7-1-2011

Ground water-surface water interaction of Rio Grande Biopark area, Albuquerque, New Mexico

Sadia Faiza

Recommended Citation

Faiza, Sadia. "Ground water-surface water interaction of Rio Grande Biopark area, Albuquerque, New Mexico." (2011). https://digitalrepository.unm.edu/ce_etds/47

Sadia Faiza
Candidate

Civil Engineering
Department

This thesis is approved, and it is acceptable in quality
and form for publication:

Approved by the Thesis Committee:

JStormont ,Chairperson

Julie Coonrod

GROUND WATER-SURFACE WATER INTERACTION OF RIO GRANDE BIOPARK AREA, ALBUQUERQUE, NEW MEXICO.

BY

SADIA FAIZA

B. Sc. in Civil Engineering

Bangladesh University of Engineering and Technology, Dhaka, Bangladesh

THESIS

Submitted in Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE
Civil Engineering

The University of New Mexico
Albuquerque, New Mexico

May, 2011

DEDICATION

To my parents

AKNOWLEDGEMENTS

First of all, I would like to thank Dr. John C. Stormont, my supervisor and thesis committee chair, for providing me with the opportunity to study for my master’s degree. His patience, his insight into my research, his supervision and his encouragement all helped me to finish this project.

Also, I thank him for giving me the opportunity to work as a Teaching Assistant, an experience which taught me many basic concepts of the geotechnical field which have been useful for my study and research.

I would like to thank my thesis committee members: Dr. Julie E.A. Coonrod and Dr. Mark Stone for their valuable recommendations pertaining to this study.

I would like to express my gratitude to the Urban Flood Development Project (UFDP), for the funding to pursue this research.

I thank all my classmates, especially Helen Sobien and Emily Kowalchuk, for helping me with my research and encouraging me.

I would like to thank Kenny Martinez, lab supervisor for teaching me about instrumentation and for providing me equipments for my lab research work.

I am very much appreciative of everyone’s help. My 24 months here were happy and productive. This will be a good memory.

Lastly, I would like to thank my husband, Dewan Muhammed Ibtesham, for making me laugh and making my life here comfortable and easy.

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Albuquerque, NM, USA 2011

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Dhaka, Bangladesh 2008

ABSTRACT

Ground water and surface water are typically considered as separate entities, but all surface water features interact with ground water in different ways. Better understanding of ground water-surface water interaction is important for effective land and water management. This study investigated the impact of surface water on ground water levels as well as soil moisture content in a small region of Albuquerque Biopark near the Rio Grande. This study involved collection of field data on soil moisture, ground water levels and observations of vegetation densities adjacent to the Biopark wetlands. Numerical models were developed of the influence of the river stage on ground water levels near the wetlands and of the interaction between the wetlands and the ground water. Model results were consistent with field measurements, suggesting that the major processes affecting surface water-ground water interaction were included and well described in the model. The study results indicate that Biopark wetlands produces elevated soil moisture surrounding the wetlands and mounds the water table locally. The additional moisture is

reflected in vegetation changes adjacent to the wetlands, consistent with the goals of the Biopark in terms of increasing biodiversity. The model and analysis approach developed for the Biopark can be used for other wetland system with shallow water tables.

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CHAPTER 1

INTRODUCTION

1.2 Motivation

The riparian zone is the crossing point between land and water. Riparian zones occur as grassland, woodland, wetland or even non-vegetated. The terms riparian woodland, riparian forest, riparian buffer zone, riparian strip, or bosque are used to characterize a riparian zone. These zones may be natural or engineered for soil stabilization or restoration (Rogers, 1995). Plant communities along the margins of rivers are called riparian vegetation. The term “wetland” actually refers to an area of land whose soil is saturated with moisture either permanently or seasonally. It may be natural or constructed. A constructed wetland, or wetpark, is an artificial marsh or swamp. Wetlands perform many ecological functions and have special characteristics that make them important and valuable natural resources. They are used for storm water and flood control, water treatment and recreation; they provide storage capacity for water recharge and discharge and habitat for ecological diversity (Mitsch et al. 2000). Hence, having a better understanding of wetlands is crucial to preserving and maintaining the ecological system and preserving biodiversity of the river and riverside system (Naiman et al. 1993).

The ground water table is a very important element of the riparian wetland system. Understanding of the role of ground water has grown over the past decade. The stream sometimes gains water from and sometimes losses water to ground water. The percentage contribution from ground water to stream is reported as high as ninety percent (Horton et al. 2001). Ground water table elevation is important for riparian vegetation. Decreasing water availability from declining water tables negatively impacts riparian trees and other vegetation (Horton et al. 2001). Ground water and surface water are typically hydraulically connected. Ground water was found to be responsive to changes in river flow. In the case of a rain event, the ground water may respond before the river due to the influence of the riverside drains of Biopark area of the Rio Grande (LeJeune, 2008). Constructed wetlands contribute to the ground water table by continuously recharging it. Understanding the available soil moisture, movement of water in soil and the influence of ground water over vegetation can help water managers make better decisions as they plan for the future.

Ground water is a major natural resource in the Río Grande riparian corridor in central New Mexico that helps to link the Rio Grande to all its watersheds. Ground water is also important to ecosystems as it develops a large, subsurface reservoir from which water is released slowly to provide a reliable minimum level of water flow to river, streams, and wetlands. Ground water discharge to streams generally provides good quality water that promotes habitat for aquatic animals and sustains aquatic plants during periods of low precipitation. Thus, the ground water contributes to restoration process.

Better understanding of the ground water and surface water connectivity is vital for effective management of water resources. Surface water-ground water interactions can be determined using a variety of modeling methods like, MODFLOW, HEC-RAS, Duflow, MicroFem, which describes the type of linkage and its importance, in either a qualitative or quantitative manner. Predicted soil moisture contour maps help to get a rough estimation about the available moisture for plants. The numerical model results and the field data of the ground moisture comparison shows the accuracy of the model used.

This thesis investigates the interaction between surface water and the ground water in the adjacent riparian zone of the Biopark area of the Rio Grande, Albuquerque, New Mexico. The results of ground water-surface water interaction research can be used for better understanding of the behavior of water movement and available moisture content of soil. This linkage needs to be fully understood best so that the possible decisions can be made about wetlands management.

1.2 Objective

The objective of this study is to determine whether the goals and objectives of the of the Albuquerque Biopark Wetland Restoration project have been achieved. The goals and objectives of this project are to improve the quality of the environment, to provide suitable habitat for wild life, to increase vegetation and biodiversity. The success of wetland restoration project is evaluated by determining increase of soil moisture in the vicinity of the wetlands to encourage vegetation and associated biodiversity.

The study site is the Biopark wetland adjacent to the Rio Grande River near Albuquerque, New Mexico. Ground water recharge is an important component of the hydrologic cycle, yet its estimation can be a difficult task. This is due in large part to the number and complexity of processes occurring in the near surface environment. Ground water recharge is dependent upon a variety of factors including climate, vegetation, topography, geology and soil character as well as differing soil layers. The available moisture for plants is also dependent on ground water and surface water availability. Soil moisture recharge is dependent on precipitation, surface water depth, flow pattern of the river, and soil characteristics. Soil moisture and ground water table depth are two of the most important factors for restoration process. Ground water contributes to soil moisture and provides available water for the plants. Vegetation density largely depends on available soil moisture. Some vegetation needs very wet soil to survive; some plants can uptake water from different depth. To restore a healthy ecological cycle, soil moisture is a very important element.

This study includes modeling and measuring the soil moisture of the Biopark wetland area to show the influence of the wetland restoration project over the available soil moisture content. The investigation is directed towards the development of an understanding of the water movement in soil adjacent to a wetland and a shallow water table. The method of the analysis is described with a flow chart below.

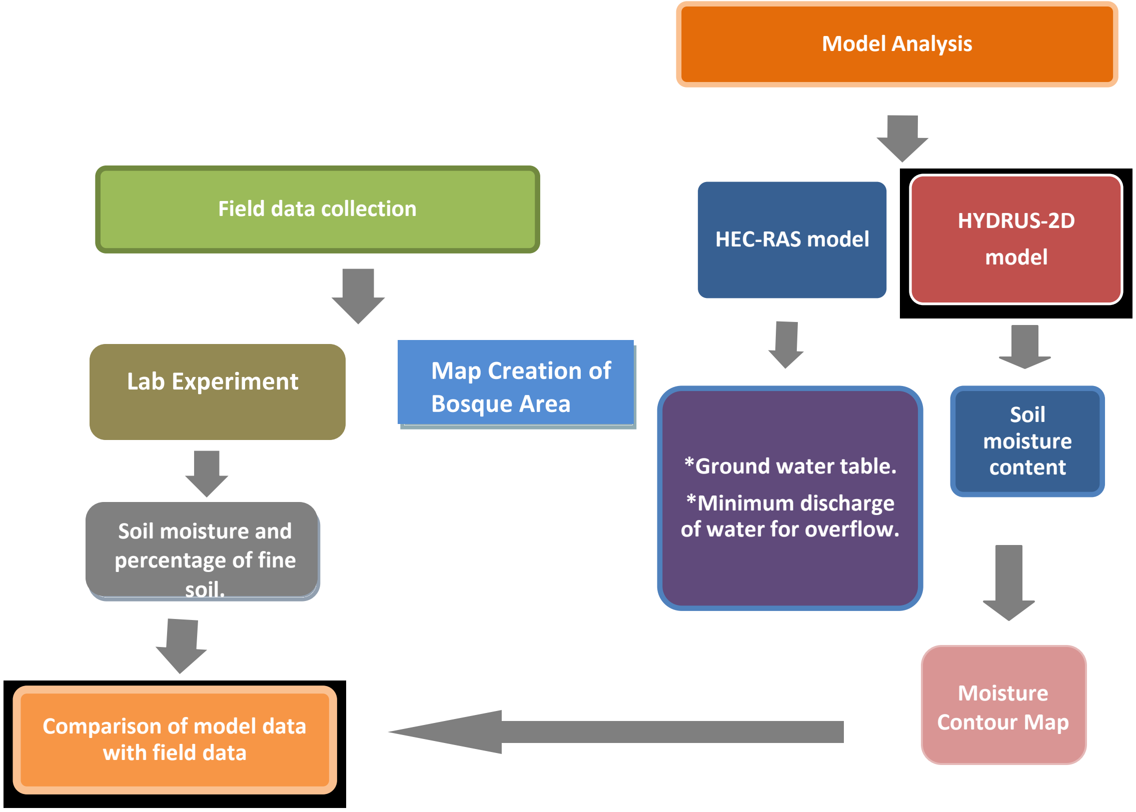


Figure 1 Flow chart of research work.

The study has been performed by three parts. First part is the field data collection; six soil cores have been collected from the Biopark area. A detailed map of the wetland area has been sketched which shows the wetland location and saturation soil boundary around the wetland. The second part is the lab experiment to determine the soil moisture content at different depths for each soil core. These data have been compared to the model data to show the model accuracy. The third part is the model analysis. Two models have been developed for the ground water table and soil moisture analysis. HEC-RAS model has been used to create ground water table of the Biopark area for different water depth at the Rio Grande and to find the minimum discharge of water in the Rio Grande for flooding of the Biopark pond. HYDRUS-2D water movement model has been developed for the analysis of surface water-ground water interaction of the wetland area. Moisture content, water velocity and water pressure head have been found from the HYDRUS-2D model for cross sections at various distances from the wetland stream. A predicted soil moisture contour map has been developed with the help of this model. The moisture content contour map has been compared with the Google photograph and field survey to show the change of vegetation with the change of soil moisture. Thus the success of the wetland restoration project to increase the vegetation and biodiversity is evaluated by determining the effects of the wetland over soil moisture and ground water table.

1.3 Outcome of research

Ground water tables for different river flows were identified for the Biopark near the Rio Grande. USGS Central gage flow data has been used for river discharge. 15 minute ground water level data for some wells in the Biopark area were used to develop the GWT (Ground water table).

A detailed map of the wetland area of the Biopark was developed by field survey. This shows the streams location, wetland location and saturated soil boundary of the Biopark area.

The soil moisture content above the ground water table was determined from field measurements. Core locations were chosen at different distances from the stream bank. Six cores were collected at different locations near the stream, and soil classification and moisture content tests were performed on these cores. Results indicate that the layering of soil is different for every core.

A HEC-RAS model was developed and this model can be used to determine the depth of river water for the Biopark area. This model can be used to determine the minimum river water discharge of overbanking and flooding of the Biopark pond.

A HYDRUS-2D model of the pond was developed to show the influence of pond water over the ground water table. This model shows that the pond water is recharging the ground water table continuously, and develops local water table mounding. Field well data also supports this model. This model can be used to estimate the moisture content of multiple distances from the pond and the stream as well.

A HYDRUS-2D model of a stream was developed to provide estimation of soil moisture content. These estimates are used to compare with field measurements of soil moisture and water table elevations. These estimates show how the stream affects the moisture content of the surrounding wetland soil. These results were used to develop a contour map of predicted water of wetlands as a function of moisture content. This contour map will be very helpful to determine the available moisture for different vegetation.

1.4 Study area

This project investigates the interaction between surface water and the ground water in the adjacent riparian zone of the Albuquerque Biopark Wetland Complex (BWC). This study considered a portion of Albuquerque reach from central bridge to the Biopark, which is 1.5 km long. The BWC has two ponds and a wetland of marsh and cattails. The ponds are located on the east side of the river immediately south of Central Avenue. The location of the Biopark is showed in Figure 2.

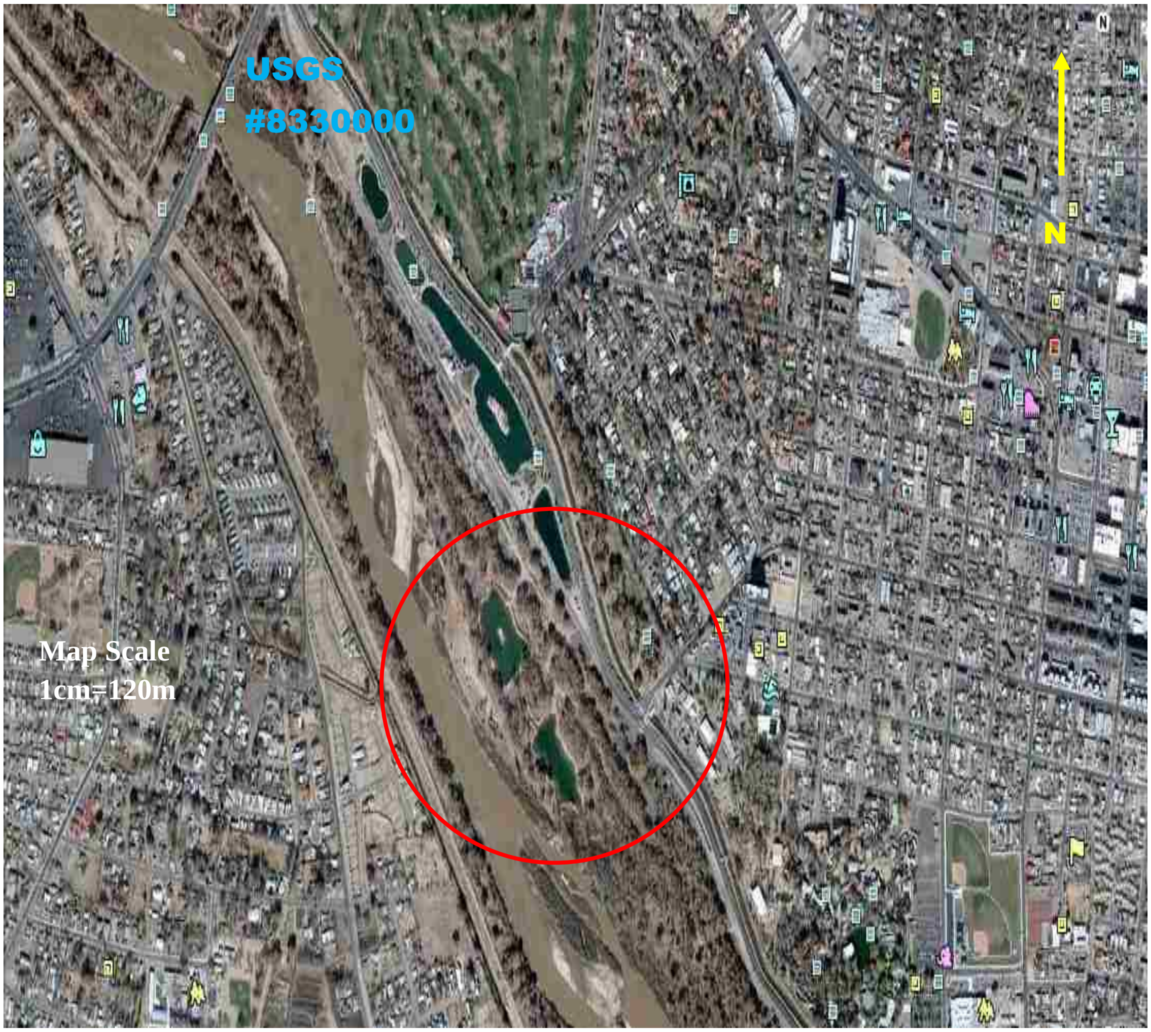


Figure 2 Study area (Photo courtesy Google map).

There are eleven ground water monitoring wells installed in the Biopark area. These wells are maintained by the Bosque Ecological Monitoring Program (BEMP) and Urban

Flood Demonstration Project (UFDP). Each of the wells is equipped with a pressure transducer which is programmed to record water level data at fifteen minute intervals. The wells were originally monitored by supervised middle school students on a periodic basis as part of an outreach program (LeJeune, 2008).

The United State Geological Survey (USGS) maintains gauge #8330000 at the Central Avenue bridge. This gauge records river stage height and discharge every fifteen minutes. The ground water data from the wells and the river stage data are used for analyzing the ground water-surface water connectivity and interaction of the study area.

CHAPTER 2

BACKGROUND

2.1 Wetland

Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or shallow water covers the land seasonally or occasionally. The wetland land predominantly supports aquatic plants at least periodically, or undrained hydric soils are the predominant substrate, or at some time during the growing season, the substrate is saturated with water or covered by shallow water. In general terms, wetlands are lands where saturation with water is the dominant factor determining the nature of soil development and the types of plant and animal communities living in the soil and on its surface (Cowardin et al. 1979). The water found in wetlands can be saltwater or freshwater. There are two basic types of wetlands: coastal (also known as tidal or estuarine wetlands) and inland (also known as non-tidal, freshwater, or palustrine wetlands). Wetlands include swamps, marshes and bogs.

Marshes is a type of wetland that is subjected to frequent or continuous flood (U.S. Environmental Protection Agency, 2009). Marshes usually have an equal area of open water and vegetation. All types receive most of their water from surface water, and many also fed by ground water. Marshes usually recharge ground water and contribute stream flow. It also helps to reduce damage caused by floods by slowing and storing the flood water. This wetland type is very important to preserve the quality of surface water.

A swamp is a type of wetland dominated by woody plants. A common feature of swamps is water stagnation. Swamps are characterized by very slow moving waters, saturated soils during the growing season, and standing water during certain times of the year. They are usually associated with adjacent rivers or lakes. Sometimes rivers become swamps for a distance. A swamp is different from a marsh as it has a greater proportion of open water and may be deeper than a marsh.

Wetlands are one of the most productive ecosystems in the world as an immense variety of species of microbes, plants, insects, amphibians, reptiles, birds, fish, and mammals are the part of wetland ecosystem. Wetlands provide many benefits to society such as improve water quality and hydrology, control flood, water storage, shoreline protection, water infiltration, fish and wildlife habitat, biological productivity opportunities for recreation and aesthetics appreciation.

2.2 Wetland restoration

Wetland restoration is the return of a degraded wetland and its functions to its original condition or preexisting naturally functioning condition, or a condition as close to that as possible. The restoration is essential to ensure the health of the watersheds. Over the past 200 years, wetlands have vanished at an alarming rate. Most of this loss is due to agriculture and development. Such losses and damage hamper wetland functions, such as water quality protection, habitat for fish and other wildlife, flood prevention, and biological diversity (Kentula, 1996).

A constructed wetland is an artificial wetland, marsh or swamp created to restore natural wetland functions. A constructed wetland system pretreats wastewater by filtration, settling and bacterial decomposition in a natural looking lined marsh. A diversity of wildlife habitat can be successfully developed on restored or constructed wetland sites. Ecosystem function can be successfully restored to degraded or impacted wetland areas. They can rapidly establish a stable biological community, including invertebrates and soil micro-organisms. Constructed wetlands are also effective in removing or stabilizing sediments, metals, and organic contaminants and it help to reduce flood. In Albuquerque the Biopark Wetland Restoration project is one of the restoration processes. The Biopark is a constructed wetland.

2.3 Ground water-surface water interaction

Ground water-surface water interaction is a critical component of the hydrology of the riparian zone. Accurate representation of water balance in these systems is complicated by several factors, including riparian evapotranspiration, artificial structures (such as diversions, canals and drains) and complex patterns of water consumption related to water rights and allocations.

Ground water and surface water are connected. Capillary action of soil is one of the reasons of the connectivity. Ground water and surface water interact throughout the landscape, as showed in the adjacent drawing Figure 3. The conceptual landscape shows, in a simplified way, ground water interaction with all types of surface water, such as streams, lakes and wetlands, in many different terrains, from the mountains to the oceans.

Ground water exists in both unsaturated and saturated zones in the soil. The interface of those two zones of water is called the ground water table (Webb et al. 2007).

The storage and movement of water between the atmosphere, land surface and underground is called the hydrologic cycle (Figure 3). This cycle is the circulation and conversion of earth's water. Earth's water consists of surface water and ground water. Surface water refers to the water that occurs in lakes, rivers, streams, wetlands and oceans. Surface water also includes the solid form of water as ice or snow on earth surface. Ground water refers to any subsurface water that occurs beneath the ground surface.

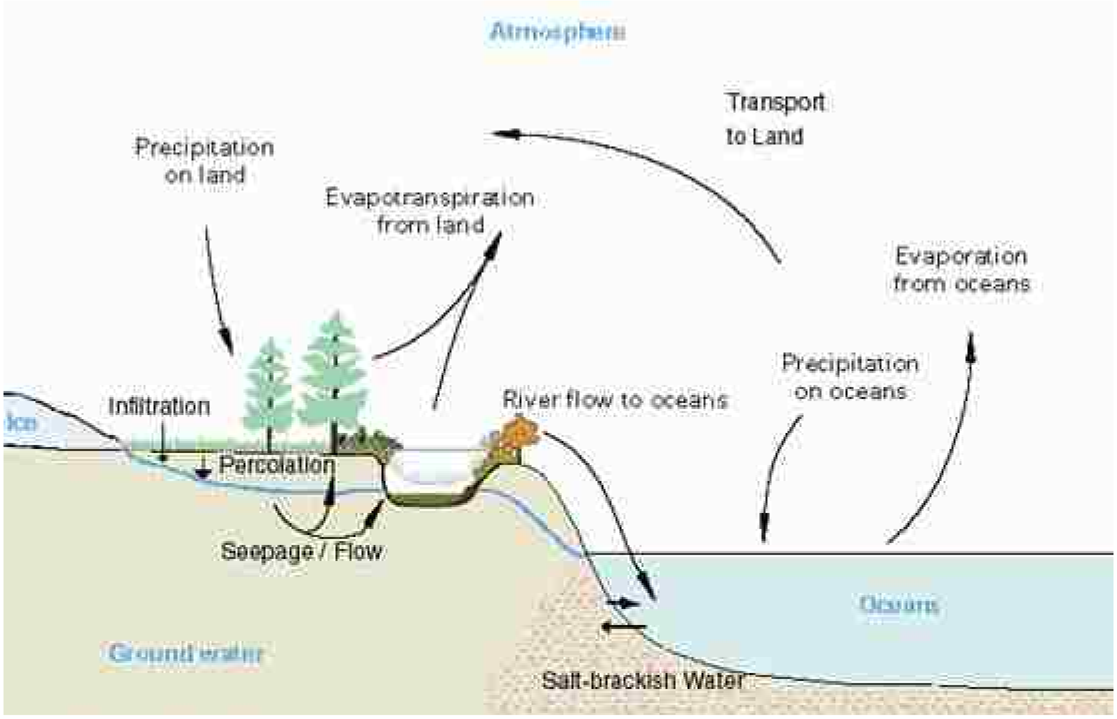


Figure 3 Ground water-surface water interaction (Adopted from USGS, 1998).

The total amount of the earth water will remains constant but it is moving continuously. Ocean, rivers, clouds and precipitation are in a frequent state of change. The surface water evaporates to become to clouds, the cloud water precipitates as rain, rainfall goes directly to surface water or infiltrates the ground surface and contributes the ground water, the ground water flows to surface water.

An aquifer is a water-bearing underground layer of permeable rock or unconsolidated materials like sand, silt, clay or gravel. Aquifers exist beneath much of the land on earth. Ground water occurs in the pores between soil and rock particles and in cracks or fractures of rock in an aquifer. In some location the aquifers partially fed by the seepage from surface water and precipitation and in some location some aquifers may discharge to surface water.

Understanding of the basic principles of interactions between ground water and surface water is important for effective management of water resources. In recent years, studies of ground water-surface water interactions have been expanded. The interaction between ground water and lakes has been studied science the 1960s because of the concerns related to acid rain as well as eutrophication or pollution. Interest in the interaction between ground water to wetland and costal area has increased in the last 20 years because of the loss of development of the ecosystem (Winter, 1995).

The interaction of ground water and surface water basically proceeds in three different configurations: losing stream, gaining stream and disconnected stream. The losing stream occurs when the altitude of the water table is lower than the surface water of the stream. In this case, seepage from the river feeds the ground water. The gaining stream occurs when the elevation of the water table is higher than the surface water. A losing stream will turn to gaining stream when the water table rises above its surface water level. The disconnected stream gains in some reaches and loses water in other reaches. It is separated from the water table by an unsaturated zone. Precipitation can alter ground water tables and stream stages and causes changes in the direction of exchange flows. A relocation of sediment grains on the streambed may cause of trapping of stream water in the sediment interstices or cause of releasing interstitial water to the stream (Elliott and Brooks, 1997). Sophocleous (2002) presented a comprehensive outline of the principle mechanisms and controlling factors of ground water-surface water interaction. Scanlon et al. (2002) presented an overview of techniques for quantifying ground water recharge on various space and time scale. Brunke and Gonser (1997) comprehensively summarize the interactions between rivers and ground water. Landon et al. (2001) presented comparison in stream methods for measuring hydraulic conductivity to determine the most appropriate techniques for ground water-surface water interaction of sandy streambeds.

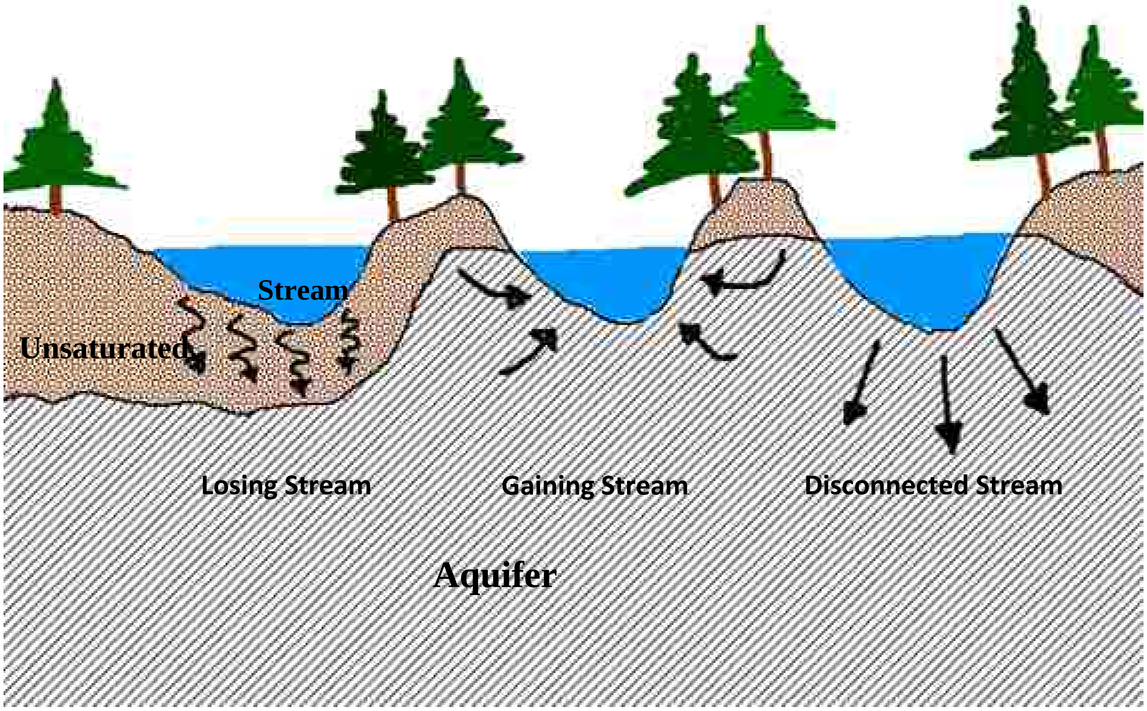


Figure 4 Gaining, losing and disconnected stream.

Figure 4 shows the losing, gaining and disconnected streams. Lakes and rivers have similar gaining and losing systems. Wetlands have complex hydrological interactions as they are subjected to rapid and periodic changes of water levels. Some wetlands are affected by periodic tidal flows and some are subjected to seasonal flooding. The term used to describe the amplitude and frequency of water level fluctuation is called hydroperiod. All the wetland characteristics, such as vegetation type, nutrient cycling and animal species as invertebrates, fishes, birds, animals are affected by the hydroperiod (USGS, 2008).

The connectivity of ground water and surface water is important in both arid and semi arid region (Jackson et al. 2001). An aquifer exists beneath most land surfaces. Ground water occurs within the pores between soil and rock particles and in cracks and fractures in rocks. The aquifers are often partially fed by seepage from streams and lakes. In other locations, same aquifers may discharge through seeps and springs from the saturated zone to feed the streams, rivers, and lakes. Water availability decreases from declining water tables that impact negatively on mature riparian trees like photosynthesis and stomatal aperture. Those plants are sensitive to depth of ground water (Horton et al. 2001). Cottonwood tree reproduction is also dependable on soil moisture. As Cottonwood tree reproduces by seed germination and seed dispersal is wind driven. Sufficient soil moisture is important for the survival of the seedling. Cottonwood tree crown dieback at depth of ground water is greater than three meters, and its mortality at ground water depths greater than five meters (Horton, et al. 2001).

Interactions between ground water and surface water play a basic role in the functioning of riparian ecosystems. Ecological studies show that the faunal (animals of a specific region or period) composition, distribution, and abundance depend on ground water-surface water interaction of the riparian zone (Brunke and Gonser, 1997). Ward at al. (1994) pointed out that small channels and riparian wetland in the alluvium of the Flathead River in Montana, USA, are a significant factor which influences the spatial distribution of a specific kind of crustaceans arthropod. Ground water-surface water interaction also influences soil temperature. Cooler stream water tends to displace warmer interstitial water of soil (Whitman and Clark, 1982). The main determinants of the interstitial habitat of wetlands are the usable pore spaces, dissolved-oxygen concentrations, temperatures, nutrient contents and organic matter. Wetland contributes soil moisture which helps to grow different variety of vegetation, create suitable habitat and increase biodiversity.

A variety of models for ground water-surface water interaction are available. Ivkovic et al. (2009) presented a variety of approaches for ground water-surface water interaction model including conceptual, empirical and physical based models. Each approach has different strengths and weaknesses. MODFLOW, HYDRUS, MIKE SHE, HEC-RAS are commonly used software for ground water-surface water interaction modeling. MODFLOW software has been used to study transmission losses and riparian restoration (Wilcox et al. 2007). The limitation of MODFLOW software is water surface elevation calculation which is presented by Rodriguez et al. (2008). He used HEC-RAS software to generated surface water elevation and MODFLOW to determine the groundwater movement. This process helps better to define the hydraulic gradient of the ground water table. MIKE SHE software is used to model surface water and ground water interaction and transport process (Hughes and Liu, 2008).

2.4 Terrain model

A terrain model is a representation of ground surface topography or terrain. It is a rigorous three dimensional (3D) model of the earth’s surface. It is widely known as a Digital Terrain Model (DTM) when represented in a digital form. For representation of terrain, an efficient alternative to dense grids is the Triangulated Irregular Network (TIN), which represents a surface as a set of non-overlapping contiguous triangular facets of irregular size and shape. Triangular irregular network and Digital Elevation models can be both constructed from Light detection and ranging (LiDAR) data.

LiDAR is a remote sensing system used to collect topographic data. The development of LiDAR was one of the most important advances in terrain imaging systems. LiDAR is an active sensor, similar to radar. It transmits laser pulses to a target and records the time between emitted and returned pluses. The processed LiDAR points are converted to three dimensional (3D) digital terrain model or triangular irregular network that represent the ground surface (Merwade et al. 2008). Green LiDAR is another technology which yields bathymetry data that helps to attain water penetration data (Wright et al. 2002). Geographic elements are typically described by one of the three data models: vector, raster or triangular irregular network.

Vector objects include three types of elements: points, lines and polygons. A point is defined by a single set of Cartesian coordinates as easting(x) and northing(y). A line is defined by a string of points. The beginning and end points of a line are called nodes and intermediate points are called vertices (Smith, 1995). A straight line consists of two nodes and no vertices, whereas a curved line consists of two nodes and a varying number of vertices.

The raster data structure consists of a rectangular mesh of points joined with lines. Raster data set has a uniformly sized square cell grid structure. Each cell is assigned a numerical value that defines the condition of any spatially varied magnitude (Smith, 1995). Grids are the basis of analysis in raster GIS. Grids are used for steady-state spatial modeling and two-dimensional modeling of surface terrain. A land surface representation in the raster domain is called a digital elevation model (DEM).

TIN is a triangulated mesh constructed on the (x, y) locations of a set of data points. A perimeter, called the convex hull is formed around the data. Triangles are created to connect the interior points. The dimension of height (z) for each triangle vertex is included to get the raised and tilted form of plane. The TIN triangles are small where the land surface is complex and varied. TIN can directly generated from random point data.

The TIN model that is used for this study is collected from the Albuquerque Metropolitan Arroyo Flood Control Authority *(*AMAFCA*)*. This model represents the realistic elevation of the land surface of the Biopark area. This model is used to delineate the cross section of the river in ARC-GIS software. The cross sections are used to calibrate river discharge for different flow.

2.5 ArcGIS, HEC-GeoRAS, HEC-RAS, HYDRUS-2D

2.5.1 ArcGIS: ArcGIS is an integrated collection of GIS (Geographic Information System) software products that provides a standards-based platform for spatial analysis, data management and mapping. This software allows one to view spatial data and create layered maps. It includes more advanced tools for manipulation of shapefiles and geodatabases. It also allows for combined of digital maps and georeferenced data. This software helps with asset/data management, planning and analysis, business operation and situation awareness. ArcGIS 9.3 has been used for this research to build the HEC-RAS model.

2.5.2 HEC-GeoRAS: HEC-GeoRAS is an extension of HEC-RAS, for use with ArcGIS for pre and post processing of GIS data. The extension allows the user to create a HEC-RAS import file containing geometric attribute data from an existing digital terrain model and complementary data set. HEC-GeoRAS requires a DTM represented by a Triangulated Irregular Network. Results can also be exported directly from HEC-RAS. HEC-GeoRAS is a set of procedures, tools and utilities for processing geospatial data in ArcView or ArcInfo using a graphical user interface. The interface allows the preparation of geometric data for import into HEC-RAS and it processes simulation results exported from HEC-RAS (Tate et al. 2002). HEC-GeoRAS Alpha has been used for this research which is compiled with ArcGIS 9.3.

2.5.3 HEC-RAS: HEC-RAS is a computer program which models the hydraulics of water flow through natural rivers and other channels and computing water surface profiles. The US Army Corps of Engineers Hydrologic Engineering Centre (HEC) released the first version of HEC-RAS (River Analysis System). HEC-RAS is a next-generation program, implemented under the Microsoft Windows operating system, and using modern graphical user interface (GUI) conversions. HEC-RAS is the successor to HEC-2 computer program, which was the most widely, used method of computing water surface profiles, floodplain boundaries and other information for stream channels

(Dodson et al. 1999). The program is one dimensional. It is used for both steady flow and unsteady flow analysis. This program is capable of modeling subcritical, supercritical and mixed flow along with the effects of bridges, culverts, weirs and other structures (Brunner et al. 1994). HEC-RAS model has been used for the steady state flow analysis.

