TANK 3**	Infl.Zone(ft)	GWT (ft)
9/26/2005	moist. (in/ft)		1.70	moist. (in/ft)		2.50	moist. (in/ft)		2.30
1400h									
Probe A									
Probe B									
Probe 1	4.32	1.20	5.18	0.44	1.00	0.44	0.92	1.40	1.29
Probe 2	4.32	0.00	0.00	1.03	1.00	1.03	3.49	1.00	3.49
Probe 3				4.32	0.00	0.00	4.32	0.90	3.89
Sat. zone	4.32	1.80	7.78	4.32	1.00	4.32	4.32	0.10	0.43
Storage			12.96			5.79			9.10

THURSDAY	**TANK 1**	Infl.Zone(ft)	GWT (ft)	**TANK 2**	Infl.Zone(ft)	GWT (ft)	**TANK 3**	Infl.Zone(ft)	GWT (ft)
9/29/2005	moist. (in/ft)		1.60	moist. (in/ft)		1.50	moist. (in/ft)		2.30
1400h									
Probe A							0.71	0.28	0.20
Probe B							0.72	0.38	0.27
Probe 1	4.32	1.10	4.75	1.05	1.00	1.05	0.96	0.75	0.72
Probe 2	4.32	0.00	0.00	4.32	0.00	0.00	3.57	0.80	2.86
Probe 3				4.32	0.00	0.00	4.32	0.00	0.00
Sat. zone	4.32	1.90	8.21	4.32	2.00	8.64	4.32	1.20	5.18
Storage			12.96			9.69			9.23

MONDAY	**TANK 1**	Infl.Zone(ft)	GWT (ft)	**TANK 2**	Infl.Zone(ft)	GWT (ft)	**TANK 3**	Infl.Zone(ft)	GWT (ft)
10/3/2005	moist. (in/ft)		1.50	moist. (in/ft)		1.40	moist. (in/ft)		2.20
1600h									
Probe A							0.91	0.28	0.25
Probe B							0.86	0.38	0.32
Probe 1	4.32	1.00	4.32	1.47	0.90	1.32	0.99	0.75	0.74
Probe 2	4.32	0.00	0.00	4.32	0.00	0.00	3.67	0.70	2.57
Probe 3				4.32	0.00	0.00	4.32	0.00	0.00
Sat. zone	4.32	2.00	8.64	4.32	2.10	9.07	4.32	1.30	5.62
Storage			12.96			10.40			9.50

THURSDAY	**TANK 1**	Infl.Zone(ft)	GWT (ft)	**TANK 2**	Infl.Zone(ft)	GWT (ft)	**TANK 3**	Infl.Zone(ft)	GWT (ft)
10/6/2005	moist. (in/ft)		0.10	moist. (in/ft)		1.00	moist. (in/ft)		1.80
1300h									
Probe A							0.82	0.28	0.23

Probe B							0.85	0.38	0.32
Probe 1	4.32	0.00	0.00	4.32	0.00	0.00	1.52	1.05	1.60
Probe 2	4.32	0.00	0.00	4.32	0.00	0.00	4.32	0.00	0.00
Probe 3				4.32	0.00	0.00	4.32	0.00	0.00
Sat. zone	4.32	3.00	12.96	4.32	3.00	12.96	4.32	1.70	7.34
Storage			12.96			12.96			9.48

MONDAY	**TANK 1**	Infl.Zone(ft)	GWT (ft)	**TANK 2**	Infl.Zone(ft)	GWT (ft)	**TANK 3**	Infl.Zone(ft)	GWT (ft)
10/10/2005	moist. (in/ft)		0.20	moist. (in/ft)		0.20	moist. (in/ft)		1.30
1430h									
Probe A							1.23	0.28	0.34
Probe B							1.54	0.38	0.58
Probe 1	4.32	0.00	0.00	4.32	0.00	0.00	3.86	0.55	2.12
Probe 2	4.32	0.00	0.00	4.32	0.00	0.00	4.32	0.00	0.00
Probe 3				4.32	0.00	0.00	4.32	0.00	0.00
Sat. zone	4.32	3.00	12.96	4.32	3.00	12.96	4.32	2.20	9.50
Storage			12.96			12.96			12.54

THURSDAY	**TANK 1**	Infl.Zone(ft)	GWT (ft)	**TANK 2**	Infl.Zone(ft)	GWT (ft)	**TANK 3**	Infl.Zone(ft)	GWT (ft)
10/13/2005	moist. (in/ft)		0.40	moist. (in/ft)		0.40	moist. (in/ft)		1.30
1230h									
Probe A							1.24	0.28	0.34
Probe B							1.63	0.38	0.61
Probe 1	4.32	0.00	0.00	4.32	0.00	0.00	3.80	0.55	2.09
Probe 2	4.32	0.00	0.00	4.32	0.00	0.00	4.32	0.70	3.02
Probe 3				4.32	0.00	0.00	4.32	0.00	0.00
Sat. zone	4.32	3.00	12.96	4.32	3.00	12.96	4.32	1.50	6.48
Storage			12.96			12.96			12.55

MONDAY	**TANK 1**	Infl.Zone(ft)	GWT (ft)	**TANK 2**	Infl.Zone(ft)	GWT (ft)	**TANK 3**	Infl.Zone(ft)	GWT (ft)
10/17/2005	moist. (in/ft)		0.20	moist. (in/ft)		1.30	moist. (in/ft)		1.70
1230h									
Probe A							0.64	0.28	0.18
Probe B							0.86	0.38	0.32
Probe 1	4.32	0.00	0.00	4.32	0.00	0.00	2.45	0.95	2.33
Probe 2	4.32	0.00	0.00	4.32	0.00	0.00	3.68	0.00	0.00
Probe 3				4.32	0.00	0.00	4.32	0.00	0.00
Sat. zone	4.32	3.00	12.96	4.32	3.00	12.96	4.32	1.80	7.78
Storage			12.96			12.96			10.60

THURSDAY	**TANK 1**	Infl.Zone(ft)	GWT (ft)	**TANK 2**	Infl.Zone(ft)	GWT (ft)	**TANK 3**	Infl.Zone(ft)	GWT (ft)

10/20/2005	moist. (in/ft)		0.50	moist. (in/ft)		1.30	moist. (in/ft)		1.70
1230h									
Probe A							0.60	0.28	0.17
Probe B							0.79	0.38	0.30
Probe 1	4.32	0.00	0.00	4.32	0.00	0.00	2.21	0.95	2.10
Probe 2	4.32	0.00	0.00	4.32	0.00	0.00	3.57	0.00	0.00
Probe 3				4.32	0.00	0.00	4.32	0.00	0.00
Sat. zone	4.32	3.00	12.96	4.32	3.00	12.96	4.32	1.80	7.78
Storage			12.96			12.96			10.34

MONDAY	**TANK 1**	Infl.Zone(ft)	GWT (ft)	**TANK 2**	Infl.Zone(ft)	GWT (ft)	**TANK 3**	Infl.Zone(ft)	GWT (ft)
10/24/2005	moist. (in/ft)		0.00	moist. (in/ft)		0.00	moist. (in/ft)		0.00
1230h									
Probe A							4.32	0.00	0.00
Probe B							4.32	0.00	0.00
Probe 1	4.32	0.00	0.00	4.32	0.00	0.00	4.32	0.00	0.00
Probe 2	4.32	0.00	0.00	4.32	0.00	0.00	4.32	0.00	0.00
Probe 3				4.32	0.00	0.00	4.32	0.00	0.00
Sat. zone	4.32	3.00	12.96	4.32	3.00	12.96	4.32	3.40	14.69
Storage			12.96			12.96			14.69

