

HYDRAULIC MODELING OF A RUNOFF RECYCLING SYSTEM  
FOR A CONTAINER NURSERY

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## Chapter 1

### Introduction

The plant nursery industry has been active in the United States for a long time. There is evidence of nursery industry beginnings as early as 1648 in the Massachusetts Bay Colony (Davidson et al., 1994). Records indicate that 500 apple trees were traded for 100 hectares (250 acres) of land. Early nurseries started in the eastern United States and progressed westward over the next two centuries. The first census that included nurseries was conducted in 1890. At that time, there were 4,500 nurseries covering approximately 69,200 hectares (173,000 acres) of land. Most nurseries were small, and produced for local customers. The total production in 1890 was estimated to be 3.4 billion plants.

The nursery industry has grown significantly since its beginnings. The United States Department of Agriculture's Economic Research Service (USDA) estimated the wholesale sales for the nursery and greenhouse industry to be \$10.9 billion for 1996. According to the USDA, nurseries encompass over 160,000 ha (400,000 acres) of open land and covered housing. Although the number of farms in the U.S. has decreased recently, the number of nurseries and greenhouses continues to increase. The USDA conservatively estimates that 45,000 people are employed year-round, and over 100,000

during the peak growing periods. The nursery industry in the United States is strong and growing.

### **Container Nursery Industry**

Production of nursery plants in containers began to develop on a large scale in 1949 (Davidson et al., 1994). A container nursery is a specialized type of plant nursery. Most of the plants are grown in some type of container filled with an artificial growing medium containing little, if any, soil (Cole et al., 1993). These plant-filled containers are placed in growing beds where they are cared for until they are ready for market. A major advantage of container production is a shorter rotation time, allowing more plants to be grown on a specific area of land during a specified amount of time compared to in-field plant production (Davidson et al., 1994). By growing plants in containers, nurseries can realize a greater profit per unit land area.

A disadvantage of container production is that large volumes of water must be applied because the growing medium provides less storage for water. If sprinkler irrigation is used, some of this water falls outside of the containers, and must be removed from the growing beds in order to reduce possibilities of disease infestation. Thus surface drainage is an important factor. This presents the problem of what to do with the runoff water from the growing beds, the main focus of this project.

### **Greenleaf Nursery**

Greenleaf Nursery Company, referred to as "Greenleaf" in this study, rests on a peninsula in the Illinois River at the mouth of Lake Tenkiller, a highly utilized

recreational water body, near Park Hill, Oklahoma. Greenleaf, which operates on approximately 230 hectares (570 acres) of land, has been ranked as the third largest container nursery in the United States (Oklahoma Department of Environmental Quality, 1997). The location is advantageous for a plant nursery because of the ample water supply. However, the terrain is rugged and hilly with elevation differences of 40 meters (130 feet) within the nursery grounds, which provides many challenges for day to day nursery operations.

Greenleaf decided to construct a recycling system to deal with nursery runoff. This recycling system was implemented for several reasons including reducing the amount of water pumped from the Illinois River, eliminating irrigation runoff discharge to the Illinois River, reducing storm water discharge, and providing storage capacity to capture rainfall runoff.

### **Recycling Advantages**

There are many advantages for recycling water at a nursery. From the economic standpoint, it is very feasible to recycle water. At Greenleaf, a large amount of energy is required to pump water up a steep bluff between the nursery and the Illinois River. Recycling water on the nursery does not eliminate the need for pumping fresh water from the river, but it does greatly reduce the amount of water that is needed from the river.

The elimination of irrigation runoff discharge from the nursery helps protect the waters of the Illinois River basin. Recycling the runoff also helps meet voluntary water quality agreements for their discharges. The recycling system was designed so that it has the capacity to capture all of the storm water runoff that flows through the nursery, with

the exception of very large and/or intense rainfall events. It is very beneficial to capture "fresh" rainfall runoff. It helps with pathogen control and saves money for the nursery by reducing pumping requirements.

There is also a benefit of recycling any nutrients that are captured in the irrigation runoff (Skimina, 1992). These nutrients would be considered contaminants downstream, but are valuable to the plants at the nursery. With recycling, the nutrients are reapplied when the runoff is captured and reused as irrigation water. This can save money for fertilization and improve the efficiency of fertilization because the recycled nutrients are applied more than once.

### **Problems Associated with Recycling**

Although there are many obvious advantages of recycling irrigation runoff, there are also factors that reduce the feasibility of recycling. The greatest disadvantage to recycling the irrigation water is the expense of implementing a recycling system. It can cost a substantial amount to design, construct, and maintain a water recycling system. In most cases this includes building retention basins, installing pumping systems, and developing a drainage system that will direct the runoff to a retention basin. A runoff recycling system should reduce operational costs and pay for itself in time, however, the initial investment has deterred many nurseries from recycling their irrigation runoff.

Any plant pathogens that are in the runoff streams also get captured in the runoff collection basins. This can increase the spread of plant diseases through the nursery as the captured pathogens are applied to healthy plants through irrigation. With proper management practices, this problem should be reduced to a minimum. Monitoring pathogen levels in the retention basins can reduce the risk of disease spread even further.



Controlling transmission of pathogens is a major concern with Greanleaf's recycling system (Wilson et al., 1998). A current project at this nursery involves monitoring pathogens in the recycled irrigation water to determine if the pathogen levels increase due to using recycled runoff water for irrigation. A goal of the project is to determine if the recycled water will need to be treated before it is used for irrigation, and what treatments can be used if treatment is required.

### **Problem Introduction**

The quantity and quality of water are the main environmental concerns for the nursery industry (Urbano, 1989). Water is a critically important resource for the nursery industry, and many container nurseries have found that recycling irrigation runoff is a worthwhile practice. As the number of container nurseries continues to increase, and because of the inherent inefficiencies in sprinkler irrigation of container grown plants, recycling irrigation runoff will continue to gain importance and interest within the nursery industry.

Management of recycling systems can be a very complex problem. It is important for nurseries to know how much water is available for irrigation purposes and how much storage capacity is available to capture rainfall. Having a system to improve management capabilities for recycling systems would be very beneficial to the nursery industry. This system would enable nurseries to manage their water in a more efficient manner.

### **Modeling Advantages**

Modeling the recycling system assists the nursery in several ways. At any given time, nursery managers will know how much water is available in retention basins for irrigation. Knowing where the water is located on the nursery will allow the managers to move water from one basin to another when the energy costs are lower, reducing the day to day operational costs for irrigation. In extended periods of drought, water rationing can be monitored using the simulation model.

The nursery managers will also be able to make irrigation practice judgments based on weather predictions and knowledge of the quantity of water available. If the weather forecast calls for a long dry period, irrigation personnel will know that they need to pump more water from the river. This will ensure that basin water levels do not drop too low, and reduce the possibility of having to pump water from the river during peak energy use times. Taking this into consideration, they will be able to use energy during off-peak times to save significantly on pumping costs.

### **Project Objective**

The main objective of this study is to develop a computer based model that simulates the hydraulics of a runoff recycling system at a large containerized nursery in eastern Oklahoma. This model will potentially be used as a management and evaluation tool for the recycling system at the nursery. This model could be used as an example in the process of developing models for other nursery recycling systems.

## **Chapter 2**

### **Literature Review**

#### **Nursery Industry - Statistical Information**

The nursery industry in Oklahoma is a significant contributor to agricultural production. According to the Oklahoma Department of Agriculture's 1997 Ag Facts, the nursery industry ranked fifth among major Oklahoma agricultural commodities in grower cash receipts for 1997. The cash receipts totaled \$264 million. Nationally, the nursery industry ranked ninth in total cash receipts during the same period. According to the United States Department of Agriculture's Economic Research Service (USDA-ERS, 1998), grower receipts have steadily increased over the past twenty years. They represent nearly 11% of the total cash receipts for all U.S. farms (USDA-ERS, 1998). USDA-ERS (1998) also estimated that retail consumer expenditures for nursery and greenhouse products were \$49.7 billion in 1996. In terms of monetary importance, the nursery industry plays a significant role in the economies of Oklahoma and the United States.

#### **Protection of Illinois River**

Eastern Oklahoma has enjoyed a great asset in the Illinois River (Bonner, 1993). It has served as a valuable attraction to the area for a long time. It is very important for

the waters near the nursery to remain unpolluted and useable for the surrounding community as both a recreational and a municipal water supply. Because of the recreational attraction of this area of the River, the Oklahoma Scenic Rivers Act was passed to protect the quality of the River.