2.5.4 HYDRUS-2D: HYDRUS-2D is a finite element program for simulating flow and transport in variably saturated media (Simunek et al. 1999). This software may be also used to analyze water and solute movement in unsaturated, partially saturated, or fully saturated homogeneous layered media. It can also include solute transport, heat flow, root water uptake and an inverse parameter estimator. The latest version of the code has the ability to simulate ground water–surface water interactions in unsaturated wetlands. HYDRUS-2D software has been used for ground water movement modeling to see the direction the water moves beneath the pond.

2.6 Moisture content in soil

Soil moisture is the water that is held in the spaces between soil particles. Surface soil moisture is the water that is in the upper ten cm of soil, whereas root zone soil moisture is the water that is available to plants, which is generally considered to be in the upper 200 cm of soil. Water enters soil through seepage and infiltration processes. Infiltration is the water entering through surface. The infiltration rate depends on soil texture, soil moisture content and soil structure as well as the supply of water to the surface. Coarse texture soil has mainly large particles with predominately large pores. On the other hand, fine textured soils have mainly small particles with predominately small pores. In coarser soils, the precipitation, irrigation and surface water most often enters and moves more easily than the fine grained soil. It takes less time for the water to move through coarse soil depending on the conditions at the surface. The infiltration rate is higher for course soil generally at ponded condition. When soil is dry, the infiltration rate is high and when the soil is wet, the rate is slower. Thus, the infiltration rate decreases slowly as the soil become wet. Loose soil structure has high infiltration rate when massive and compacted soil has low infiltration rate. Soil moisture is affected by the layering of soil, conductivity of different soil in different layers, pumping or draws down of water, weather, and depth of ground water table.

Water in the soil resides within soil pores. After irrigation or precipitation, the largest pores drain due to gravity and water is held by the attraction of small pores and soil particles. After gravity drainage soil with small pores such as clayey soils will hold more water per unit volume than soils with large pores like sandy soil. The amount of water held in a soil after a complete wetting and subsequent gravity drainage is referred to a field capacity. The soil moisture content of the soil above the water table often varies from a minimum where extraction by the plant stops (permanent wilting point) and a maximum when the pores are full of water which is called soil saturation. At field capacity, the water and air contents of the soil are considered to be the ideal for crop growth (Brouwer, 1985). The moisture between field capacity and the permanent wilting point is known as the plant available water. Soil-water potential and hydraulic conductivity vary widely and nonlinear with water content for different soil textures (Saxton et al. 1986).

The principal unsaturated soil properties used in engineering calculations are the relationships between suction or water pressure, h (cm of water or KPa) and volumetric water content Θ (cm^3/cm^3), and between suction and hydraulic conductivity (k). Those two relationships are known as water retention curve (WRC) and hydraulic conductivity function, respectively.

The water retention curve is used to predict the soil water storage, water supply to the plants (field capacity) and soil aggregate stability. Because of differences in how water fills and drains in soil pores, different wetting and drying curves may be distinguished. The shape of water retention curve is often represented by the Van Genuchten model (van Genuchten, 1980) which is briefly described in Equation 5.2, Chapter 5.

CHAPTER 3

BIOPARK: THE RESEARCH SITE

3.1 Introduction

The riparian area or riparian zone is the intersection between land and a water body. Plant communities along the margins of rivers are called riparian vegetation. Riparian zones occur as grassland, woodland, wetland or even non-vegetation. The terms riparian woodland, riparian forest, riparian buffer zone or riparian strip are used to characterize a riparian zone. These zones may be natural or engineered for soil stabilization or restoration. The term “wetland” refers to an area of land whose soil is saturated with moisture either permanently or seasonally. It also can be natural and constructed. A constructed wetland or wetpark is an artificial marsh or swamp, created for anthropogenic discharge such as wastewater, storm water, runoff or sewage treatment and as habitat for wildlife, or for land reclamation after mining or other disturbance. The Albuquerque Biological Park Wetland Restoration project area is also a constructed wetland area in Albuquerque, New Mexico.

3.2 Location

The Albuquerque Biological Park Wetland Restoration Project is located in the City of Albuquerque, Bernalillo County, New Mexico. The Biological Park consists of the Tingley ponds, Biopark ponds and wetland area. The ponds and the wetland area are located south of Central Avenue and east of the Rio Grande and between the Albuquerque Botanical Gardens and Aquarium and Zoo. Central Avenue is known as the Historic Route 66 traversing through the Albuquerque. All of these features are located within a mile of one another. The wetlands are located west of the ponds. East of the project area includes the Albuquerque Country Club Golf Course. The location of Biopark wetland restoration area is showed in Figure 5 and Figure 6.

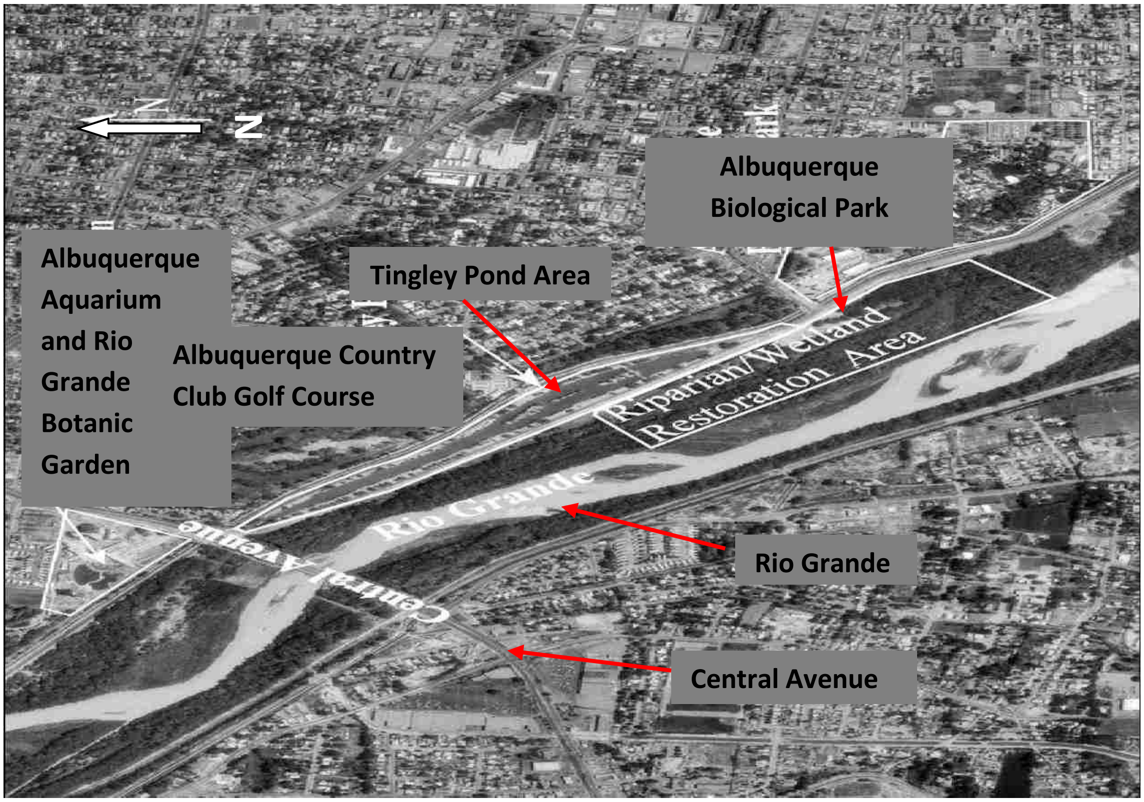


Figure 5 Location of the project area in Albuquerque, New Mexico; adapted from USGS Digital Ortho Quarter Quadrangle Image: Albuquerque West, New Mexico (35106-A6-2, Data Flown 1996-98; NAD83, UTM Zone 13),Not to Scale.

Figure 6 Location of ponds and Biopark ground water monitoring wells (Photo courtesy Google map).

3.3 Background of constructed wetland development

The US Army Corps of Engineers (Corps) and the Bureau of Reclamation (BOR) considered the lack of adequate flood control within the Middle Rio Grande Valley in 1943 to be a problem (U.S. Army Corps of Engineers, 2003). This inspired the construction of flood control reservoirs, clearing of floodway, installation of jetty fields, rehabilitation, modification and extension of the levee system and wetland. The cumulative process increases the conveyance capacity of the channel that help it to resist the natural tendency to meander.

Cochiti Dam and Jemez Canyon Dam are the two most important dams for controlling flood of this floodplain. The Flood Control Act of 1960 authorized the construction of artificial structure like the Cochiti dam for flood and sediment control. In 1964, the P.L. 88-293 Act authorized the establishment of a permanent pond and wetland area for the conservation and development of fish and wildlife and also for recreational purpose (U.S. Army Corps of Engineers, 2004). Thus the riparian wetland was constructed at the riverside area of Rio Grande.

The construction of artificial structures, such as Cochiti Dam, reservoirs and levees create adverse impact over nature like less frequent flooding, change of flow pattern, and change of vegetation in the riparian forest (Tahmiscioglu et al. 2007). This is the reason for the restoration projects after the construction of dams. The restoration activities of the riverside area are; wetland creation, exotic species removal, replanting and seeding of native riparian vegetation, dead plant removal, jetty jack removal and increase of marsh area. The area of riparian restoration and wetland creation at Biopark are approximately $1.94*10^5$ square meters (U.S. Army Corps of Engineers, 2004).

3.4 Existing environmental setting of Biopark

3.4.1 Physiography and geology

The Middle Rio Grande lies within the Basin and Range and Southern Rocky Mountain physiographic provinces (Crawford, 1993). The project area of constructed wetland lies within the Rio Grande Rift Valley, which extends more than 804,672 meters from central Colorado through New Mexico (Crawford, 1993). The Albuquerque Biopark constructed Wetland Creation Project is located in the Middle Rio Grande subsection of the Basin and Range Physiographic Province (Williams, 1986). The headwaters of the Rio Grande are located in the San Juan Mountains of southern Colorado. The river flows from Colorado through New Mexico. Then it forms the international boundary between Texas and Mexico and meets the Gulf of Mexico. The Rio Grande drains approximately $8.5*10^{10}$ square meters of land (Bullard et al. 1992).

3.4.2 Soils

The soil in the wetland project area includes the Vinton and Brazito soils. These soils are found inside the levee next to the Rio Grande and occasional flooding occurs. The soils are stabilized by vegetation. The Brazito soil layer ranges from sand to clay, with the dominant components being sand, loamy sand, and sandy loam. Runoff and water erosion are minor except during periods of flooding. Hydraulic conductivity is somewhat high and the seasonal water table is generally encountered within 1.5 meters of the surface (USDA, 1977). The Vinton surface layer ranges from sand to clay. Soils along the wetlands belong to the Vinton Series, which are moderately alkali to strongly alkali and have a seasonal water table above a depth of 1.5 meters from the surface (U.S. Army Corps of Engineers, 2004).

3.4.3 Climate

Climate of the project area is characterized as arid continental, which is a hot summer with a significant range of temperature (65-96°F). Winter temperatures vary from moderate in the lower elevation to severe in the adjacent mountainous area. The spring and fall seasons are generally short. July and August are the most active month for thunderstorms which usually reach peak activity in late afternoon. The thunderstorm activity ceases and is followed by clear weather in winter, which dominates between winter frontal passages. The average growing season is about 165 days (NRCS, 1999).

Mean annual precipitation at Albuquerque Airport is 8.70 inches (0.22 meters) (U.S. Army Corps of Engineers, 2004); mean monthly precipitation is given in Figure 7. About one-third of the annual precipitation occurs during July and August as thunderstorms. The driest month is February with 0.44 inch (0.0111 meters) of precipitation, and, with 1.73 inches (0.0439 meters), August is the wettest month.

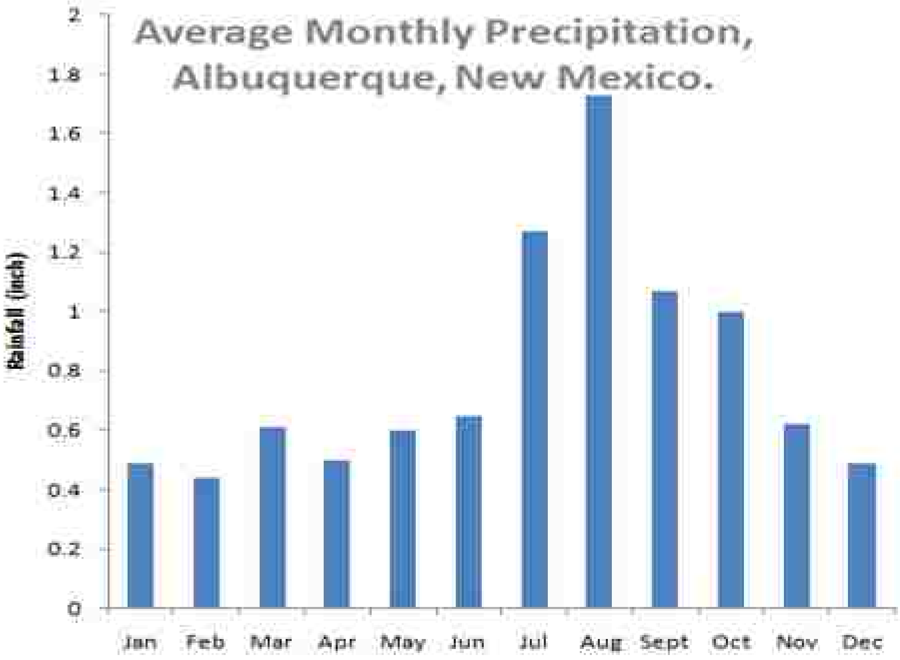


Figure 7 Average precipitation in Albuquerque-1971-2000 (rssWeather.com)

3.4.4 Hydrology

Hydrology in the Albuquerque Reach of the Rio Grande follows a pattern of high flows during spring snowmelt runoff and low flows during the fall and winter months. High flow also occurs in the late summer due to the short duration thunderstorms. This thunderstorm flow portion of the Rio Grande hydrology has been altered by the flood control dams such as Cochiti and Jemez Canyon Dams.

Cochiti Dam primarily acts to reduce peak flows which reduce the chance of flooding and has a much smaller impact on low flows. Hence, the average annual flows have been less affected. Average yearly hydrographs for pre- and post-Cochiti Dam periods are shown in Figure 8.

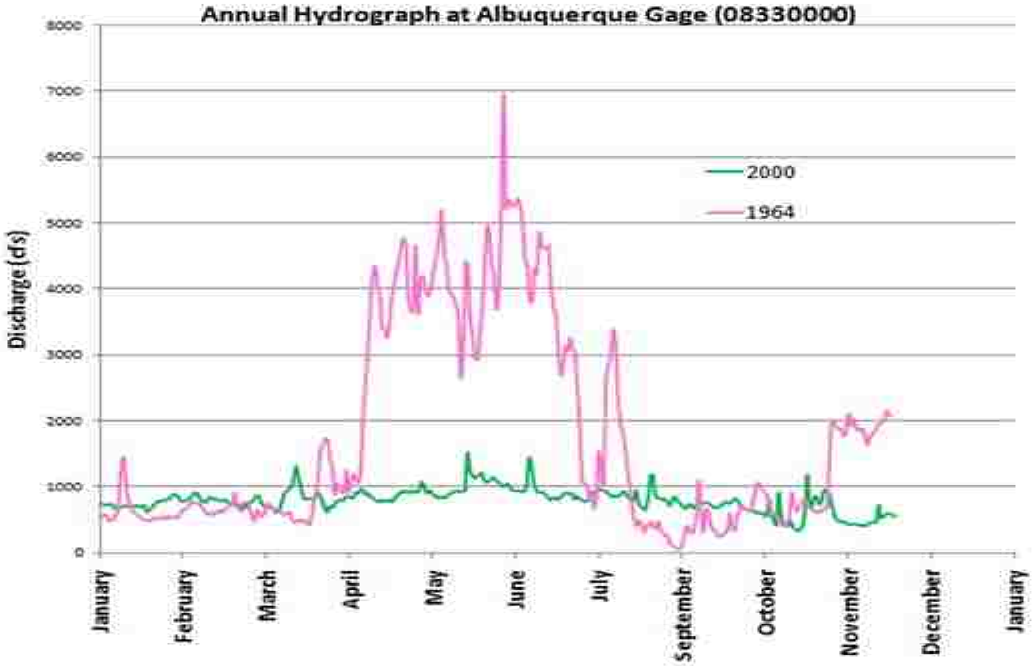


Figure 8 Annual hydrograph at Albuquerque gage station (USGS 08330000) for pre- and post-Cochiti dam.

The annual hydrograph shows that the influence of Cochiti Dam has been to reduce the peak flows and extend the duration of the high flow period. Winter flows have fairly bigger pick during the post-dam period. Annual peak series data analysis also exhibits the influence of flood control.

3.4.5 Geomorphology and floodplains

The Rio Grande in the Albuquerque area is predominately a sandbed river with low, sandy banks. The Rio Grande through Albuquerque has a uniform channel width averaging 182 ± 29 meter and the slope of the river is less than 0.01 (Tashjian, 1999). Due to jetty jack fields and levee placement, there are numerous sandbars and the river channel tends to be straight (Crawford et al. 1993).

3.4.6 Water quality

The New Mexico Department of Game and Fish (NMDGF) and the City of Albuquerque monitor the water quality at the ponds. This quality fluctuates throughout the year, as it depends on the quality of the water feeding into the pond. The pond water comes from the City well ground water, from wells. This water is rich in nutrients that can cause eutrophication problems. Eutrophication is water pollution which is caused by the excessive plant nutrients such as phosphorous, nitrogen and carbon. Heavy growths of aquatic vegetation or eutrophication and nuisance blooms of algae have been observed in other aquatic Systems of the wetland ponds (City of Albuquerque, 1991). Ground water qualities in the wetland area are quite stable. The Biopark well data shows that the groundwater level of the Biopark area changes with the change of river water elevation.

3.4.7 Air quality and noise

Undeveloped open space and recreation areas typically experience relatively low-level ambient background noise. The project area is not an exception and existing noise conditions there are low. Central Avenue and Tingley Drive contribute to the ambient noise levels (City of Albuquerque, 1994).

3.4.8 Populous species of wetland

3.4.8.1 Pond vegetation

The majority of vegetation at Tingley ponds are non native, or exotic, to North America. The predominant landscape is bare ground with Siberian elm (Ulmus pumila) surrounding the ponds. Closer to the ponds, the woody species are salt ceder (Tamarix sp.), Russian olive (Elaeagnus angustifolia) and tree of Heaven (Ailanthus altissima). Annual herbaceous plants, coyote willow (Salix exigua), Russian thistle (Salsola kali) and some composite species are associated with the bank in the pond (U.S. Army Corps of Engineers, 2004).

3.4.8.2 Riparian vegetation

The vegetation of the constructed wetland is dominated by woody riparian vegetation. Dominant woody plants are Russian olive (Eleagnus angustifolia), Native cottonwoods (Populus fremontii), white mulberry (Morus alba) and tree-of-heaven (Ailanthus altissima). Most of them are exotic to this bosque. Woody plant density increases from levee to river, or east to west (BEMP, 2006).

The wetlands are integral component of the bosque ecosystem. They are important for increasing its diversity but also enhancing the value of surrounding plant communities for wildlife. Historical bosque wetland consists of marsh, wet meadows and seasonal ponds that typically support the hydrophytic plants such as cattails, sedges and rushes. From 1918 to present, wetland-associated habitats have undergone a 93% reduction in the constructed wetland of Rio Grande (BEMP, 2007).

Wetlands are now decreasing fast. For the greatest contribution of the health of the riparian ecosystem, the protection of existing wetlands and expansion or creation of additional constructed wetlands should be made a priority.

3.4.8.3 Noxious weeds and invasive species

Noxious weeds are the plants which are not native to New Mexico that have negative impacts in the economy or environments. This noxious weed consists of salt ceder, Russian olive, Siberian elm etc (BEMP, 2006).Those plants are targeted for management or control. The federal Noxious Weed act of 1974 (P.L. 93-629; 7 U.S.C. 2801) provides for the control of noxious weeds (U.S. Army Corps of Engineers, 2004).

3.4.9 Fish

Tingley Pond is one of the most heavily fished areas in New Mexico. The NMDGF (New Mexico Department of Game and Fish) maintains a “put and take” fishery in the lake. Hatchery raised rainbow trout are released between November 1 and March 31. Summer catfish are released during May, June and July. The wetland ponds have almost no fish (U.S. Army Corps of Engineers, 2004) but some aquatic habitat (i.e. surface water) like frogs, water insects etc currently exist in the location of the proposed wetlands area. This area is dominated by riparian vegetation

3.4.10 Wildlife

The wetland area supports a limited amount of wildlife. The waterfowl and resident Canadian Geese are the most common fauna of this area. Wildlife species within and in the wetland project area are typical for the Middle Rio Grande Valley. Neotropical migrants and resident avian species live within the bosque. These species include: Coopers Hawk (Accipiter cooperii), American Crow (Corvus brachyrhynchos), Great-Horned Owl (Bubo virginianus), Downy Woodpecker (Picoides pubescens), Greater Roadrunner (Geococcyx californianus), American Kestrel (Falco sparverius), Black-

Chinned Hummingbird (Archilochus alexandri), American Robin (Turdus migratorius), Green Heron (Butorides virescens), Canada Goose (Branta canadensis), House Finch (Carpodacus mexicanus), and various species of waterfowl. Also various other animals inhabit the area such as mice, coyote, rabbits, beaver, skunks, and lizards (U.S. Army Corps of Engineers, 2004).

3.5 Restoration by the wetland

The Biopark wetland consists of two ponds and a small channel parallel to the river which carries water to create the wetland. This wetland is significant in ecology, environmental management and civil engineering because of its role in soil conservation, biodiversity and its influence on aquatic ecosystems. This wetland restores the ecosystem in the following ways.

3.5.1 Water treatment

The wetland is used to treat the water and also act as a buffer and biofilter. Physical, chemical and biological processes combine in wetlands to remove contaminants from wastewater (Jan Vymazal, 2006). An understanding of these processes is fundamental not only to designing wetland systems but also to understand how the chemicals are removed by the wetland, once they have entered it. Vegetation in the wetland provides a substrate (roots, stems and leaves) upon which microorganisms can grow as they break down organic materials (Moshiri, 1993). This type of micro organisms is called periphyton. The periphyton and natural chemical processes are responsible for approximately 90 percent of pollutant removal and waste breakdown. The plants remove about seven to ten percent of pollutants and act as a carbon source for the microbes when they decay. Different species of aquatic plants have different rates of heavy metal uptake capacity (Scott D. Bridgham, 1999).

3.5.2 Recharging ground water table

The wetland contributes the ground water table by adding water. Ground water recharge is the process by which aquifers are replenished with water from the surface (Van der Kamp, 1998). A number of factors influence the rate of recharge including the soil type, plant cover, slope, rainfall intensity, and the presence and depth of confining layers and aquifers. Most of the ground water recharge occurs in the summer months when precipitation is highest. Recharge also occurs with locally heavy rainstorms during the rest of the year. Ground water typically discharges into a lake or river, maintaining its level or flow in dry seasons. The wetland also contributes root zone soil moisture by adding water content to the surface soil within a certain distance. That moisture is responsible for the marsh and dense vegetation area. The ground water table is very important for the plants. If the ground water declines for any reason, ecosystem in that area will be at a risk (Stromberg, 1996).

3.5.3 Soil Conservation

Soil conservation is a set of management strategies for prevention of soil being eroded from the earth’s surface or becoming chemically altered by overuse, acidification, salinization or other chemical contamination. (Fritz L.Knopf, 1988). Riperian forest prevent soil errosion and stable the river banks.

3.5.4 Climate

The riparian vegetation and plants help to lower the temperature of the wetland by providing shade. Too warm of a climate in summer sometimes is not suitable for the floodplain habitat (Bridgham, 1999).

3.5.5 Aquatic ecosystem

An aquatic ecosystem is an ecosystem located in a body of water. Communities of organisms that are dependent on each other and on their environment live in aquatic ecosystems. An aquatic ecosystem performs many important environmental functions. It recycles nutrients, purifies water, attenuates floods, recharges ground water and provide habitat for wildlife. That’s how, wetland restoration speeds the functions of aquatic ecosystem (Diamond et al. 1997).

3.5.6 Biodiversity

Biodiversity is the variation of life forms within a given ecosystem, biome or on the entire Earth. Biodiversity is often used as a measure of health of biological systems (Pollock et al. 1998). The global ecosystem has suffered serious damage, including a rapid decline in biodiversity, climate change, pollution, soil erosion and recourse depletion. Restoration process aims to minimize the biodiversity declination.

3.5.7 Source of food and shelter

A riparian area provides food for the floodplain habitat as beaver, bird and other animals. It also provides shelter for those animals too. The vegetation also contributes wood debris to the stream, which is important for maintaining geomorphology. This wood debris is the source of food and shelter for the fish. Thus, nutrients from terrestrial vegetation are transferred to aquatic food webs.

3.5.8 Fishing and aesthetics

Riparian wetlands are also used for human recreation, and they are very important to the tourism industry too.

3.6 Wetland map

There are two ponds in the Biopark. The shallow pond’s (south pond) levels are maintained in part via gravity flow from the deep pond (north pond). The south pond drains into a cattail marsh and develop the wetland; the wetland is consist of an upper terrace strip of old cottonwoods, a mid-level terrace of young cottonwoods, and a low terrace of mainly coyote willows that extends to the river.

Figure 9 Detailed map was drawn from a field survey in December, 2009 (Adopted from Google Earth).

A detailed map of the Biopark wetland area was created by field survey. The developed map is Figure 9 and it shows the detail picture of the wetland area. The map shows the termination of pond, creation of streams, and locations of wetland and marsh area and saturated soil boundary can be observed from this map. There are lines 46.4m, 200m, 400m and 600m separate different areas of the wetlands. The boundary between the 46.4m and 200m lines represents the boundary of the cattail marsh at that time. To the east of the 200m boundary line, there are three creeks; two of them are really short (about 50m long) and terminated by saturating into the soil. The long creek meets again into a marsh to the east of the 400m line. The boundary between the 400m line and the 600m line represents the boundary of cattail marsh. The 600m line is the end point of the marsh and to the east of the 600m line there is another small creek which is almost 77m long. This creek is also terminated by saturating the soil. There is an indication of a dry channel from the creek to the river which indicates that some water also goes to river. Figure 10, Figure 11, and Figure 12 are the pictures of the wetland area.

Figure 10 Marsh boundary in Biopark.

Figure 11 Creek at Biopark.

Figure 12 Termination of wetland.

The marsh boundary and the length of creek are variable with the season. In the dry season, the wetland area decreases both in length and in width and some vegetation dies. In the wet season or rainy season, the area increases and vegetation increases significantly which is observed from the field survey of July, 2010. This map represents the wetland of November, 2009.

3.7 Wetland soil classification analysis

3.7.1 Soil cores

Soil cores have been collected from six different locations in the field with the help of hand auger from November to December, 2009. The locations of the cores were selected at different distances from the stream. The cores were dug to the ground water level. The classifications of soil for different levels were performed and the moisture content for each layer and location was analyzed. The sieve analysis method was used for soil classification and the moisture content measurement was used for moisture measurement for lab work. The six soil core locations are shown in Figure 13. Two cores are at the 46.4m line. One of them is 10m from the south BEMP well. The other one is 20m from the south BEMP well. Two other cores are at 200m line. One is 1m from the saturated soil boundary of the wetland and the other is at 10m from the 1m core. The last two cores are near the 400m line. One is 9m NE from the 400m line and the creek intersection. The other is 46m north from the 400m line and the creek intersection.

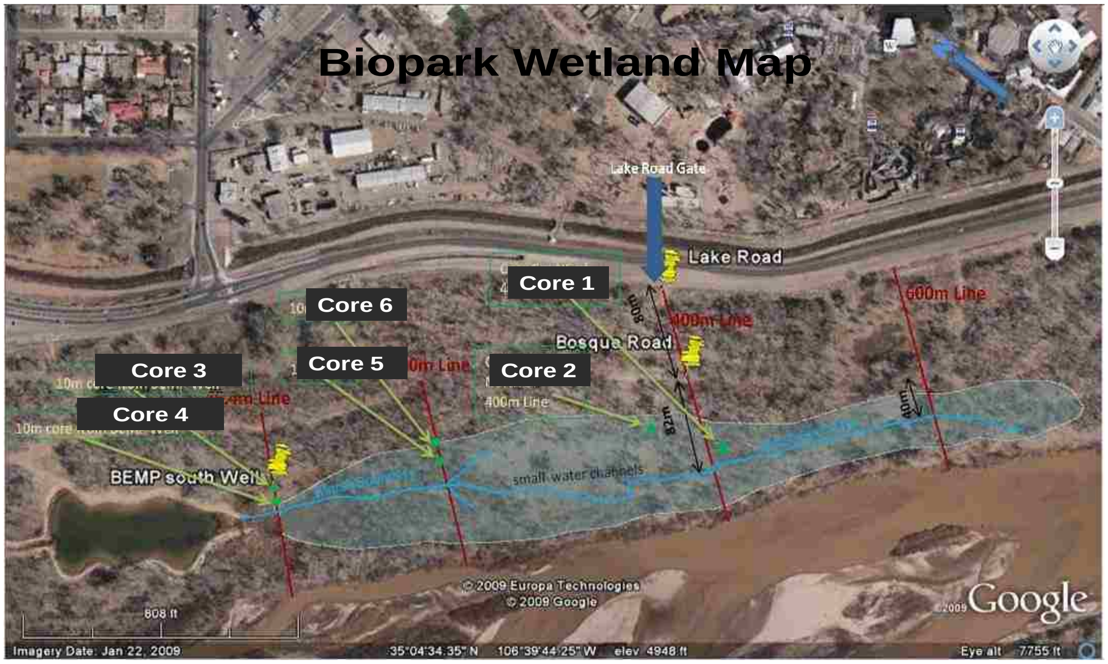


Figure 13 Soil core locations.

These soil cores show the soil type percentage at different depths as well as the moisture content. Table 1, 2 and 3 show the layering of soil of six locations. The soil classification and water content of different cores are shown below.

CORE 3	NO	Depth(cm)	Clay and silt%	Moisture content (%)
(20m from BEMP well)	1	0-10	12	19
	2	10-27	21	16
	3	27-40	37	27
	4	40-57	20	24
	5	57-68	9	23
	6	68-90	1	7
	7	90-105	2	11
	8	105-117	2	19
	9	117-128	2	23
	10	128-138	2	23
	11	138-142	2	23
CORE 4	NO	Depth(cm)	Clay and silt%	Moisture content (%)
(10m from BEMP well)	1	0-10	22	36
	2	10-29	47	19
	3	30-47	52	17
	4	47-63	53	20
	5	63-76	3	8
	6	76-95	1	7
	7	95-116	2	20
	8	116-123	2	22
	9	123-135	3	27
	10	135-141	3	25

Table 1 Core 3 and core 4 near 200m line in figure 13.

CORE 5	NO	Depth(cm)	Clay and silt%	Moisture content%
1m from saturated soil boundary on the 200m line	1	0-14	28	37
	2	14-29	40	26
	3	29-43	55	32
	4	43-57	24	18
	5	57-70	9	10
	6	70-81	8	8
	7	81-97	4	13
	8	97-108	7	22
	9	108-118	10	23
CORE 6	NO	Depth(cm)	Clay and silt%	Moisture content%
9m from saturated soil boundary on the 200m line.	1	0-15	49	38
	2	15-30	45	16
	3	30-44	33	18
	4	44-59	34	13
	5	59-75	13	5
	6	75-91	22	9
	7	91-106	15	15
	8	106-118	21	21

Table 2 Core 5 and core 6 near 400m line in figure 13.

CORE 1	NO	Depth(cm)	Clay and silt%	Moisture content%
9m from 400m line	1	0-10	39	35
	2	10-22	36	18
	3	22-35	64	30
	4	35-49	20	20
	5	49-66	38	14
	6	66-77	51	26
	7	77-93	24	27

CORE 2	NO	Depth(cm)	Clay and silt%	Moisture content%
46m from 400m line.	1	0-14	27	26
	2	14-31	32	8
	3	31-43	11	9
	4	43-57	19	9
	5	57-73	5	9
	6	73-87	7	10
	7	87-98	6	22
	8	98-110	38	27

Table 3 Core 1 and core 2 near BEMP well in figure 13.

The tables show the percent of fine material (clay and silt) and moisture content are different in every core. The moisture content is also inconsistent in every layer. The fine soil percentage is high on top and low at the bottom of the ground in most of the cores and some of the cores show discrete layering. The moisture content is high at top as the finer soil holds more water then coarse soil particle. The moisture content increases again close to the ground water table. The finer soil percentage of each core is individual as well. Hence, it is very hard to generalize regarding the soil layers at the Biopark.

3.7.2 Data analysis

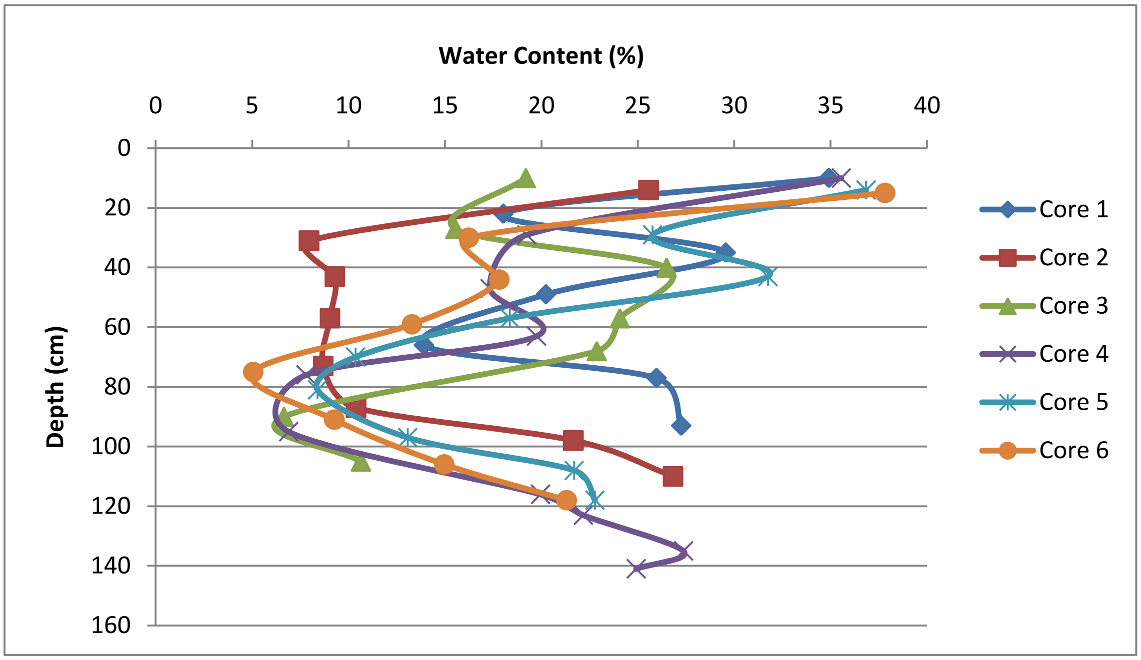


Figure 14 The water content vs. depth curve for six cores of the wetland.

Figure 14 shows the water content vs. depth of the six cores. Figure 14 shows general trend of, at the surface, the water content is high and decreases with depth until it approaches the ground water table, where it increases again. This type of soil moisture change can takes place for various reasons. One of the reasons can be the wetland water contribution to the surface soil and the capillary rise from the water table increases the moisture in the adjacent soil. A HYDRUS-2D model in chapter 5 has been developed to shows the contribution of the wetland over soil moisture content with predicted moisture contour map with different pond conditions. It also shows different layers of soil of different conductivity. The soil conductivity increases with grain size. The water content appears to reflect the soil layering.