THURSDAY	**TANK 1**	Infl.Zone(ft)	GWT (ft)	**TANK 2**	Infl.Zone(ft)	GWT (ft)	**TANK 3**	Infl.Zone(ft)	GWT (ft)
10/25/2005	moist. (in/ft)		0.70	moist. (in/ft)		1.30	moist. (in/ft)		1.50
1230h									
Probe A							1.47	0.28	0.40
Probe B							2.17	0.38	0.81
Probe 1	4.32	0.00	0.00	4.32	0.00	0.00	4.32	0.75	3.24
Probe 2	4.32	0.00	0.00	4.32	0.00	0.00	4.32	0.00	0.00
Probe 3				4.32	0.00	0.00	4.32	0.00	0.00
Sat. zone	4.32	3.00	12.96	4.32	3.00	12.96	4.32	2.00	8.64
Storage			12.96			12.96			13.10

APPENDIX E: PHASE 1 – EVAPORATION CALCULATIONS

Table 12: Phase 1 - Tank 1 Evaporation Calculations

	Storage	**Δ Storage**	**H2O added**	**H2O removed**	**Evaporation**	**ET rate**
	S	**ΔS**	**P**	**W**	**ET**	
	(in water)	(in water)	(in water)	(in water)	(in water)	(in/day)
9/2/2005	2.92					
1400h		0.23	0.43	0.00	0.20	0.22
9/3/2005	3.15					
1200h		-0.11	0.01	0.00	0.12	0.11
9/4/2005	3.04					
1400h		-0.07	0.00	0.00	0.07	0.07
9/5/2005	2.97					
1400h		-0.08	0.00	0.00	0.08	0.09
9/6/2005	2.89					
1200h		1.01	0.45	0.00	-0.56	-0.56
9/7/2005	3.90					
1200h		-0.33	0.40	0.00	0.73	0.73
9/8/2005	3.57					
1200h		0.30	0.03	0.00	-0.27	-0.27
9/9/2005	3.87					
1200h		0.52	0.10	0.00	-0.42	-0.14
9/12/2005	4.39					
1400h		0.02	0.00	0.00	-0.02	-0.02
9/13/2005	4.41					
1030h		0.01	0.00	0.00	-0.01	-0.01
9/14/2005	4.42					
1130h		-0.02	0.00	0.00	0.02	0.02
9/15/2005	4.40					
1430h		-1.58	0.00	0.00	1.58	1.61
9/16/2005	2.82					
1400h		1.21	0.00	0.00	-1.21	-0.40
9/19/2005	4.03					
1400h		2.39	0.00	0.00	-2.39	-0.82
9/22/2005	6.42					
1200h		-0.63	2.76	0.00	3.39	0.83
9/26/2005	5.79					
1400h		3.90	0.08	0.09	-3.91	-1.30
9/29/2005	9.69					
1400h		0.71	3.56	0.00	2.85	0.70
10/3/2005	10.40					
1600h		2.56	0.38	0.00	-2.18	-0.76
10/6/2005	12.96					

1300h		0.00	0.42	0.00	0.42	0.10
10/10/2005	12.96					
1430h		0.00	0.56	0.26	0.30	0.10
10/13/2005	12.96					
1230h		0.00	0.52	0.90	-0.38	-0.10
10/17/2005	12.96					
1230h		0.00	0.26	0.90	-0.64	-0.21
10/20/2005	12.96					
1230h		0.00	5.01	0.00	5.01	1.25
10/24/2005	12.96					
1230h		0.00	0.00	0.00	0.00	0.00
10/25/2005	12.96					
1230h						

Table 13: Phase 1 - Tank 2 Evaporation Calculations

	Storage	**Δ Storage**	**H2O added**	**H2O removed**	**Evaporation**	**ET rate**
	S	**ΔS**	**P**	**W**	**ET**	
	(in water)	(in water)	(in water)	(in water)	(in water)	(in/day)
9/2/2005	2.92					
1400h		0.23	0.43	0.00	0.20	0.22
9/3/2005	3.15					
1200h		-0.11	0.01	0.00	0.12	0.11
9/4/2005	3.04					
1400h		-0.07	0.00	0.00	0.07	0.07
9/5/2005	2.97					
1400h		-0.08	0.00	0.00	0.08	0.09
9/6/2005	2.89					
1200h		1.01	0.45	0.00	-0.56	-0.56
9/7/2005	3.90					
1200h		-0.33	0.40	0.00	0.73	0.73
9/8/2005	3.57					
1200h		0.30	0.03	0.00	-0.27	-0.27
9/9/2005	3.87					
1200h		0.52	0.10	0.00	-0.42	-0.14
9/12/2005	4.39					
1400h		0.02	0.00	0.00	-0.02	-0.02
9/13/2005	4.41					
1030h		0.01	0.00	0.00	-0.01	-0.01
9/14/2005	4.42					
1130h		-0.02	0.00	0.00	0.02	0.02
9/15/2005	4.40					
1430h		-1.58	0.00	0.00	1.58	1.61
9/16/2005	2.82					
1400h		1.21	0.00	0.00	-1.21	-0.40
9/19/2005	4.03					
1400h		2.39	0.00	0.00	-2.39	-0.82
9/22/2005	6.42					
1200h		-0.63	2.76	0.00	3.39	0.83
9/26/2005	5.79					
1400h		3.90	0.08	0.09	-3.91	-1.30
9/29/2005	9.69					
1400h		0.71	3.56	0.00	2.85	0.70
10/3/2005	10.40					
1600h		2.56	0.38	0.00	-2.18	-0.76
10/6/2005	12.96					
1300h		0.00	0.42	0.00	0.42	0.10
10/10/2005	12.96					
1430h		0.00	0.56	0.26	0.30	0.10

10/13/2005	12.96					
1230h		0.00	0.52	0.90	-0.38	-0.10
10/17/2005	12.96					
1230h		0.00	0.26	0.90	-0.64	-0.21
10/20/2005	12.96					
1230h		0.00	5.01	0.00	5.01	1.25
10/24/2005	12.96					
1230h		0.00	0.00	0.00	0.00	0.00
10/25/2005	12.96					
1230h						

Table 14: Phase 1 - Tank 3 Evaporation Calculations

	Storage	**Δ Storage**	**H2O added**	**H2O removed**	**Evaporation**	**ET rate**
	S	**ΔS**	**P**	**W**	**ET**	
	(in water)	(in water)	(in water)	(in water)	(in water)	(in/day)
9/2/2005	4.60					
1400h		0.40	0.43	0.00	0.03	0.03
9/3/2005	5.00					
1200h		-0.27	0.01	0.00	0.28	0.26
9/4/2005	4.73					
1400h		-0.23	0.00	0.00	0.23	0.23
9/5/2005	4.50					
1400h		-0.12	0.00	0.00	0.12	0.13
9/6/2005	4.38					
1200h		0.94	0.45	0.00	-0.49	-0.49
9/7/2005	5.32					
1200h		0.20	0.40	0.00	0.20	0.20
9/8/2005	5.52					
1200h		-0.19	0.03	0.00	0.22	0.22
9/9/2005	5.33					
1200h		-0.05	0.10	0.00	0.15	0.05
9/12/2005	5.28					
1400h		-0.03	0.00	0.00	0.03	0.03
9/13/2005	5.25					
1030h		0.00	0.00	0.00	0.00	0.00
9/14/2005	5.25					
1130h		-0.02	0.00	0.00	0.02	0.02
9/15/2005	5.23					
1430h		0.18	0.00	0.00	-0.18	-0.18
9/16/2005	5.41					
1400h		-0.61	0.00	0.00	0.61	0.20
9/19/2005	4.80					
1400h		4.22	0.00	0.00	-4.22	-1.45
9/22/2005	9.02					
1200h		0.08	2.76	0.00	2.68	0.66
9/26/2005	9.10					
1400h		0.13	0.08	0.09	-0.14	-0.05
9/29/2005	9.23					
1400h		0.27	0.28	0.00	0.01	0.00
10/3/2005	9.50					
1600h		-0.02	0.38	0.00	0.40	0.14
10/6/2005	9.48					
1300h		3.06	0.42	0.00	-2.64	-0.65
10/10/2005	12.54					
1430h		0.01	0.56	0.26	0.29	0.10