The Oklahoma Scenic Rivers Act has helped to ensure the quality of the water flowing in the Illinois River, which receives runoff waters from Greenleaf Nursery. This act designated the area around the Illinois River as a "scenic river area" (Scenic Rivers Act, 1991). With this designation, the waters are required to be preserved as a part of Oklahoma's diminishing resource of free-flowing rivers and streams. This act also gives authorities the right to assist in preventing and eliminating the pollution of the scenic rivers area. These waters are to be protected from all sources of pollution or other factors that may adversely affect the ecosystem and the environment (Bonner, 1993).

In the Federal Clean Water Act, CWA, there is a specific exemption for non-point agricultural return flows. The CWA states that no permit is required for the return flows from agricultural lands consisting entirely of agricultural runoff. The non-point discharges from Greenleaf Nursery are composed entirely of agricultural return flows and storm water.

As a result of a 1987 complaint against Greenleaf for allegedly discharging runoff containing high levels of nitrates, the Oklahoma Department of Agriculture began a project, the Illinois River Irrigation Tailwater Project, with nurseries in eastern Oklahoma that have irrigation runoff discharging into the Illinois River or its tributaries. The focus of this project was to monitor the irrigation runoff entering the Illinois River. Greenleaf Nursery, along with other nurseries discharging runoff to the Illinois River, made

voluntary agreements with the Oklahoma Department of Agriculture dealing with their irrigation discharge waters.

The most limiting restrictions that Greenleaf faces are due to the voluntary agreement they made with the Oklahoma State Department of Agriculture. Within this agreement, Greenleaf agreed to meet drinking water standards for nitrate nitrogen (10 ppm), and control phosphate-P to 1 mg/L. They also agreed that they would eliminate all pesticides from their runoff waters.

Several changes had to be made to comply with this agreement. These included changing the method of application for fertilizer to slow-released encapsulated fertilizer instead of application through irrigation sprinklers (Reaves, 1997). They also are using pesticides that break down more readily in sunlight and water (Greenleaf Nursery Company, 1997). The biggest change in their practices was the implementation of the irrigation runoff recycling program.

### **Nursery Runoff Recycling**

American horticulture is facing massive environmental-policy changes (Arnold and Wilkerson, 1994). As a result of these changes, many nurseries have explored runoff recycling. One Florida container nursery has implemented recycling as a result of regulations and compliance requirements for runoff and water usage. Their system included growing the plants on an impervious surface, overhead sprinkler irrigation, and channeling runoff to a recycling pond (Rackley, 1992). The growing plots were also sloped so that the irrigation runoff was directed toward the channels.

Growers in California were forced to take actions because of legislation and limits placed on nurseries. This legislation made water runoff a major concern for the California nursery industry. One study detailed two nurseries that implemented recycling systems to reduce water use and irrigation runoff (Kabashima, 1993). The first nursery simply channeled irrigation runoff to sedimentation ponds. After settling, the water is filtered and pumped to an irrigation reservoir. This system was able to reduce runoff 88%. The second nursery was able to reduce runoff 25% by constructing concrete channels in major flow areas. Recycling runoff water is one option that can be implemented by nurseries to help meet regulations on their water usage and runoff.

### **Project Uniqueness**

This project is very unique, and I was not able to find any literature dealing with a similar modeling project of a nursery recycling system. Nor is there much published information about recycling systems for nurseries. Since there was a lack of available literature, this project was started with a general concept of what needed to be done and from that a functioning computer simulation model was developed.

## **Chapter 3**

### **Greenleaf Nursery - The Setting**

Greenleaf Nursery was founded in 1945 as a retail and landscape nursery in Muskogee, Oklahoma. They began experimenting with different methods of growing plants in containers in 1954. By 1957, they decided that they had learned enough through their experiments that they purchased the land on the Illinois River that still serves as the nursery headquarters today. The first crops grown at the nursery were ready to be sold in 1960. Annual production at that time was only 20,000 plants.

Today, Greenleaf employs over 600 people during the peak growing season. They currently produce over 10,000,000 liners, and 8,500,000 finished plants on approximately 230 hectares (570 acres). This includes 70 varieties of conifers, 570 varieties of broadleaf evergreens and deciduous shrubs, and 145 varieties of shade and flowering trees. Their customer base is approximately 3,000 businesses in 40 states, Canada, and Mexico.

Expansion at Greenleaf continues at a controlled and organized pace. This will ensure that they do not outgrow their human and natural resources. However, continued expansion seems likely as their sales have continued to grow.

### **Greenleaf's Water Source**

The Illinois River is the only source of fresh irrigation water for the nursery. There are two pump stations located on floating docks on the Illinois River. These stations pump fresh water up a steep bluff to the nursery. Nearly all of this water is directly applied to the nursery crops, but a small percentage is first pumped to one of the basins within the nursery. The recycling system has a number of basins that provide storage capacity for water to be used for irrigation purposes. These basins will be discussed in the following sections.

### **Greenleaf's Recycling System**

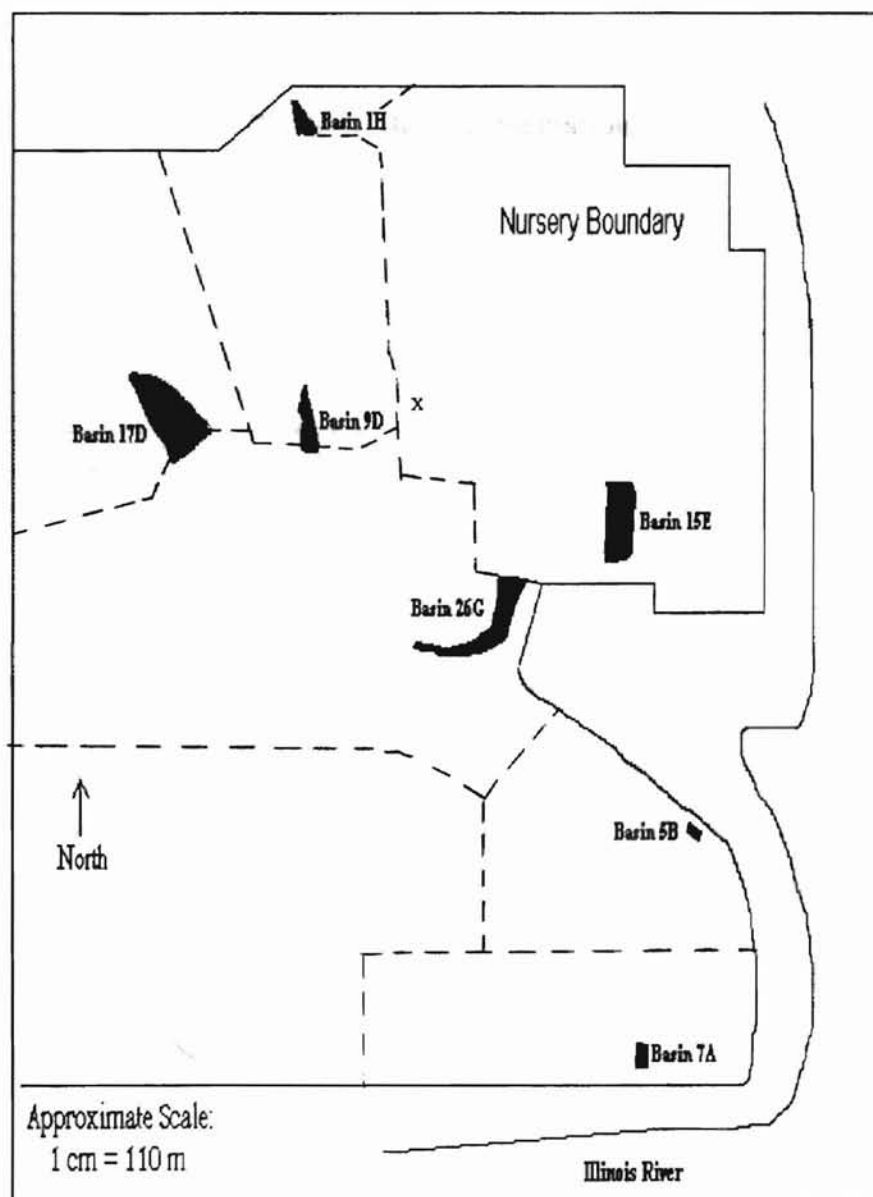
Greenleaf Nursery has invested considerable money and effort in the development of their irrigation runoff recycling system. Construction of this system began in 1992 and was completed by January 1, 1999. Greenleaf has taken on the task of designing and constructing the system themselves with some technical assistance from outside sources. The recycling system is a complex network of basins, pumps, pipes, and channels. Each component is essential to the proper operation of the system.