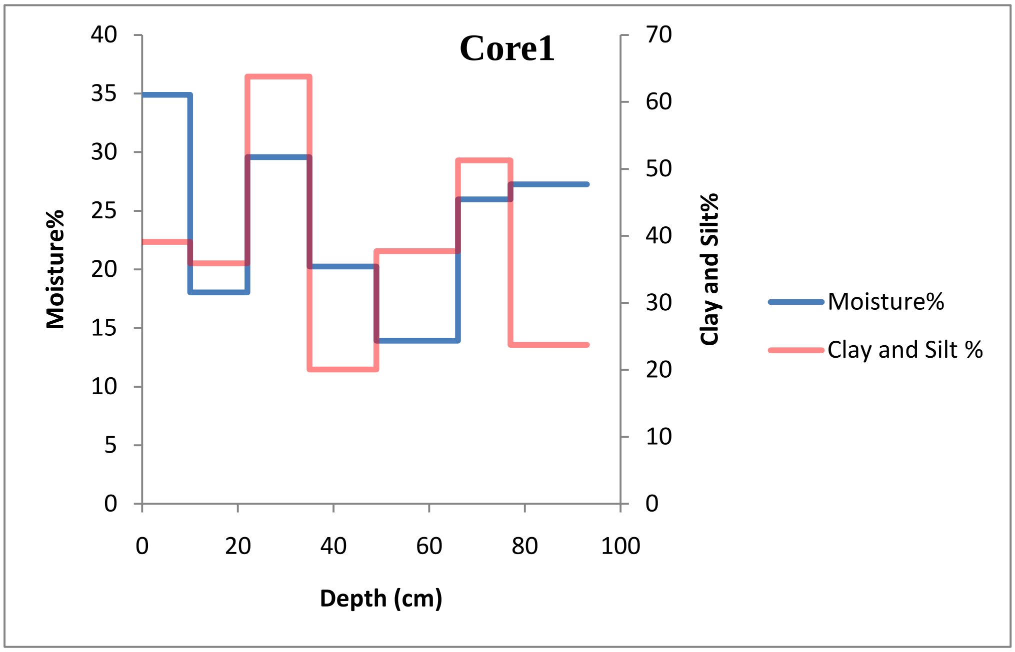


Figure 15 Soil moisture vs. depth graph with soil classification (Core 1).

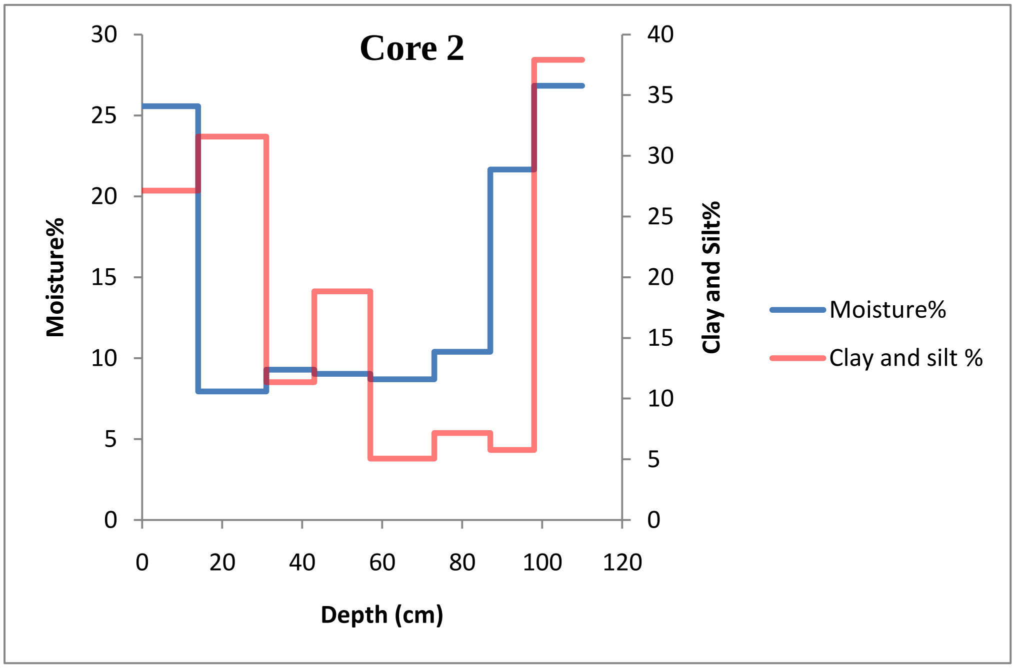


Figure 16 Soil moisture vs. depth graph with soil classification (Core 2).

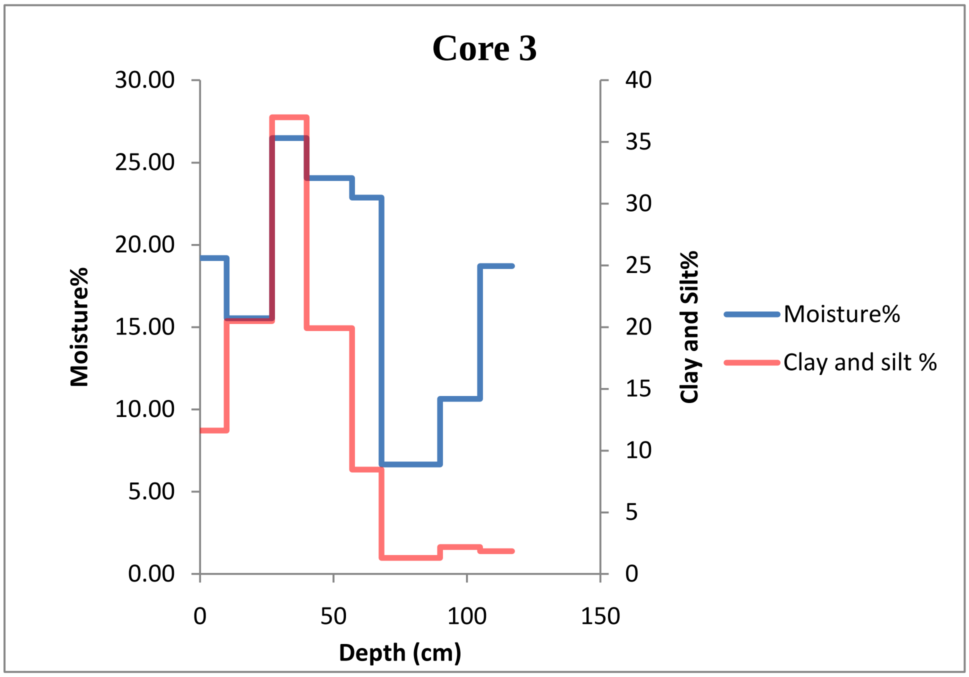


Figure 17 Soil moisture vs. depth graph with soil classification (Core 3).

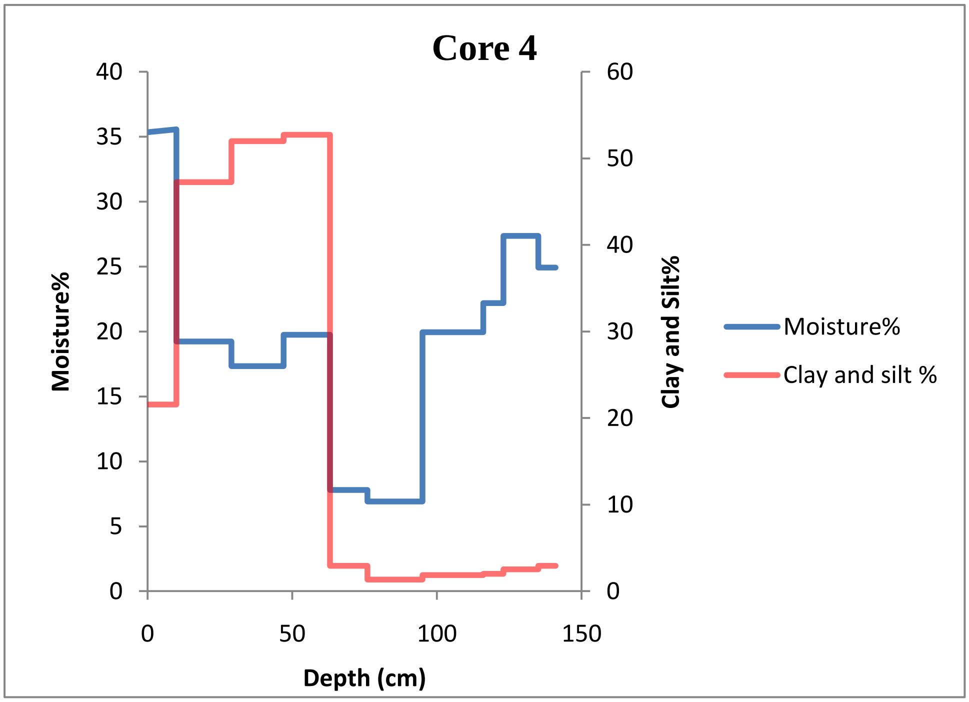


Figure 18 Soil moisture vs. depth graph with soil classification (Core 4).

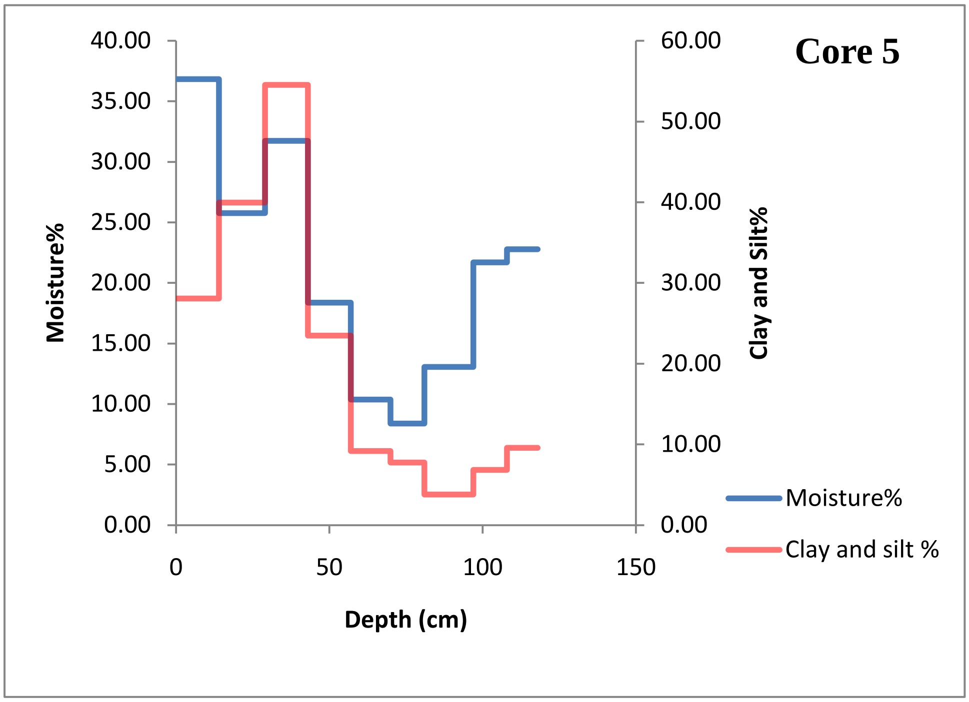


Figure 19 Soil moisture vs. depth graph with soil classification (Core 5).

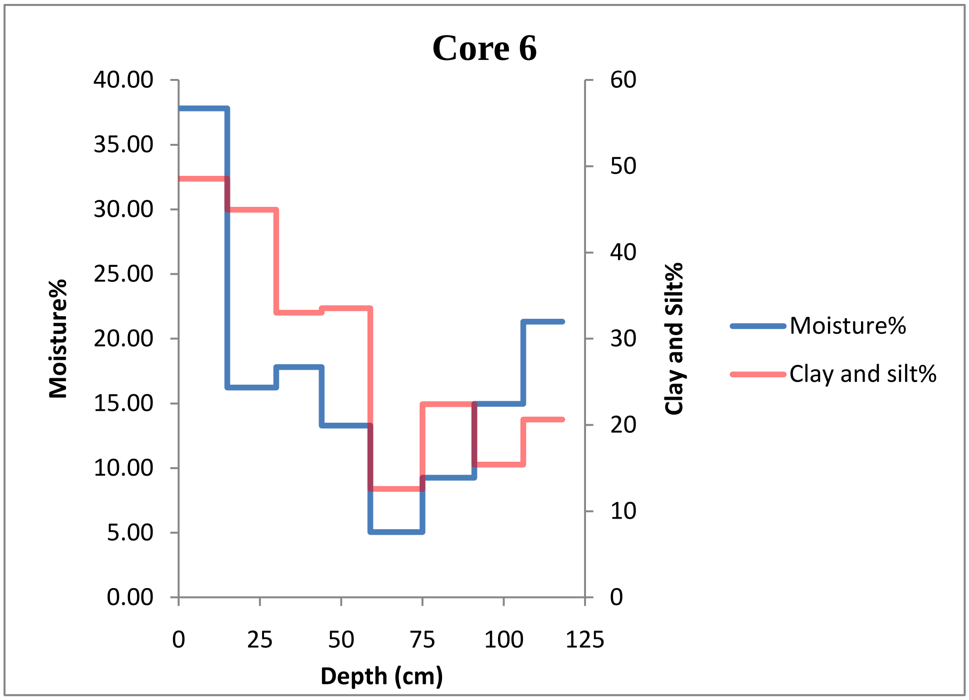


Figure 20 Soil moisture vs. depth graph with soil classification (Core 6).

Figure 15, 16, 17, 18, 19, and 20 show the detail composition and layering of soil of six cores. These graphs show the moisture content and finer soil (clay and silt) percentage with depth. The change of moisture content is not linear with depth. The reason of the sharp change of moisture content can be due to the complex layering of soil. The soil close to the surface has higher finer soil content and can hold water to a large extent. The lower part is close to the water table and has less fine soil percentage. There are other factors that can influence the soil moisture beyond soil texture. Capillary action from ground water may be the cause of high water content at the bottom portion. If the core location is close to the river, the soil moisture content may fluctuate in response to river level changes. The wetland water and ground water may contribute the soil moisture, and depth of ground water table. Some of soil moisture content and fine soil content data appear to be correlated and some do not. Table 4 shows the Pearson Correlation to show how these soil cores correlate.

A correlation is a number between -1 and +1. Correlation measures the degree of association between two variables (as X and Y). A positive value implies a positive association and negative value shows negative or inverse association.

Assume two variables X (soil moisture) and Y (Finer soil percentage), with means $\overline{X}$ and $\overline{Y}$ and standard deviations S_x and S_y respectively. The correlation is computed as

$$r = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{(n-1)S_x S_y} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{3.1}$$

Pearson value test

Core	**P value**
Core 1	0.33
Core 2	0.4336
Core 3	0.689
Core 4	0.0644
Core 5	0.7079
Core 6	0.6778

Table 4 Correlation test.

For this correlation the ‘X’ value is percentage of soil moisture and ‘Y’ value is the amount of clay and silt (finer soil). The correlation coefficient p-value measures the strength of a linear relationship between two variables. The closer the value of P is to +/-1, the closer to a perfect linear relationship. The p-value of core 1 is 0.33 which shows weak association and weak positive correlation. The p-value of Core 2 and core 3 is 0.4336 and 0.689 respectively, which show weak association or correlation. Core 4 has the p-value of 0.0643 which shows no association. Core 5 and core 6 have p-value of 0.7079 and 0.6778 which show strong positive association. It can be suggested from the statically significant test that the moisture content does not show a consistently good correlation for soil core layering.

3.8 Ponds Effect (Influence of Biopark ponds)

The wetland contributes to livelihoods, creates habitat, provides valuable ecosystem to society, contributes to ground water, soil moisture for plants, increases biodiversity, changes climate, and also creates riparian forest. The aim of Biopark wetland creation is in part to increase the riparian forest. Several photos have been selected from Google map to show how the wetland changes over time.

Figure 21 Biopark wetland, 1996 before construction of pond (Peak flow at Rio Grande is 920 cfs).

Figure 22 Biopark wetland, 2005 (Peak flow is 2500 cfs).

Figure 23 Biopark wetland 2006 (Peak flow is 720 cfs).

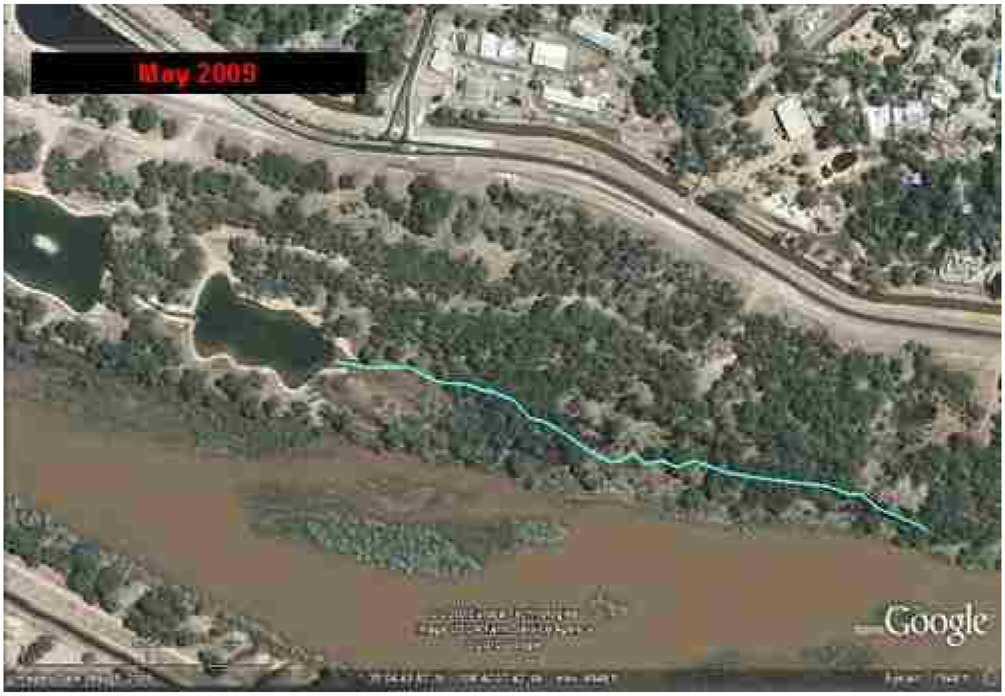


Figure 24 Change of vegetation of Biopark wetland with time at 2009 (Peak flow rate is 4900 cfs).

Figure 21, 22, 23 and 24 shows the photo of the wetland around the Biopark ponds. Those photos represent the picture of 1996, 2005, 2006 and 2009 of Biopark area. Figure 21 represents the photo of the Biopark area before construction of ponds and Figure 22, 23 and 24 represent the photo after the pond construction. It is very hard to say from the photos exactly what the volume of vegetation is. The resolution of photo, range of zoom, different time period, river flow rate and lowering, vegetation clearing, and human effect introduce uncertainty. Those factors preclude describing completely the reasons for any apparent change of vegetation.

The Google earth images are of varying resolutions. Most land is covered in at least 15 m resolution. It has a limited zoom range. This is the reason that the marsh area is not visible in those images. Also the time at which the image was taken is an influencing factor. Part of the year, most of the tree does not have any leaves and the small plants become brown which is hard to distinguish from the land. River lowering can affect the available soil moisture which affects the vegetation. Images from two different years of same month can show the different vegetation for this reason. May, 2006 and May, 2009 images show two different flows in the Rio Grande. The clearing of exotic plant from the riparian zone starts from 2006. This exotic plant consist of salt ceder, Russian olive, Siberian elm etc. It is also one of the causes of vegetation reduction with time.

The Google images give a better understanding of the vegetation of Biopark area but only with those pictures it is very difficult to analyze the effect. The Biopark wetland restoration project contributes soil moisture but on the other hand pumping to feed the ponds may lower the ground water table which can be the cause of change of vegetation at wetland. From the Google image survey, it can be said that with the photo proof, it is not possible to develop any statement about the change of the land use with time. A numerical model analysis of soil moisture changes from the presence of the wetland would provide alternative evidence to support a hypothesis regarding vegetation changes. Such an analysis is described in chapter 5.

CHAPTER 4

COUPLING OF GROUND WATER-SURFACE WATER USING ArcGIS, HEC-GeoRAS AND HEC-RAS

4.1 Introduction

The function of a wetland mostly depends on water availability, which depends on the flood frequency, and the location of the ground water table. This chapter presents modeling of the ground water table and the evaluation of the frequency of flooding of the wetland near the Biopark adjacent to the Rio Grande in Albuquerque. For this analysis, ArcGIS, HEC-RAS and HEC-GeoRAS software have been used.

In ArcGIS, a combination of field survey data and topographic data are used to create the terrain model.

HEC-RAS was used for determining the water depth for any cross section of a river profile. It required the input of geometric data to represent river networks, channel cross-section and hydraulic structures such as bridge and culvert. These data were imported to the ArcGIS program for analysis using the HEC-GeoRAS extension. Further analysis using the integration of ArcGIS and HEC-RAS produced the maps depicting the predicted ground water table.

By integrating HEC-RAS into ArcGIS using the HEC-GeoRAS extension, the computed water profiles from HEC-RAS can be exported into a readable format in ArcGIS and therefore produce flood risk maps that provide the depth, extent and probability of a specific flood with a certain average recurrence interval. Hence, minimum discharge of river flow for flooding the Biopark ponds can be found from HEC-RAS analysis and exported to ArcGIS to find the inundation map for that area as well.

This chapter shows the integration of ArcGIS and HEC-RAS model using HEC-GeoRAS extension to assess and predict the ground water table and minimum river discharge for flooding of Biopark wetlands pond.

4.2 Study area

The study area is focused on a small portion of the Middle Rio Grande, from the Central Bridge to the end of Biopark. The upstream United States Geological Survey (USGS) gage is the Central Bridge at Albuquerque, NM (08330000). There are two ponds in the Biopark. The shallow pond's (south pond) level is maintained, in part, via gravity flow from the deep pond (north pond). The south pond drains into a cattail marsh and then develops a wetland; and a combination of upper terrace strip of old cottonwoods, a mid-level terrace of young cottonwoods, and a series of three terraces of mainly coyote willows that extend to the river.

There are eleven monitoring wells around the Biopark south ponds. These monitoring wells continuously record ground water level. All wells are instrumented with pressure transducers that record data at 15-minute intervals. These data are paired with 15-minute USGS river stage data to interpret ground water-surface water interactions. The east drain wells from Figure 25 are 'the ground water Monitoring well-1' which is needed to create the slope of ground water surface is at upstream of the Central Bridge. Figure 26 shows the location of other Biopark monitoring wells.

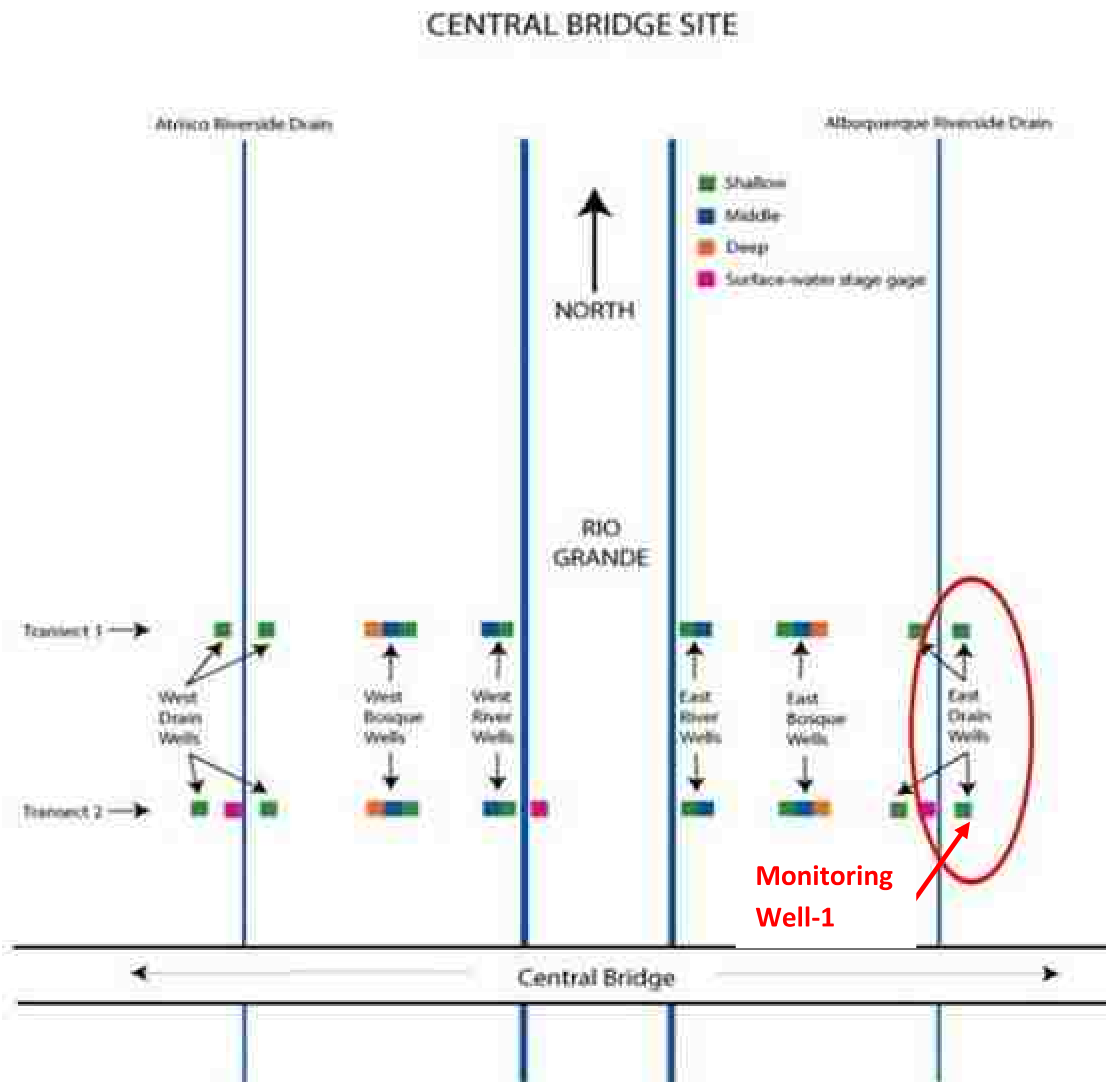


Figure 25 Location of Monitoring well-1 (USGS ground water monitoring well).

Figure 26 : Location of Biopark ground water monitoring wells (Lejuene & Crawford, 2008). The Colored dots indicate wells.

4.2 ArcGIS Model

The Triangulated Irregular Networks (TIN), used for the ArcGIS model was collected from the Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA).

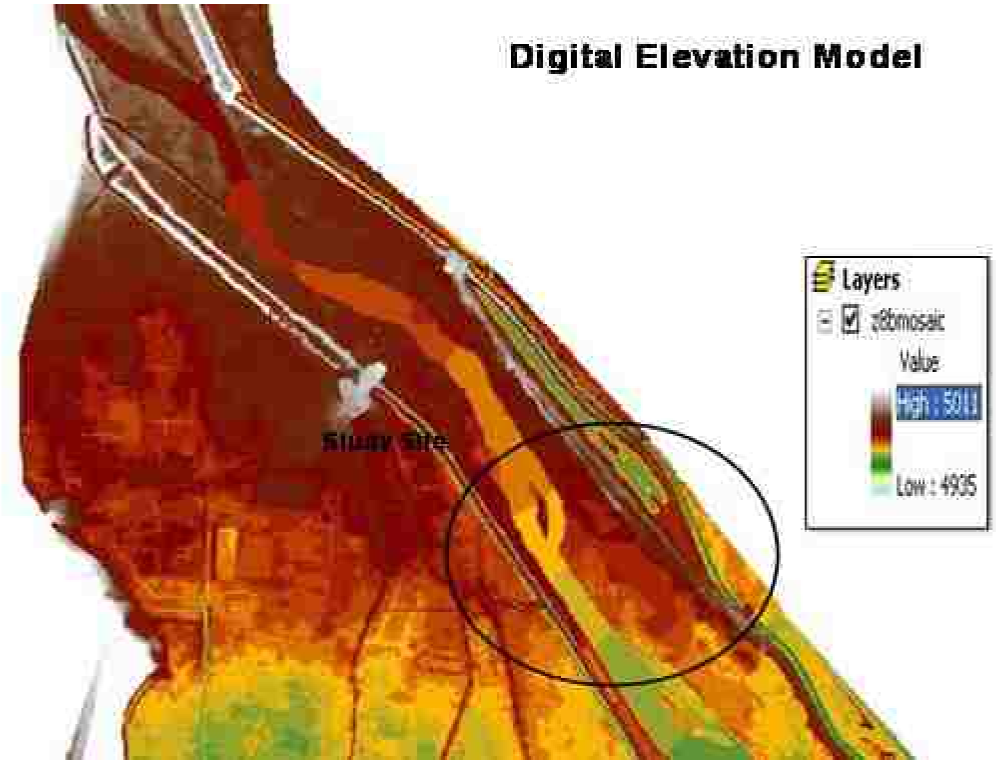


Figure 27 Digital elevation model for Rio Grande reach.

The terrain model (Figure 27) was used in ArcGIS to get realistic elevation of the river and river valley.

HEC-GeoRAS was used to create the HEC-RAS geometry from the terrain model. HEC-RAS requires a number of files to be delineated in ArcGIS including stream centerline, center flowpath centerlines, cross section cut lines, river banklines, bank stations, and left overbank, right overbank, Manning N and landuse file.

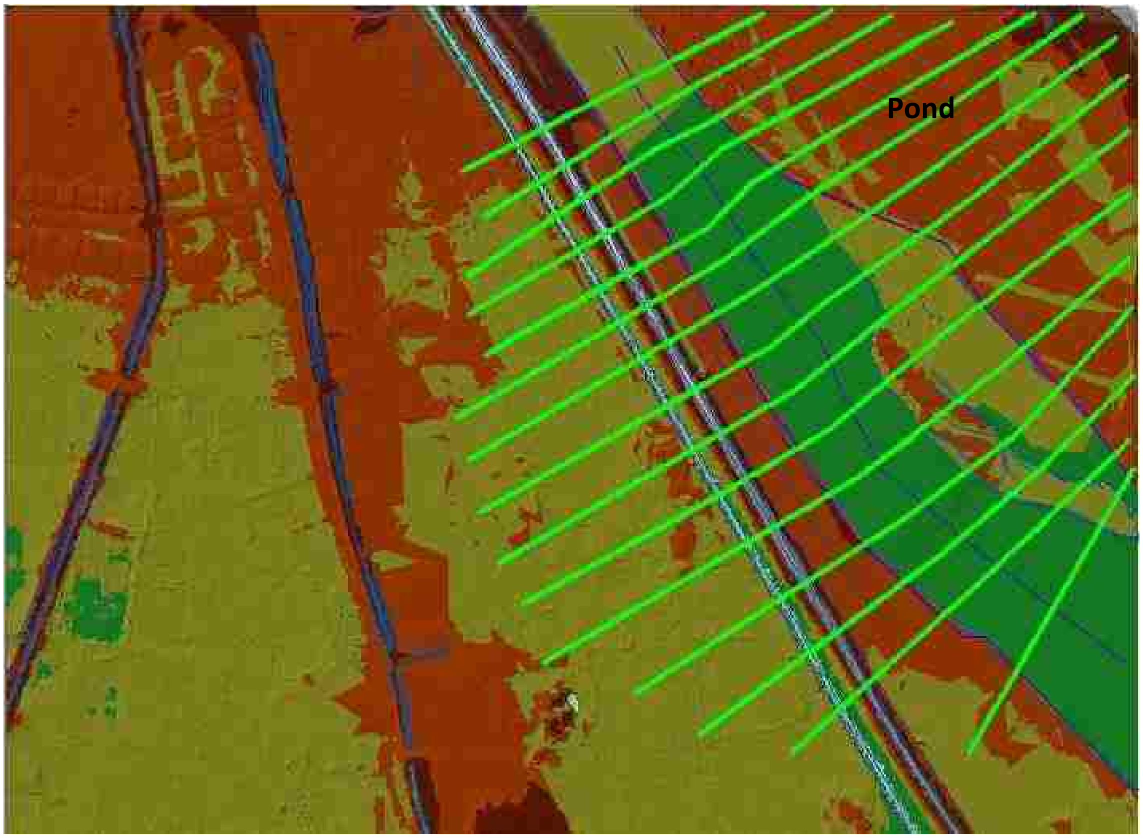


Figure 28 Sketching of cross section by HEC-GeoRAS .

The river centerline was sketched in ArcGIS using aerial photos and the terrain model. The cross section cut lines were also sketched in ArcGIS to be perpendicular to the flow path centerlines. HEC-GeoRAS is used to assign elevations to each of the cross sections, river centerline, backlines, and levees. HEC-GeoRAS calculated downstream reach lengths for each cross section, assigned bank station values at the intersection of bank lines and cross section lines, and assigned river and reach names to each cross section. The cross sections locations are shows in Figure 28 and Figure 29.

Land use polygons were sketched and Manning N was assigned for each polygon. Considering that the landscape is a riparian forest, the Manning N of 0.08 was assigned to the entire polygon. For the river channel, Manning N was assigned as 0.03. These N values are typical for natural streams that are “clean, straight, full stage, no rifts or deep pools” (0.03), and a flood plain with trees and a “heavy growth of sprouts” (0.08) (Sturm, 2009). For the channel islands, a Manning N value of 0.05 is used for island polygons.

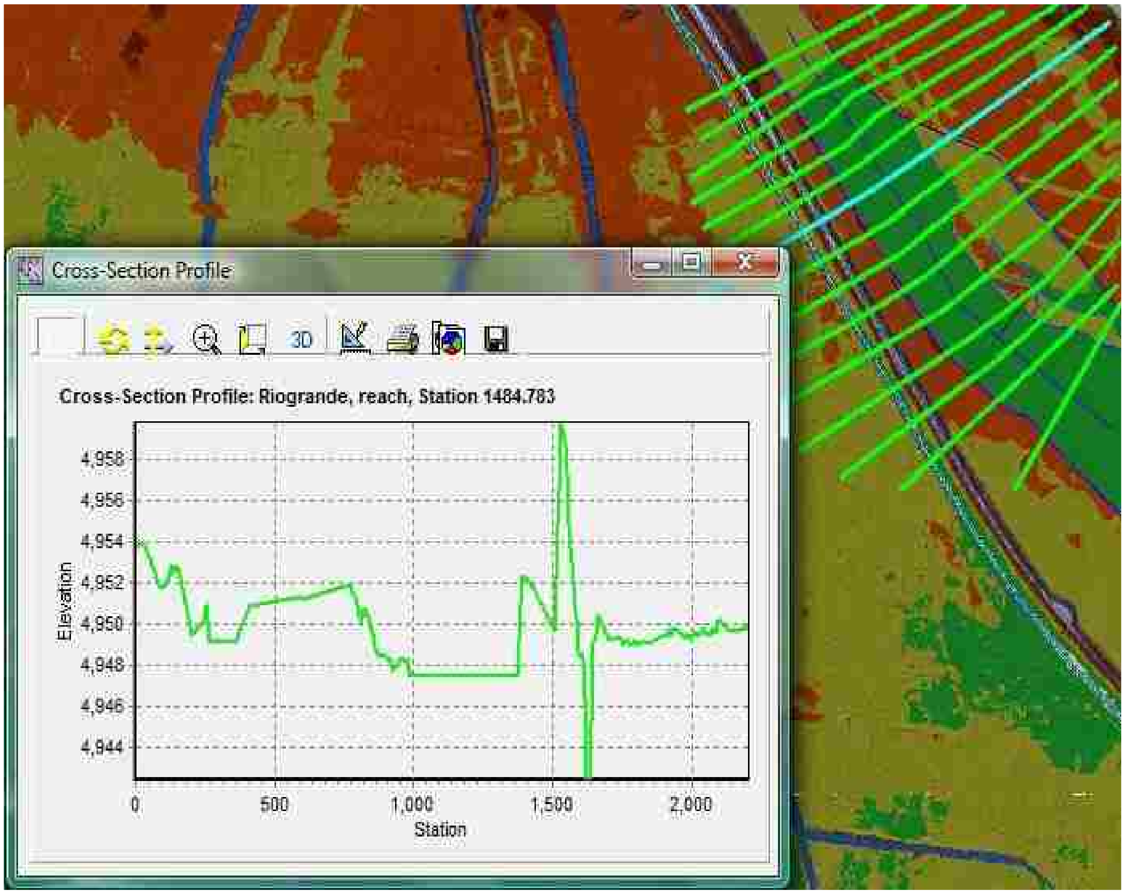


Figure 29 Cross section of Rio Grande in HEC-GeoRAS.

All of this information was then compiled into one file by HEC-GeoRAS and converted to a HEC-RAS readable format in the HEC-GeoRAS by ‘Toolbar > RAS Geometry > Extract GIS data’. Figure 30 shows the cross sections of the river and the HEC-GeoRAS tool for extracting data.