10/13/2005	12.55					
1230h		-1.95	0.52	0.36	2.11	0.53
10/17/2005	10.60					
1230h		-0.26	0.26	0.90	-0.38	-0.13
10/20/2005	10.34					
1230h		4.35	5.01	0.00	0.66	0.17
10/24/2005	14.69					
1230h		-1.59	0.00	0.00	1.59	1.59
10/25/2005	13.1					
1230h						

APPENDIX F: PHASE 2 – FIELD READINGS

Table 15: Phase 2 - Field Readings

SUNDAY	H2O added (in)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
2/26/2006	1.64	moist. (in/ft)		4.00	moist. (in/ft)		4.00
1700h							
Probe A					0.79	0.25	
Probe B					1.11	0.50	
Probe 1		0.19	1.00		1.29	1.00	
Probe 2		0.77	2.00		0.75	2.00	
Probe 3		4.00	3.00		2.17	3.00	

TUESDAY	Water added (in)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
2/28/2006	1.64	moist. (in/ft)		3.50	moist. (in/ft)		3.50
1800h							
Probe A					0.64	0.25	
Probe B					0.85	0.50	
Probe 1		0.25	1.00		0.98	1.00	
Probe 2		0.86	2.00		1.16	2.00	
Probe 3		4.32	3.00		3.94	3.00	

THURSDAY	Water added (in)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
3/2/2006	1.64	moist. (in/ft)		3.20	moist. (in/ft)		3.00
1200h							
Probe A					0.63	0.25	
Probe B					0.83	0.50	
Probe 1		0.30	1.00		0.99	1.00	
Probe 2		0.92	2.00		1.58	2.00	
Probe 3		4.32	3.00		3.95	3.00	

SATURDAY	Water added (in)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
3/4/2006	0	moist. (in/ft)		2.80	moist. (in/ft)		2.60
1800h							

Probe A					0.61	0.25	
Probe B					0.83	0.50	
Probe 1		0.33	1.00		0.92	1.00	
Probe 2		1.08	2.00		3.02	2.00	
Probe 3		4.32	3.00		3.90	3.00	

SUNDAY	Water added (in)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
3/5/2006	0	moist. (in/ft)		2.90	moist. (in/ft)		2.60
1600h							
Probe A					0.60	0.25	
Probe B					0.84	0.50	
Probe 1		0.32	1.00		0.94	1.00	
Probe 2		1.06	2.00		3.08	2.00	
Probe 3		4.32	3.00		3.92	3.00	

TUESDAY	Water added (in)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
3/7/2006	0	moist. (in/ft)		2.90	moist. (in/ft)		2.60
1300h							
Probe A					0.59	0.25	
Probe B					0.83	0.50	
Probe 1		0.29	1.00		0.94	1.00	
Probe 2		1.10	2.00		3.43	2.00	
Probe 3		4.32	3.00		3.91	3.00	

THURSDAY	Water added (in)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
3/9/2006	1.64	moist. (in/ft)		2.90	moist. (in/ft)		2.60
1300h							
Probe A					0.58	0.25	
Probe B					0.78	0.50	
Probe 1		0.28	1.00		0.94	1.00	
Probe 2		1.15	2.00		3.18	2.00	
Probe 3		4.32	3.00		3.92	3.00	

SATURDAY	Water added (in)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)

3/11/2006	0	moist. (in/ft)		2.40	moist. (in/ft)		2.10
1200h							
Probe A					0.60	0.25	
Probe B					0.85	0.50	
Probe 1		0.30	1.00		1.47	1.00	
Probe 2		1.60	2.00		3.52	2.00	
Probe 3		4.32	3.00		3.85	3.00	

APPENDIX G: PHASE 2 – STORAGE CALCULATIONS

Table 16: Phase 2 - Storage Calculations

SUNDAY	Water added (in)	Probe depth (ft)	**TANK 2**	GWT (ft)	Probe depth (ft)	**TANK 3**	GWT (ft)
2/26/2006	1.64		moist. (in/ft)	4.00		moist. (in/ft)	4.00
1700h					0.00	0.00	
Probe A					0.25	0.79	
Probe B		0.50	0.00		0.50	1.11	
Probe 1		1.00	0.19		1.00	1.29	
Probe 2		2.00	0.77		2.00	0.75	
Probe 3		3.00	4.00		3.00	2.17	
		3.50	4.00		3.50	2.17	

TUESDAY	Water added (in)	Probe depth (ft)	**TANK 2**	GWT (ft)	Probe depth (ft)	**TANK 3**	GWT (ft)
2/28/2006	1.64		moist. (in/ft)	3.50		moist. (in/ft)	3.50
1800h					0.00	0.00	
Probe A					0.25	0.64	
Probe B		0.50	0.00		0.50	0.85	
Probe 1		1.00	0.25		1.00	0.98	
Probe 2		2.00	0.86		2.00	1.16	
Probe 3		3.00	4.32		3.00	3.94	
		3.50	4.32		3.50	4.32	

THURSDAY	Water added (in)	Probe depth (ft)	**TANK 2**	GWT (ft)	Probe depth (ft)	**TANK 3**	GWT (ft)
3/2/2006	1.64		moist. (in/ft)	3.20		moist. (in/ft)	3.00
1200h					0.00	0.00	
Probe A					0.25	0.63	
Probe B		0.50	0.00		0.50	0.83	
Probe 1		1.00	0.30		1.00	0.99	
Probe 2		2.00	0.92		2.00	1.58	
Probe 3		3.00	4.32		3.00	4.32	
		3.20	4.32		3.50	4.32	
		3.50	4.32				

SATURDAY	Water added (in)	Probe depth (ft)	**TANK 2**	GWT (ft)	Probe depth (ft)	**TANK 3**	GWT (ft)
3/4/2006	0		moist. (in/ft)	2.80		moist. (in/ft)	2.60

1800h					0.00	0.00	
Probe A					0.25	0.61	
Probe B		0.50	0.00		0.50	0.83	
Probe 1		1.00	0.33		1.00	0.92	
Probe 2		2.00	1.08		2.00	3.02	
Probe 3		2.80	4.32		2.60	4.32	
		3.00	4.32		3.00	4.32	
		3.50	4.32		3.50	4.32	

SUNDAY	Water added (in)	Probe depth (ft)	**TANK 2**	GWT (ft)	Probe depth (ft)	**TANK 3**	GWT (ft)
3/5/2006	0		moist. (in/ft)	2.90		moist. (in/ft)	2.60
1600h					0.00	0.00	
Probe A					0.25	0.60	
Probe B		0.50	0.00		0.50	0.84	
Probe 1		1.00	0.32		1.00	0.94	
Probe 2		2.00	1.06		2.00	3.08	
Probe 3		2.90	4.32		2.60	4.32	
		3.00	4.32		3.00	4.32	
		3.50	4.32		3.50	4.32	