### **Basins**

Greenleaf had seven basins in operation throughout the duration of this project with the eighth and final basin under construction. Of the seven basins in operation, five are earthen basins and 2 are small concrete basins. Figure 1 shows a diagram of the layout of the basins at the nursery. The basins are labeled with the designations defined by nursery personnel. Basins 7A and 5B are the concrete basins. These two basins, along



with Basin 9D, an earthen basin, are relift basins. No irrigation is done from the relift basins. They provide temporary storage for irrigation runoff, which is then pumped directly to one of the larger irrigation basins.



**Figure 1. Greenleaf's Basin Layout Showing Approximate Drainage Areas.**

The five earthen basins are much larger than the concrete basins. The earthen basins capture runoff from a larger area of nursery stock. Table 1 shows the estimated

surface area and volumes for each of the 7 operating basins. The surface areas were estimated using GPS data collected around the basins (see Chapter 5). The volumes were estimated using these areas, and depth measurements at various locations throughout the basins. These latter measurements were provided by nursery personnel.

**Table 1. Basin Information.**

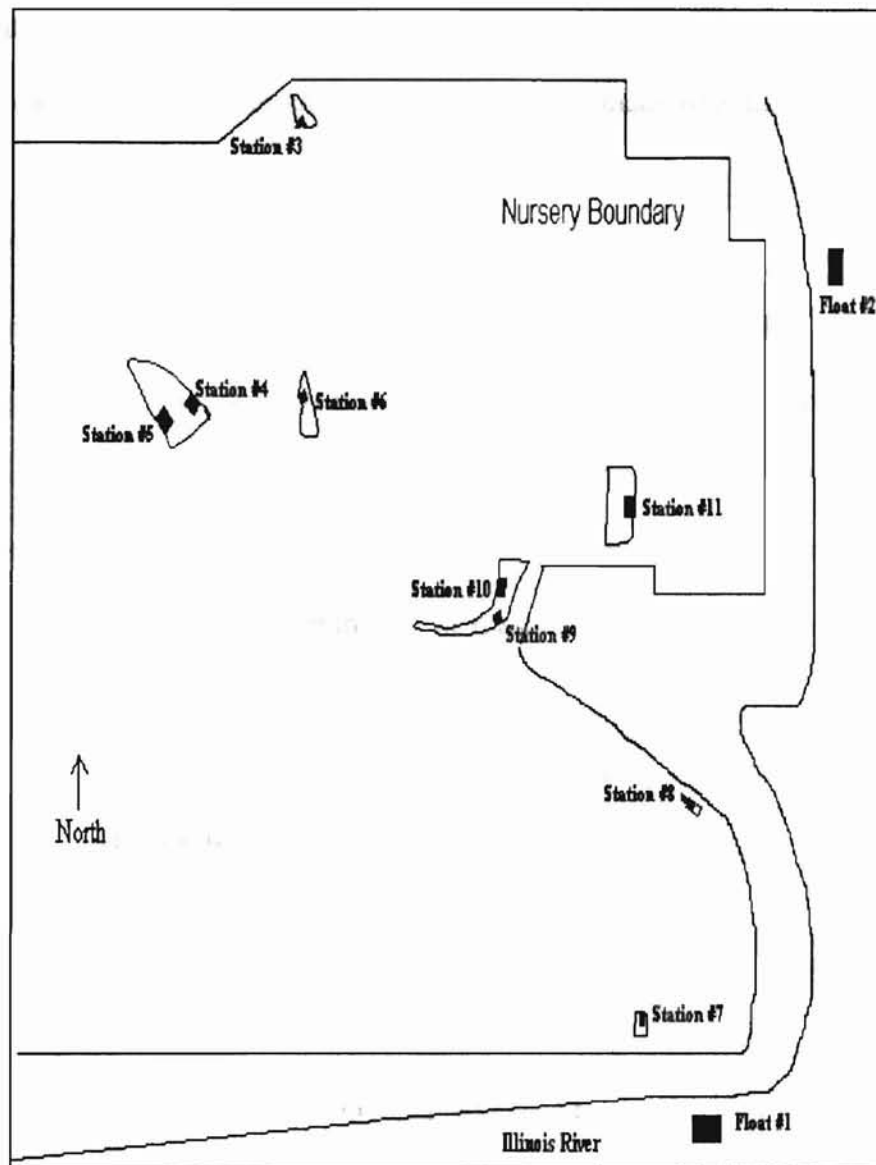
Basin	Surface Area (m <sup>2</sup> )	Volume (m <sup>3</sup> )
1H	1120	4500
26G	3400	14200
15E	7050	29000
7A	400	1360
5B	375	1150
17D	9480	43300
9D	2320	9200

### Pumps

There are twenty-seven pumps used at the nursery. These pumps serve two purposes. They move water from one basin to another, or pump irrigation water to the nursery stock, and a few pumps are used for both purposes. The pumps are located on a series of nine pump stations located on the nursery grounds and two additional stations located on floats on the Illinois River. Table 2 shows each pump, its characteristics, and the station on which it is located. Figure 2 shows the location of each pump station on the basins and in the Illinois River.

Table 2. Pump Information.

Pump ID	Location	Design Head (ft)	Shut-off Head (ft)	Design Discharge (gpm)
1 - #1 - 125	Float #1	291	338	1377
1 - #2 - 60	Float #1	250	275	800
1 - #3 - 60	Float #1	250	275	800
2 - #1 - 125	Float #2	291	338	1377
2 - #2 - 125	Float #2	291	338	1377
2 - #3 - 125	Float #2	291	338	1377
2 - #4 - 60	Float #2	250	275	800
3 - #1 - 60	Station #3	250	275	800
3 - #2 - 60	Station #3	250	275	800
4 - #1 - 60	Station #4	250	275	800
4 - #2 - 60	Station #4	250	275	800
5 - #1 - 60	Station #5	250	275	800
5 - #2 - 60	Station #5	250	275	800
6 - #1 - 25	Station #6	139	97	1075
7 - #1 - 30	Station #7	79	105	1000
8 - #1 - 15	Station #8	79	90	457
9 - #1 - 60	Station #9	250	275	800
9 - #2 - 60	Station #9	250	275	800
10 - #1 - 20	Station #10	43	51	1500
10 - #2 - 60	Station #10	250	275	800
10 - #3 - 60	Station #10	250	275	800
10 - #4 - 75	Station #10	151	187	1500
11 - #1 - 60	Station #11	250	275	800
11 - #2 - 60	Station #11	250	275	800
11 - #3 - 60	Station #11	250	275	800
11 - #4 - 60	Station #11	250	275	800
11 - #5 - 20	Station #11	43	51	1500



**Figure 2. Greenleaf's Pump Stations.**

### Pipes

The pipe network that interconnects the pumps and basins is complex. There are over 8.8 km (5.5 miles) of underground distribution pipe. These pipes range in size from 20 to 30.5 cm (8 to 12 in) in diameter. The majority of these pipes are asbestos cement.

There are also approximately 100 km (60 miles) of 1.25 to 10 cm (1/2 to 4 in) diameter irrigation pipe. These above ground irrigation pipes are made of aluminum.

### Drainage Channels

Drainage channels have been constructed along nearly all of the container beds. Most of the channels have concrete bottoms and sides with a few of the older channels having concrete bottoms and wooden sides. These channels direct the irrigation runoff to one of the basins on the nursery. They also reduce the opportunity for runoff to infiltrate.

These components make up the physical aspects of the recycling system. Each component has an important role in the recycling of irrigation and rainfall runoff. They all work together to allow the recycling system to function as it was designed. If one component is unable to fulfill its role, the system will not function properly.

### Why Greenleaf Chose to Recycle

There are several reasons that Greenleaf chose to recycle their irrigation runoff. Economic, legislative, and environmental reasons all played a part in their implementation of an irrigation runoff recycling system. The economic reasons stem from the high cost of raising water from the lake elevation up to the nursery elevation. Increasing pressure from regulatory agencies influenced the nursery to consider alternatives to their previous water management practices where irrigation runoff flowed directly into the Illinois River. The location of the nursery near a popular recreational area makes the nursery an easy target for criticism any time there are water quality

problems (Davis, 1998). The nursery also made voluntary agreements with the Oklahoma State Department of Agriculture concerning irrigation runoff.