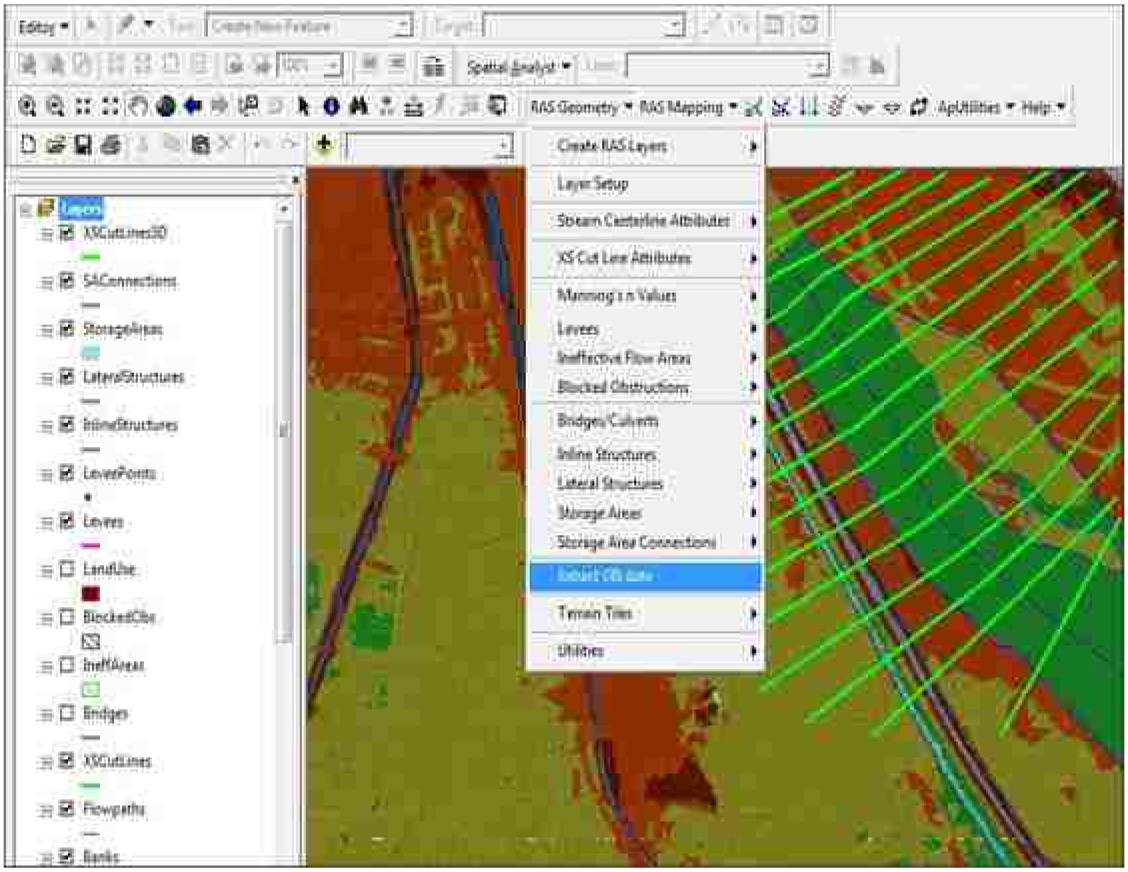


Figure 30 Extracting GIS data for HEC-RAS.

4.3 Ground water data

Eleven wells around the following south pond were selected for ground water table modeling. The BBP wells (Figure 26) are maintained by the Bosque Ecosystem Monitoring Program (BEMP) well and the UBP wells are maintained by the Urban Flood Development Project well. The ground water level data from those wells shows that the level fluctuates with river water level.

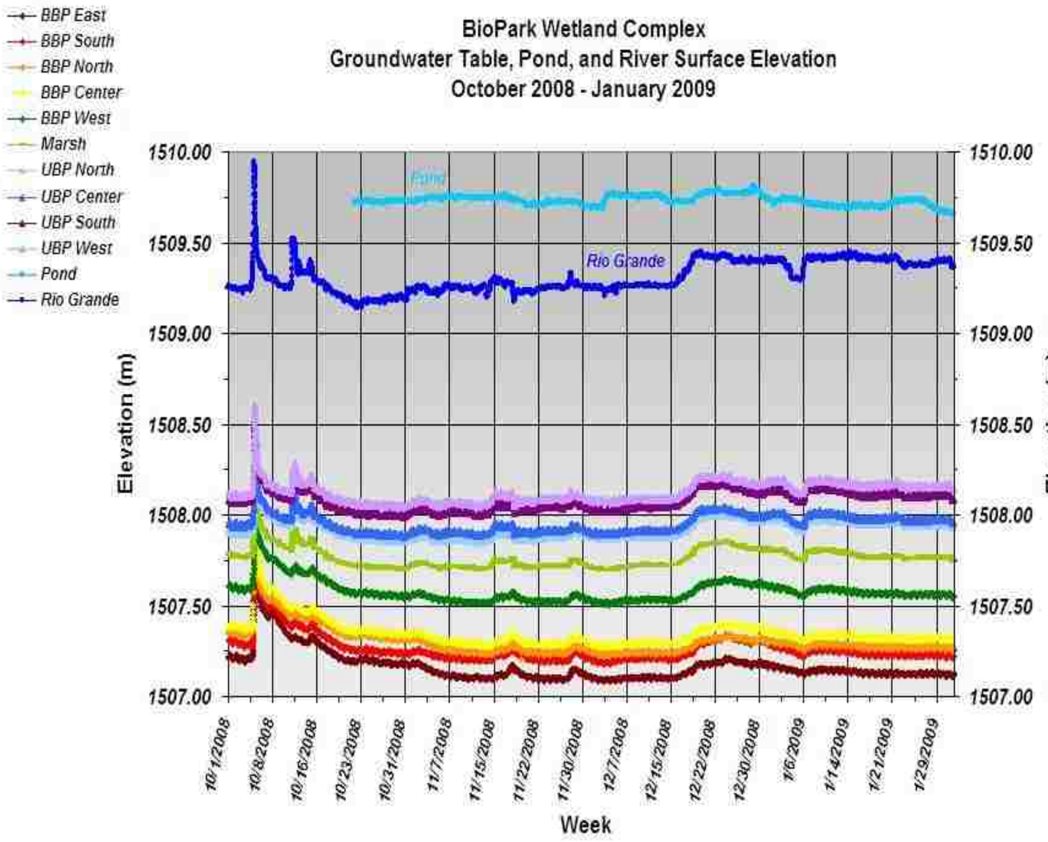


Figure 31 Baseline data from the Biopark wetland complex site (LeJeune & Crawford, 2008).

Figure 31 shows that the water depth of well water (ground water) fluctuates with the river water depth. The wells locations are shown in Figure 26. The data was collected from October 1st 2008 to January 22nd 2009. The spike in early October 2008 was the result of a rain event. The record of precipitation occurred at 5th October at USGS Central bridge rain gage is 3.53 cm. All the USGS river data are provisional. The pond water data in the Figure 31 varies less. The ground water data shows same character as the river water data. The two data were selected for additional analysis: low flow and high flow conditions. For the low flow condition 20th February 10 AM 2009 data has been used which is 776 csf in Rio Grande at central Bridge gage. 4860 cfs discharge at Central Bridge of 13th May 1 PM 2009 data has been selected for the high flow condition.

BioPark Well	**Ground Water Elevation(m)**	
	20th February 2009 776 cfs	13th May 2009 4860 cfs
South Pond Well	1507.22	1509.81
Marsh Well	1507.78	1508.6
BEMP Well Cluster (East)	1507.12	1507.69
BEMP Well Cluster (West)	1507.56	1508.24
BEMP Well Cluster (North)	1507.26	1507.87
BEMP Well Cluster (South)	1508.91	1507.88
BEMP Well Cluster (Centre)	1507.31	1507.04
UFDP Well Cluster (North)	1507.96	1508.88
UFDP Well Cluster (South)	1508.15	1509.04
UFDP Well Cluster (West)	1508.19	1509.16
UFDP Well Cluster (Centre)	1508	1508.97

Table 5 Ground water elevation of monitoring wells.

Table 5 represents the ground water surface data of 20th February 10 AM 2009 and 13th May 1 PM 2009 of Biopark wells. The ground water table is developed by adding the river water surface and the ground water surface of a well. The location of the ground water well is very important for the gradient of the ground water table. The well should be close to the river to get the accurate gradient. The Monitoring well-1 close to the river is chosen to define the boundary condition. The location of Monitoring well-1 is not shown in the Figure 32 as it is located at a far distance from the river. Figure 25 shows the location of Monitoring well-1. Figure 32 shows the location of river and BEMP and UFDP monitoring wells.

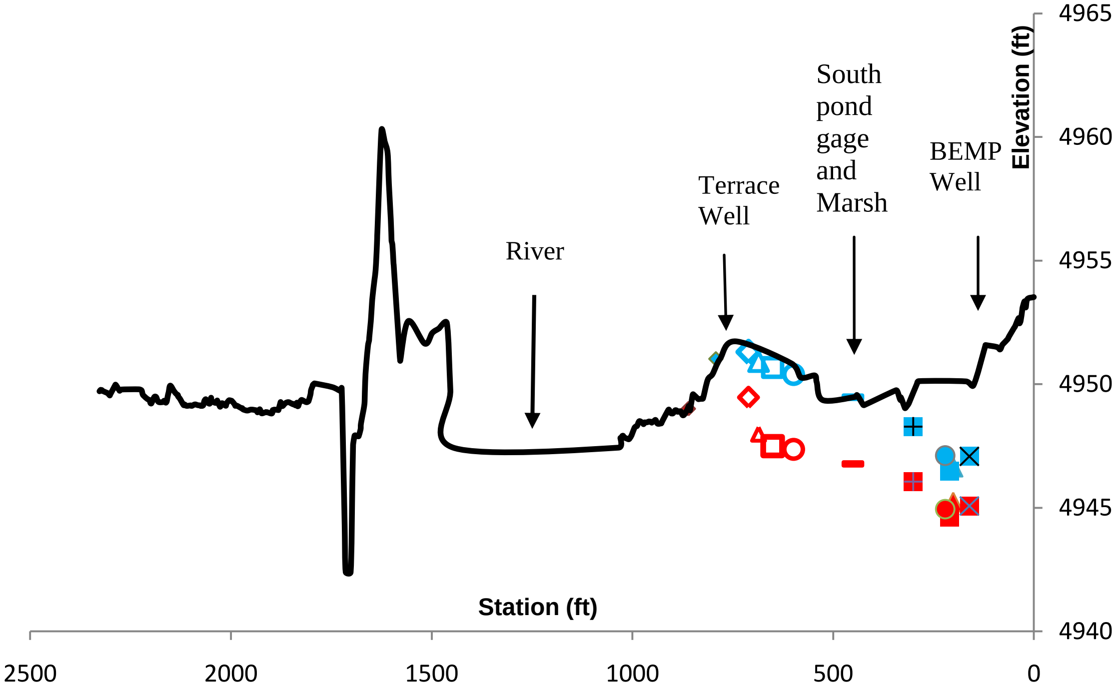


Figure 32 Cross section of the Biopark and well locations.

4.4 River discharge data

River surface water data is one of the boundary condition to develop the ground water table. Gage 08330000 Rio Grande at Central Bridge has been selected for this case.

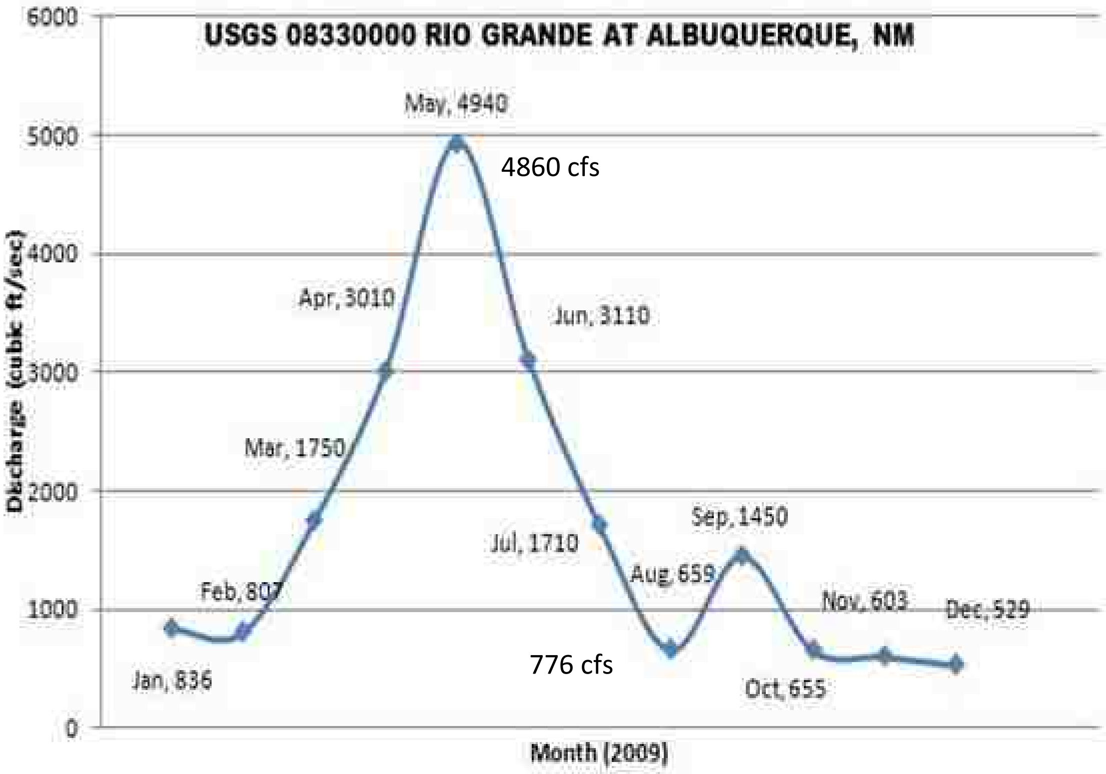


Figure 33 Discharge during 2009 of gage 08330000 Rio Grande at Central Bridge.

Figure 33 shows the daily discharge vs. time data of the gage at Central Bridge. The plot has two sharp peaks, one is around May and other peak is at September. Discharge of 13th May and 20th February 2009 of USGS Central gage was selected as the calibration flow and the discharge are 4860 and 776 ft^3/sec, respectively.

4.5 HEC-RAS model

The HEC-RAS model was created with the help of Geometric Data Editor, the file converted by HEC-GeoRAS has been imported by File > Import Geometry Data > GIS Format. Figure 34 shows the cross section location of river in HEC-RAS.

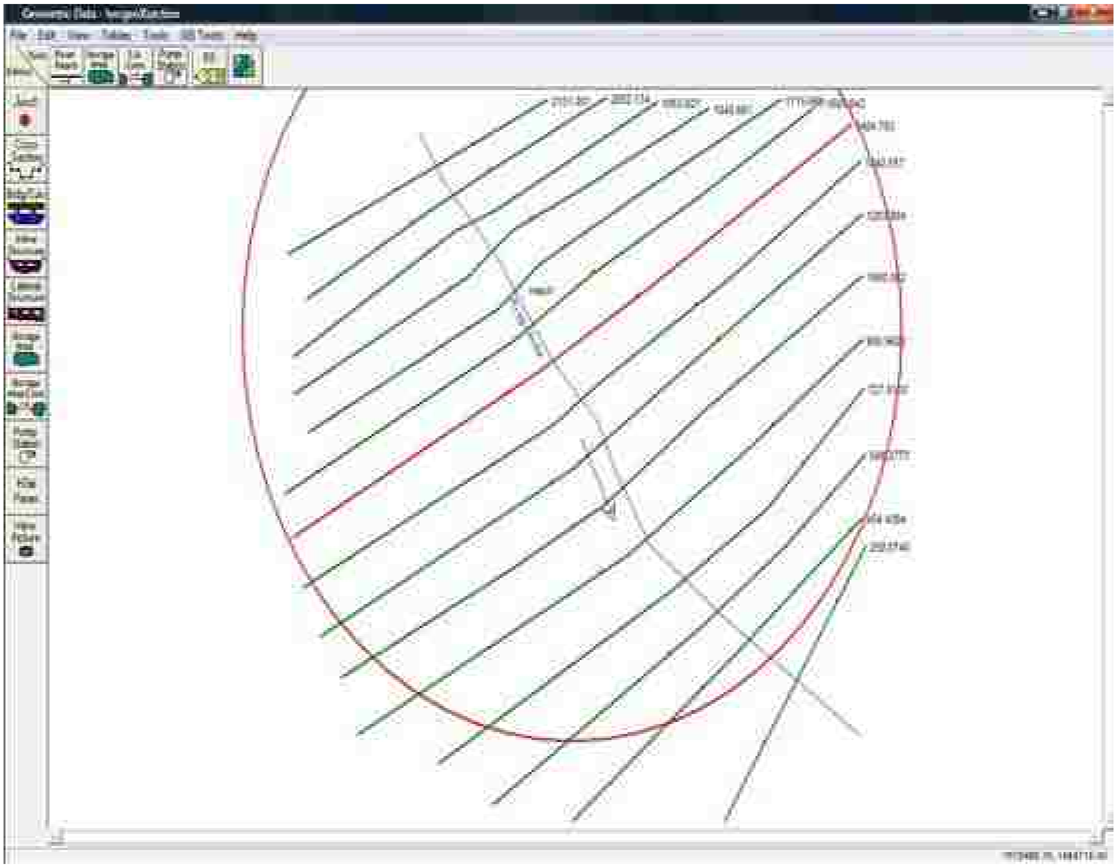
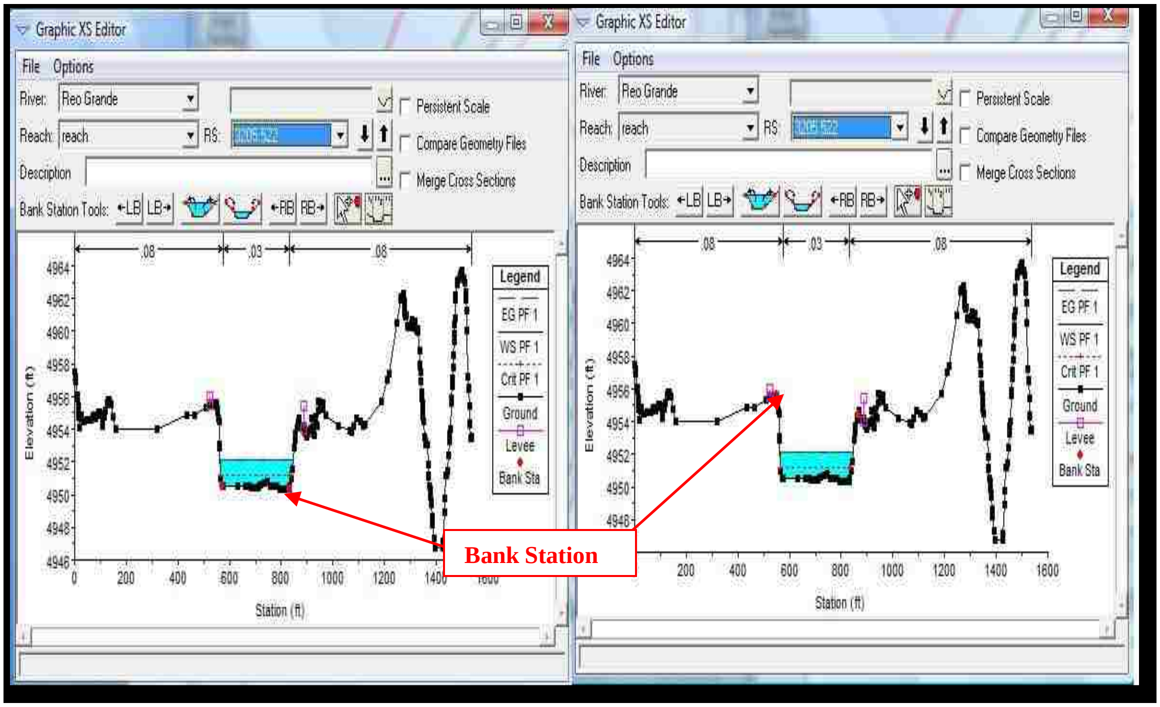


Figure 34 Cross section locations in HEC-RAS.

For this import file, some corrections have been made. The bank lines selected from the terrain model were revealed to be the edges of the river bottom. The bank stations were shifted in the Graphic XS Editor in HEC-RAS to be at the top of the bank instead of the bottom. Figure 35 shows the bank station before and after correction.



River: Reo Grande

Reach: reach

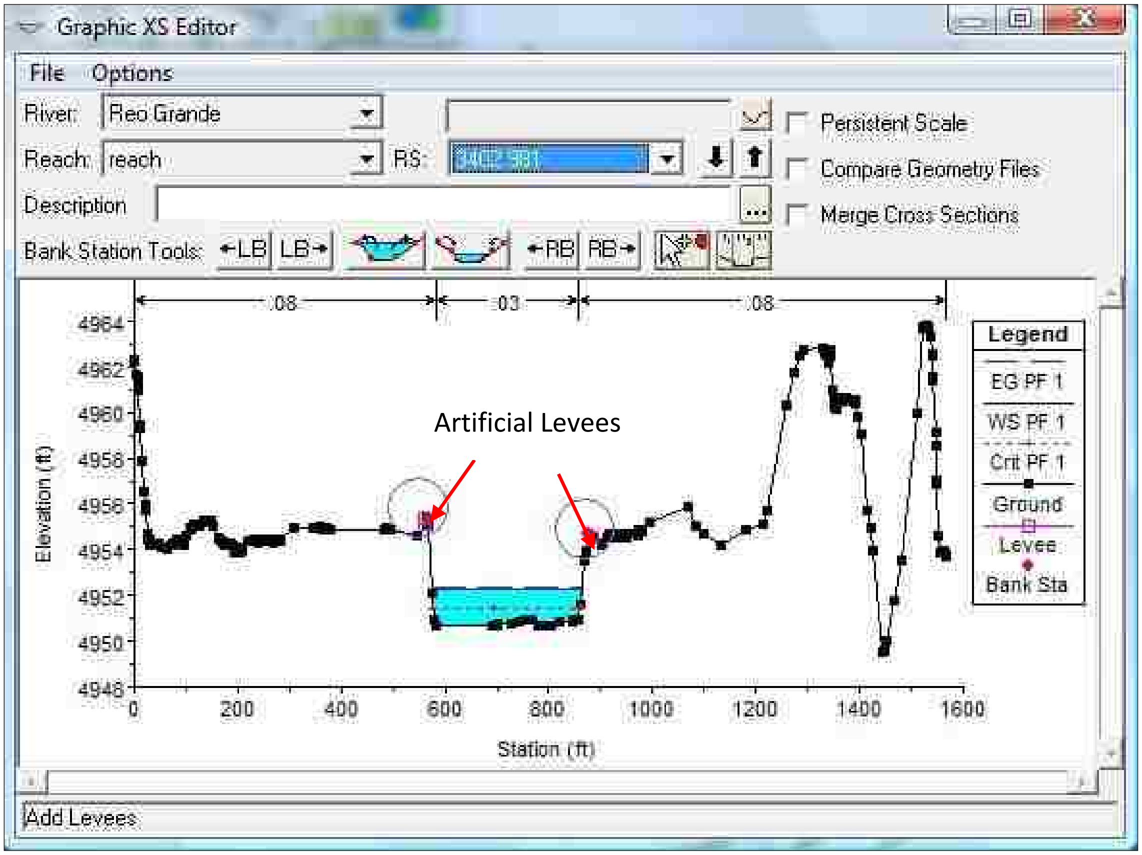
Figure 35 Bank stations before and after correction.

The cross section points filter was applied to the cross sections that had more than 300 points. “Minimize Area Change” was selected and points were removed so that each cross section had a maximum of 300 points. This was done to minimize the repetitions of same point again and again.

Some of the cross sections were not assigned from right to left direction in HEC-GeoRAS. Those cross sections were subsequently corrected in HEC-RAS.

HEC-GeoRAS incorrectly assigned levee locations. Therefore, water from the channel covers every possible location of the cross section. For that reason, artificial levees of minimum height have been assigned to the stations to ensure the flow remains in the river until it is high enough to cross the levees. Levees have been manually assigned by

‘Graphical XS Editor > Options > Add Levees’. Figure 36 shows the artificial levees location.



River: Reo Grande

Reach: reach

RS: 3402.931

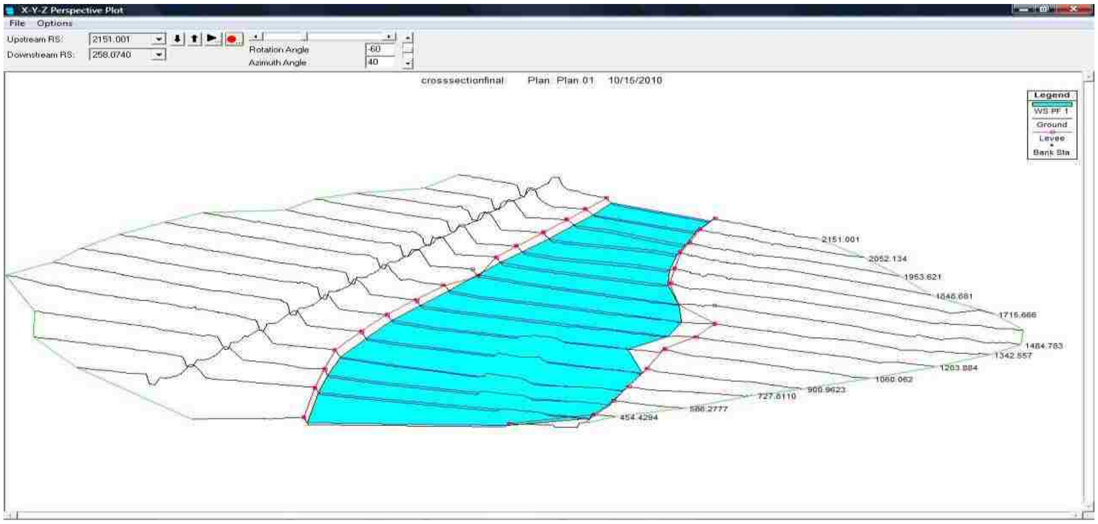
Description:

Figure 36 Assigned artificial levees.

After the geometry was established, the model was run for steady state flow. One stream flow discharge from the Central gage (USGS gage) was selected. For the boundary condition, normal depth have been selected and assigned a slope of 0.001 from the Central Bridge to the Biopark wetland.

The models were run for water surface elevation instead of peak discharge, because the point of this study is to correlate river water surface elevation to ground water depth.

HEC-RAS outputs a lengthy list of parameters at each cross section, including water surface elevation. The coordinate system of the elevation is the same as the input geometry. After simulation, a profile summary table, river profile and water surface elevation for each cross section, for a certain discharge were created.



Upstream RS: 2151.001
Downstream RS: 258.0740
Rotation Angle -60
Azimuth Angle 40

Figure 37 River profile for 776 CFS discharge.

Cross section XS 1342.557 station has been selected for the analysis as it crosses through the wetland south pond. Figure 37 shows the river profile and Figure 38 shows the cross section.

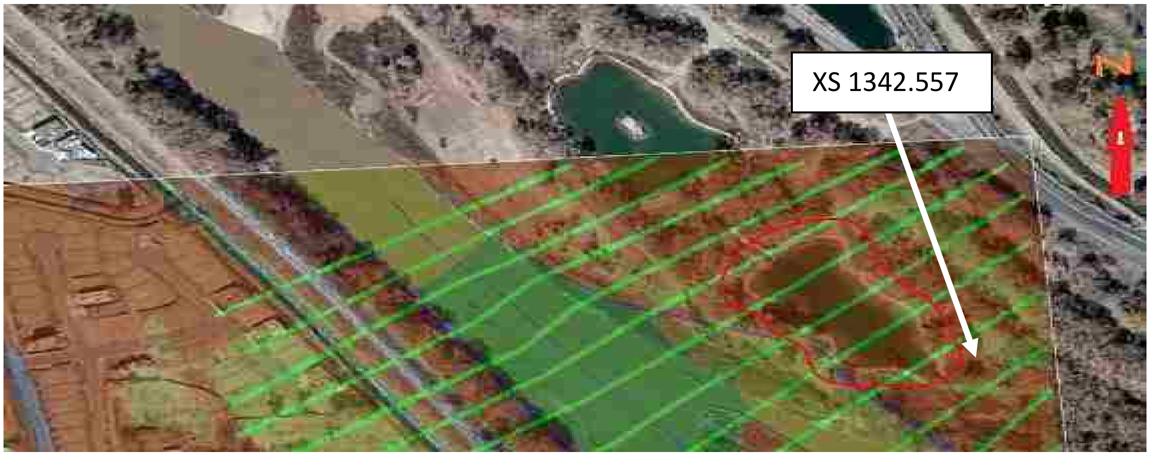


Figure 38 Cross section 1342.557 crosses the south pond at Biopark.

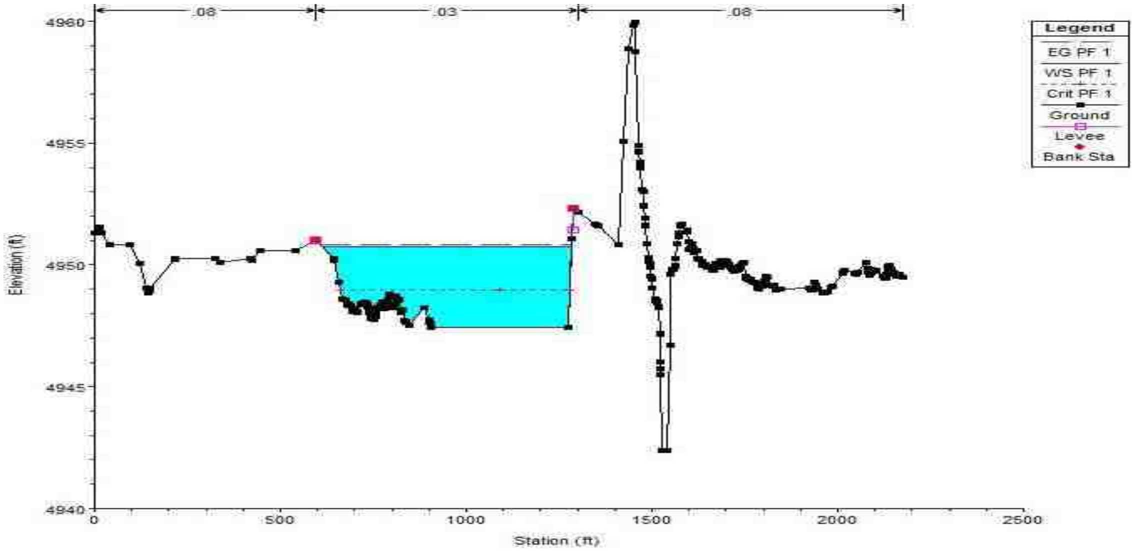


Figure 39 Cross section (XS 1342.557) at 4860 cfs discharge.

The profile summery table of the cross section is exported to Excel with the elevation point of water surface. Figure 39 is the cross section of station XS 1342.557 for high flow condition.

4.6 Ground water table

The HEC-RAS model produces the shape of the ground water table at the Biopark pond area. The Monitoring well-1 and the Biopark wells location are selected with the help of Google map and the distance data have been collected from Google map. The cross section and the water depth data also have been collected from HEC-RAS. The data was then exported to Microsoft Excel. The ground water table was developed from river water surface elevation point and ground water elevation point from the Monitoring well-1.

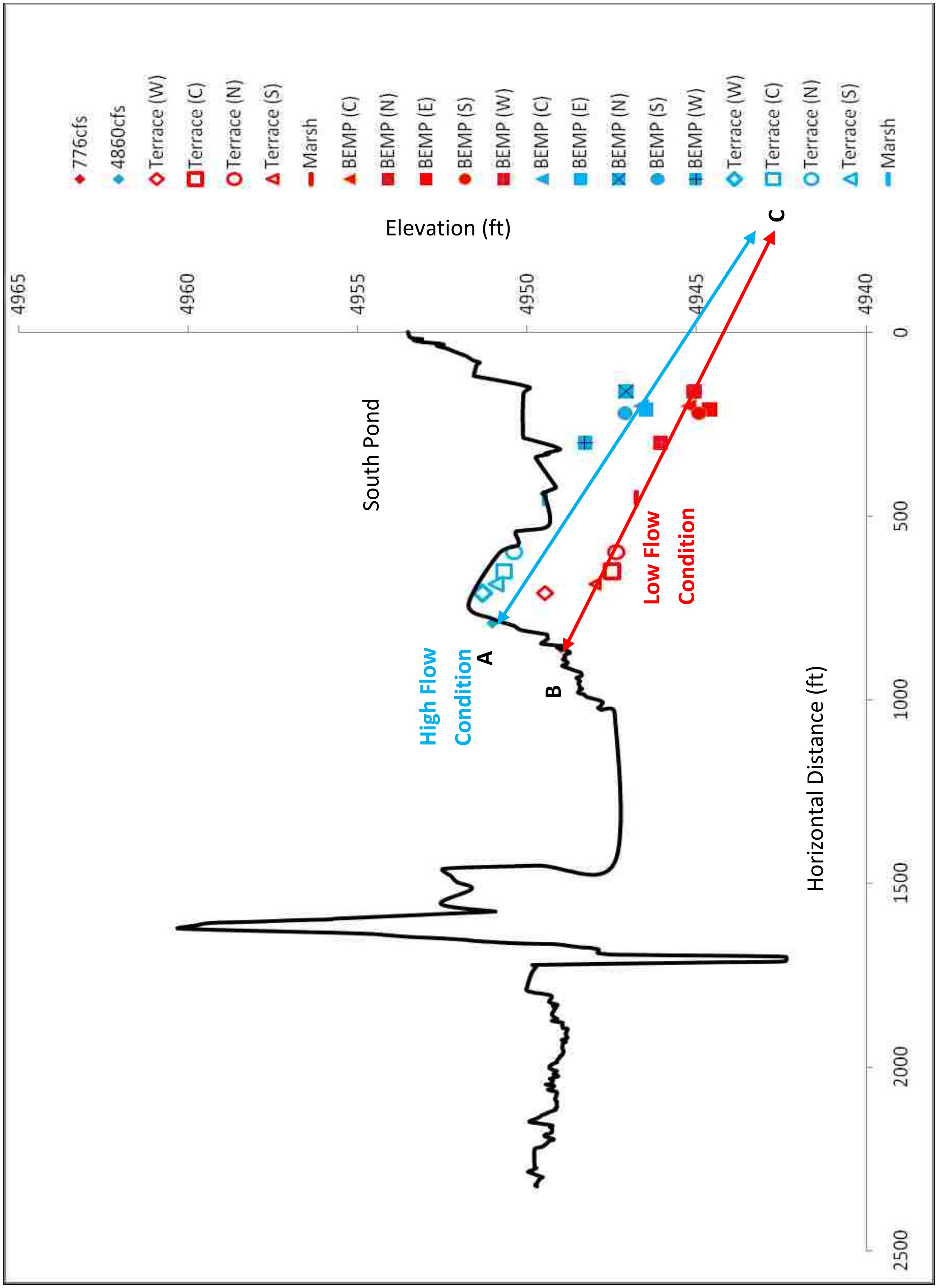


Figure 40 Extrapolated ground water table shown by solid lines.

Figure 40 represents the cross sections at XS 1484.7 station. For 766 cfs discharge, the ground water table is line BC and for 4860 cfs discharge, the ground water table is line AC. The ‘A’ and ‘B’ points are the river water depth points for the selected discharge. The ground water table is assumed to be straight line and is not influenced by other water source or pumping.

There are some other points at ‘A’ and ‘B’ locations under the ground surface. Those points represent the water surface elevation of 13th May and 20th February 2009 of Biopark monitoring wells.

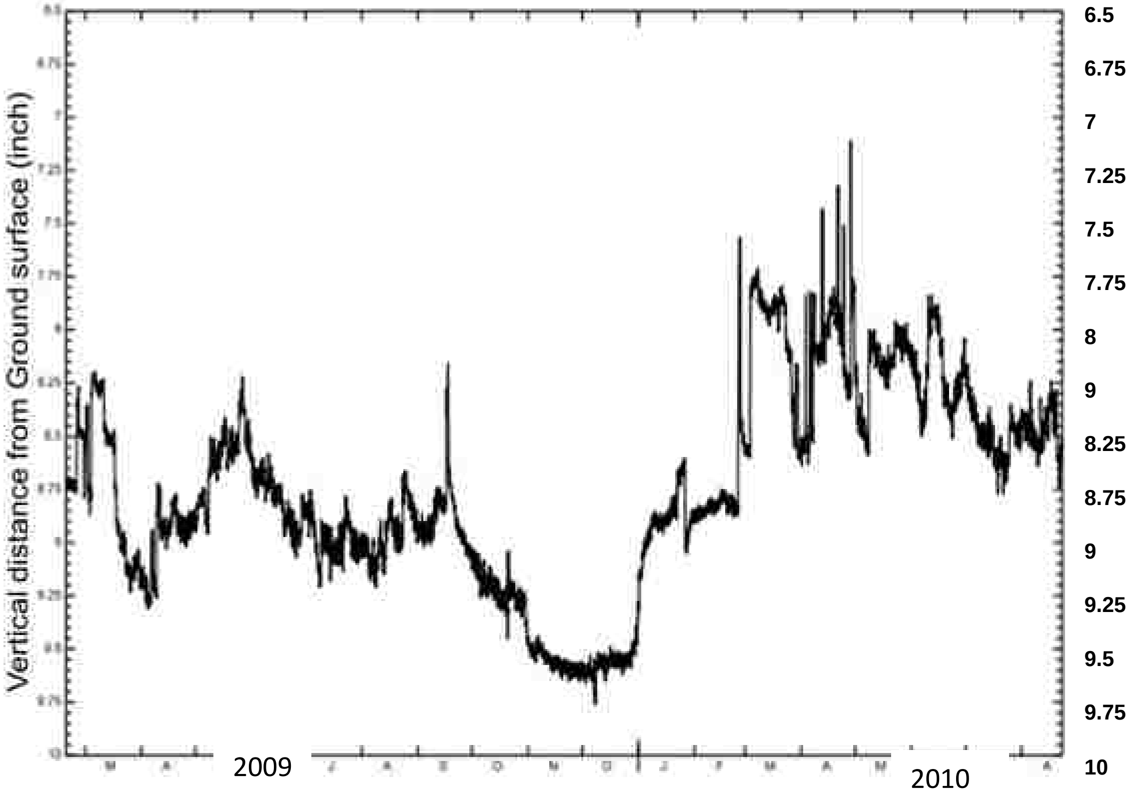


Figure 41 Change of ground water elevation with time for Monitoring well-1 (Adopted from USGS website).