TUESDAY	Water added (in)	Probe depth (ft)	**TANK 2**	GWT (ft)	Probe depth (ft)	**TANK 3**	GWT (ft)
3/7/2006	0		moist. (in/ft)	2.90		moist. (in/ft)	2.60
1300h					0.00	0.00	
Probe A					0.25	0.59	
Probe B		0.50	0.00		0.50	0.83	
Probe 1		1.00	0.29		1.00	0.94	
Probe 2		2.00	1.10		2.00	3.43	
Probe 3		2.90	4.32		2.60	4.32	
		3.00	4.32		3.00	4.32	
		3.50	4.32		3.50	4.32	

THURSDAY	Water added (in)	Probe depth (ft)	**TANK 2**	GWT (ft)	Probe depth (ft)	**TANK 3**	GWT (ft)
3/9/2006	1.64		moist. (in/ft)	2.90		moist. (in/ft)	2.60
1300h					0.00	0.00	
Probe A					0.25	0.58	
Probe B		0.50	0.00		0.50	0.78	
Probe 1		1.00	0.28		1.00	0.94	
Probe 2		2.00	1.15		2.00	3.18	
Probe 3		2.90	4.32		2.60	4.32	

		3.00	4.32		3.00	4.32	

SATURDAY	Water added (in)	Probe depth (ft)	**TANK 2**	GWT (ft)	Probe depth (ft)	**TANK 3**	GWT (ft)
3/11/2006	0		moist. (in/ft)	2.40		moist. (in/ft)	2.10
1200h					0.00	0.00	
Probe A					0.25	0.60	
Probe B		0.50	0.00		0.50	0.85	
Probe 1		1.00	0.30		1.00	1.47	
Probe 2		2.00	1.60		2.00	3.52	
Probe 3		2.40	4.32		2.10	4.32	
		3.00	4.32		3.00	4.32	
		3.50	4.32		3.50	4.32	