### **Challenges for the Recycling System**

Greenleaf has faced many challenges with the construction and implementation of the recycling system. The process of building the retention basins was not an easy task due to the underlying rock that the nursery sits atop. Dynamite was required to blast through the solid rock to allow the basins to provide the necessary water capacity for capturing the irrigation runoff and rainfall runoff for smaller storms.

The terrain has also provided many challenges for the recycling system. The drainage paths are not well defined for all areas of the nursery. This made sizing the basins more challenging. To be successful the system had to provide the storage capacity for the runoff that would flow to each basin. If a basin did not provide the necessary capacity, extra pumping would be required to prevent runoff from leaving the nursery.

As previously mentioned, pathogens are a major concern for the recycling system. If pathogens create a situation that causes the recycling system to be harmful to the health of the plants being produced, other alternatives must be considered.

## **Chapter 4**

### **WaterCAD Description**

WaterCAD, version 3.1, is a computer program that helps engineers design and analyze complex pressurized piping systems (WaterCAD, 1998). One of the specific uses of WaterCAD is to perform extended period simulations to analyze the piping system's response to varying supply and demand schedules. This software was selected because it fit the need for this project, which is to simulate the hydraulics of the runoff recycling system at Greenleaf for an extended period of time. Consideration was also given to the fact that WaterCAD had a user-friendly interface that was relatively simple to understand and use. Upon completion of this project, the computer model will be given to nursery personnel for use at the nursery. This made the user interface an even more important factor.

Several elements are required in the development of a model using WaterCAD. The hydraulics of the nursery involve basins, reservoirs, pumps, and pipes. Each element requires input of basic parameters. These parameters are entered into the model one time and remain constant throughout the operation of the model.

## **Basins (Tanks)**

WaterCAD does not have a basin element per se, so the basins had to be modeled as tanks. Within the model, tanks are a type of water storage node. As water leaves or enters the tank, the water level changes. Measured water levels in the basins were to be used to eventually validate the model, so tanks were selected to simulate the basins since they allow the water level to change. To reduce confusion, tanks will be referred to as basins from this point forward.

There are several input parameters necessary for adding a basin to the model. These parameters include a basin label, its planimetric location, shape, average area, inactive volume, and the basin operating range. The depth of water in the basins can be monitored as either specific elevation or water level relative to the base elevation. Due to the relatively small operating ranges of the basins, the basins were modeled as having vertical sides. This means that the surface area is assumed to be constant throughout the operating range.

The basin names defined by the nursery were used as the basin labels. These labels were chosen to help in communications with nursery personnel, and to make the transfer of the model to nursery personnel less difficult. The planimetric location is the x, y, and z coordinates of each basin. The shape of the basin must be defined as either circular or non-circular. All of the basins were defined as non-circular.

The basin operating range parameter has four components. These are the maximum, initial, minimum, and base elevations. The maximum elevation is defined as the overflow point for the basin. For Greenleaf, this was the level of the weir exits or culvert exits from the basins. The initial elevation is the water level elevation on the first



day of the modeling period. The minimum level is the lowest point at which water can be pumped out of the basin. It is the depth at which the intake pipe for the pump ends. The base elevation is the approximated elevation of the bottom of the basin.

### **Reservoirs**

In WaterCAD, a reservoir is a second type of storage node. The difference between a reservoir and a basin is that the water level in a reservoir remains constant as water flows into or out of the reservoir. Reservoirs are used to represent several water resources in the modeling process. The first purpose is to represent the Illinois River at the two floating pump stations located on the river. Small basins that have a relatively constant water volume can also be modeled as reservoirs. Reservoirs can also be used to receive or provide water for various needs with specialized models such as this one.

The parameters required for adding a reservoir to the model are a label, its location, and hydraulic grade line. Labels were selected for the reservoirs with input from nursery personnel. The location for a reservoir requires only the x and y coordinates. The hydraulic grade line is the water surface elevation.

### **Pumps**

The next elements to be added to the model are the pumps. Pumps are used to deliver water from one location to another. This element requires the entry of several parameters. As with the basins, each pump requires a label, location, and elevation. Several options are available for the type of pump to be used. For this project, the

standard three point type pump was selected. Information needed for this type of pump included shut-off, design, and maximum operating head, and design and maximum operating discharge. This information is used to define the pump curve based on three points. These points are the shut-off head (pump head at zero discharge), the design point, and the maximum operating point (the highest discharge at which the pump performs predictably). Initial settings, “on” or “off”, for the pump are entered using the pump tools.

The pump tools also include the control data input screen. Controls are the commands that turn each pump on and off during a modeling period. The control input screen is used to enter the time that the pumps are turned on and off during the day. The model does not have an efficient method of entering the control data. Each control must be entered individually for each pump. One control operation was required to start the pump and a second control was necessary to turn the pump off.

## **Pipes**

The final elements to add to the model are the pipes. They are added last because each pipe end must be connected to other elements. Pipes are used as connections between any two elements in the model. To add a pipe to the model, the pipe tool is selected. Then it is simply a matter of selecting the elements that are to be connected by the pipe. Pipes require only a few inputs: pipe material, diameter, length, and minor losses. WaterCAD provides a drop down menu with several pipe materials. The pipe materials used at Greenleaf are available on this menu. The pipe diameters are the inside diameter for the pipe. The pipe lengths and minor losses were estimated based on

information provided by the nursery. Another useful option in this tool is the “user defined length” option. This allows the user to enter the length of the pipe. The pipe roughness factor can be entered manually, or values programmed into the software for selected pipe materials can be used. WaterCAD uses pipe roughness factors to internally calculate energy losses due to friction using the Hazen Williams Equation. This is the most frequently used method of determining losses related to friction for design and analysis of pressure pipe systems for water distribution (WaterCAD, 1998).

## **Chapter 5**

### **Model Input**

Greenleaf covers a large area of land and has various pipes, pumps, and basins scattered throughout the nursery. Knowing the location of each element of the water distribution network is essential to the development of the computer model. By entering the exact locations for model components, the model can be "to scale". This should improve the operation of the model. The best way to achieve this goal was to use the Global Positioning System, GPS.

#### **Global Positioning System**

GPS was developed by the U.S. Department of Defense (Hurn, 1989). This system is used to determine the locations of points on the earth based on twenty-one satellites orbiting our planet. Satellite ranging determines the distance from the satellite to the GPS equipment. Knowing the distance to three satellites provides the system with enough information to determine the location to one of two points in space. A fourth satellite range is used to determine which of the two points is the correct location on the Earth's surface.

The operation of the GPS is based on the time that it takes for a radio signal from the satellite to reach the equipment. Since radio waves travel at a known rate of 186,000 miles per second, the speed of light, the distance to the satellite can be determined mathematically. Using this method of data collection provides enough information to determine the location of the point to within a few meters. However, differential GPS, DGPS, can improve the accuracy of the locations even further.

The GPS unit used, Trimble Model 4000, is owned by the Department of Plant and Soil Sciences at Oklahoma State University. Its accuracy is within 0.01 meters in the x-, and y- directions, and within 0.02 meters for the elevation.

In differential mode, fifteen minutes of data are collected at a stationary location. A complex computer program is used to analyze this data and define the exact location of that point to within a few centimeters. Knowing the location of a few control points throughout the nursery allows for very accurate surveying of the entire nursery grounds. Roving data can be collected based on the accurate locations of the control points.

### **GPS Data Collection**

The preliminary work required for collecting the GPS data included a scouting trip to the nursery. During this trip, several days were spent walking the nursery and determining what locations needed to be surveyed. Specific points were recorded to insure that all of the necessary points would be surveyed during the data collection process. The points were recorded in a notebook and then a data sheet was prepared showing each of the desired points.

The first step in gathering the GPS data was to select locations for a benchmark and control points. These locations are critical for the success of gathering GPS data. The GPS unit works on a line-of-site rule. The roving unit must be able to "see" the stationary unit to be able to collect data. The stationary unit is set up at benchmark and control points. All critical locations must be within the line-of-site of one of the control points.