The change of ground water surface in Monitoring well-1 is as small as couple of inch throughout the year. The change of ground water elevation is shown in Figure 41. The change is small because the monitoring well is at far distance from the river and is not influenced by the change of surface water in river. Hence, the ground water in Monitoring well-1 is relatively stable. The other BEMP and UFDP monitoring wells around the south ponds are close to the river and show the change of ground water surface with the change of river water.

The high flow is 4860 cfs and the low flow is 776 cfs at USGS gage at Central. In Figure 40, line AC is the ground water table for low flow and all the water elevations of south pond wells for low flow condition fall on the line. These data suggest that the pond water does not appear to significantly alter the ground water. At high flow of 4850 cfs the ground water table in Figure 40 is line BC. The ground water table BC is higher than ground water table for low flow (AC line). It shows that the south pond monitoring wells do not fall into the lines.

It can be noted that for high flow, the ground water table is near surface, and all the wells water elevations are above the ground water table. This can occur for several reasons such as all discharge data are collected from central gage for HEC-RAS model, but the water surface data for that cross section may vary. Water from other sources such as precipitation, water from pumping, surface water can contribute the river water and makes the elevation high. River flow pattern is another uncertainty in the relationship between river water elevation and adjacent water table. If there is a peak discharge before the selected flow than the water elevation remains high as it takes time to drop. The discharge vs. time graph for central gage show in Figure 42. This graph shows there is no other peak before 4860 cfs peak that can contribute the high water elevation of the monitoring wells.

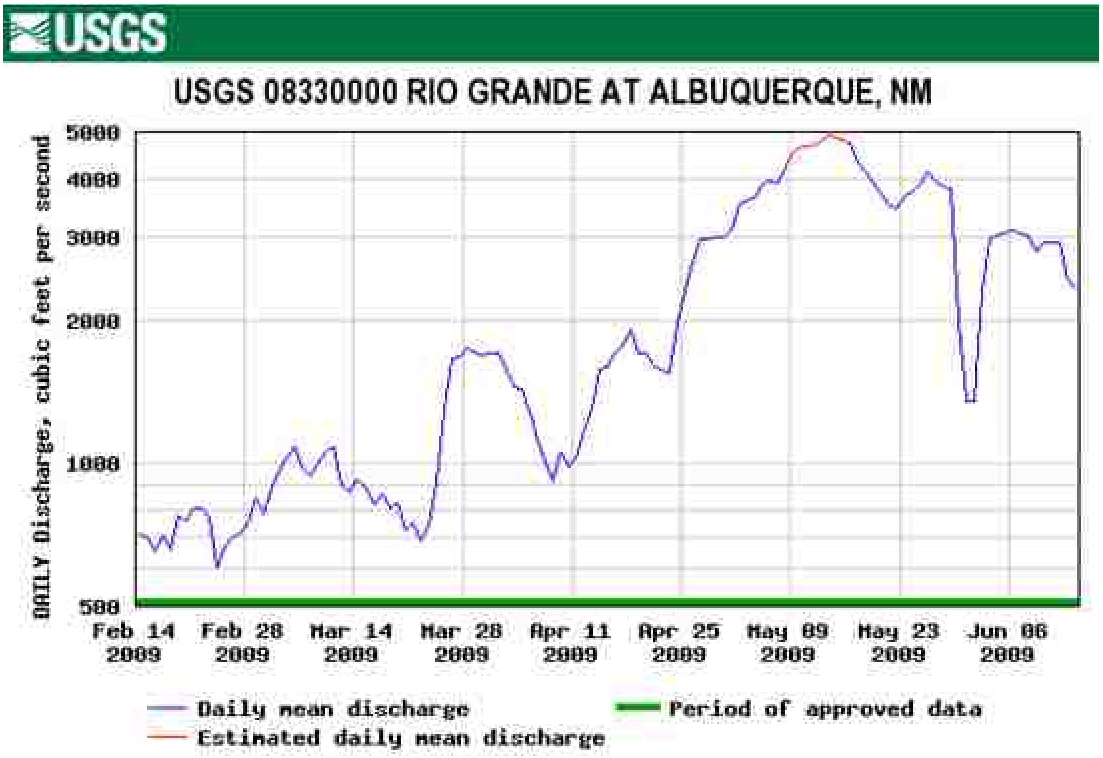


Figure 42 Discharge vs. time graph for Central bridge gage (Adopted from USGS).

Other possibility is that the precipitation may occur at that area and water infiltrates into the soil and makes the ground water level higher. The pond's contribution to the ground water can be explained with this model but cannot say precisely that the pond does not have any influence over ground water table mounding. There are several uncertainties such as soil response, precipitation, pumping effect, calibration, actual channel geometry, and flow pattern of Rio Grande affect the ground moisture and water table which can be the reason of well's high water elevation for 4860 cfs flow.

4.7 Flood frequency

The flood control projects including upstream dams, levees and jetty jacks were installed to control flood as flood is a very common phenomenon in Albuquerque before 1975. These artificial structures altered the sediment regime, hydrograph and high peak flows of the Rio Grande. The Cochiti Dam is one of these flood control projects which starts operating in 1975. The reservoir releases are restricted at approximately 6000 cfs which is the non-damaging capacity of the downstream channel (U.S. Army Corps of Engineers, 1996). This HEC-RAS model shows the minimum flow in the Rio Grande for flowing over near the ponds. Sometimes the bank flows over but water does not reach the levees. This type of flooding is not harmful. HEC-RAS model shows that at 6000 cfs flow at central bridge, the Biopark pond overflows by the river water and for 3200 cfs, the banks overflows. Figure 43 shows the overflowing of pond at 6000 cfs at the Rio Grande.

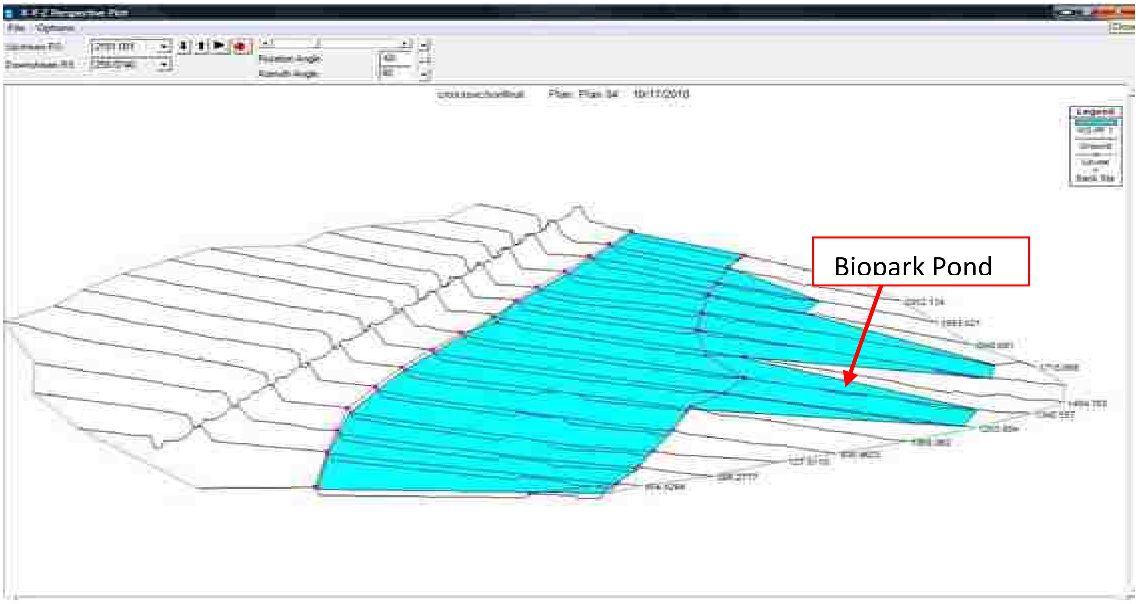


Figure 43 Biopark ponds overflow at 6000 cfs at the Rio Grande.

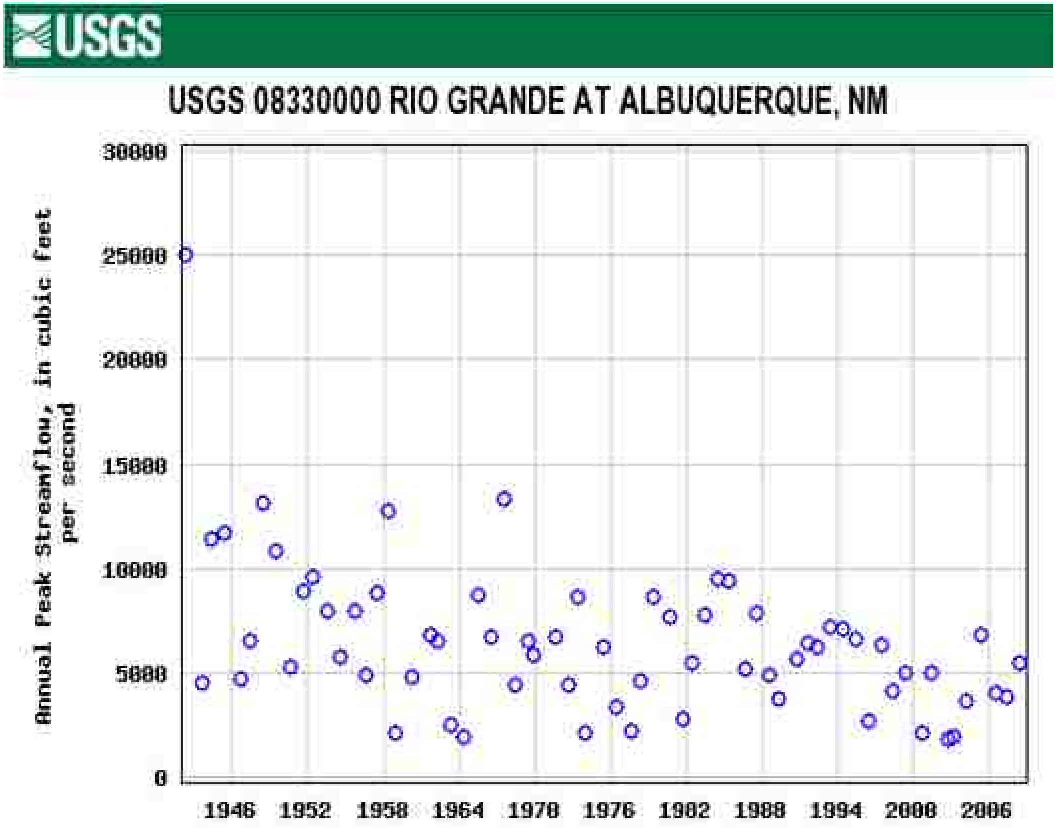


Figure 44 Peak flow at Central gage. (Adapted from USGS)

Figure 44 shows peak flow data for last seventy years of the Rio Grande at Central Bridge gage. This chart shows that 6000 cfs is not an uncommon peak flow for Rio Grande. The bank over flows frequently and flood water reaches the pond but not the levees.

4.8 Conclusion

The ground water-surface water interaction has been analyzed by HEC-RAS software. The results of overbanking discharge can be used for designing river side structures and also for restoration purposes. The ground water table for any discharge of Rio Grande can be predicted with this model. Ground water elevation data are very important to understand and predict the available moisture content of soil and for the restoration of riparian forest. From the HEC-RAS model results it can be assumed by the position of the ground water table and well water elevation that the pond water has not much significant influence over the ground water table mounding. The HYDRUS-2D model is used to support the hypothesis of Biopark pond’s impact over ground water table mounding. HYDRUS-2D model analysis is described at chapter 5.

CHAPTER 5

HYDRUS-2D WATER MOVEMENT MODEL

5.1 Introduction

Sub-surface water flow associated with a wetland can be simulated successfully using available simulation programs for unsaturated flow, here, HYDRUS-2D was used.

5.2 Objective

The objectives of this study were to monitor ground water table levels in response of infiltrating water from a pond, to develop predicted moisture content contour map for the Biopark area and to analyze the impact of the pond on water table mounding. These wetland ponds are often utilized in urban settings to recharge water to the water table. Localized recharge by these relatively small ponds can cause a water table mound below the pond. Mound formation may reduce the thickness of the unsaturated soil available from the ground surface. Therefore, an accurate understanding of water table mound formation is very important.

A pond near the riparian wetland of the Rio Grande, Albuquerque, NM, was instrumented for this study. The two-dimensional variably saturated numerical model HYDRUS-2D has been used for this study (Simunek et al. 1999). A good fit was achieved between modeled and observed data for the timing and magnitude of water table rise for certain duration. Mound height and soil moisture were most sensitive to the layering of the soil and the saturated hydraulic conductivity.

5.3 Model description

5.3.1 Mathematical model

The effect of infiltrative-surface conditions on water flow through soil under a pond is investigated by conducting numerical simulations using the unsaturated flow model HYDRUS-2D (Simunek et al. 1999).

HYDRUS-2D numerically solves the Richards' equation for variably-saturated water flow and convection-dispersion type equations for heat and solute transport. The Richard’s equation considers two-dimensional isothermal Darcian flow of water where the soil is a variably saturated rigid porous medium and assumes that the air phase plays an insignificant role in the liquid flow process.

The governing flow equation is the modified form of the Richards' equation:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x_i}\left[K\left(K_{ij}^{A} * \frac{\partial h}{\partial x_j} + K_{iz}^{A}\right)\right] - S \qquad 5.1$$

Where, θ is the volumetric water content [L^3L^{-3}],

h is the pressure head [L], S is a sink term [T^{-1}],

x_i (i=1,2) are the spatial coordinates [L],

t is time [T],

K_{ij}^{A} is components of a dimensionless anisotropy tensor,

K, and K is the unsaturated hydraulic conductivity function [LT^{-1}]

The unsaturated hydraulic conductivity relationship is:

$K(h, x, z) = K_s(x, z)\, K_r(h, x, z)$;

[Equation form the Van Genuchten (Van Genuchten, M.Th. 1980) function with the Mualem (Mualem, Y. 1976) pore-size distribution model.]

Where, K_r is the relative hydraulic conductivity,

K_s the saturated hydraulic conductivity [LT^{-1}].

The anisotropy tensor K_{ij}^A is used to account for an anisotropic medium.

The diagonal entries of K_{ij}^A equal one and the off-diagonal entries zero for an isotropic medium.

For this simulation model, the Van Geuchen model has been used for unsaturated soil hydraulic properties. In this model Van Genuchten used the statistical pore-size distribution model of Mualem to obtain a predictive equation for the unsaturated hydraulic conductivity function in terms of soil water retention parameters. The expressions of Van Genuchten are given by

$$\theta(h) = \theta_r + \frac{\theta_s - \theta_r}{[1 + |\alpha h|^n]^m}, (h < 0) \qquad 5.2$$

$$= \theta_s, (h \geq 0) \qquad 5.3$$

$$K(h) = K_s S_\alpha^l \,[1 - (1 - S_\alpha^{\frac{1}{m}})^m\,]^2 \qquad 5.4$$

m=1-1/n and n>1

The above equations contain five independent parameters: θ_r, θ_s, α, n, and K_s. The pore-connectivity parameter l in the hydraulic conductivity function was to be about 0.5 as an average for many soils.

The simulations were conducted without modeling hysteresis.

5.3.2 Physical model

The physical system represents an infiltration trench and is shown in Figure 45. A two-dimensional cross section was selected for the system. The dimensions of the cross section in HYDRUS-2D represent with actual cross section of a stream and the land surrounding the stream. The cross section is 4m high and 50m long. The model includes a stream and layering of soil which is similar to the field condition. The width of the stream is 2m in this symmetric model and depth is 0.4m.

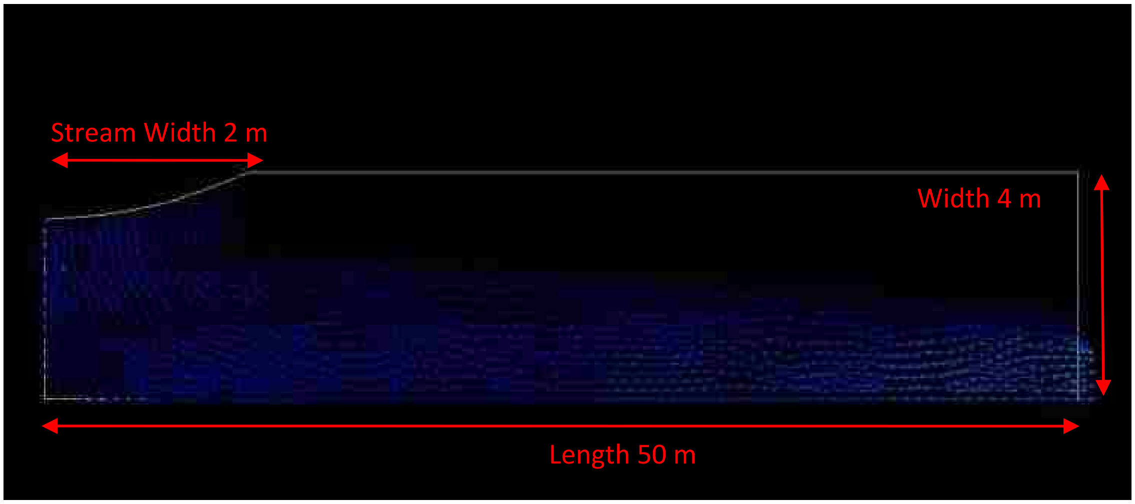


Figure 45 Schematic diagram of physical model.

The HYDRUS-2D model requires soil moisture content, soil water velocity, water pressure head, boundary flux, and seepage head data for each location of the model. HYDRUS-2D can then calculate water content, velocity and water pressure. This calculated data is extremely dependent on soil layering, soil materials and the initial boundary condition. The total water content exiting the model's boundaries can be calculated by this model as well.

Initial condition, boundary conditions, materials, subsurface depth, etc. are required input for HYDRUS-2D. The water is assumed to be continuously ponded at a constant total pressure head above the infiltrative surface of the pond. It is assumed that the lower boundary of the model domain is specified as a zero flux boundary condition. It is assumed that the base and sidewall of the model have constant pressure head up to ground water surface, and there is a seepage face from ground surface to ground water table. The simulations were run until steady-state water flow conditions were reached.

Layer	ϴr	ϴs	A(1/m)	n	Ks(cm/s)	l
Layer 1	0.0448	0.3822	3.64	1.4896	0.5648	0.5
Layer 2	0.0672	0.393	2.4	1.3348	0.1224	0.5
Layer 3	0.0515	0.3769	3.32	2.5032	3.2201	0.5
Layer 4	0.0535	0.3753	3.22	3.3314	7.2269	0.5

Table 6 Soil Parameter.

Table 6 shows the soil hydraulic parameters for the Van Geuchen model. These soil parameters of soil are predicted by HYDRUS-2D as a combination different material for each layer by percentage of clay, silt and sand. The sand percentage and the silt and clay soil percentage for different layers have been estimated using the sieve analysis method for all soil cores. Table 1, 2 and 3 in chapter 3 show the finer soil percentage of six cores from the field. The soil has been divided into four layers and an approximate percentage of fine and course soil have been assigned based on soil core data.

This 4m high and 50m long model is used to determine the evolution of soil moisture content at different distance from the stream. The stream is developed by the water from the pond which creates the wetland and the marsh. The stream is assumed to be 4m wide. Figure 46 shows the initial boundary condition.

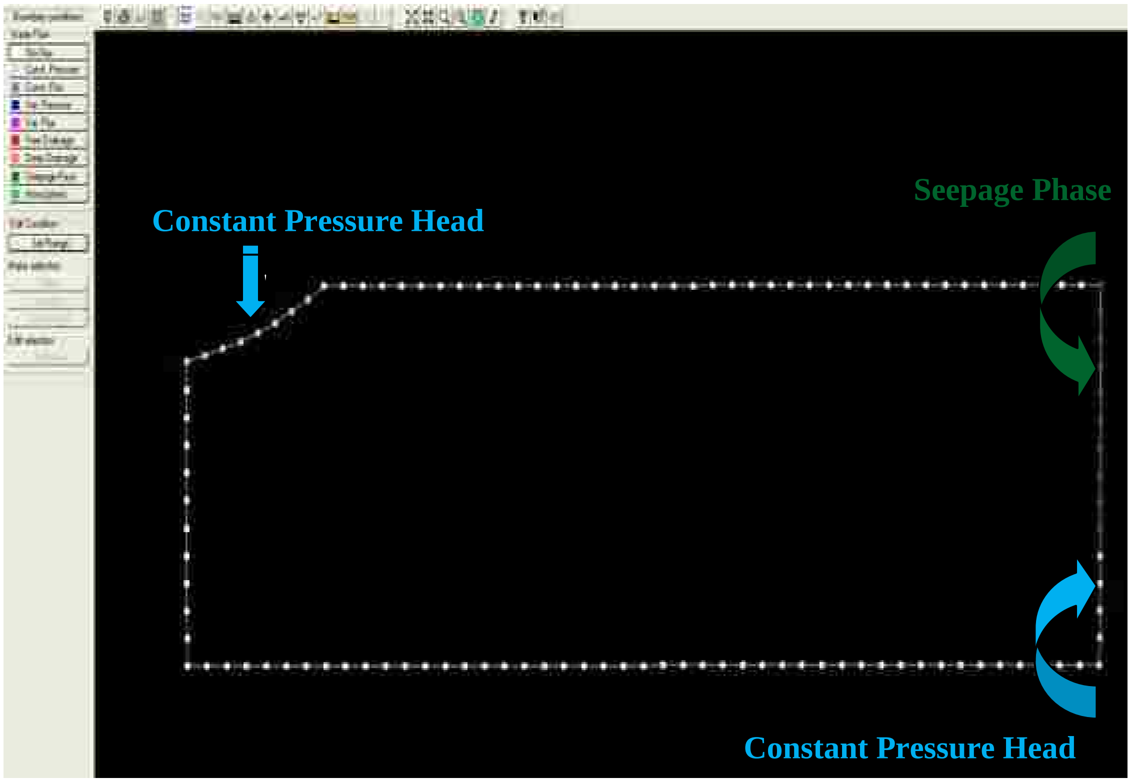


Figure 46 Boundary conditions.

The 2D mesh of the model used for the simulations consists of 3397 nodes and 2225 elements. Four types of soil have been used based on the data from the soil cores (Chapter 3, table 1, 2 and 3). The model is for a single set of four differing soil layers. The top layer has 50% sand and 50% clay and silt, second layer has 70% sand and the rest is silt and clay, third layer has 80% sand, 20% clay and silt. The last layer has 95% sand and 5% is clay and silt. Figure 47 shows the material distribution.

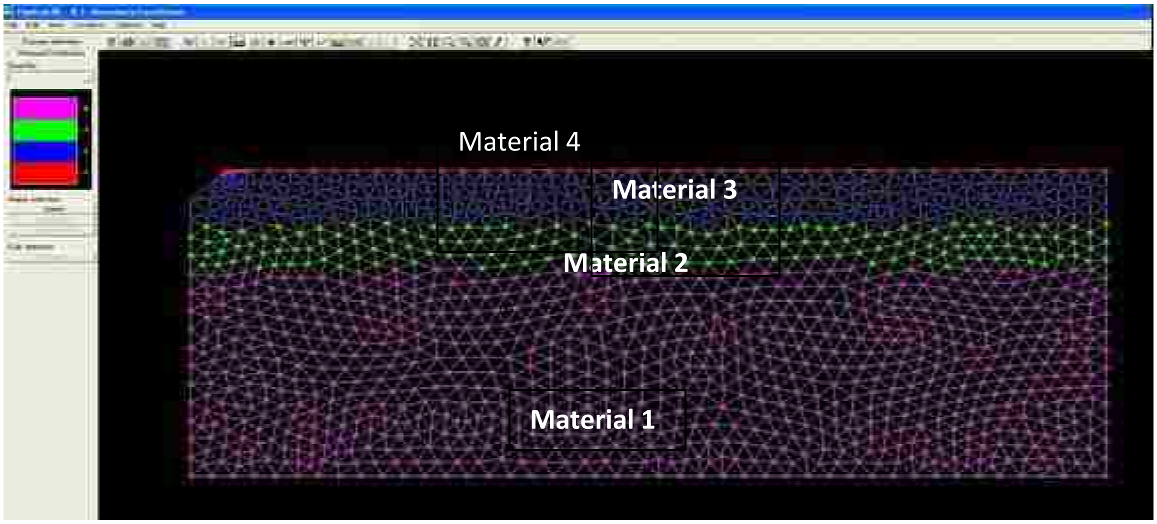


Figure 47 Material distribution.

The initial condition of this model, the top pressure head, h = –1.5 m and bottom pressure head, h=+2.5 m, are distributed linearly with depth. This condition is intended to simulate a water table 1.5 m below the ground surface. This pressure distribution is consistent with depth below the ground surface. The simulation period is 150 days. Figure 48 shows the initial pressure distribution.

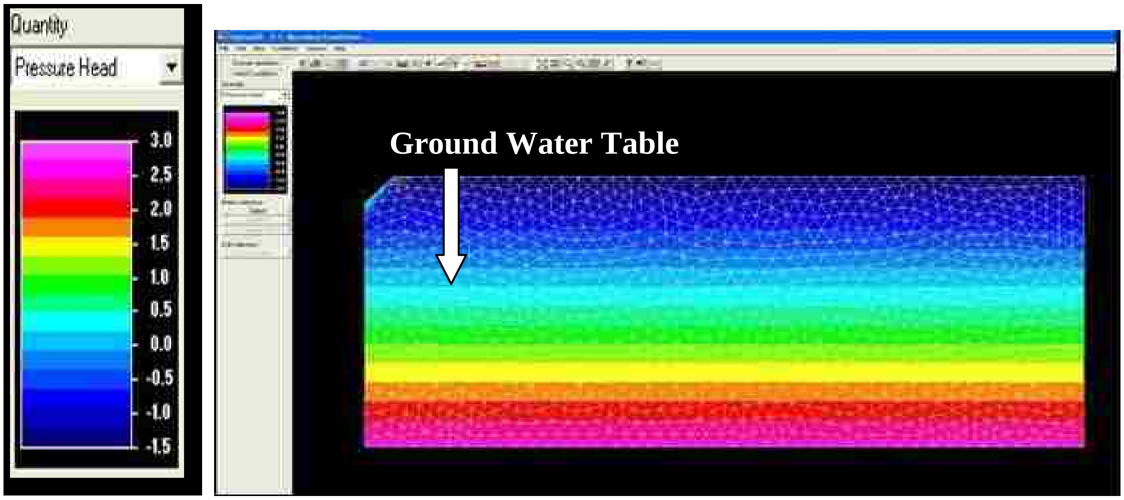


Figure 48 Initial pressure distribution.

5.4 RESULTS

Water content results are shown in Figure 49 after 150 days of simulation. At this time, the simulation had reached steady state. The maximum water content corresponding to saturated conditions is below the stream and below the ground water table. The ground surface is not wet beside the pond.

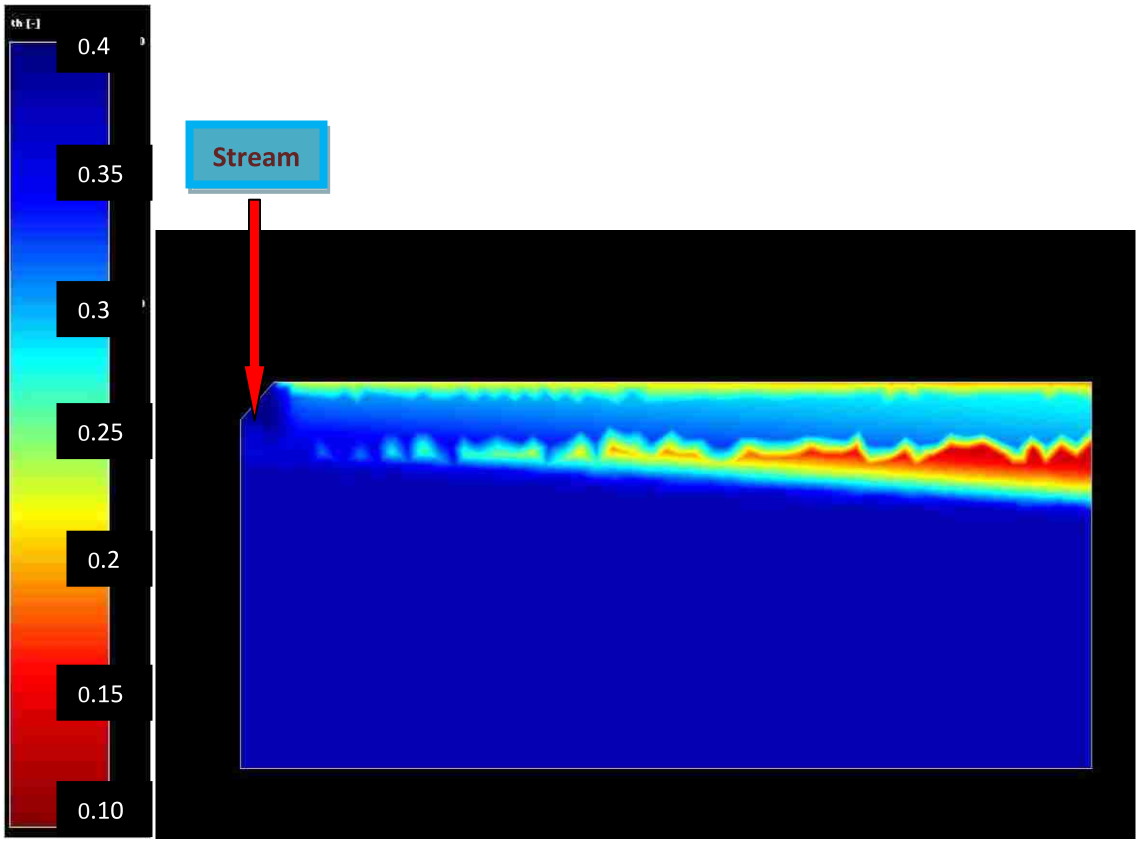


Figure 49 Water content at day 150.

Figure 50: Water velocities at day 150.

The water velocity is very high just below the pond and it becomes low when the water moves laterally after the simulation starts. The velocity range is 10 to 60 cm per day up to day 10. At day 150, velocities decrease and become 0 to 20 cm per day. At day 150 the model reached steady state and the water velocity became stable. Water velocities are shown in Figure 50 after 150 days.

The water velocity at boundary from the Mass Balance Information from the model shows that is very high at day 0.5 m/day and decreases with time. The velocity becomes very low at day 150 when the model reaches steady state condition.

5.5 Result analysis

Three cross sections at 1m, 9m and 46m distance from the stream and up to 2m depth have been selected to illustrate moisture content, pressure head and water velocity. Figure

51, Figure 52, and Figure 53 show the volumetric water content, pressure head and water velocity for three cross sections from the model.

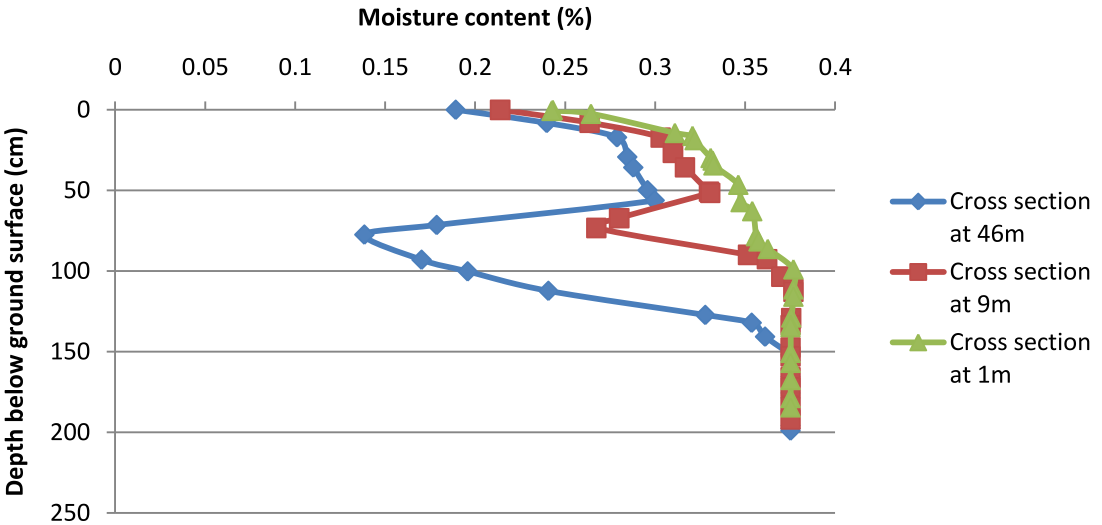


Figure 51 Soil moisture content vs. depth below ground surface for 1m, 9m and 46m lateral distance from the stream.

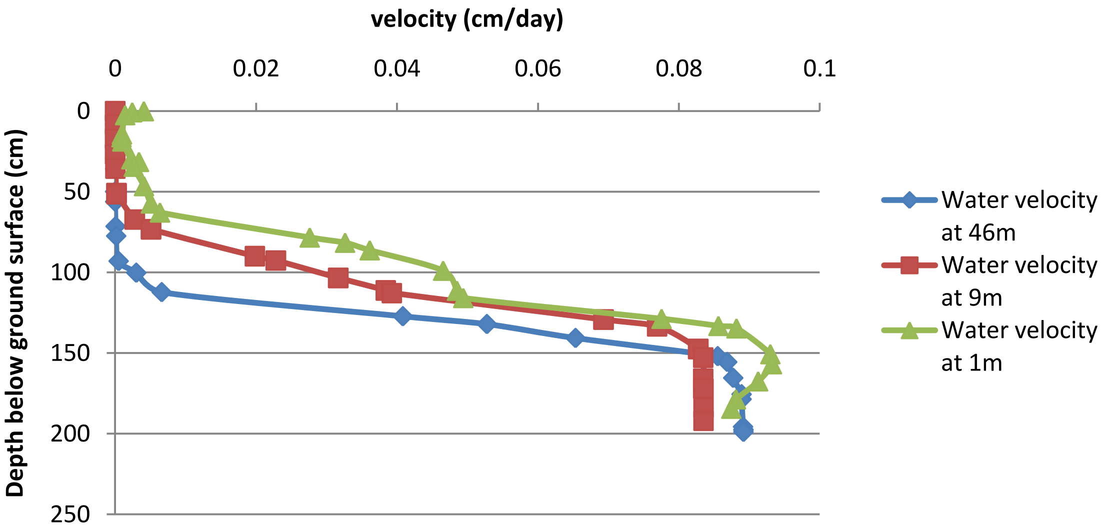


Figure 52 Water velocity vs. depth for 1m, 9m and 46m lateral distance from the stream.