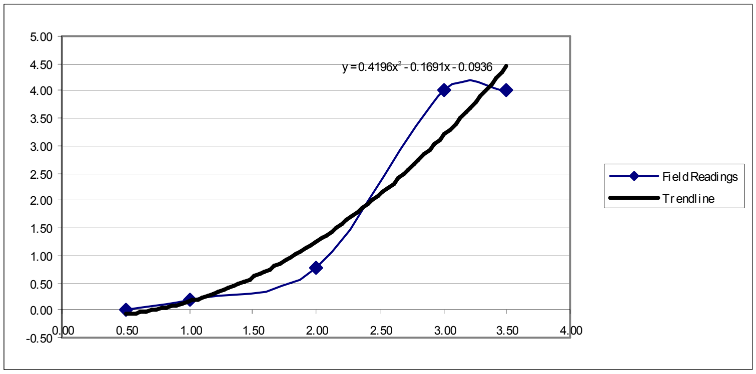

Figure 188: Tank 2 - 2/26/2006 Storage

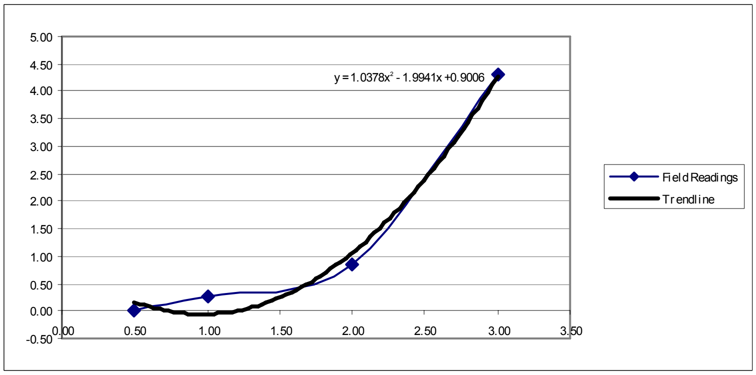

Figure 199: Tank 2 - 2/28/2006 Storage

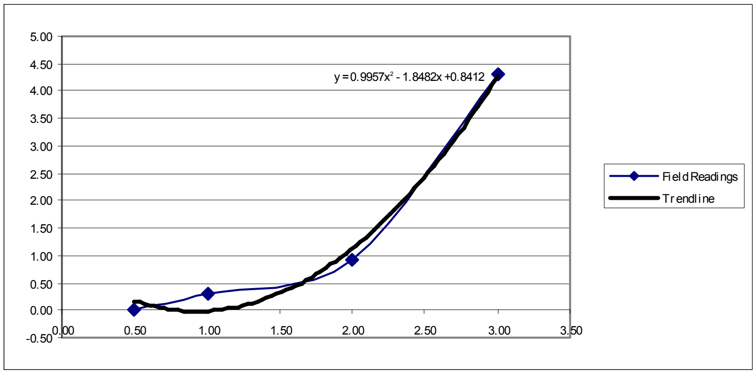

Figure 200: Tank 2 - 3/2/2006 Storage

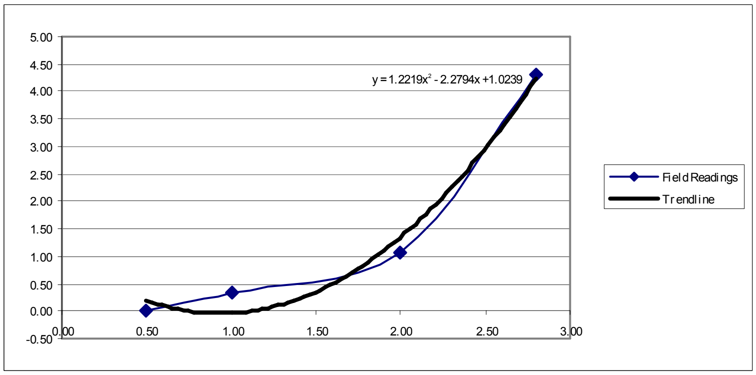

Figure 211: Tank 2 - 3/4/2006 Storage

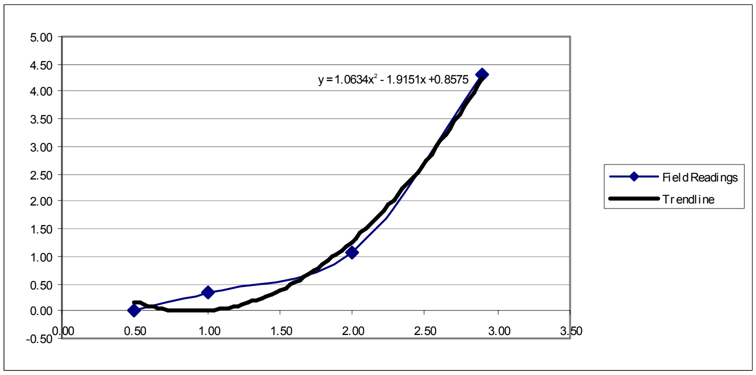

Figure 222: Tank 2 - 3/5/2006 Storage

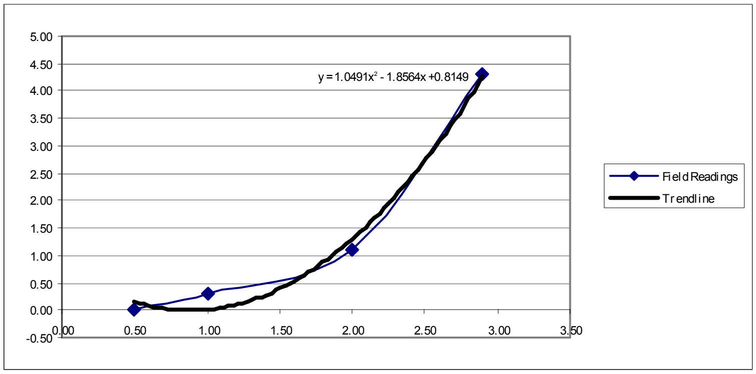

Figure 233: Tank 2 - 3/7/2006 Storage

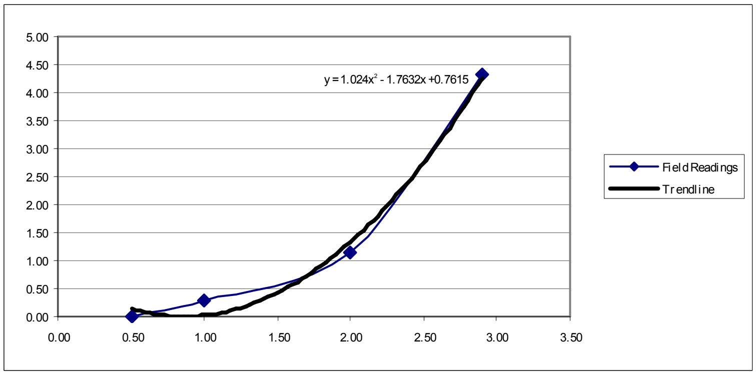

Figure 244: Tank 2 - 3/9/2006 Storage

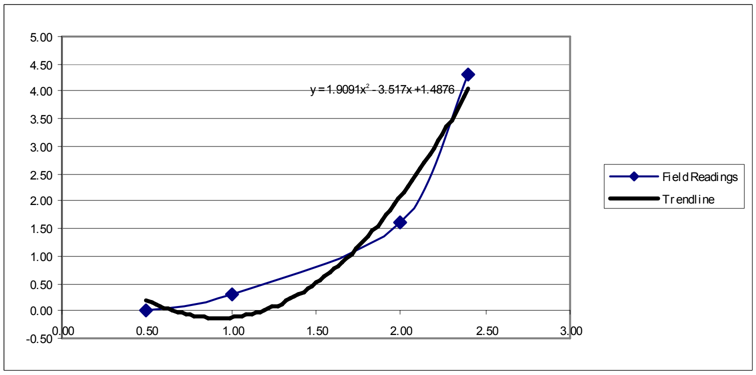

Figure 255: Tank 2 - 3/11/2006 Storage

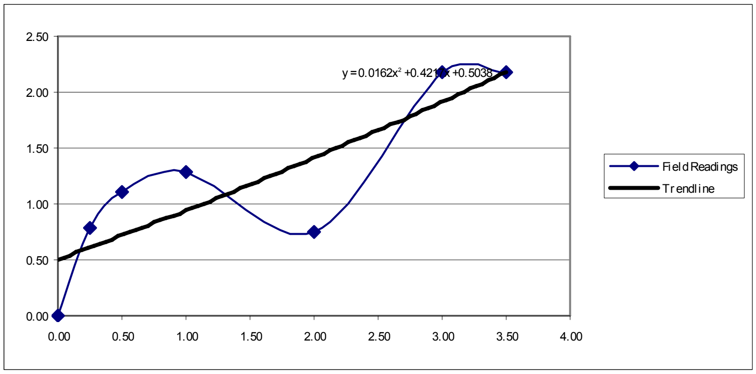

Figure 266: Tank 3 - 2/26/2006 Storage

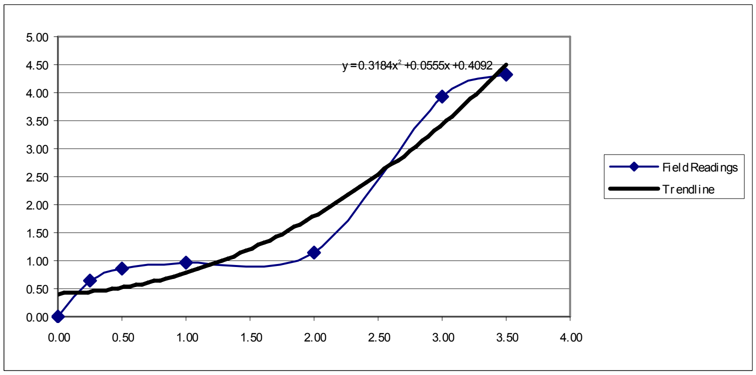

Figure 277: Tank 3 - 2/28/2006 Storage

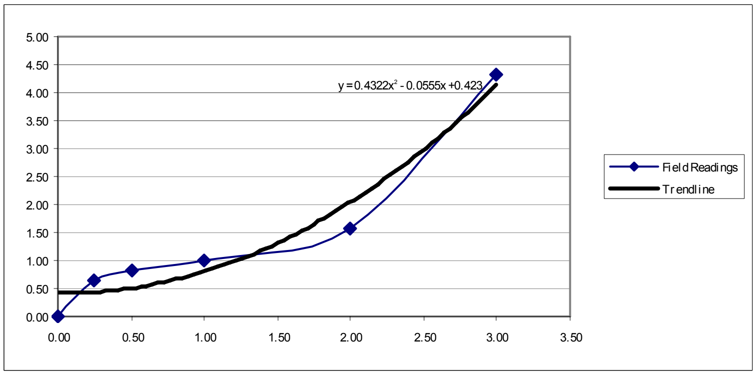

Figure 288: Tank 3 - 3/2/2006 Storage

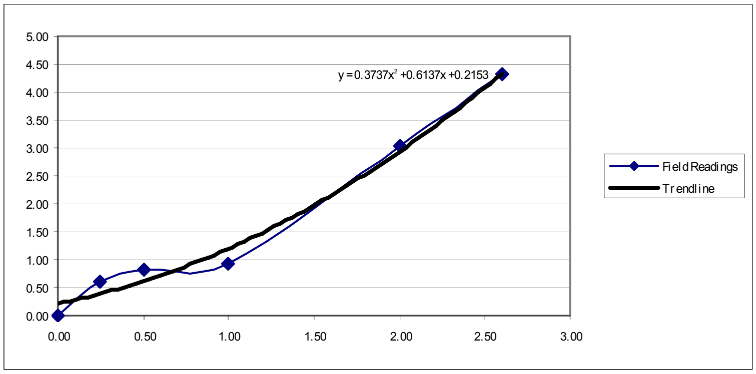

Figure 299: Tank 3 - 3/4/2006 Storage

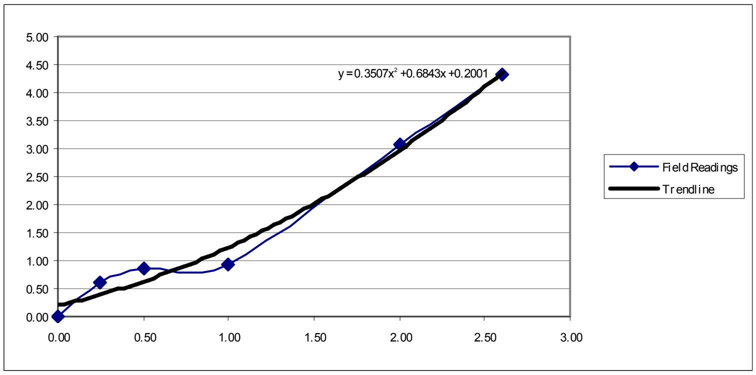

Figure 300: Tank 3 - 3/5/2006 Storage

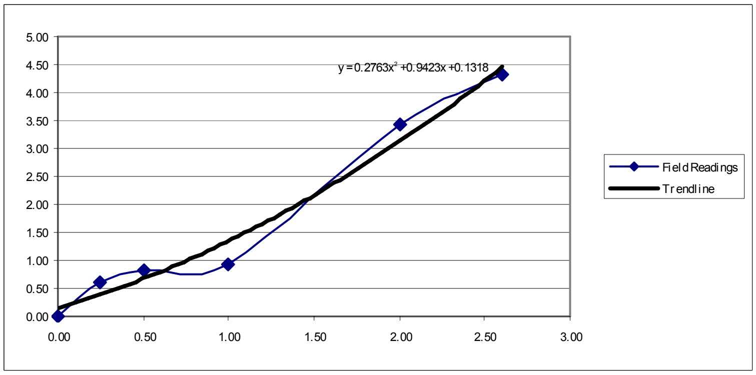

Figure 311: Tank 3 - 3/7/2006 Storage

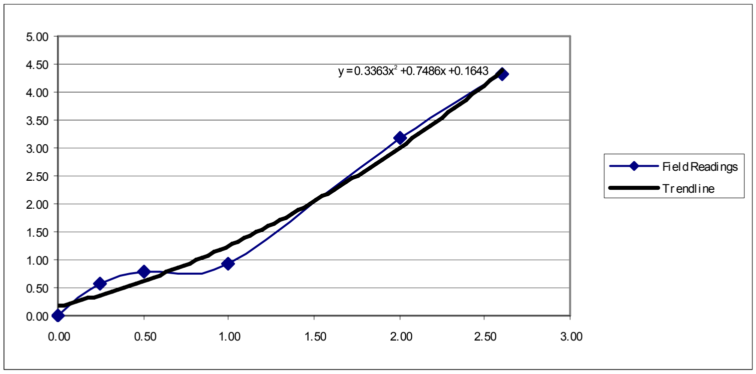

Figure 322: Tank 3 - 3/9/2006 Storage

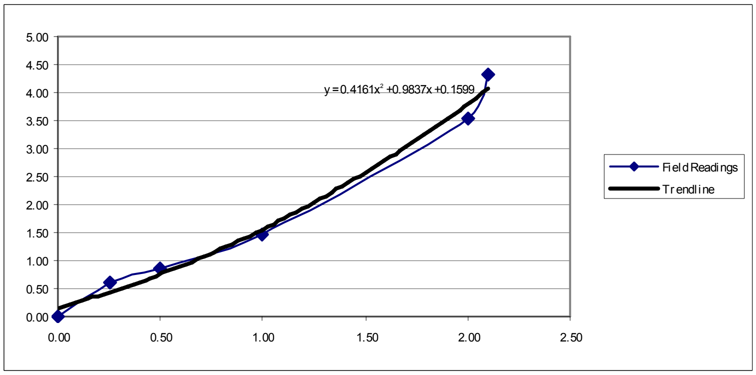

Figure 333: Tank 3 - 3/11/2006 Storage

APPENDIX H: PHASE 2 – EVAPORATION CALCULATIONS

Table 17: Phase 2 - Tank 2 Evaporation Calculations

Tank 2					
	Storage	Δ Storage	H2O added	Evaporation	ET rate
	S	ΔS	P	ET	
	(in water)	(in water)	(in water)	(in water)	(in/day)
2/26/2006	4.68				
1700h		0.32	1.60	1.28	0.63
2/28/2006	5.00				
1800h		0.10	1.60	1.50	0.86
3/2/2006	5.10				
1200h		0.51	1.60	1.09	0.48
3/4/2006	5.61				
1800h		-0.19	0.00	0.19	0.21
3/5/2006	5.42				
1600h		-0.81	0.00	0.81	0.43
3/7/2006	4.61				
1300h		0.89	0.00	-0.89	-0.45
3/9/2006	5.50				
1300h		1.10	1.60	0.50	0.23
3/11/2006	6.60				
1800h					

Table 18: Phase 2 - Tank 3 Evaporation Calculations

	Tank 3				
	Storage	Δ Storage	H2O added	Evaporation	ET rate
	S	ΔS	P	ET	
	(in water)	(in water)	(in water)	(in water)	(in/day)
2/26/2006	4.56				
1700h		2.66	1.60	-1.06	-0.52
2/28/2006	7.22				
1800h		-0.15	1.60	1.75	1.00
3/2/2006	7.07				
1200h		1.66	1.60	-0.06	-0.03
3/4/2006	8.73				
1800h		0.05	0.00	-0.05	-0.05
3/5/2006	8.78				
1600h		0.25	0.00	-0.25	-0.13