All of the control points are established based on a single selected point at the nursery, the benchmark (shown by an "x" on Figure 1). The establishment of the control points was a simple process. The stationary unit was set up on the selected benchmark location, a central point in the nursery. The benchmark used in this project was a concrete cylinder that was made to be a permanent marker. The center of the cylinder has a screw inserted so that the center will be easy to locate. This cylinder was buried in the ground so that only the top was visible. It was located on a small section of land that serves as an erosion control area that is not likely to change for many years. Setting up this unit involved placing a surveying tripod over the benchmark point and placing the GPS receiver atop the tripod. The roving receiver was then transported to the location of a control point and set up. The same procedure was used to set up this unit. Once the roving receiver was in place, a static survey was started on both units. The two units must collect data simultaneously for at least 15 minutes. After collecting data for 15 minutes, the roving unit is dismantled and moved to the location of the next control point being established. This procedure was repeated until data had been collected at all of the control points that were necessary.

Processing the GPS control point data was the next step. The collected data were downloaded from the GPS units onto a personal computer. The data were corrected and processed by an experienced GPS technician. Once the processing was complete, the technician provided us with data sheets showing the precise location of the benchmark and each control point that had been surveyed. The information obtained from these static surveys is necessary for the collection of GPS data in the roving data collection procedure.

Collection of the roving GPS data was the most time consuming part of the GPS data collection process. The first step in this procedure was to set up the stationary, base, GPS unit on the benchmark or one of the control points. Using a hand-held data controller, the survey job was configured by entering the information about that point from the printed data sheet. Once the job was configured, the base was started using the data controller. The controller was then disconnected from the base unit.

The controller was then connected to the roving GPS unit. On the data controller, the survey option was selected. Before surveying any points, the unit must be initialized. This tells the roving receiver where it is relative to the location of the base receiver. An initialization board is placed on the tripod with the base receiver. The roving receiver is then connected to the initialization board and initialization is selected on the data controller. The data stored for the roving points that are surveyed are relative to the configured base receiver location. Once initialization is completed, the roving antenna is attached to a range pole. The unit is ready for collection of the roving data.

The roving unit starts in the roving mode, which allows you to walk with the receiver. Once you are at the selected location for the desired data point, the OK button

on the data controller is pressed. This tells the receiver that you are ready to survey a point. The unit is then in static mode. The range pole has a leveling bubble, which is used to ensure that the pole is directly vertical. Once you are satisfied with the level, the OK button is pressed again and the data point is surveyed. The data controller labels each surveyed point, and displays the point label on the screen. This label is recorded on the prepared data sheets that shows all of the points that need to be surveyed from each control point. The data sheet describes the point so that when the data is processed, each point can be matched to the label and can be used in the model. The GPS unit is in roving mode again, and can be moved to the site of the next point to be surveyed. This process is repeated until all of the desired points from that control point are surveyed.

After all of the desired locations were surveyed, the survey is ended using the end survey command on the data controller. The end survey command must be confirmed, so that a survey is not accidentally ended prematurely. The roving receiver is then turned off using the data controller, and the base is turned off using the power button. Then the base unit is moved to another control point and the entire process is started over. Once all of the control points were utilized, the data collection process was complete, and the only remaining step was to process the roving data.

For this project, nine control points were utilized. From those control points, over 350 roving data points were surveyed. The data was downloaded from the data controller using a software package called Trimdata. The output files from the downloading process provided the data label, and the corresponding latitude, longitude and elevation for each of the surveyed points. This information was converted to an x-, y-, and z-coordinate system for use in the model.



The GPS data were utilized exclusively for the locations and elevations for the critical elements of the water distribution network. Every basin, pump, and large above ground distribution pipeline was surveyed and the resulting data were used in the model. The latitude and longitude, along with the corresponding x and y model coordinates and elevation for the benchmark and control points, are shown in Appendix A.

### **Hour Meter Data**

The operation of the pumping network is an integral part of modeling the system. To accurately model the water movement throughout the nursery, it is necessary to know how long each irrigation and distribution pump operates on a daily basis. The most feasible option for recording the daily pump operation times was to install elapsed time meters (hour meters) to the controls for each pump at the nursery.

Most of the pump motors operate on 480 volts, so standard 120-volt hour meters could not be wired to the electrical wiring for the pumps. However, the hour meters were installed on the control switches for each pump because the voltage was only 120 volts at that point for many of the pumps. Yokogawa elapsed time meters model number 240611AAAD were used for locations that had 120 volt controls. For the pumps that had 480 volt controls, Yokogawa model number 240611ACAD elapsed time meters were installed. These meters have 6.35 cm square cases and are nonresetable, which ensures that the meter does not get accidentally reset. The meters have a display that shows the number of hours the pump has operated to the nearest 0.1 hour. The meters were mounted in the control boxes for the pumps, and can easily be read without getting near any high voltage wiring.

One major drawback of using this type of meter was that it does not record the actual times when the pumps start and stop operating. For this project, it was necessary to know how long each pump operated on a daily basis. In order to have the desired data, a nursery employee was assigned the task of reading the hour meters at approximately the same time each day, 9:00 A.M. An example of the data sheet used to collect this data is shown as Figure 3. It was not feasible for the nursery to have someone read the meters on the weekends or during holidays; therefore, the weekly data available for this project were four daily readings, and a single 3-day reading. The four daily readings represent the operation time for each pump from Monday through Thursday of each week. The 3-day reading represents the operation of the pumps from Friday through Sunday.

Figure 3. Pump Station Readings

Time:	
PUMP STATION # 1	
Pump #	Hour Meter Time
1	
2	
3	

Time:	
PUMP STATION # 2	
Pump #	Hour Meter Time
1	
2	
3	
4	

Time:	
PUMP STATION # 3	
Water Level:	
Pump #	Hour Meter Time
1	
2	

Time:	
PUMP STATION # 4	
Water Level:	
Pump #	Hour Meter Time
1	
2	

Time:	
PUMP STATION # 5	
Water Level:	
Pump #	Hour Meter Time
1	
2	

Time:	
PUMP STATION # 6	
Water Level:	
Pump #	Hour Meter Time
1	

Time:	
PUMP STATION # 7	
Water Level:	
Pump #	Hour Meter Time
1	

Time:	
PUMP STATION # 8	
Water Level:	
Pump #	Hour Meter Time
1	

Time:	
PUMP STATION # 9	
Water Level:	
Pump #	Hour Meter Time
1	
2	

Time:	
PUMP STATION # 10	
Water Level:	
Pump #	Hour Meter Time
1	
2	
3	
4	

Time:	
PUMP STATION # 10	
Water Level:	
Pump #	Hour Meter Time
1	
2	
3	
4	
5	

### **Rainfall Data**

Rainfall data are required to estimate the amount of water that must be added to the basins after a rainfall event. The total volume of water is determined based on the area that drains into each respective basin. Rainfall runoff is a significant input into the basins over the modeling period, therefore, accurate rainfall measurements are imperative to the operation of the model.

The nursery has an automated weather station that is mounted on top of a building on the nursery grounds. Included in this weather station is an automated tipping bucket rain gauge. This gauge collects rainfall in 0.0254 cm (0.01inch) increments. Once the gauge has collected 0.0254 cm of rain, the bucket tips over releasing the water. It then is ready to collect another bucket of rain. Information is sent to a computer that records the amount of rainfall that is measured. Since the rainfall recording system is automated, data is available for every day of the modeling period. Daily rainfall records during the time of this project are shown in Appendix B.

### **Irrigation Runoff Recharge**

Irrigation runoff is an important parameter to determine for the model. The runoff flows into one of the retention basins where it is reused for irrigation, or distributed to another basin. The amount of irrigation runoff and its distribution are very important to the model because it is a significant inflow into the basins.

For this study, irrigation runoff was estimated as a percentage of the irrigation water that was applied to the plant beds. The percentage used ranged between 35 and 50% for different areas throughout the nursery. This variation between specific areas was

based on conversations with long time irrigation managers at the nursery, the slopes of the growing beds, and the runoff flow direction on the growing beds.

In order to determine the amount of runoff recharge for each basin, the irrigation areas must be overlaid with drainage areas (shown by dashed lines on Figure 1). A topographic map with both the irrigation areas and the drainage areas was used to determine the distribution of all irrigation runoff. With the drainage and irrigation areas defined, the runoff was estimated using the hour meter pumping data that had been collected. The hours each irrigation pump operated was multiplied by the pump flow rate to estimate the total amount of water applied through irrigation. Then the volume of total applied water was multiplied by the estimated runoff percentage to determine the volume of runoff. This runoff volume was then multiplied by the percentage of the irrigation area that drained to a specific basin.