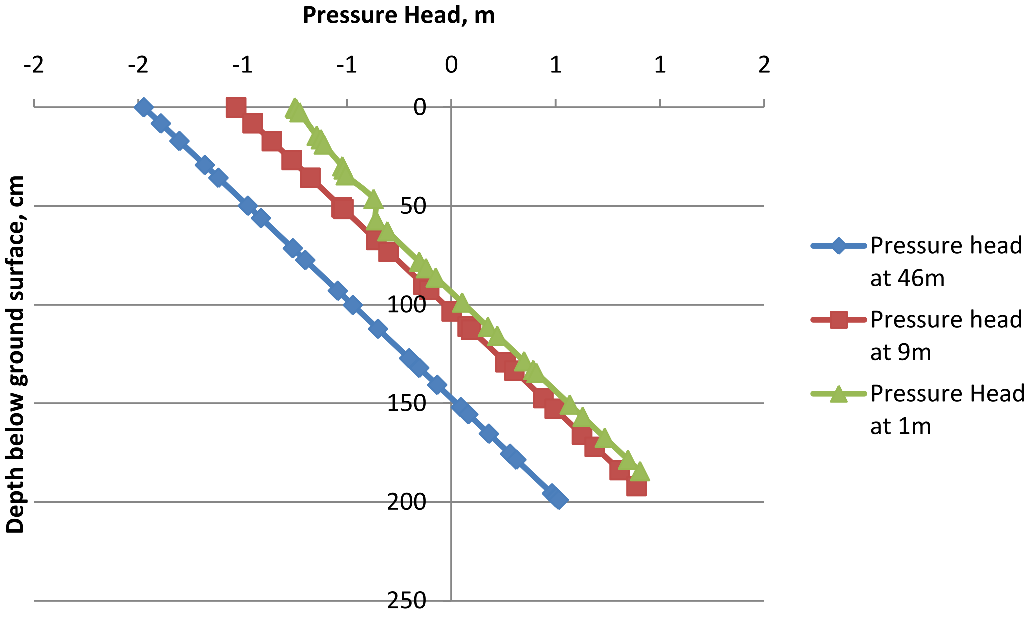


Figure 53 Pressure head vs. depth below ground surface of 1m, 9m and 46m lateral distance from stream.

Soil moisture is dependent on distance to the ground water table, location of water source (ponds, streams, rivers,) soil materials, and soil layers. There are different soil layers around and beneath the stream of HYDRUS-2D model that cause the shape of soil moisture plot. Figure 51 shows that in the cross section closest to the stream, soil moisture is linear with depth and relatively wet. The impact of soil layering can be clearly seen on the Figure 51. The moisture content for the 9m and the 46 m cross sections indicate regions of lower moisture content at 10cm to 60cm and from 60 cm to 100 cm. This is because of different soil properties in layers at those depths.

In Figure 52 shows the velocity of water with depth. The HYDRUS-2D model shows that the water movement velocity is highest close to the ground water table. At ground surface the velocity is nearer to zero. The pressure head is linear with depth of soil as shown in Figure 53 as the system seems to be in equilibrium. The results indicate that the majority of water flow direction is vertical through the base of the pond and horizontal at ground water and the steady-state flux-averaged velocity is about 0 to 10 cm/day.

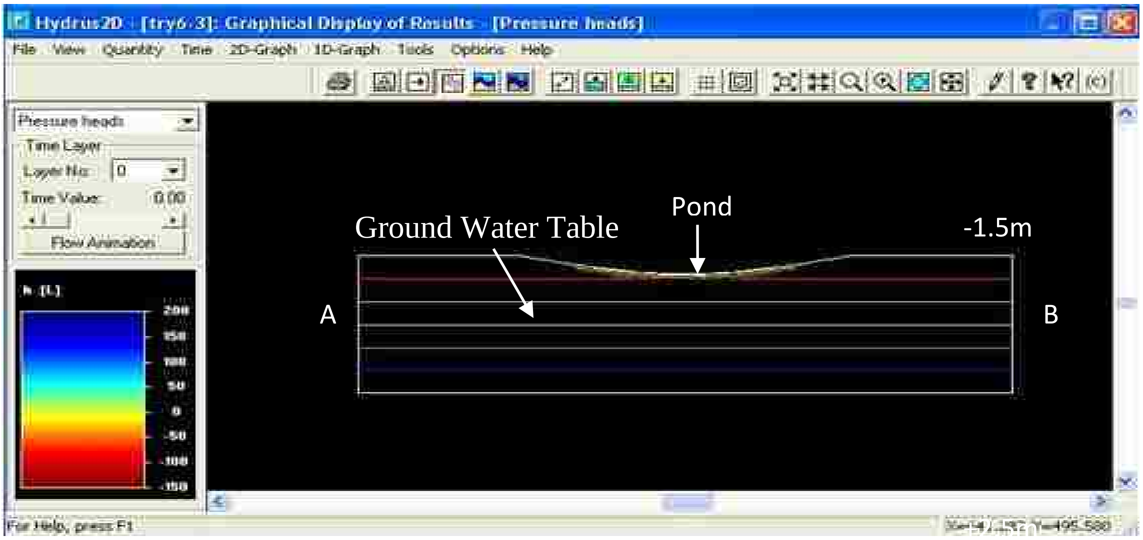
5.6 Pond water impact over ground water table fluctuation

The HYDRUS-2D numerical model can be used to simulate the impact of the Biopark pond. The Biopark ponds are fed by water from nearby wells. Those ponds are continuously recharging the ground water table, creating wetlands and recharging the soil moisture. It is assumed that the pond’s water makes the ground water table higher. This model shows how the ground water table changes with time and the contribution of the pond.

This 4m high and 150m long new model is used to determine the evolution of the impact of pond water. The Biopark ponds continuously contribute the ground water and eventually the water from the pond overflows, creating a stream, wetlands and marsh. The pond is assumed to be 50 m wide.

The initial conditions, boundary condition and geometrics are the same as for the model described previously.

The pressure head diagram of this model shows that before simulation starts, the pressure head at ground surface is -1.5m and at bottom the pressure head is +2.5m. At day 25 the pressure head changes and the zero pressure head line mounds a little. The pressure head at 0 day and 25 day is shown in Figure 54 and Figure 55. The simulation period was chosen 25 days for this model as it achieved steady state at 25th day, and the stretching factor is 0.4 in Y direction.


Hydrus2D - [try6-3]: Graphical Display of Results - [Pressure heads]

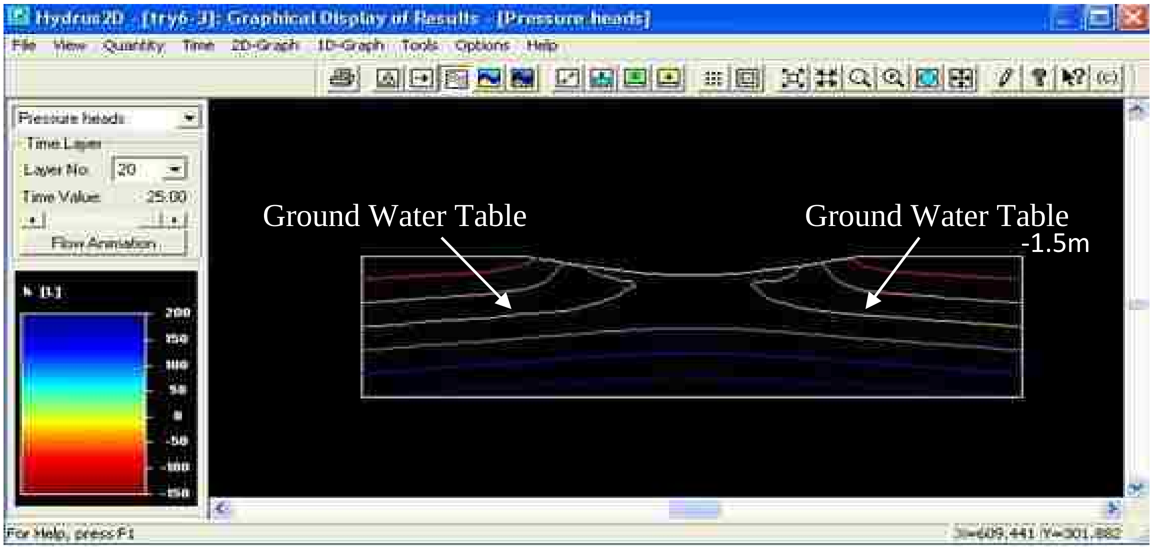
Pressure heads

Time Layer

Layer No: 0

Time Value: 0.00

Figure 54 Pressure head at day 0. (AB line is the water table)


Hydrus2D - [try6-3]: Graphical Display of Results - [Pressure heads]

Pressure heads

Time Layer

Layer No: 20

Time Value: 25.00

Figure 55 Pressure head after 25 days.

The pressure head diagram shows that the ground water table is horizontal when simulation starts and after 25 days it has tilted to a very small angle at the edge of the model. The pond has only a local impact over ground water table elevation, and does not elevate the ground water table in the surrounding area beyond about 20m from the pond.

5.7 HYDRUS-2D model simulation

Output from HYDRUS-2D was compared with field data to find the accuracy of the model. Simulations were conducted with a stream and without a stream and with different ground water table elevations. The moisture content graph developed from these simulations supports the pond’s impact over ground water table analysis. A new HYDRUS-2D model with several sets of soil layer at different locations similar to field conditions, are used for this purpose. The layer combinations are similar to the core layers at 1m, 10m, 20m, and 48m distance from the stream. The layering of different cores are showed in Chapter 3, Table 1, 2 and 3.The previous model has four layer of soil and the soil composition for each layer is same throughout the whole layer. This new model has multiple layering and it is referred as a complex model. Figure 56 shows the layering of soil.

Material 1 soil has 50% sand and 50% clay and silt, material 2 has 70% sand and the rests is silt and clay, material 3 has 80% sand, 20% clay and, silt. Material 4 has 95% sand and 5% is clay and silt. Figure 56 shows the material distribution and table 7 shows the arrangement of the materials.

Material-1	50% sand and 50% clay and silt
Material-2	70% sand and 30% clay and silt
Material-3	80% sand and 20% clay and silt
Material-4	95% sand and 5% clay and silt

Table 7 Material distribution of HYDRUS-2D model.

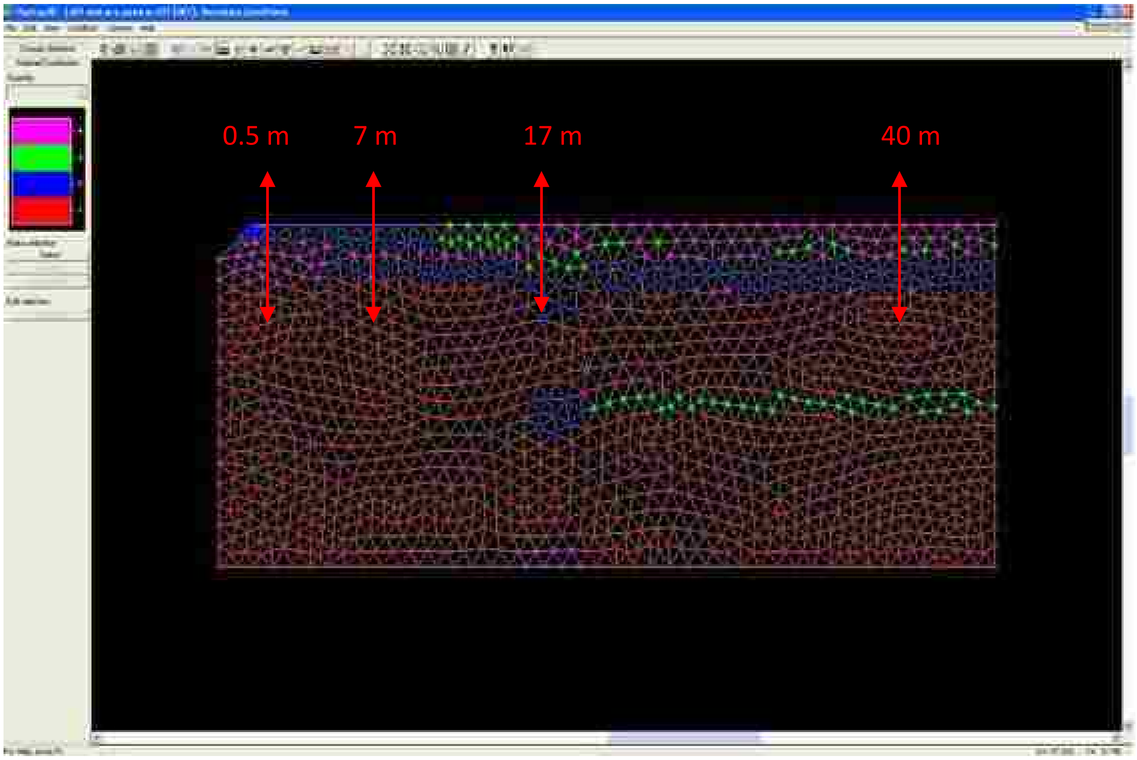


Figure 56 Soil material distribution at different layers. Colors indicate soil composition given in Table 7.

5.7.1 Validation of complex model

The complex model of Figure 56 has been compared to simple model that has a uniform soil type. The complex model has different layers at different distance from the pond. Four different sets of soil types were used, which correspond to the type of soil found in the field investigations. The initial conditions, boundary condition and geometrics are the same as for the complex model. These models are run to steady state condition. Cross sections are taken from both simple model and complex model at 0.5m, 7m, 17m, and 40m laterally from the stream. The locations of the cross sections are showed in Figure 56.

Figure 57 represents the layering of 1 m core at 0.5m from the stream. Figure 58 represents 10m core soil layering, Figure 59 represents 20m core soil layering, and Figure 60 presents 48m core soil layering.

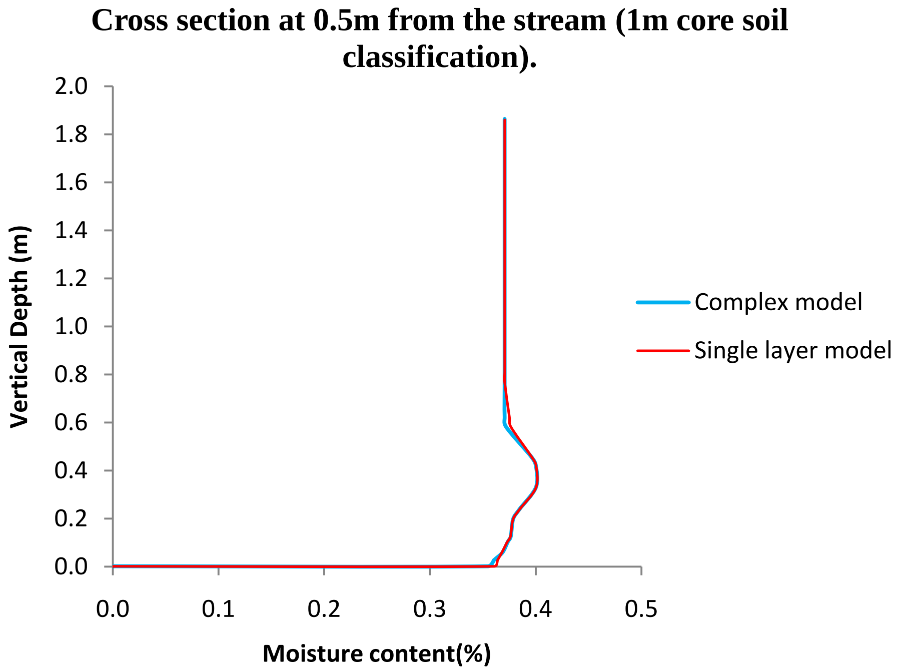


Figure 57 Moisture content vs. vertical depth graph for cross section at 0.5m from the stream.

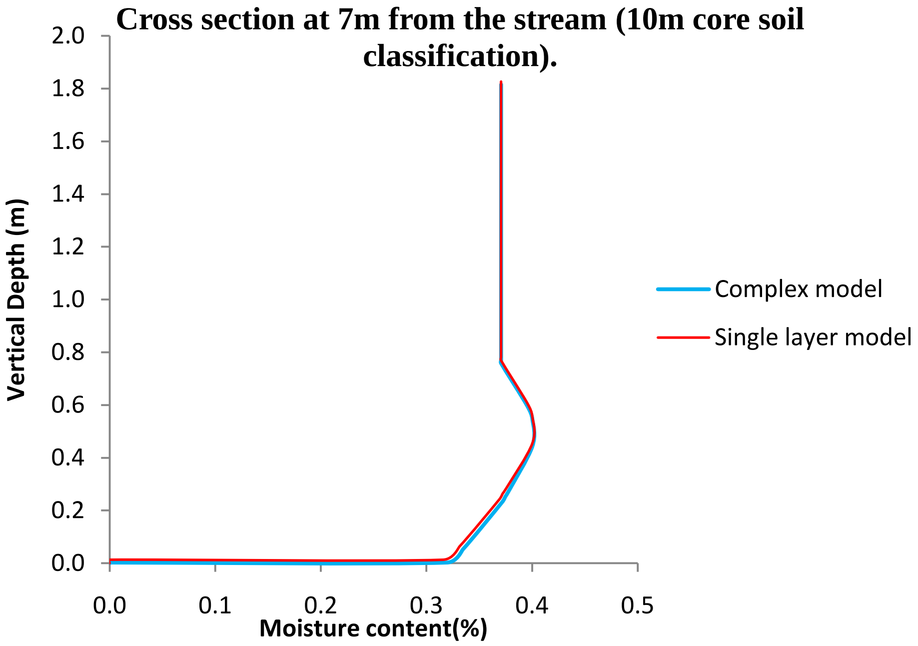


Figure 58 Moisture content vs. vertical depth graph for cross section at 7m from the stream.

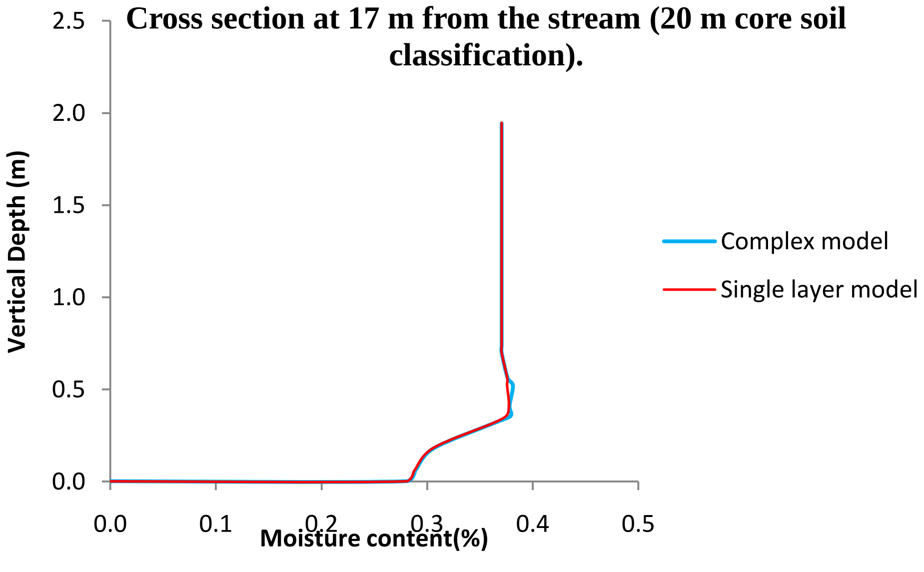


Figure 59 Moisture content vs. vertical depth graph for cross section at 17m from the stream.

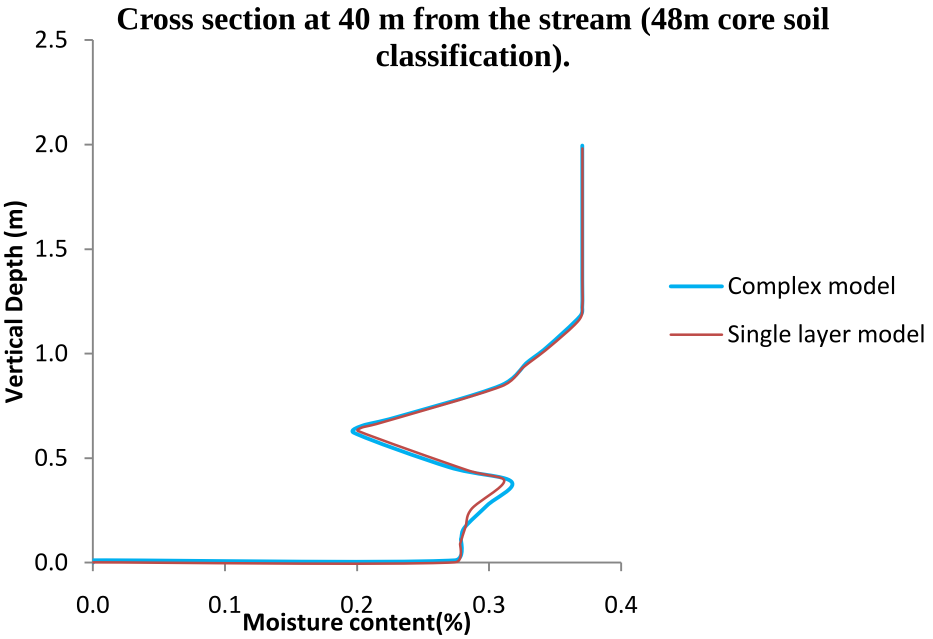


Figure 60 Moisture content vs. vertical depth graph for cross section at 48m from the stream.

Figure 57, 58, 59 and 60 show the graph of moisture content with vertical depth for cross sections at a distance of 0.5m, 7m, 17m and 48m. These graphs show the comparison of outputs of a complex model and a model with single set of soil properties. The single soil model and complex model both yield almost the same moisture content. Hence, a single similar of the complex model can be used to provide reasonable estimates at locations where core were taken and different stratigraphy was encountered.

5.7.2 Simulation with stream

Initially the complex model was used to simulate conditions with stream and pond. The stream is developed with the pond in existence and the pond feeds the streams. The

Biopark stream is about four meters in width and the depth is almost sixty centimeters. The water head in the stream was assigned forty centimeters.

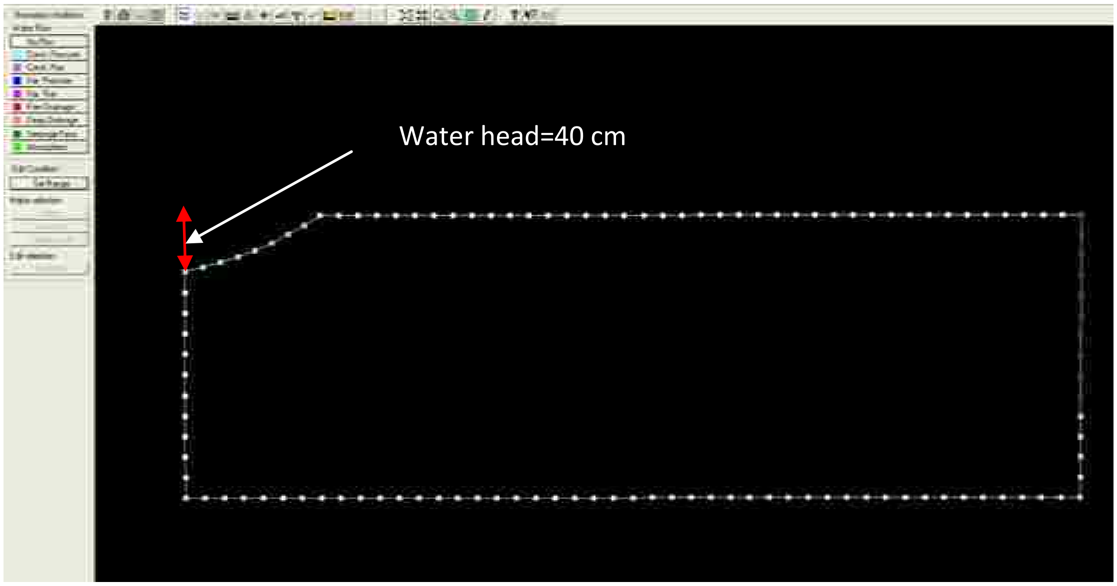


Figure 61 HUDRUS-2D model with stream condition.

Figure 61 shows the 4 m high and 50 m long HYDRUS-2D model. For the initial condition, the seepage face was assigned above the water table and the constant head below the water table. The pressure head was assigned such that the ground surface has -1.5 m pressure head and the bottom of the cross section has +2.5 m pressure head boundary condition at the stream bottom to represent a ground water table 1.5 m below the ground surface. The water pressure head for the stream is 0.4 m, representing 0.4m of water in the stream.

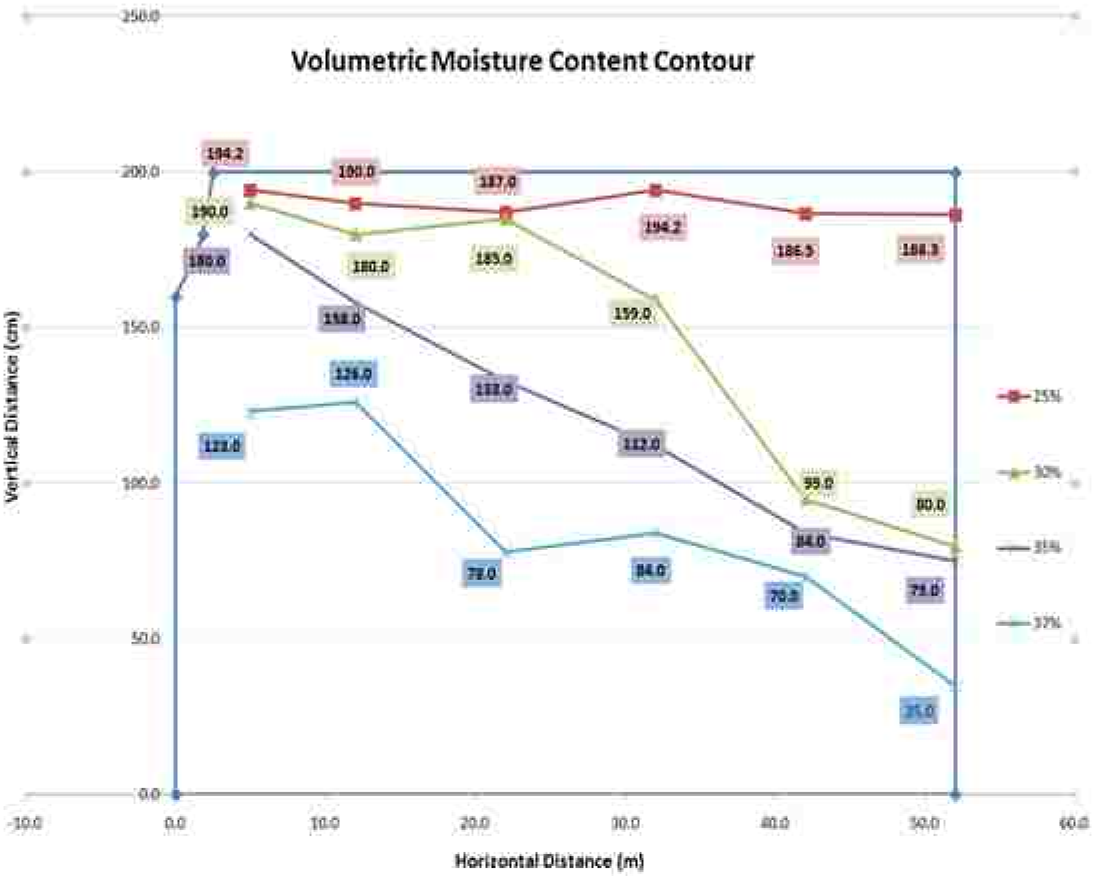


Figure 62 Soil moisture contour for the cross section with stream flow.

Figure 62 shows 25%, 30%, 35% and 37% soil moisture contour lines. The contour lines at high elevation are close to the pond and inclined to the ground water table with distance. The soil moisture is decreasing with distance from the stream and with vertical depth. The model shows saturation of the soil occurs at 37% to 38% volumetric water content, so the water table surface is estimated from the 37% volumetric water content contour.

5.7.3 Simulation without stream

The model was used to simulate conditions with no stream and pond. The water head in the stream was assigned zero centimeters. For this case the water table is 1.5 m below the ground surface.

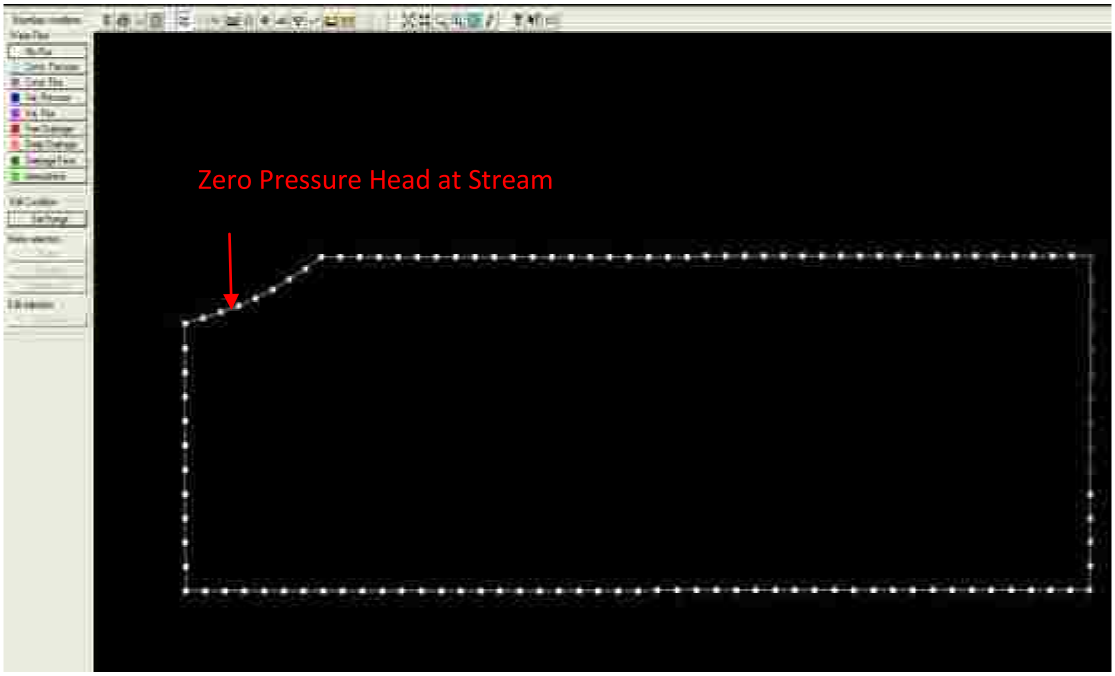


Figure 63 HUDRUS-2D model without stream.

Figure 63 shows the 4 m high and 50 m long HYDRUS-2D model. For the initial condition the seepage face was assigned above the water table and constant head was assigned below the water table. The pressure head was assigned such that the ground surface has -1.5 m pressure head and the bottom of the cross section has +2.5 m pressure head. The water pressure head for the stream is 0 m as there is no water in the stream.

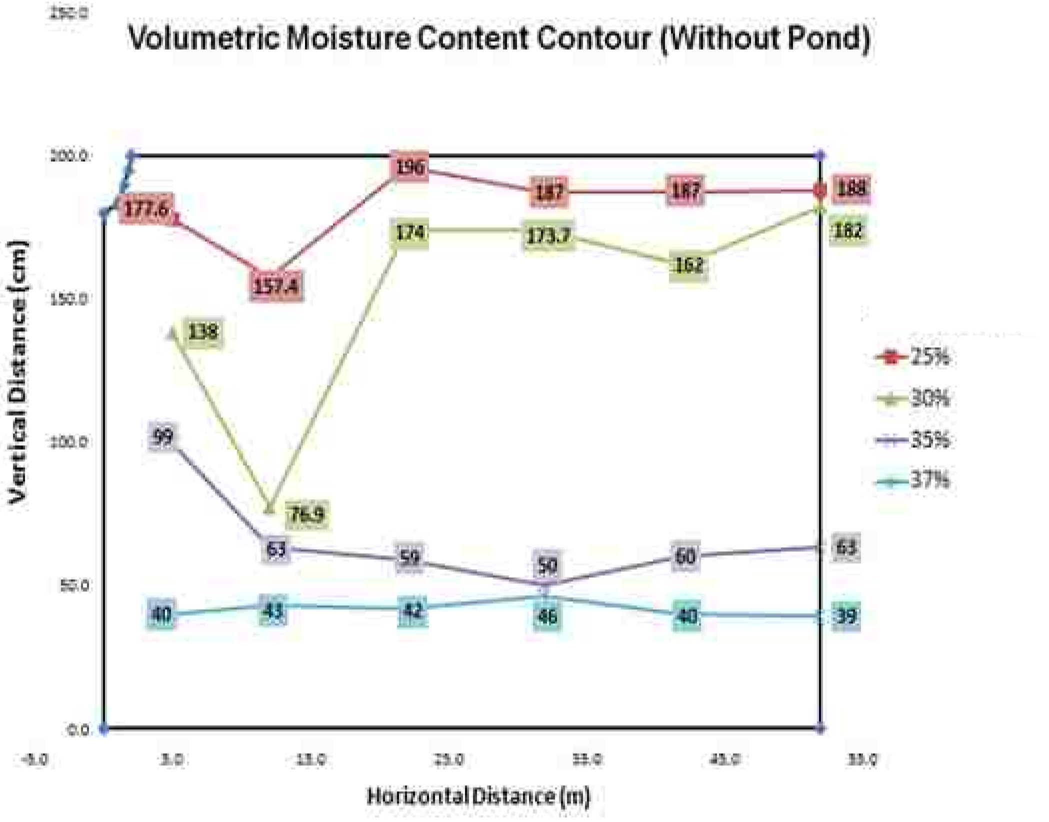


Figure 64 Soil moisture contour for the cross section with stream flow.

The 25%, 30%, 35% and 37% soil moisture contour lines are shown in Figure 64. The contour lines are generally horizontal with the ground surface with some changes of deflection at 25% and 30% moisture content as the soil layering is different at that location. Each soil layer has its own moisture characteristic curve, so the layering will affect the predicted water content. The soil is almost uniform below the ground water table, and consequently the contour of 35% and 37% moisture content lines are horizontal. Contrasting Figure 62 and Figure 64 reveal the influence of the stream on the local water table and moisture content values.

5.7.4 Simulation with different ground water table

5.7.4.1 High flow

The model was used to simulate conditions for the high flow condition of the river. For high flow the ground water table is 0.6 m below the ground surface. The water head in the stream was assigned 40 centimeters. The layering of soil is similar to the field layering of soil cores (Figure 56).

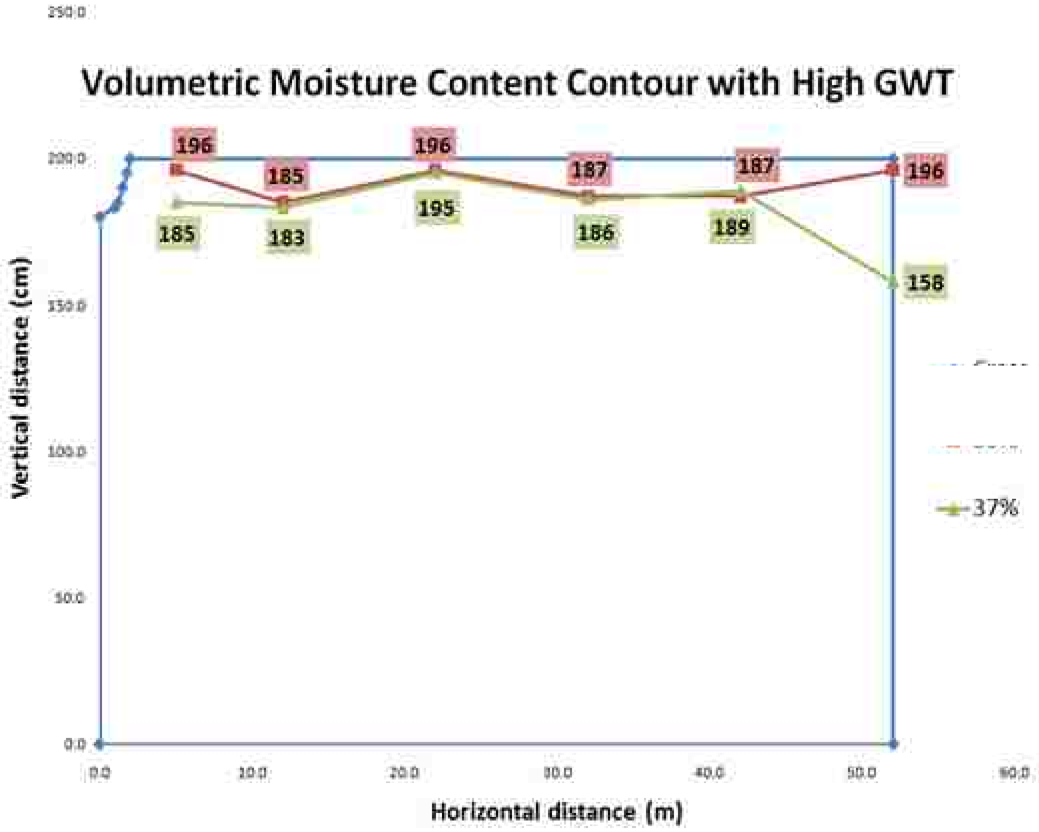


Figure 65 Soil moisture for high ground water table condition.