3/7/2006	9.03				
1300h		-0.21	0.00	0.21	-0.11
3/9/2006	8.82				
1300h		1.03	1.60	0.57	0.26
3/11/2006	9.85				
1800h					

APPENDIX I: PHASE 3 – FIELD READINGS

Table 19: Phase 3 - Field Readings

SUNDAY	H2O added (in)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
2/26/2006	1.64	moist. (in/ft)		4.00	moist. (in/ft)		4.00
1700h							
Probe A					0.79	0.25	
Probe B					1.11	0.50	
Probe 1		0.19	1.00		1.29	1.00	
Probe 2		0.77	2.00		0.75	2.00	
Probe 3		4.00	3.00		2.17	3.00	

TUESDAY	Water added (in)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
2/28/2006	1.64	moist. (in/ft)		3.50	moist. (in/ft)		3.50
1800h							
Probe A					0.64	0.25	
Probe B					0.85	0.50	
Probe 1		0.25	1.00		0.98	1.00	
Probe 2		0.86	2.00		1.16	2.00	
Probe 3		4.32	3.00		3.94	3.00	

THURSDAY	Water added (in)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
3/2/2006	1.64	moist. (in/ft)		3.20	moist. (in/ft)		3.00
1200h							
Probe A					0.63	0.25	
Probe B					0.83	0.50	
Probe 1		0.30	1.00		0.99	1.00	
Probe 2		0.92	2.00		1.58	2.00	
Probe 3		4.32	3.00		3.95	3.00	

SATURDAY	Water added (in)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
3/4/2006	0	moist. (in/ft)		2.80	moist. (in/ft)		2.60
1800h							

Probe A					0.61	0.25	
Probe B					0.83	0.50	
Probe 1		0.33	1.00		0.92	1.00	
Probe 2		1.08	2.00		3.02	2.00	
Probe 3		4.32	3.00		3.90	3.00	
SUNDAY	Water added (in)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
3/5/2006	0	moist. (in/ft)		2.90	moist. (in/ft)		2.60
1600h							
Probe A					0.60	0.25	
Probe B					0.84	0.50	
Probe 1		0.32	1.00		0.94	1.00	
Probe 2		1.06	2.00		3.08	2.00	
Probe 3		4.32	3.00		3.92	3.00	
TUESDAY	Water added (in)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
3/7/2006	0	moist. (in/ft)		2.90	moist. (in/ft)		2.60
1300h							
Probe A					0.59	0.25	
Probe B					0.83	0.50	
Probe 1		0.29	1.00		0.94	1.00	
Probe 2		1.10	2.00		3.43	2.00	
Probe 3		4.32	3.00		3.91	3.00	
THURSDAY	Water added (in)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)
3/9/2006	1.64	moist. (in/ft)		2.90	moist. (in/ft)		2.60
1300h							
Probe A					0.58	0.25	
Probe B					0.78	0.50	
Probe 1		0.28	1.00		0.94	1.00	
Probe 2		1.15	2.00		3.18	2.00	
Probe 3		4.32	3.00		3.92	3.00	
SATURDAY	Water added (in)	**TANK 2**	Depth (ft)	GWT (ft)	**TANK 3**	Depth (ft)	GWT (ft)