### **Storm Water Runoff Recharge**

Drainage areas, shown in Table 3, were used to determine the volume of storm water, rainfall and rainfall runoff entering each basin. As with irrigation runoff recharge, storm water recharge was estimated as a percentage of actual rainfall, ranging between 40 and 50% for different areas. The depth of rainfall measured at the weather station was assumed to be constant for the entire nursery and the off-site drainage area. Off-site rainfall drainage areas for Basins 17D, 1H, and 15E were estimated based on conversations with nursery personnel. The drainage areas were multiplied by the depth of rainfall to get a volume of rainfall for each drainage area. The estimated rainfall runoff

percentage was multiplied by the total volume of rainfall for that drainage area to get the total rainfall runoff volume for each basin.

**Table 3. Storm Water Drainage Areas.**

Basin #	On-site Drainage Area (ha)	Off-site Drainage Area (ha)
26G	30	0
15 E	52	38
17 D	22	10
9D	18	0
1H	2	11

## **Chapter 6**

### **Model Development**

A strategic plan must be followed to develop a model using WaterCAD. A specific hierarchy must be observed. Basins and reservoirs must be added first. These are added first since the locations of other elements are dependent on them. Pumps are then added near the basin or reservoir on which they are located. Pipes are the final elements added to the system. They are the connecting pieces for the pumps and water bodies.

#### **Basins**

There are seven retention basins in operation at Greenleaf. However, only five were modeled as basins. The two concrete temporary storage basins were modeled as reservoirs, which will be discussed in the following reservoir section. Basins 1H, 17D, 9D, 15E, and 26G were added to the model. The input parameters for each basin are shown in Table 4. The GPS data were used for the locations of the basins. The X and Y locations represent the approximate center of the basins.

**Table 4. Basin Input Parameters.**

Basin Label	B1H	B26G	B9D	B17D	B15E
X Location (ft)	2,000	3,291	2,026	1,200	4,119
Y Location (ft)	5,700	3,188	4,265	4,200	3,675
Base Elevation (ft)	625	490	540	573	486
Max. Level (ft)	13.0	13.5	13.6	15.0	13.5
Min. Level (ft)	5.0	2.0	5.0	5.0	3.5
Average Area (ft <sup>2</sup> )	13,000	37,000	25,000	102,000	70,000

### Reservoirs

Reservoirs were added after the basins. One reservoir was added at the locations of the floating pump stations on the Illinois River. These two reservoirs were labeled River1 and River2. These are the only actual reservoirs at the nursery.

Basin 7A and Basin 5B were also modeled as reservoirs. They were modeled as reservoirs because they are very small compared to the other basins, and they are not designed to store water for an extended period of time. They simply capture runoff and deliver it to Basin 26G. Modeling these two basins as reservoirs simplifies the model and greatly reduces input requirements, making the model easier to use upon delivery of the model to Greenleaf personnel at the end of this project.

Additional “artificial” reservoirs were added to the model. These reservoirs served two purposes in the model. They receive irrigation water, and provide a source of water for irrigation runoff and rainfall runoff that must be “pumped” into each basin. Two reservoirs were added near each basin, one to provide irrigation runoff and the second to provide rainfall runoff. Since the model was developed to scale, seven reservoirs were required at various locations throughout the nursery to collect irrigation



water at the ends of irrigation pipes. These reservoirs only collected the “non-runoff” portion of the irrigation water.

### **Pumps**

Pumps were added after the basins and reservoirs. The 27 pumps used at the nursery were added first. Two pumps were removed from Float #1, and three pumps were removed from Float #2. This was done to simplify the model and reduce the required input. Removing these pumps had no effect on the operation of the model because they were for irrigation only. Since they pumped water from one reservoir to another, they did not change the model results at all. That left each floating station with one pump that moved water directly from the Illinois River into a basin on the nursery. These pumps were included in the model to account for the additional water entering the basins. GPS data was available for each pump location. The nursery provided pump characteristics for each pump, shown in Chapter 3. This information was entered into the model at this point.

A pump was added near each of the irrigation and rainfall runoff source reservoirs. A single point operating type pump was used for this application. They provide a known constant flow rate while they are operating. The purpose of these pumps is to add water to the nursery basins to simulate the actual runoff the basins capture during an irrigation or rainfall event. The initial setting for every pump was in the off position. Pump controls were added later to control the operation of the pumps.

To determine the operating point of the pumps, an ultrasonic flow meter was taken to the nursery and used to measure the flow rate in the pipes. These flow rates were

measured while a “normal” irrigation set was operating for the irrigation pumps. Measurements were also made for the pumps moving water from basin to basin. The model, when operated in steady-state mode, shows the pumps’ flow rates. These flow rates were compared with the ultrasonic flow rates to make sure the model accurately simulates the nursery system. The ultrasonic flow measurements are shown in Appendix C. These measurements were made since a small error in the flow rate for pumps could make a significant error in the model results. Table 5 shows the water level errors associated with a 10% error in the pumping rates, determined based on the average daily pumping volume for each basin.

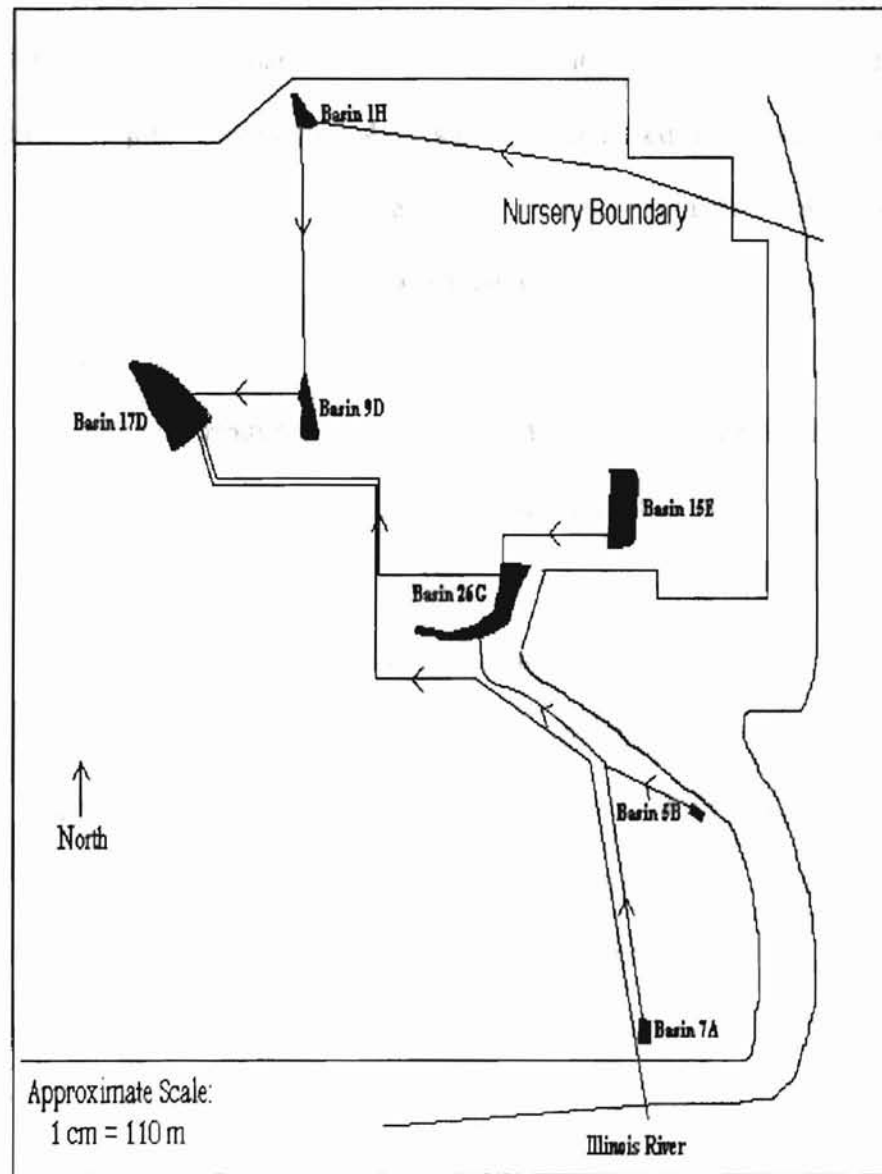
**Table 5. Water Level Error Associated With 10% Pumping Volume Error.**

Basin	Water Level Error Associated With 10% Error in Pumping Volume (ft)	Average Volume Pumped (gal/day)
17D	0.11	836,000
1H	0.29	265,000
9D	0.18	330,000
26G	0.60	1,642,000
15E	0.23	1,280,000

### **Pipes**

Pipes were the final element added to the model. They were relatively easy to add since the basins, reservoirs and pumps were all in place. A simple point and click process is used to add pipes to the model. Pipes were added by selecting the pipe tool icon. After “clicking on” the pipe icon, the two elements that the pipe is “connecting” are selected by clicking on them one at a time. The pipe materials used at the nursery were asbestos cement, PVC, and aluminum. Inside pipe diameters were also entered on this screen.