Figure 65 shows the soil moisture contour for high ground water table condition. Compared to Figure 62 (lower water table condition), the soil moisture is very high here. The soil is almost saturated, that's why the moisture contour lines are close to the surface.

3.7.4.2 Low flow

The low water table model was used to simulate with two conditions (with stream and without stream). In the low water table model, the river has the least flow and the water table was found at 2 m depth from the surface. In the first case, the model was run with a stream and the water pressure at the stream was 0.4 m. In the second case, the model has no stream and the water pressure at the stream is zero. The initial pressure head was assigned to the top surface of the model as -2m pressure head and the bottom surface as +2m pressure head, the pressure head varied linearly with depth.

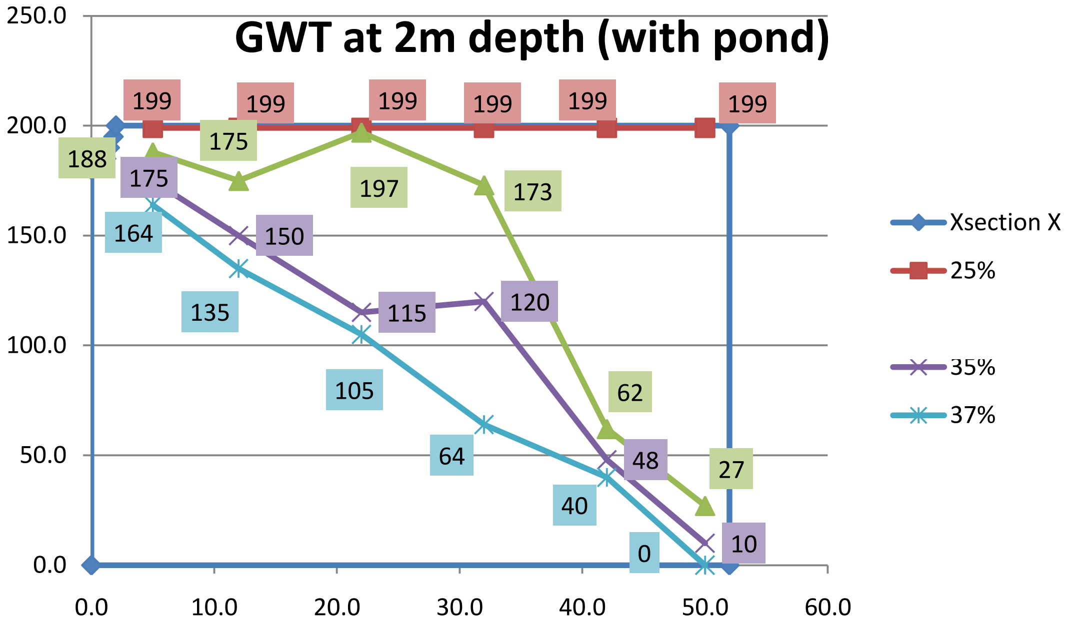


Figure 66 Soil moisture for low ground water table condition (with pond).

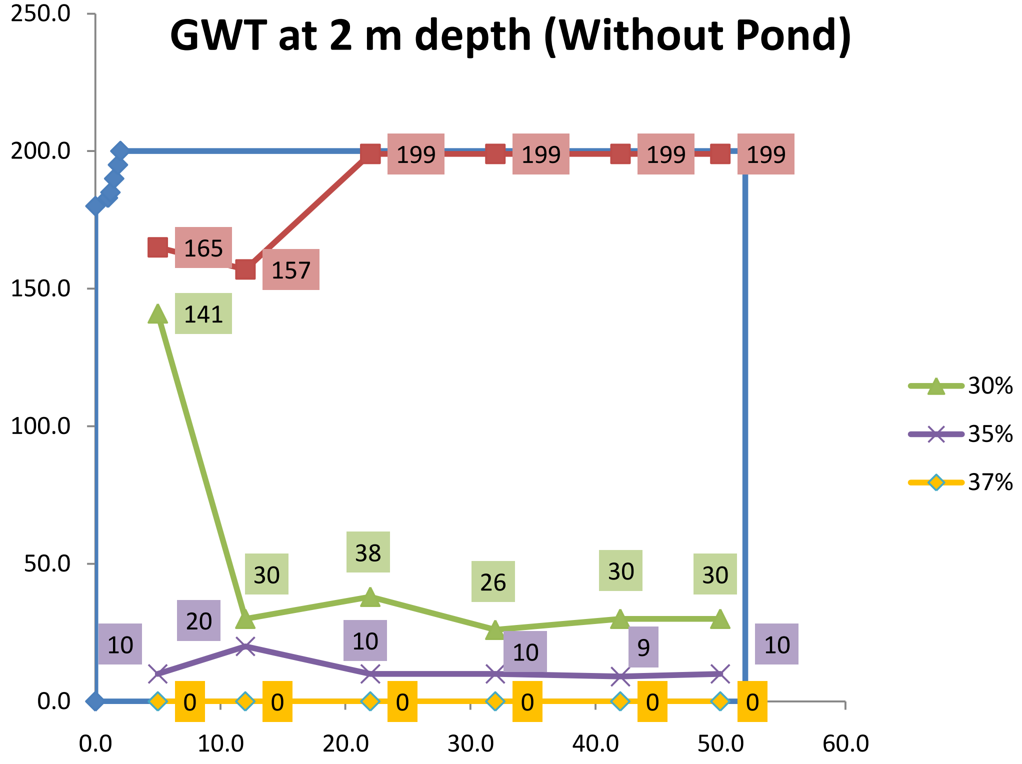


Figure 67 Soil moisture for low ground water table condition (without pond).

Figure 66 and Figure 67 show the soil moisture contours of 25%, 30%, 35% and 37%. For low GWT and without pond condition, the surface is relatively dry at the top and 30% water content was found at least 3m below the ground surface.

With the ponded condition, the soil water decreased with distance from the pond (Figure 66). The water is available in the upper portion and lower portion of the model as well. This indicates that the pond has influence over the soil moisture. The shape of the moisture contour also indicates the mound of water table is linear. Therefore it can be explained that the pond has an impact over the ground water table mounding.

CHAPTER 6

COMPARISON OF MODEL DATA WITH FIELD DATA

6.1 Introduction

Soil moisture is the water that is held in the spaces between soil particles. Soil moisture is of fundamental importance to hydrological, biological and biogeochemical processes. Soil moisture content information is needed for studies across a variety of disciplines, such as hydrology, soil science, meterology, ecology, agronomy, etc. This study compares the change of soil moisture content by field analysis and numerical model analysis.

Water content, pressure head and velocity data have been obtained by numerical simulation using the HYDRUS-2D program. Various configurations were considered as described in the previous chapter.

Field data are obtained from field sampling and subsequent lab measurements. Soil cores have been collected, analyses of soil moisture content and finer soil percentage have been performed in the lab for different numerous materials.

The aim of this study is to compare the water contents from predicted from numerical model simulation with field data. In addition contours of soil moisture in the vicinity of the Biopark wetlands are given.

6.2 Comparison of model data with field data

The south pond creates the wetland by draining into a cattail marsh and creating a small stream. The wetland is being maintained in part via gravity flow from the pond to the wetlands. The area of the wetland changes with season. The soil core data from the wetland have been selected for the HYDRUS-2D model validation analysis. The field data and model data have been compared to show the results and compared with some photos from the wetland to support this analysis.

6.3 Soil core

Six soil cores have been collected from six different locations in the wetland. Among them, three cores have been selected for the purpose of comparison. The three soil cores are at 1m, 9m and 46m distance from the ponds. The cores have been dug to ground water level depth. The moisture content for each level and location has been found from lab analysis. Soil moisture content measurement tests are used to determine moisture content. Table 8, 9, and 10 show the soil moisture with depth for three field locations, and these results are plotted vs. distance above water table.

	Depth(cm)	moisture content%
Soil core at 9m distance	0-10	34.9
	10-22	18.03
	22-35	29.56
	35-49	20.24
	49-66	13.91
	66-77	25.97
	77-93	27.25

Table 8 Soil moisture content at different depth of core at 9m.

	Depth(cm)	moisture content%
Soil core at 46m distance	0-14	25.56
	14-31	7.95
	31-43	9.29
	43-57	9.04
	57-73	8.69
	73-87	10.39
	87-98	21.66
	98-110	26.83

Table 9 Soil moisture content at different depth of core at 46 m.

	Depth(cm)	moisture content%
Soil core at 1 m distance	0-14	36.84
	14-29	25.77
	29-43	31.75
	43-57	18.38
	57-70	10.36
	70-81	8.39
	81-97	13.07
	97-108	21.70
	108-118	22.78

Table 10 Soil moisture content at different depth of core at 1 m.

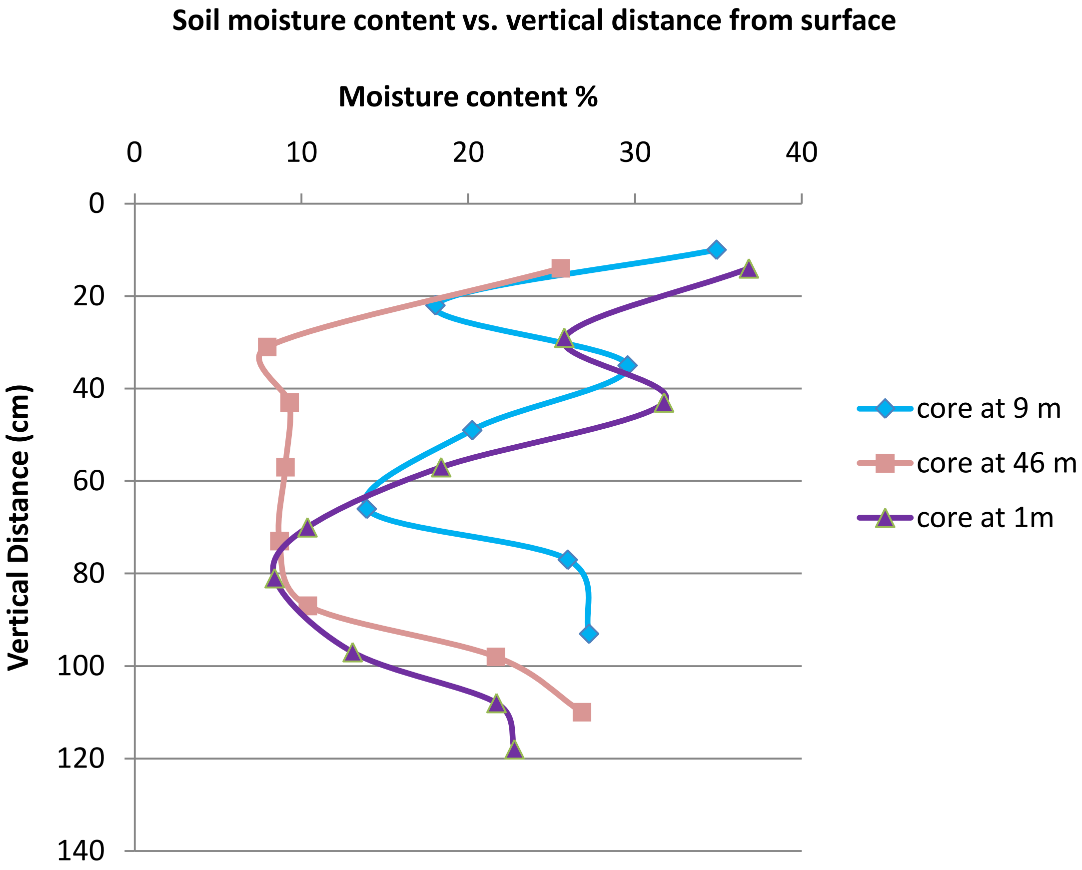


Figure 68 Soil moisture content vs. vertical distance from ground surface for three soil cores.

The results in Figure 68 indicate the moisture content is different in each core, and suggests that soil layering may be responsible for some of the variations. The layering of soil is described in Table 1, 2 and 3 in chapter 3 shows that the finer soil percentage is high near the ground surface. The moisture content curve is different for every soil core. High finer soil content may be the reason of high moisture content. Water from wetland and ponds can be the source of moisture at surface. The moisture content increases again close to the ground water table as expected.

6.4 Comparison of field data with model data

The HYDRUS-2D cross sections have been selected to determine water content in the water movement model. The cross sections are of the same lateral distance from the pond or stream as the cores in the field.

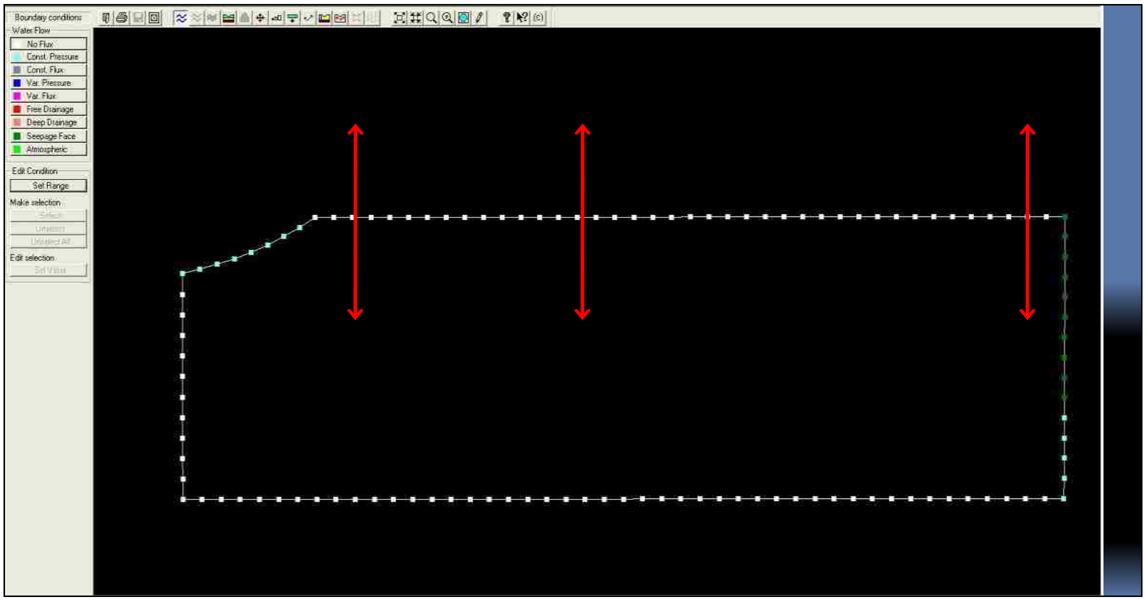


Figure 69 Cross section at 1m 9m and 46 m.

In Figure 69, the cross sections of the HYDRUS-2D model are shown. Three HYDRUS-2D models have been developed with three sets of soil layering similar (table 1, 2 and 3 in Chapter 3) to the field data.

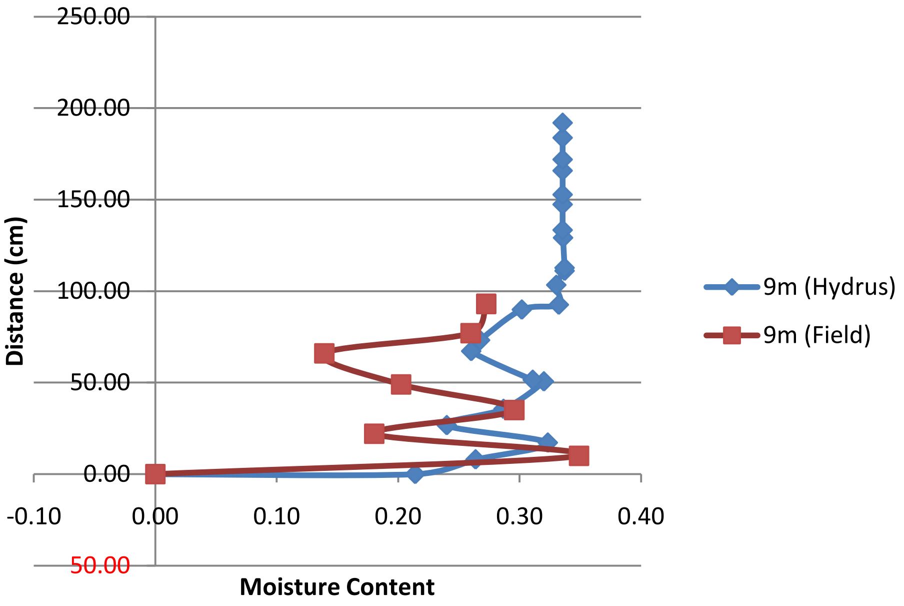


Figure 70 Moisture content vs. distance plot for soil core at 9m.

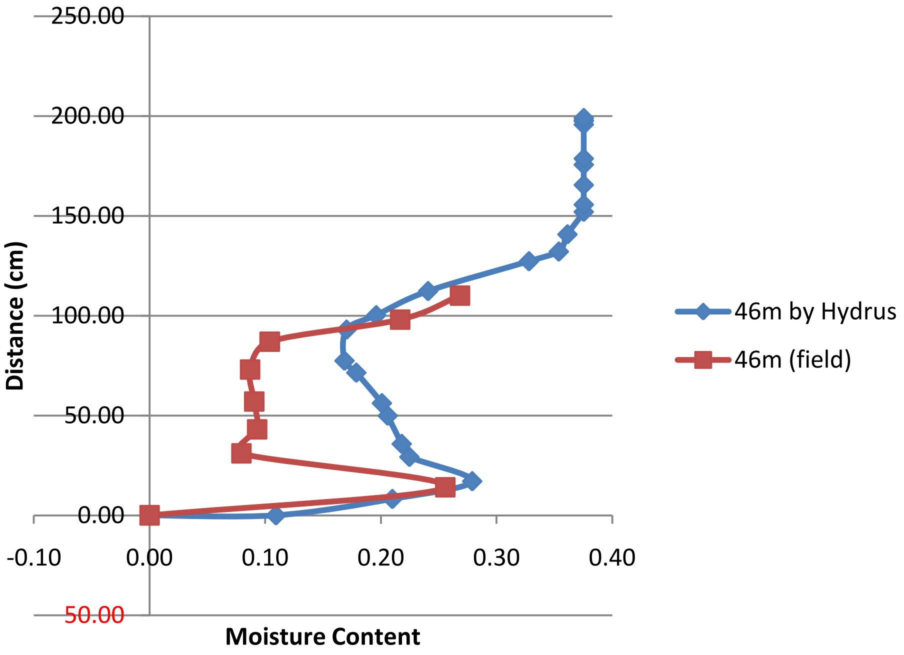


Figure 71 Moisture content vs. distance plot for soil core at 46 m.

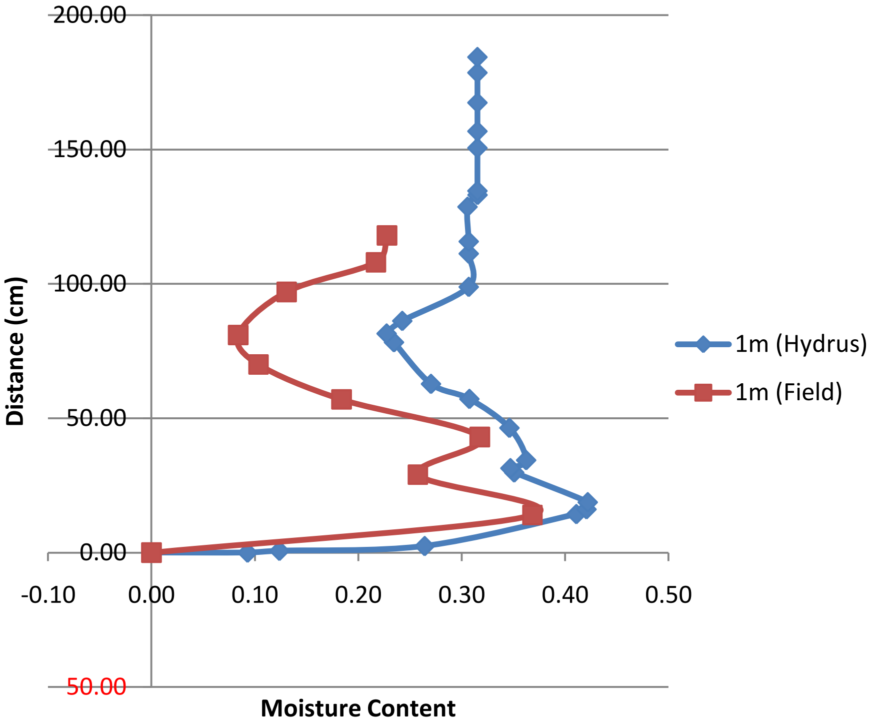


Figure 72 Moisture content vs. distance plot for soil core at 1 m.

Figure 70, 71 and 72 shows moisture content at three lateral distances from the HYDRUS-2D simulations and field data. Those plots yield a reasonable match to the field data and numerical data.

6.5 Discussion

Soil layering may be a principle cause of differences between the field data and the model results. The HYDRUS-2D water movement model includes different soil layers above the ground water table. However, the field data reveals a very complicated soil profile: soil layering is different at every location where core was obtained.

Evaporation, evapotranspiration, precipitation, humidity of air, etc are not considered in the numerical model and could also significantly affect the estimated water contents. The soil properties used in the numerical simulations are another source of potential error. The HYDRUS-2D model predicts the hydraulic conductivity based on the percentage of sand, clay and silt input data. However, differing sands and clays have differing hydraulic conductivities. Yet another possible difference between the field results and those from the numerical model is that the field soil water content are influenced by the water of pond, water from the wetland stream, water from the river and precipitation. The water movement model only considers water from the stream. River water, pond water, climate conditions, draw down of water by pumping etc. have not been considered in the model.

6.6 Comparison of contour map with field observation

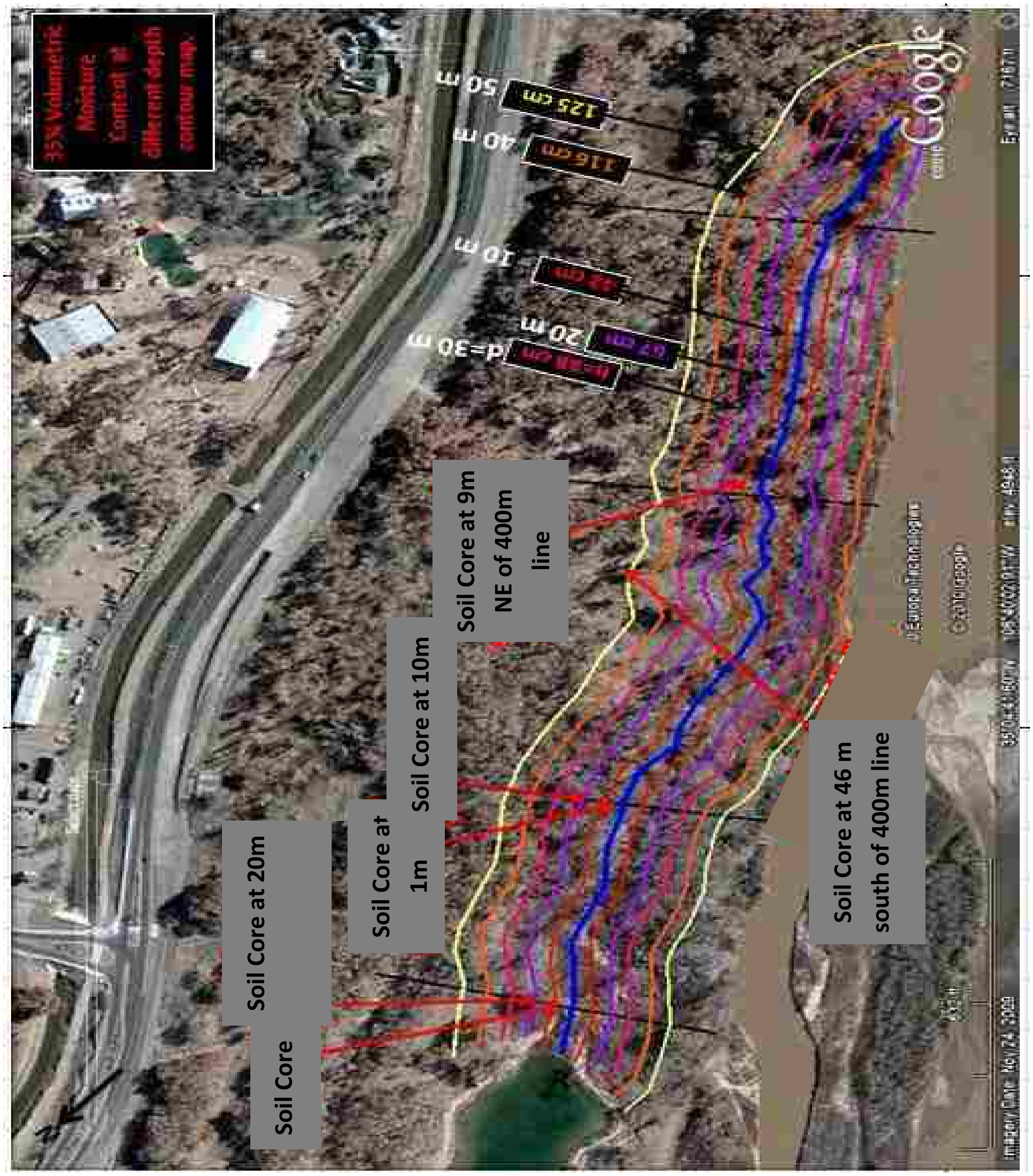


Figure 73 Soil moisture contour map for Biopark area.

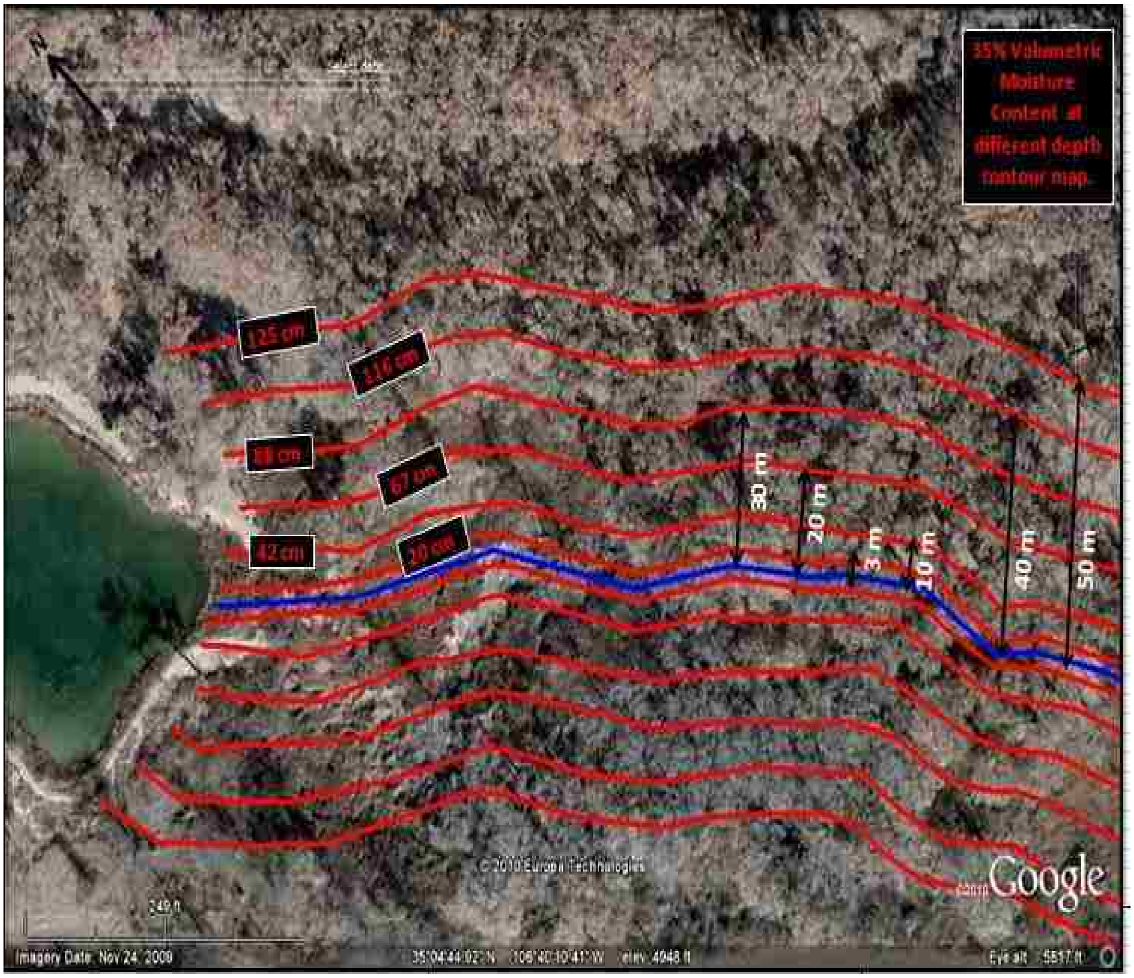


Figure 74 Soil moisture contour map for Biopark area with zoom view.

Figure 73 and Figure 74 show the soil moisture contour map for the Biopark wetland area derived from simulation results. This contour is for a single soil moisture content of 35%, for different distances from the stream and for different vertical depth. For the 3m distance from the stream, 35% soil moisture is found at a 20 cm depth from the ground surface. For the 20m distance from the stream, 35% moisture content is found at 67 cm depth from the ground surface. 35% volumetric moisture is found at a 125 cm depth for the 50 m distance location. These results show the influence of the surface water or subsurface water decreases with lateral distance from the surface water source. There is a direct link between soil moisture and vegetation growth. Field observation supports the soil moisture analysis. The vegetation after the stream at the Biopark area is marsh and after the marsh area, there is densely populated vegetation and the vegetation density decreases with distance from the stream.

6.7 Field observation

The maximum marsh width, from one side of the stream is 20 m. A qualitative field survey has been done to estimate the plant density of the Biopark. The marsh plants include Russian olive, long grasses, cattails, Coyote willow, Russian thistle, herbaceous plants etc. The marsh plants have short root lengths; that’s why those plants are close to the stream. Close to the stream, the water table is high, so plants can easily uptake the ground water and survive.

Figure 75 Marsh of Biopark wetland.

Figure 76 Marsh of wetland with small stream.

Figure 75 and Figure 76 are the pictures of the marsh area of the Biopark wetland. The marsh area is dense with small plants and with small amount of wooded area. The plants within 20 m width area of the stream are marsh plants. A densely populated area of woods is located from 20 m from the stream to 60 m. Most of the trees in the woods are salt ceder (Tamarix sp.), Russian olive (Elaeagnus angustifolia) and tree of Heaven (Ailanthus altissima), Native cottonwoods (Populus fremontii), white mulberry (Morus alba) etc. In the densely populated area, those trees and small grasses, and plants are available.

Figure 77 Dense vegetation of wetland.

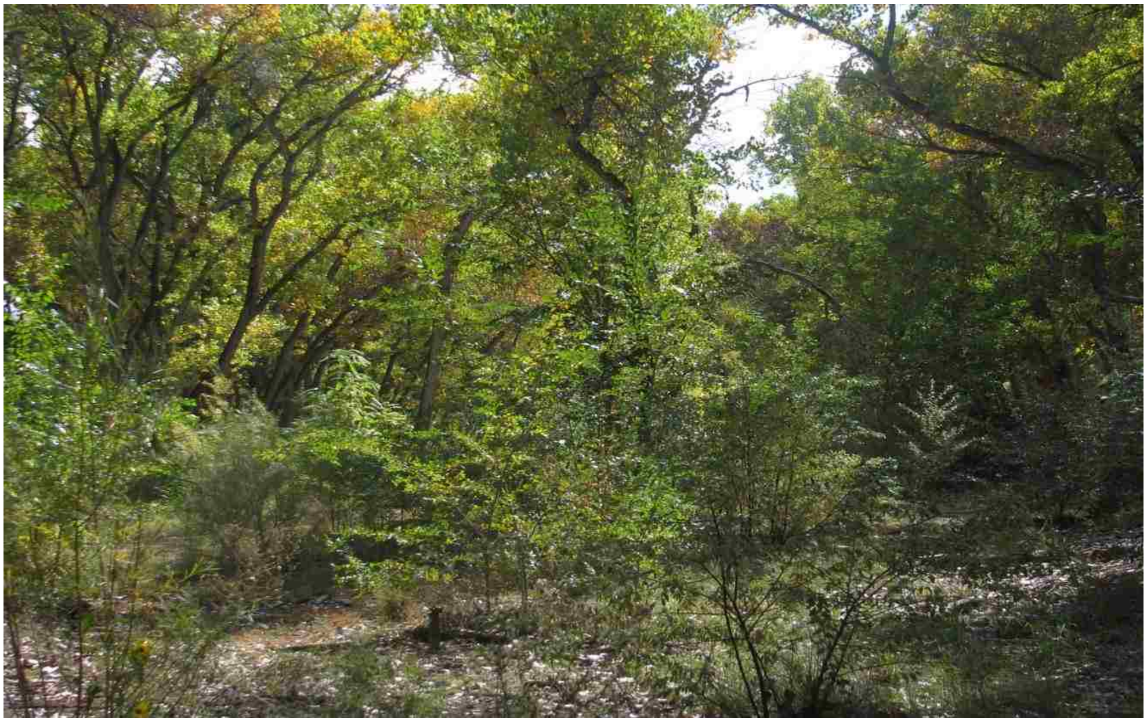


Figure 78 Vegetation of wetlands just after the marsh area.

Figure 77 and Figure 78 shows the densely populated vegetation area of the Biopark. The Biopark walking trail is at a 60 m distance from the stream. Beyond the Biopark walking trail, the density of woods decreases. The woods of this area also contains salt ceder (Tamarix sp.), Russian olive (Elaeagnus angustifolia) and tree of Heaven (Ailanthus altissima), Native cottonwoods (Populus fremontii), and white mulberry (Morus alba).

Figure 79 and Figure 80 show the change of vegetation density along the Biopark walking trail to Tingley Dr SE.

Figure 79 Decreasing of vegetation with distance from stream.

Figure 80 Low density vegetation at the Biopark wetland past the marsh and dense vegetation area.

The pictures from the field clearly show the change of vegetation in respect to distance from the stream. Close to the stream, the volume of small bushes, cattails, marshes are higher and after the marsh the density of trees are high. The density of vegetation is decreasing with distance from the stream. The moisture content contour map is consistent with the change of vegetation with distance. There are also other factors like soil characteristics, plant species characteristics, cleaning of exotic plants etc. that are responsible for the change of vegetation. This moisture change can be the reason of a high volume of trees after the marsh area. The volume of trees is decreasing with distance as the moisture content is decreasing may be due to lower vertical ground water table depth.

The comparison shows that the experimental data are in satisfactory agreement with the results of the theoretical analysis. It must be noted, however, that the comparison was qualitative.

CHAPTER 7

SUMMARY

The Albuquerque Biopark was used as a study site for investigating ground water-surface water interaction. This study includes the available moisture of the soil in that area, the movement of the water in the soil and the impact of Biopark pond water over ground water table. HEC-RAS and HYDRUS-2D programs are used to evaluate surface water-ground water interaction of Biopark area. Ground water-surface water interaction successfully explains the impact of Biopark pond over soil moisture and ground water elevation.

Minimum surface water discharge of the Rio Grande for flooding of the Biopark ponds is evaluated by the HEC-RAS program. A HYDRUS-2D model is used for the study of soil moisture. Soil moisture profiles of different cross sections and moisture contour map have been developed. An estimation of the soil moisture content above the ground water table and a soil moisture map of the wetland area are generated. Soil moisture contour map for the Biopark area also has been developed. The model estimates were found to reasonably match field measurements of soil moisture and water table elevations. The results shows that the impact of the wetland over soil moisture and vegetation density. The model results show that the goals and objectives of the Albuquerque Biopark Wetland Restoration project have been achieved as the wetland contributes water to ground water and soil moisture which is important to increase a suitable habitat for the vegetation and wildlife.

The models were developed for the Albuquerque Biopark area, but similar models can be used to study other systems. Ground water-surface water interaction modeling can be used to create ground water gradients. Knowledge about ground water elevation can be used to find the right vegetation for that area.

CHAPTER 8

FUTURE WORK

An important step is to improve the estimation of moisture content of HYDRUS-2D model. The soil moisture estimate can be improved by having more climatic input data. Precipitation, temperature and humidity have influence over soil moisture. These inputs improve the moisture content estimate.

HYDRUS-2D models are developed with no well pumping influence boundary condition. No pumping influence indicates, there is assumed to be no draw down of water table and the water table is assumed to be horizontal at depth 2.5m initially. The study site is assumed to have no water pumping influence and the ground water movement is gravity driven. This makes the model simpler. Pumping influence can change the soil water movement pattern. Pumping influence should be considered at the necessary location. Initial conditions, material distribution, mesh size, and layering of soil should be carefully identified for HYDRUS-2D model.