3/11/2006	0	moist. (in/ft)		2.40	moist. (in/ft)		2.10
1200h							
Probe A					0.60	0.25	
Probe B					0.85	0.50	
Probe 1		0.30	1.00		1.47	1.00	
Probe 2		1.60	2.00		3.52	2.00	
Probe 3		4.32	3.00		3.85	3.00	

APPENDIX J: PHASE 3 – STORAGE CALCULATIONS

Table 20: Phase 3 - Storage Calculations

TUESDAY	Water added (in)	Probe depth (ft)	**TANK 2**	GWT (ft)	Probe depth (ft)	**TANK 3**	GWT (ft)
4/11/2006	1.64		moist. (in/ft)	4.00		moist. (in/ft)	4.00
1300h							
Probe A		0.50	0.00		0.00	0.00	
Probe B		1.00	0.33		0.25	0.40	
Probe 1		2.00	0.65		0.50	0.53	
Probe 2		3.00	2.27		1.00	0.93	
Probe 3		3.50	4.00		3.00	2.11	
					3.50	4.32	

THURSDAY	Water added (in)	Probe depth (ft)	**TANK 2**	GWT (ft)	Probe depth (ft)	**TANK 3**	GWT (ft)
4/13/2006	1.64		moist. (in/ft)	3.60		moist. (in/ft)	3.50
1300h							
Probe A		0.50	0.00		0.00	0.00	
Probe B		1.00	0.37		0.25	0.55	
Probe 1		2.00	0.66		0.50	0.73	
Probe 2		3.00	2.76		1.00	0.90	
Probe 3		3.50	4.32		3.00	3.20	
					3.50	4.32	

SATURDAY	Water added (in)	Probe depth (ft)	**TANK 2**	GWT (ft)	Probe depth (ft)	**TANK 3**	GWT (ft)
4/15/2006	1.64		moist. (in/ft)	3.20		moist. (in/ft)	3.10
1700h							
Probe A		0.50	0.00		0.00	0.00	
Probe B		1.00	0.36		0.25	0.47	
Probe 1		2.00	0.71		0.50	0.70	
Probe 2		3.00	4.32		1.00	0.78	
Probe 3					3.00	3.24	
					3.10	4.32	

SUNDAY	Water added (in)	Probe depth (ft)	**TANK 2**	GWT (ft)	Probe depth (ft)	**TANK 3**	GWT (ft)
4/16/2006	0		moist. (in/ft)	2.70		moist. (in/ft)	2.50

1600h							
Probe A		0.50	0.00		0.00	0.00	
Probe B		1.00	0.39		0.25	0.50	
Probe 1		2.00	1.15		0.50	0.74	
Probe 2		2.70	4.32		1.00	0.87	
Probe 3					2.50	4.32	

MONDAY	Water added (in)	Probe depth (ft)	**TANK 2**	GWT (ft)	Probe depth (ft)	**TANK 3**	GWT (ft)
4/17/2006	0		moist. (in/ft)	2.70		moist. (in/ft)	2.50
1200h							
Probe A		0.50	0.00		0.00	0.00	
Probe B		1.00	0.40		0.25	0.52	
Probe 1		2.00	1.18		0.50	0.72	
Probe 2		2.70	4.32		1.00	0.89	
Probe 3					2.50	4.32	