WaterCAD allows for adding bends to pipes that are not straight from one element to another. This allows the model to more accurately simulate the actual system at the nursery. With the addition of the pipes, the physical model is completed. The basin pipe interconnections are shown in Figure 4.



**Figure 4. Basin Pipe Interconnections.**

### **Modeling Period**

With all of the elements added to the model, it was ready for operation. The only additional information required to operate the model is the pump control times. Before entering controls, the appropriate modeling period must be defined.

Determining the most appropriate modeling period is vitally important to the success of the model. One consideration was that the nursery could be interested in projecting their pumping operations 1-4 days in advance based on weather forecasts for the area. A second consideration was to effectively utilize the pumping data that had been collected. Since weekend readings were not available, there was a three-day period where operating times were unknown on a daily basis. This would require making assumptions about the distribution of the operating times. There were daily readings available for four days for most weeks, and three days for a few weeks. Taking this into consideration, the modeling period was chosen to be four days. As a result of the method of data collection, the four consecutive daily readings each week were used and the three-day reading between Friday a.m. and Monday a.m. was not used for model testing.

Pumping data were available for every weekday excluding holidays for the period from August 17, 1998 through October 30, 1998. The pumping data were separated into eleven weekly data sets. Eight of the weeks had four consecutive daily readings. Due to holidays, three weeks had only three consecutive daily readings. These three and four consecutive daily readings were used to perform eleven "weekly" analyses using the model.

### **Irrigation Pump Controls**

The pump controls were the final input before running the model. Since a majority of the irrigation occurs during the morning time, the irrigation pump controls were turned on at 7:00 A.M. The hour meter data was used to determine how long each pump operated between consecutive daily readings. A second control was added to each pump to turn it off after operating the appropriate length of time.

The model operates based on a specified number of hours. Since we were interested in modeling the water levels on a daily basis, we had to adapt the available data to the format required for the model. Day one of the modeling period corresponds to 0-24 hours for the model. Day two of the modeling period corresponds to 24-48 hours within the model. Day three represents 48-72 hours and day four 72-96 hours. For day two of the modeling period, the "on" time is 31 hours, representing 7:00 A.M. on model day two. Controls were entered in this manner for each pump for each day of the modeling period.

### **Irrigation Runoff Pump Controls**

Runoff controls were entered following a procedure similar to that for irrigation controls. The "on" control was set for 7:30 A.M. daily to provide a short delay between the beginning of an irrigation event and runoff returning to the basin as a result of that irrigation event. The length of time these "pumps" operate was determined based on the calculated runoff volumes and pumping rate for that irrigation runoff pump. The pumping rates were set at 500 gpm for the smaller basins and 2000 gpm for Basin 17D and 15E.

### **Storm Water Runoff Pump Controls**

Storm water runoff pump controls were entered in the same manner as the irrigation runoff controls. Since the time of the rainfall event was known, it was used as the "on" time for the pumps. Pumping rates for rainfall runoff were set at 1500 gpm for the smaller basins and 4800 gpm for the larger basins, Basins 17D and 15E. The "off" time was determined by the length of time the pump needed to operate, based on the set pumping rate and estimated rainfall runoff volume for each basin.

The amount of rainfall runoff was assumed to be 40 to 50% of the total amount of rainfall. This assumption introduced a source of error for the modeling, because it remained constant despite the depth of rainfall. A small rainfall event would likely result in a lower percentage of runoff, and larger events would have a larger percentage of runoff. A SCS curve number approach (Haan et. al, 1994) was evaluated, but the results were not reasonable. The poor performance of the curve number approach was likely due to the fact that the ground at the nursery is wetted every day by irrigation. Thus even small rainfall events cause runoff to occur.

### **Special Case – Pump Operation**

The two pumps located on the Illinois River are more complicated than the other pumps used at the nursery and must be treated as a special case. These pumps are used for two purposes. Based on an estimate from nursery personnel, these pumps deliver water directly to a basin 35% of the time that they are operating. The remaining 65% of the time they operate is for irrigation of nursery plants. To account for this in the model,

the hour meter data is multiplied by 35%. This value is used in the model's pump controls to operate the pump for the appropriate length of time.

The remaining water must be accounted for to keep the water balance in check. This volume of water, multiplied by the appropriate runoff percentage, is added to the nursery model as irrigation runoff recharge. The non-runoff portion of the irrigation volume has no impact on the model since this water is being moved from one reservoir (the Illinois River) to another (an artificial reservoir receiving irrigation water).

Although there are only two pumps that are operated in the model based on this estimate, it has a significant impact on the model results. These pumps deliver a large volume of water to their two receiving basins. The uncertainty in length of time the pumps serve each purpose directly influences the results for two basins, making it vitally important that the estimate is accurate.

## **Chapter 7**

### **Model Output, Validation, & Application**

The WaterCAD model provides an output screen that includes the status of each pump, and the water level in each basin for each time step of the model. The output information of interest in this study is the water level in each basin at the beginning of each modeling day. The water level in the basin tells us how much water is available for irrigation use. The model also gives output information for each intermediate change, i.e. each time a pump is turned on or off, during the modeling period. These items are found in the hydraulic status section of the output (Figure 5). Shown are the status of all pipes, pumps, and basin water levels in the model at that specific time. The basin water levels are used for the validation of the model.



**HYDRAULIC STATUS:**

Hydraulic status at 0.00 hr

Balanced Trials = 4, Accuracy = 0.000243

Flow Supplied 190.2 gpm

Flow Demanded 0.0 gpm

Flow Stored 190.2 gpm

B17D Tank: Closed Or Stagnant, Tank Level = 14.5 ft

B26G Tank: Closed Or Stagnant, Tank Level = 13.5 ft

B15E Tank: Closed Or Stagnant, Tank Level = 13.7 ft

B1H Tank: Closed Or Stagnant, Tank Level = 12.8 ft

RIVER Reservoir: Closed Or Stagnant

Irrig. Coll. 9 Reservoir: Closed Or Stagnant

RO Recharge Bas Reservoir: Closed Or Stagnant

Irrig Coll #5 Reservoir: Closed Or Stagnant

B9D Tank: Closed Or Stagnant, Tank Level = 13.5 ft

Irrig.Coll.#5 Reservoir: Closed Or Stagnant

Irrig.Coll.#6 Reservoir: Closed Or Stagnant

Irrig.Coll.Stat Reservoir: Closed Or Stagnant

RO Recharge S#3 Reservoir: Closed Or Stagnant

RO Recharge S#6 Reservoir: Closed Or Stagnant

RO Recharge S#4 Reservoir: Closed Or Stagnant

RO Recharge S#9 Reservoir: Closed Or Stagnant

Irrig.Coll.#3 Reservoir: Closed Or Stagnant

Irrig. Coll. #1 Reservoir: Closed Or Stagnant

Rain1 Reservoir: Closed Or Stagnant

rain2 Reservoir: Closed Or Stagnant

Rain3 Reservoir: Closed Or Stagnant

Rain4 Reservoir: Closed Or Stagnant

rain5 Reservoir: Closed Or Stagnant

B7A Reservoir: Closed Or Stagnant

B8B Reservoir: Closed Or Stagnant

10-#4-75 Pump: Off

7-#1-30 Pump: Off

8-#1-15 Pump: Off

10-#1-20 Pump: Off

9-#1-60 Pump: Off

9-#2-60 Pump: Off

10-#3-60 Pump: Off

10-#2-60 Pump: Off

2-#3-125 Pump: Off

11-#5-20 Pump: Off

11-#2-60 Pump: Off

11-#1-60 Pump: Off

RO-B26G Pump: Off

RO-B15E Pump: Off

RO-B17D Pump: Off

RO-B1H Pump: Off

3-#1-60 Pump: Off

3-#2-60 Pump: Off

6-#1-25 Pump: Off

RO-B9D Pump: Off

11-#3-60 Pump: Off

11-#4-60 Pump: Off

4-#1-60 Pump: Off

4-#2-60 Pump: Off

5-#2-60 Pump: Off

5-#1-60 Pump: Off

Rain-1H Pump: Off

Rain-9D Pump: Off

Rain-17D Pump: Off

Rain-15E Pump: Off

Rain-26G Pump: Off

1H-Overflow Pump: Off

9D-Overflow Pump: Off

**Figure 5. Hydraulic Status Section of Model Output.**

It is important to be able to understand the output screen and know what information it is showing. For instance, the line showing "B15E Tank: Closed Or Stagnant, Tank Level = 13.7 ft" means that the water level in Basin 15E is 13.7 ft. This output screen also gives the status, "on" or "off", of each pump in the model. The status of every element in the model is given in this output screen.