Another improvement would be to determine the hydraulic properties of soil for each layer and use these values rather than the default properties in the HYDRUS-2D model. Currently, the ground water-surface water interaction has been predicted for two different river flows. The HEC-RAS model needs to be run for several river discharges and the corresponding ground water table should be determined. Thus the ground water tables of different slopes can be created and ground water table as a function of season can be developed. An empirical formula for estimating the GWT can be developed in this way.

Additional GWT monitoring wells close to the pond and the existing BEMP wells should be installed to develop more accurate understanding of the GWT.

In this study, only six soil cores have been collected. The core locations are at the east side of the stream. The influence of river water over soil moisture content of wetland area is not accounted for in the model. More soil cores, especially at the west side of the stream are required for better understanding of the wetland area. The map presented in this thesis is from December 2009. It shows the wetland location, saturated soil boundary of winter season. Maps of different seasons should be developed to determine the actual boundary of the wetland.

REFERENCES

BEMP. (2007). Bosque Ecosystem Monitoring Program (BEMP) Intern Handbook. Department of Biology, University of New Mexico.

BEMP. (2006). Bosque Ecosystem Monitoring Program: Vegetation Data. Department of Biology, University of New Mexico.

Brunner, G. W., and Bonner, V. R. (August 1994). HEC River Ana;ysis System (HEC-RAS). US Army Coprs of Engineers.

Brunke, M., and Gonser, T. (1997). The ecological significance of exchange processes between rivers and ground-water. Fresh-water Biol 37:1–33

Brouwer, C. (1985). In C. Brouwer, A. Goffeau, & M. Heibloem, Irrigation Water Management: Training Manual No. 1 - Introduction to Irrigation (Vol. Chapter 2). FOA- FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS.

Bullard, T., and Wells, S. (1992). Hydrology of the Middle Rio Grande from Velarde to Elephant Butte Reservoir. New Mexico. U.S. Fish and Wildlife Service, Resource Publication 179. 51 pp.

City of Albuquerque. (1991). Master Plan The Albuquerque Biological Park: The Tingley Aquatic Park, Albuquerque Aquarium, and Rio Grande Botanic Garden. Albuquerque, New Mexico.

City of Albuquerque. (1994). Noise Control Ordinance. Ordinance Amending Chapter 9, Article 9, ROA 1994, The Noise Control Ordinance. Albuquerque, New Mexico. 18 pp.

Cowardin, L. M., Carter, V., Golet, F. C., and LaRoe, E. T. (1979). Classification of wetlands and deepwater habitats of the United States. U.S. Department of the Interior-Fish and wildlife service.

Crawford, C. A. (1993). Middle Rio Grande Ecosystem: Bosque Biological Management Plan. Albuquerque, New Mexico.

Crawford, C.S., Cully, R.Leutheuser, Sifuentes, M.S., White, L.H., and Wilber, J.P. (1993). Middle Rio Grande Ecosystem: Bosque Biological Management Plan. Albuquerque, New Mexico.

Dodson, R., and Li, X. (1999). The accuracy and efficiency of GIS-based floodplain determinations. 19th ESRI Int. User Conf. ESRI, Redlands, Calif.

Elliott, A. H. and Brooks, N. H. (1997). Transfer of nonsorbing solutes to a streambed with bed forms: Theory, Water Resour. Res., 33(1), 123–136.

Garth van der Kamp, M. H. (Spring 1998). The Groundwater Recharge Function of small Wetland in the Semi-Arid Northen Prairies. Great Plains Research: A Journal of Natural and Social Sciences, 39-56.

Horton, J., Kolb, T., and Hart, S. (2001). Physiological response to groundwater depth varies among species and with river flow regulation. Ecological Applications, 11(4) , 1046-1069.

Hughes, Joseph., and Liu, Jie. (2008). MIKE SHE: Software for Integrated Surface Water/Groundwater Modeling. Groundwater, 46 (6), 797-802.

Ivkovic, K., Letcher, R., and Croke, B. (2009). Use of a simple surface groundwater interaction model to inform water management. Australian Journal of Earth Sciences, , 56: 71-80.

Jackson, R., Robert, N., Running, S., Carpenter, S., Dahm, C., and Macknight, D., (2001). Issue in Echology Technical Report: Water in a changing world. Echological Applications, 11 (4): 1027-1045.

Jan Vymazal, M. G. (2006). Constructed Wetlands for Wastewater Treatment . Springer Berlin Heidelberg . 69-96.

Kentula, M. E. (1996). Wetland retoration and Creation. Natural Water Summary on Wetland Resources. United States Geological Survey. Water supply paper 2425. Reston, Verginia, USA.

Knopf. F. L., Johnson, R.R., Rich, T., Samson, F.B., and Szaro, R.C. (1988). Conservation of Riperian Echosystem in the United States. Wilson Bulletin . 272-284.

Landon, M. K., Rus, D. L., and Harvey, F. E. (2001). Comparison of in-stream methods for measuring hydraulic conductivity in sandy streambeds, Ground Water, 39(6), 870–885.

Diamond, ML and Helfield, JM. (May, 1997). Use of Constructed Wetlands for Urban Stream Restoration: A Critical Analysis . Environmental Management, Springer New York , 329-341.

LeJeune, C. (2008). Master's Thesis: Multi-Year Investigation of Groundwater - Surface Water Interactions in the Vicinity of the Albuquerque Drinking Water Diversion Dam. University of New Mexico.

Lejuene, C., and Crawford, C. (2008). Summery of UFDP Ecologycal Work Unit. Department of Biology, University of New Mexico.

Merwade, V., Cook, A., and Coonrod, J. (2008). GIS techniques for creating river terrain models for hydrodynamic modeling and flood inundation mapping. Environmental Modelling & Software , 23(10-11), 1300-1311.

Pollock, Michael M.; Robert. J. Naiman and Thomas, A. Hanley (January 1998). Plant species richness in riperian wetlands- A test of biodiversity theory. Echology, esa online journal , 94-105.

Mitsch, W. J., and Gosselinkb, J. G. (2000). The value of wetlands: importance of scale and landscape setting. Ecological Economics , 25-33.

Moshiri, G. (1993). Constructed wetlands for water quality improvement. Boca Raton, New York: Lewis Publishers.

Mualem, Y. (1976). A new model for predicting the hydraulic conductivity of unsaturated porous media. Water Resources Research, 12: 513–522.

Naiman, Robert J.; Decamps, H., and Pollock, M. (1993). The Role of Riparian Corridors in Maintaining Regional Biodiversity. Ecological Applications, 3:209–212.

NRCS. (1999). Soil Survey of Sandoval County, New Mexico,Unpublished data.

Rogers, K. (1995). Riparian wetlands-wetlands of south Africa. wetlands.sanbi.org.

Rodriguez, Leticia, Cello, Pablo, Vionnet, and Carlos. (2008). Fully conservative coupling of HEC-RAS with MODFLOW to simulate stream-aquifer interactions in a drainage basin. Journal of Hydrology, 353, 129-142.

Saxton, K., Rawls, W., Romberger, J., and Papendick, R. (1986). Estimating Generalized Soil-water Characteristics from Texture. Soil Sci.Soc. , Am.J 50:1031-1036.

Scanlon, B. R., Healy, R. W., and Cook, P. G.(2002). Choosing appropriate techniques for quantifying groundwater recharge, Hydrogeol. J., 10(1), 18–39.

Scott D. Bridgham, J. P. (November 1999). Ecosystem control over temperature and energy flux in Northern Peatlands. ESA journal , Vol.9, No.4 , 1345-1358.

Simunek, J., M., S., and M.Th., V. G. (1999). The HYDRUS-2D software package for simulating water flow and solute transport in two-dimensional variably saturated media. Version 2.0 IGWMC-TPS-53C. Golden, Colorado: International Groundwater Modeling Center, Colorado School of Mines.

Smith, B. (1995). Spatial Information Theory—A Theoretical Basis for GIS. International Conference CISIT 95. Semmering.Austria. A. Frank and W. Kuhn. Berlin, Springer Verlag., (pp. 988: 475-484.).

Sophocleous, M. (2002). Interactions between groundwater and surface water: the state of the science, Hydrogeol. J., 10, 52–67.

Stromberg, J. C. (1996). Effects of ground-water decline on riparian vegetation of semiarid regions: the San Pedro River, Arizona, USA . Ecological Applications. 6:113–131.

Sturm, T. W. (2009). Open Channel Hydraulics (Vol. Second Edition). McGraw-Hill Higher Education.

Tahmiscioglu, M.S., Anul, N., Ekmekci, F., and Durmus, N. (2007). Positive and Negetive Effects of Dams on the Environment. Anakara, Turkey: DSI.

Tashjian, P. (1999). Geomorphology and Hydrology Data. Retrieved from http://bhg.fws.gov/geomorph.htm.

Tate, E. C., Maidment, D. R., Olivera, F., and Anderson, D. J. (2002). Creating a Terrain Model for Floodplain Mapping. J.Hydrologic Engrg. Vol 7, Issue 2 , 100-108.

U.S. Army Corps of Engineers. (2004). Finding of nosignificant impact: Albuquerque Biological Park wetland restoration project, Albuquerque, New mexico. Prepared by the U.S. Army Corps of Engineers, Albuquerque District.

U.S. Army Corps of Engineers. (2003). Method and Cost Evaluation Report for the Middle Rio Grande Bosque Jetty Jack Removal Evaluation Study. Albuquerque District. Albuquerque, New Mexico. Prepared by the U.S. Army Corps of Engineers, Albuquerque District.

U.S. Army Crops of Engineers. (1996). Water Control Manual – Jemez Canyon Dam and Reservoir, Jemez River, New Mexico. Prepared by the U.S. Army Corps of Engineers, Albuquerque District, New Mexico.

U.S. Environmental Protection Agency. (2009). Characterization of marshes. Retrieved from http://water.epa.gov/type/wetlands/marsh.cfm.

USDA. (1977). Soil Survey of Bernalillo County and Parts of Sandoval and Valencia Counties, New Mexico. Albuquerque, New Mexico: Soil Conservation Service.

USGS. (2008). Natural process of Ground-water and Surface-water interaction. Retrieved from http://pubs.usgs.gov/circ/circ1139/htdocs/natural_processes_of_ground.htm

Van Genuchten, M. TH. (1980). A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. Soil Science Society of Americal Journal. 44 (5): 892–898.

Ward, JV., Stanford, JA., and Voelz, NJ. (1994) Spatial distribution pat-terns of Crustacea in the flood plain aquifer of an alluvial river. Hydrobiologia 287:11–17

Webb, R., Leake, S., and Turner, R. (2007). The Ribbon of Green: Change in Riparian Vegetation in the Southwestern United States. The University of Arizona.

Whitman, RL., and Clark, WJ. (1982) Availability of dissolved oxygen in interstitial waters of a sandy creek. Hydrobiologia 92:651–658

Williams, J. (1986). New Mexico in Maps-Jerry L. Williams, ed. 2nd Ed. Albuquerque, New Mexico: University of New Mexico Press.

Wilcox, Laura Jean, Bowman, Robert S., Shafike, and Nabil G. (2007). Evaluation of Rio Grande Management Alternatives Using a Surface-Water/Groundwater Model. Journal of the American Water Resources Association, 43 (6), 1595-1603.

Winter , TC (1995) Recent advances in understanding the interaction of groundwater and surface water. Rev Geophys (Suppl):985–994

Wright, C. W., and Brock, J. C. (2002). A LiDAR for mapping shallow coral reefs and other coastal environments. Seventh International Conference on Remote Sensing for Marine and Coastal Environments. Miami F.

APPENDICES

APPENDIX A: Data sources

Bernalillo country has aerial photos of the entire Albuquerque at http://ims.bernco.gov/website/metadata/PDFs/Ortho/Orthoindex2008BC.pdf . Shapefile map of Biopark area was collected from AMAFCA (Albuquerque Arroyo and Flood Control) and brought into ArcGIS.

Real time water data is available in United States Geological Survey (USGS). Water Data from http://waterdata.usgs.gov/nm/nwis/uv?site_no=08330000 was used in HEC-RAS. USGS 08330000 gage data was used for this study. Ground water data for Monitoring well-1 was found at http://nm.water.usgs.gov/projects/riograndesections/alamedagw.html Biopark ground water monitoring well data was collected from Christian LeJeune, Research scientist, Biology Department, University of New Mexico. Google Map was used to develop soil moisture contour map and detailed Biopark map.

APPENDIX B: Soil core properties

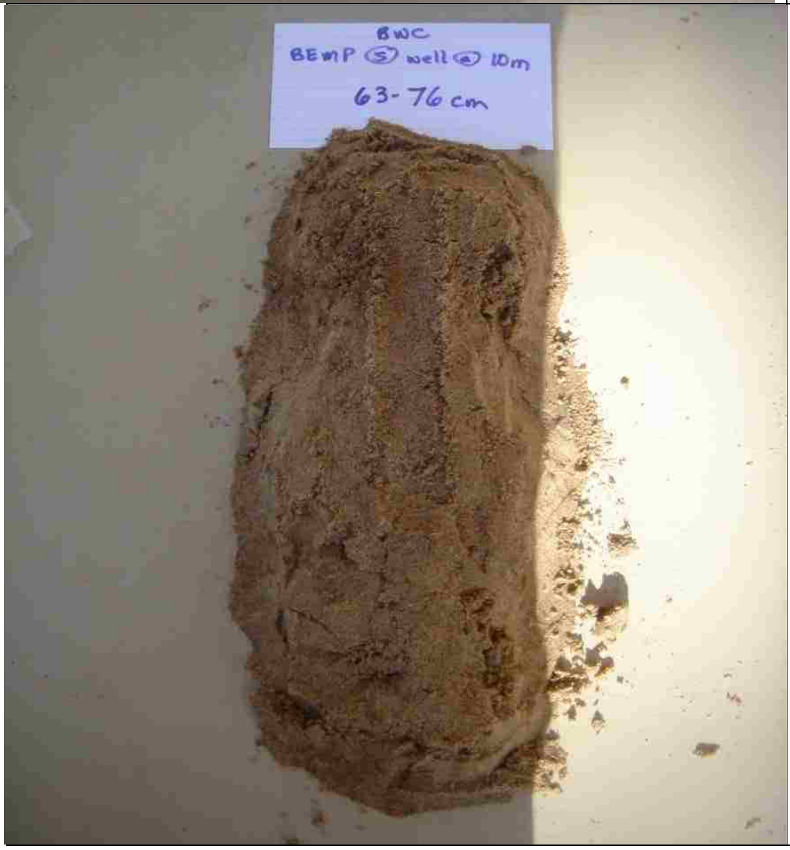
Six soil cores were collected from different location at Biopark. Every soil layer is different in appearance and content. The color of the soil changes with change of moisture content and finer soil percentage. The photos of all layering for every soil core are attached in the following.

CORE1: 10m from BEMP well	
	**0-10 cm depth** **Clay and silt is 21.58%.** **Moisture content is 35.56%**

10-30 cm depth
Clay and silt is
47.25%.
Moisture content is
19.24%

30-47 cm depth
Clay and silt is
51.99%.
Moisture content is
17.33%

47-63 cm depth
Clay and silt is 52.73%.
Moisture content is 19.75%



63-76 cm depth
Clay and silt is 2.92%.
Moisture content is 7.8%

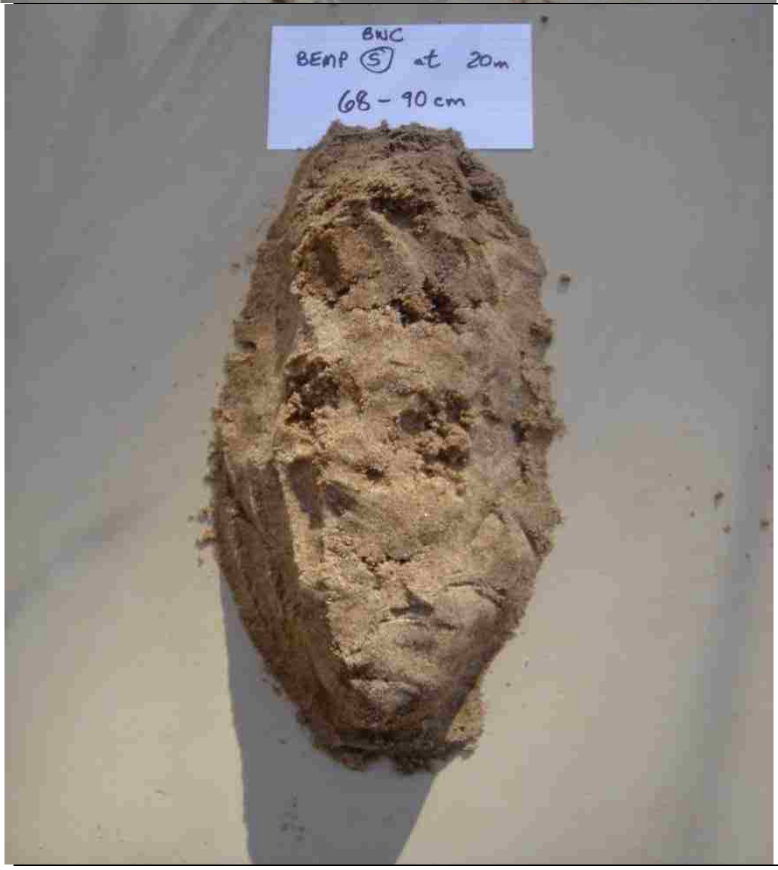
	**76-95 cm depth Clay and silt is 1.36%. Moisture content is 6.9%**
	**95-116 cm depth Clay and silt is 1.86%. Moisture content is 19.96%**

	**116-123 cm depth Clay and silt is 2.03%. Moisture content is 22.18%**
	**123-135 cm depth Clay and silt is 2.52%. Moisture content is 27.37%**

135-141 cm depth
Clay and silt is 2.93%.
Moisture content is 24.92%

CORE2: 20m from BEMP well	
	**0-10 cm depth Clay and silt is 11.63%. Moisture content is 19.19%**
	**10-27 cm depth Clay and silt is 20.49%. Moisture content is 15.54%**

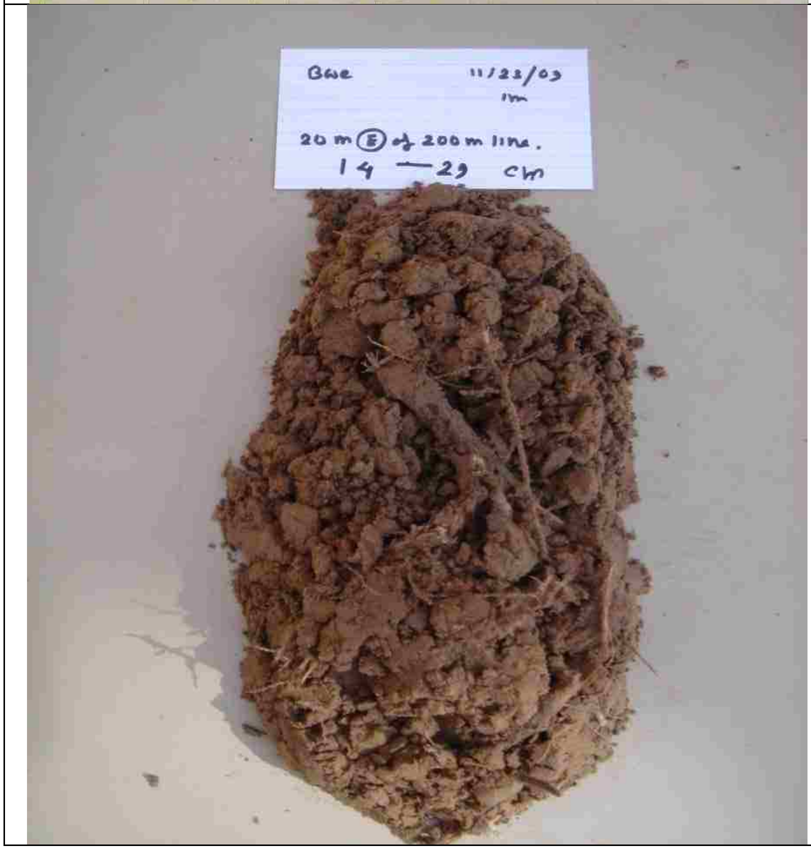
	**27-40 cm depth Clay and silt is 37%. Moisture content is 26.49%**
	**40-57 cm depth Clay and silt is 19.93%. Moisture content is 24.06%**

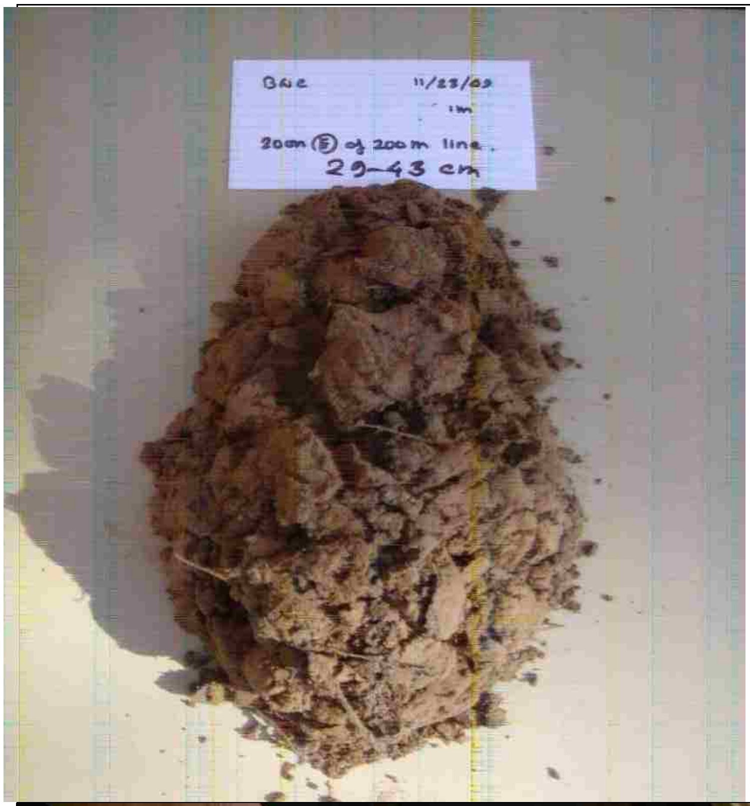
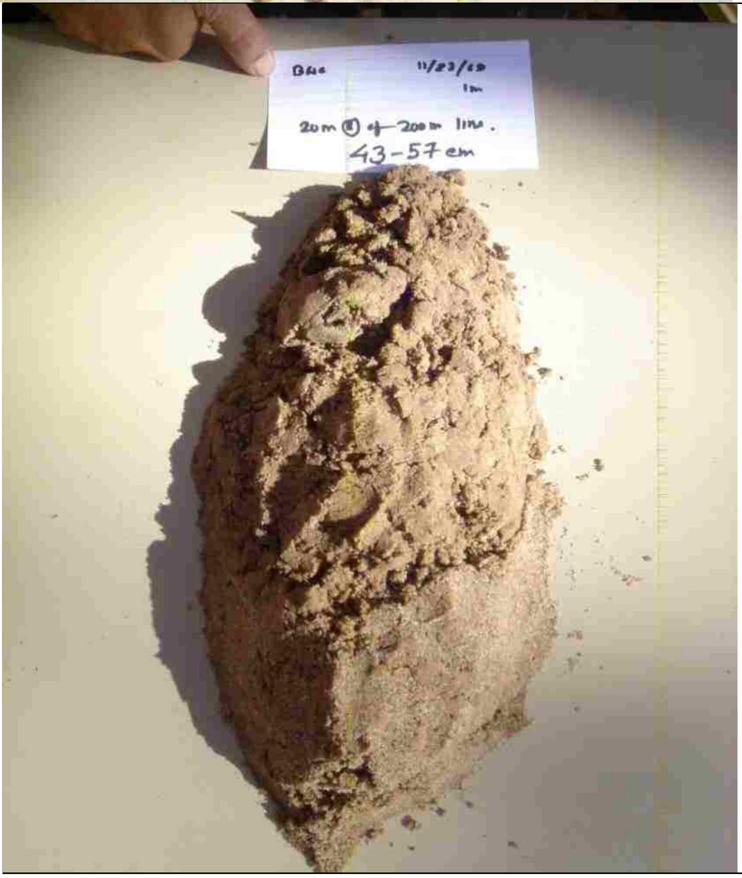
		**57-68 cm depth** **Clay and silt is 8.45%.** **Moisture content is 22.87%**
		**68-90 cm depth** **Clay and silt is 1.3%.** **Moisture content is 6.65%**

		**90-105 cm depth Clay and silt is 2.19%. Moisture content is 10.64%**
		**105-117 cm depth Clay and silt is 1.84%. Moisture content is 18.71%**

		**117-128 cm depth Clay and silt is 2.3%. Moisture content is 22.96%**
		**128-138 cm depth Clay and silt is 2.33%. Moisture content is 22.96%**

	**138-142 cm depth** **Clay and silt is 1.96%.** **Moisture content is 22.64%**

CORE3: 1m from 200m line	
	**0-14 cm depth Clay and silt is 28.06%. Moisture content is 36.84%**
	**14-29 cm depth Clay and silt is 39.95%. Moisture content is 25.77%**

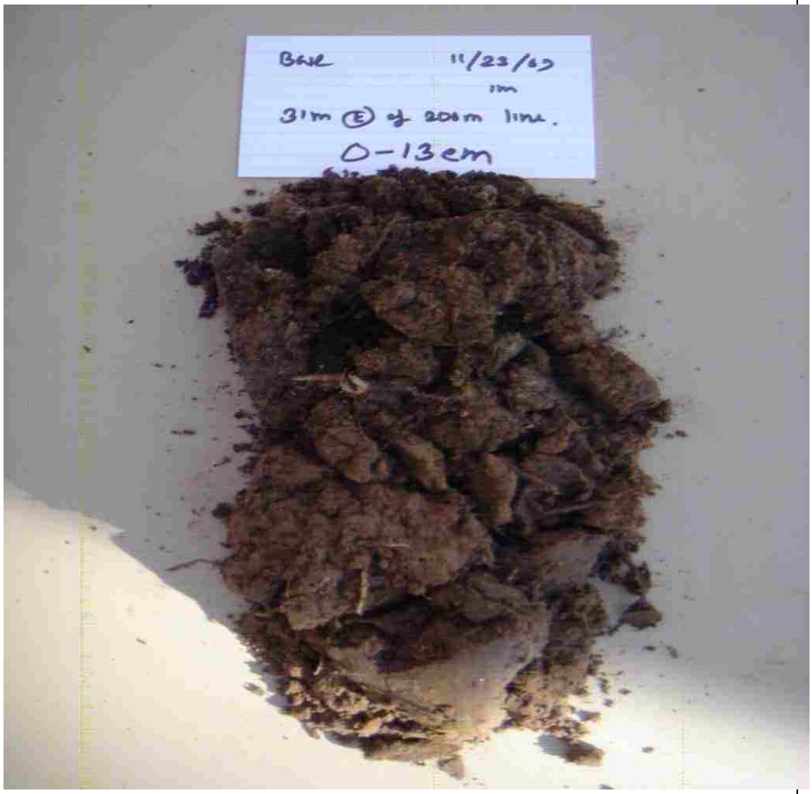
	**29-43 cm depth Clay and silt is 54.45%. Moisture content is 31.75%**
	**43-57 cm depth Clay and silt is 23.49%. Moisture content is 18.38%**

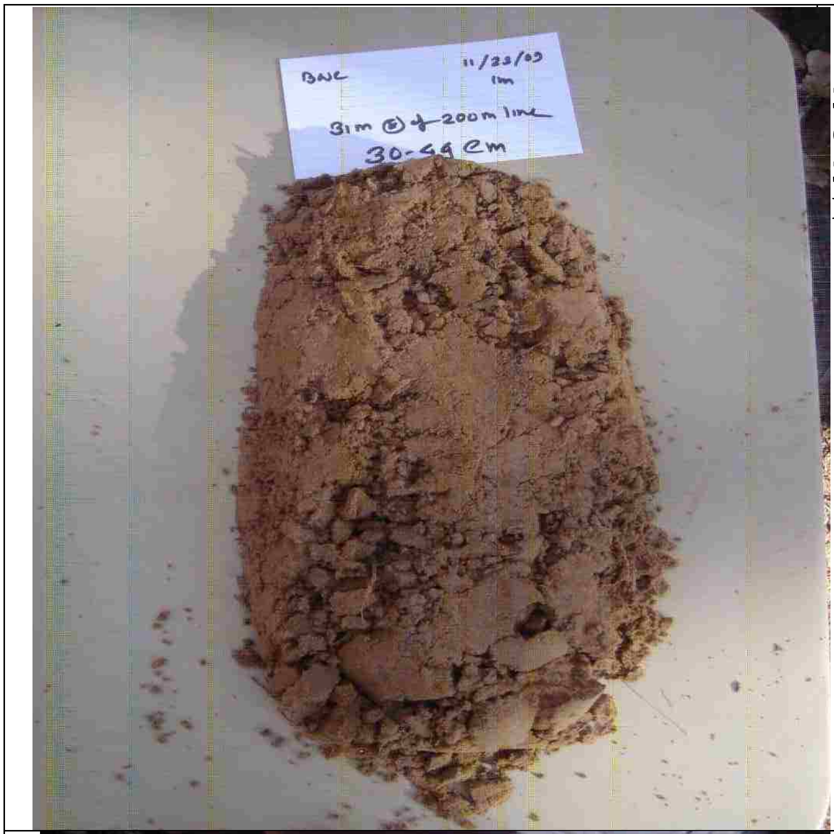
	**57-70 cm depth Clay and silt is 9.19%. Moisture content is 10.36%**
	**70-81 cm depth Clay and silt is 7.76%. Moisture content is 8.39%**

81-97 cm depth Clay and silt is 3.78%. Moisture content is 13.07%

97-108 cm depth Clay and silt is 6.84%. Moisture content is 21.69%

	**108-118 cm depth Clay and silt is 9.58%. Moisture content is 22.77%**

CORE4: 9m from 200m line	
	**0-15 cm depth Clay and silt is 48.55%. Moisture content is 37.82%**
	**15-30 cm depth Clay and silt is 44.96%. Moisture content is 16.23%**



30-44 cm depth
Clay and silt is 33.02%.
Moisture content is 17.82%

44-59 cm depth
Clay and silt is 33.54%.
Moisture content is 13.29%

	**59-75 cm depth Clay and silt is 12.57%. Moisture content is 5.06%**
	**75-91 cm depth Clay and silt is 22.42%. Moisture content is 9.26%**

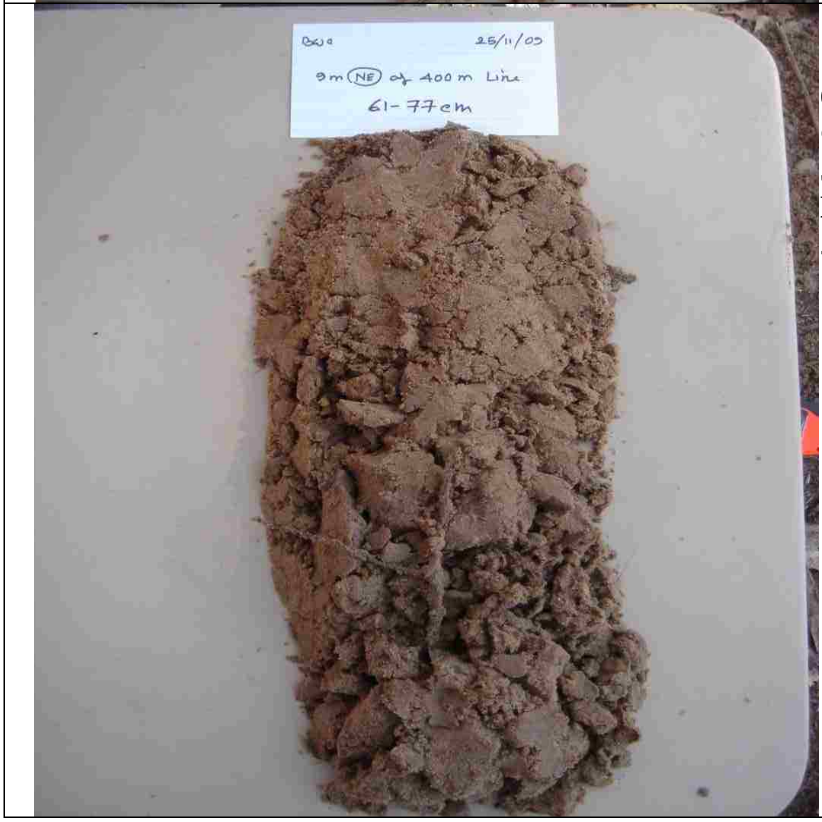
91-106 cm depth
Clay and silt is 15.4%.
Moisture content is 14.96%

106-118 cm depth
Clay and silt is 20.63%.
Moisture content is 21.31%

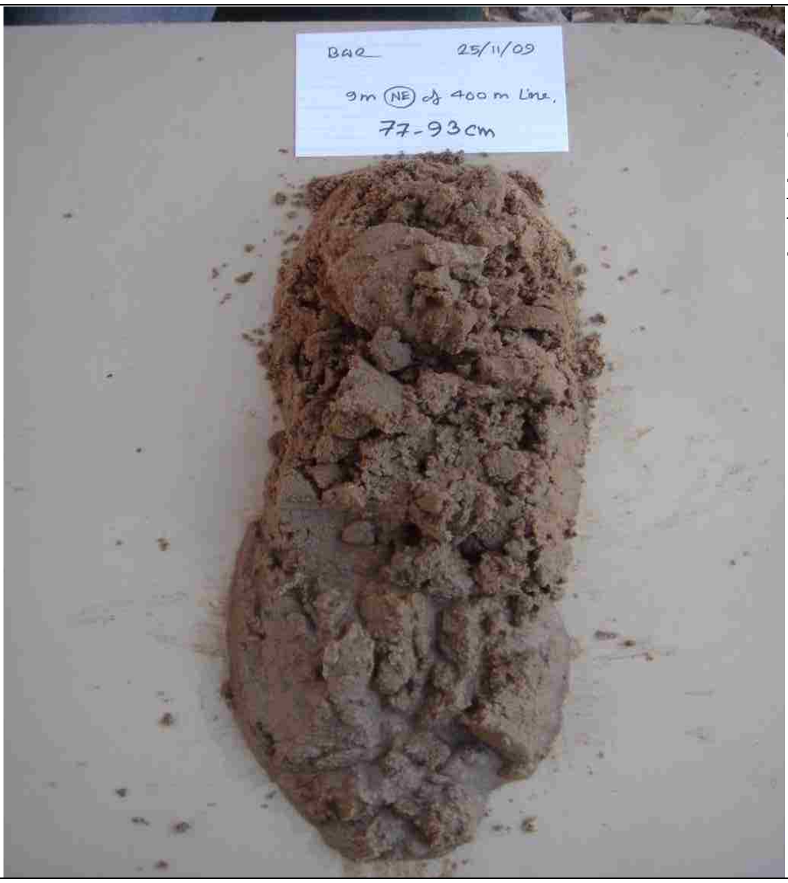
CORE5:9m from 400m line	
	**0-10 cm depth** **Clay and silt is 39.11%.** **Moisture content is 34.89%**
	**10-22 cm depth** **Clay and silt is 35.92%.** **Moisture content is 18.02%**

	**22-35 cm depth Clay and silt is 63.78%. Moisture content is 29.56%**
	**35-49 cm depth Clay and silt is 20.06%. Moisture content is 20.24%**

49-61 cm depth
Clay and silt is 37.69%.
Moisture content is 13.91%



61-77 cm depth
Clay and silt is 51.25%.
Moisture content is 25.97%



77-93 cm depth
Clay and silt is 23.73%.
Moisture content is 27.25%

CORE6: 46m from 400m line	
	**0-14 cm depth Clay and silt is 27.14%. Moisture content is 25.56%**
	**14-31 cm depth Clay and silt is 31.58%. Moisture content is 7.95%**

	**31-43 cm depth Clay and silt is 11.58%. Moisture content is 9.29%**
	**43-57 cm depth Clay and silt is 18.84%. Moisture content is 9.04%**

57-73 cm depth
Clay and silt is 5.05%.
Moisture content is 8.69%

73-87 cm depth
Clay and silt is 7.16%.
Moisture content is 10.39%

	**87-98 cm depth** **Clay and silt is 5.76%.** **Moisture content is 21.66%**
	**98-110 cm depth** **Clay and silt is 37.9%.** **Moisture content is 26.8%**