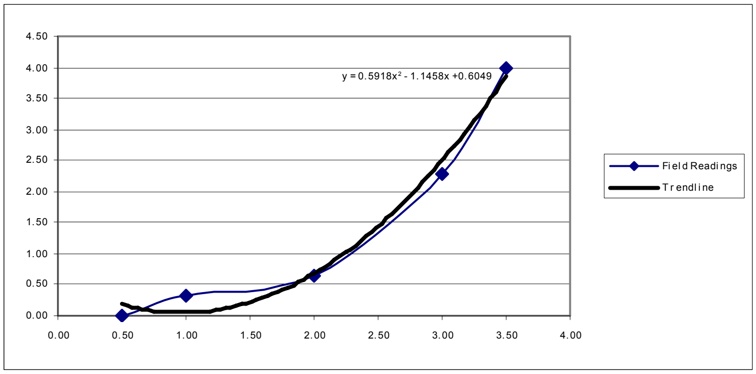

Figure 344: Tank 2 - 4/11/2006 Storage

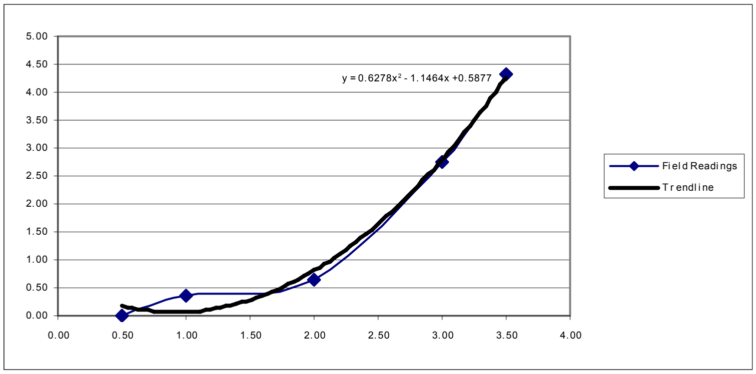

Figure 355: Tank 2 - 4/13/2006 Storage

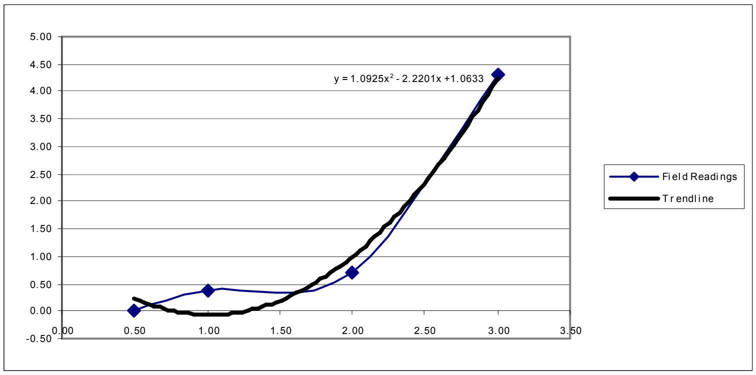

Figure 366: Tank 2 - 4/15/2006 Storage

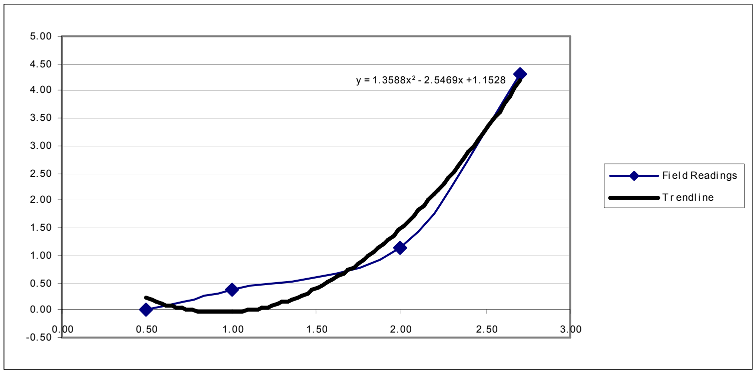

Figure 377: Tank 2 - 4/16/2006 Storage

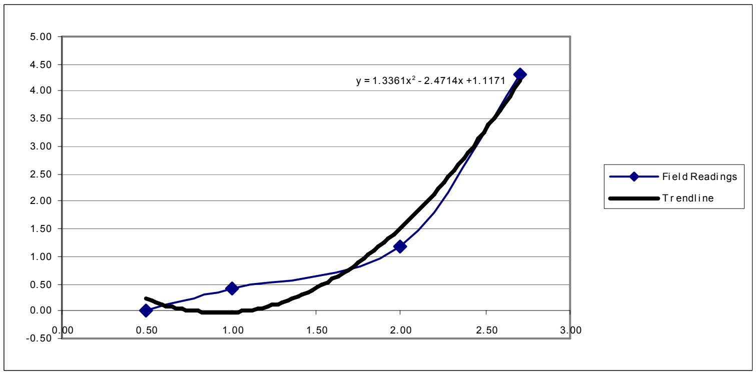

Figure 388: Tank 2 - 4/17/2006 Storage

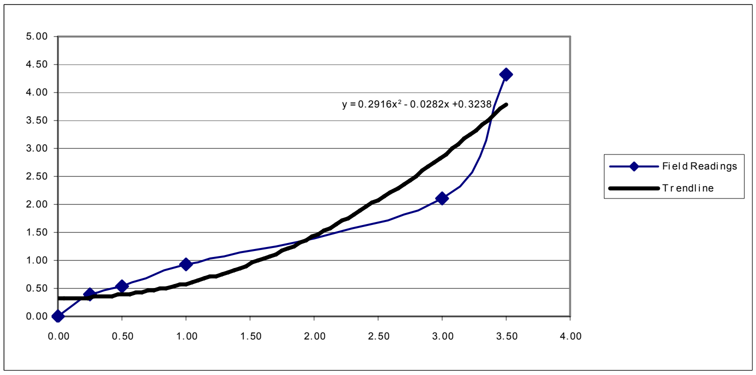

Figure 399: Tank 3 - 4/11/2006 Storage

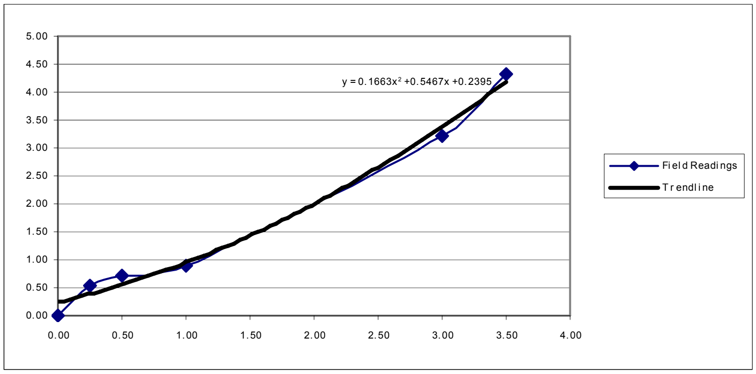

Figure 400: Tank 3 - 4/13/2006 Storage

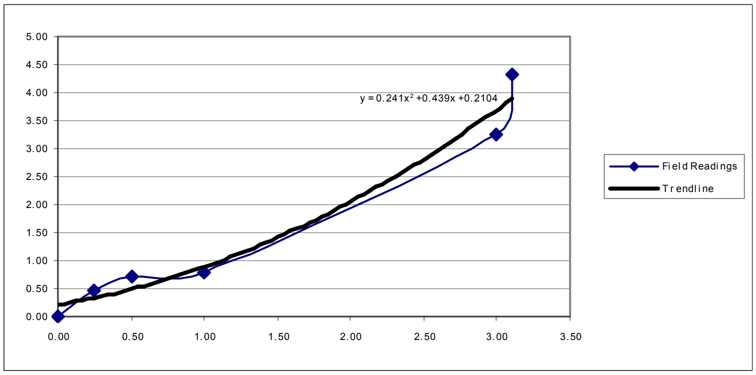

Figure 411: Tank 3 - 4/15/2006 Storage

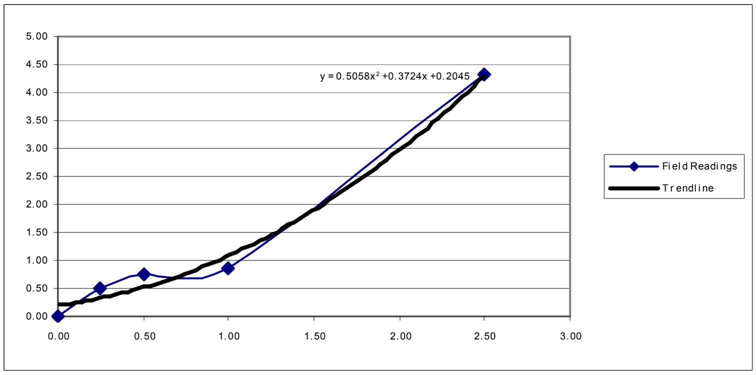

Figure 422: Tank 3 - 4/16/2006 Storage

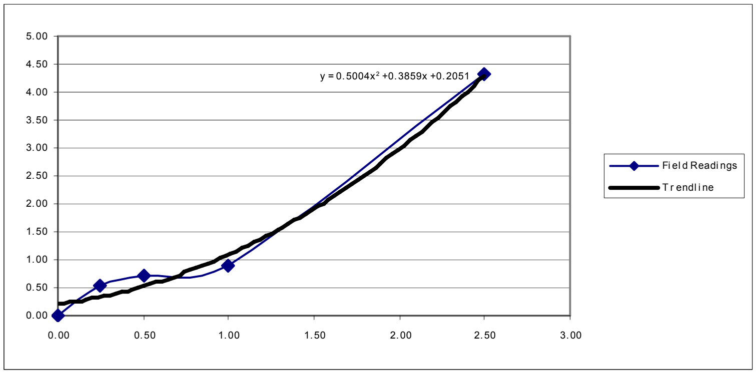

Figure 433: Tank 3 - 4/17/2006 Storage

APPENDIX K: PHASE 3 – EVAPORATION CALCULATIONS

Table 21: Phase 3 - Tank 2 Evaporation Calculations

	Tank 2				
	Storage	Δ Storage	H2O added	Evaporation	ET rate
	S	ΔS	P	ET	
	(in water)	(in water)	(in water)	(in water)	(in/day)
4/11/2006	3.37				
1300h		0.45	1.60	1.15	0.58
4/13/2006	3.82				
1300h		1.94	1.60	-0.34	-0.16
4/15/2006	5.76				
1700h		0.12	1.60	1.48	1.54
4/16/2006	5.88				
1600h		0.04	0.00	-0.04	-0.05
4/17/2006	5.92				
1200h					

Table 22: Phase 3 - Tank 3 Evaporation Calculations

	Tank 3				
	Storage	Δ Storage	H2O added	Evaporation	ET rate
	S	ΔS	P	ET	
	(in water)	(in water)	(in water)	(in water)	(in/day)
4/11/2006	5.12				
1300h		1.44	1.60	0.16	0.08
4/13/2006	6.56				
1300h		0.31	1.60	1.29	0.60
4/15/2006	6.87				
1700h		1.76	1.60	-0.16	-0.17
4/16/2006	8.63				
1600h		0.02	0.00	-0.02	-0.02
4/17/2006	8.65				
1200h					

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