Although the hydraulic status screen shows a significant amount of information, only a small portion is needed for the model validation. The "tank level" for each of the five basins is the information that is used to evaluate the model. That portion of the output was copied to Microsoft Excel to compare with the actual measured water levels for the model validation.

### **Model Validation**

Having a model that operates means little if you are not able to evaluate the performance of the model. For this project, the method selected for evaluating the performance of the model was to compare the actual basin water levels with the calculated water levels from the model output. The actual basin water levels were measured daily at the same time the hour meter readings were recorded. Water levels for each basin were available for every day that hour meter readings were recorded.

Modeled water levels were computed for each day of the modeling period for the eleven weekly model runs. The model output was arranged in Microsoft Excel along with the measured water levels. The comparison of the modeled and observed water levels was done by plotting a time series of the modeled and observed water levels. A second way of looking at the data was to plot the modeled water levels versus the

observed water levels, and calculate the associated regression statistics. These comparisons will be an indicator of how well the model simulates the hydraulic system of Greenleaf Nursery.

### **What-if Scenarios**

The main potential application for this model will be to perform what-if scenarios for the nursery. This will provide nursery managers a valuable tool in determining what irrigation and pumping practices to use during certain extended weather conditions. Weather predictions can be considered to estimate approximately how much irrigation water must be applied to maintain the health of the crops. By entering this information into the model, they will know how much water to expect to be in the basin the following day. With this knowledge, they will know if they need to add fresh water from the river to replenish the basin.

### **Storm Water Capacity**

The model can be used to estimate the amount of storage available in each basin for capturing storm water runoff. If Greenleaf is expecting a storm, basins can be pumped down during the days prior to the rainfall. This would enable them to capture more of the rainfall runoff, and reduce the amount of water that must be pumped from the river. This would provide a significant financial saving since the rainfall runoff costs nothing to capture, but pumping water from the river is expensive.

### **Public Relations Value**

The model will also provide the nursery with some valuable information to share with the public. They will know how much river water is brought onto the nursery. They will also be able to state that they have recycled X gallons of water during the main irrigation period. Without the runoff recycling system, all of the irrigation water would be pumped from the river. Keeping in mind that all of the recycled runoff would be discharged to the Illinois River without the recycling system, they will be able to state that they have reduced their discharge to the river by Y gallons as a result of their system. This information demonstrates to the residents of the surrounding communities just how serious an effort Greenleaf is making toward maintaining the quality of the water in the Illinois River.

### **Additional Model Value**

The model input data were also used to determine the amount of irrigation water that was available at different stages for each basin. This information can also be used to estimate how much storm water runoff can be held based on the available storage capacity in the basin. This can be used in the water management plan to optimize water resources and potentially save money on irrigation costs. The stage-storage relationships are shown for each basin in Appendix D. These relationships are based on the water levels above the bottom of the pump intake pipe.

## **Chapter 8**

### **Results & Discussion**

#### **Initial Model Testing**

The initial testing process was used to determine if there were any serious problems with the input parameters. The second purpose of the initial testing was to determine if any model components had been overlooked in the process of developing the model that would create inaccuracies in the model performance.

The initial testing of this model was encouraging. However, it was apparent that an important water movement had been omitted from the model. Basins 1H, 17D, and 9D all have the possibility of overflowing and draining into other basins on the nursery. This action had not been accounted for in the initial model. In order to correct this problem, an additional pump was added near each of the three basins. Pump controls had to be added to turn the pumps on or off at the appropriate times. Unlike the controls used earlier, a water level based control was selected. This type of control turns the pump on or off when a specified water level condition is met in a specific basin. For example, when the water level in Basin 9D reached 1.27 cm higher than the overflow point, the pump was turned on to take water from that basin and deliver it to Basin 26G. Basin 1H required an overflow pump to deliver water to Basin 9D, and Basin 17D needed a pump

to remove overflow water to Basin 26G. A second control was added to turn the pumps off after the water level had dropped below the overflow level. Additional model testing confirmed that the addition of the overflow pumps greatly improved the modeling results.

### **Model Calibration**

Once the initial model testing was completed and the model seemed to be free of major problems and errors, the model had to be calibrated. The input parameter that needed calibration was irrigation runoff percentage. The first calibration effort was to add and subtract 5% to the original runoff percentage. In other words, if the original runoff percentage was 45%, the runoff values used for calibration were 40 and 50%. This was done for each of the 11 sets of weekly data. After completing this procedure, it was evident that the model was not highly sensitive to the runoff percentage because there was very little change in the model output, even for the last day of the modeling period where the changes would have accumulated from the previous days.

A second set of calibration model runs were performed by adding and subtracting 10% to the original runoff percentages. This change had a greater influence on the model output, especially on days 3 and 4 of the modeling period where the daily changes had accumulated to make a substantial difference in the water levels. After completing this set of calibration modeling runs, the initial runoff percentages were selected as the best overall values for the model. Considering that the initial values worked very well in the model and that the model was not highly sensitive to runoff percentage, the initial values (35 – 50%) were used for the final model.

Storm water runoff percentage was also calibrated using the same method as for the irrigation runoff. The initial runoff percentages ranged from 40 to 50% for different areas. Slight adjustments in the runoff percentages were made as a result of the calibration process. The final runoff percentages still range from 40 to 50%.

## **Results**

The model evaluation was done by comparing the modeled water levels to the observed water levels. Two plots were made for each basin. The first plot is a time series plot of the modeled and observed water levels. This plot shows the ability of the model to predict the trends shown in the observed water levels. The second is a plot of the modeled water levels versus the observed water levels. A simple regression line shows the trend of the data. The regression statistics are shown in Appendix E. An additional test was performed to determine if the slope of the regression line was significantly different from one. This test was conducted at a 95% confidence interval.

To relate the modeling error to the average volume of water pumped, bounding lines were added to the second chart for each basin. The bounding lines represent the equivalent depth of water equal to 25% of the average daily water volume pumped from each basin (shown in Table 6). The bounding lines are parallel to the 1:1 line. A basin by basin analysis of the model performance is discussed in the following sections. Additional model performance calculations were made for each basin (see Table 6). The data used to generate the plots shown in this section are located in Appendix F.

Basin 9D. Basin 9D was the most simple basin to model. This basin has only one pump, representing the only outflow from the basin with the exception of when the basin overflows. The only regular inflow into the basin is through irrigation runoff. As expected, the model did simulate the actual water levels very well. A time series plot of the modeled and observed water levels is shown in Figure 6. This figure shows that the water levels predicted by the model followed the same general trends of the observed water levels. The model performed nearly perfectly for week three for this basin.

The model under predicted the water levels for the final three weekly modeling periods. This indicates that the basin was receiving more runoff than the model predicted. One factor that could have caused the model to add less runoff to the basin than what was happening in reality is that the weather conditions changed during this time in such a manner that more runoff was occurring. The time series chart shows there was a very small amount of rainfall recorded several days during this period suggesting that the conditions were appropriate for increased runoff.

The modeled water levels were plotted versus the observed water levels, shown in Figure 7. The 1:1 line shows where the modeled water levels matched the observed levels. There were many points scattered along the 1:1 line indicating that the model performed well for this basin most of the period. One-third of the modeled water levels were outside of the 25% bounding lines. This chart also shows that the model under predicted the water levels at a greater magnitude than when over predictions occurred. Additional information calculated on the results for Basin 9D are shown in Table 6.



## Basin 9D

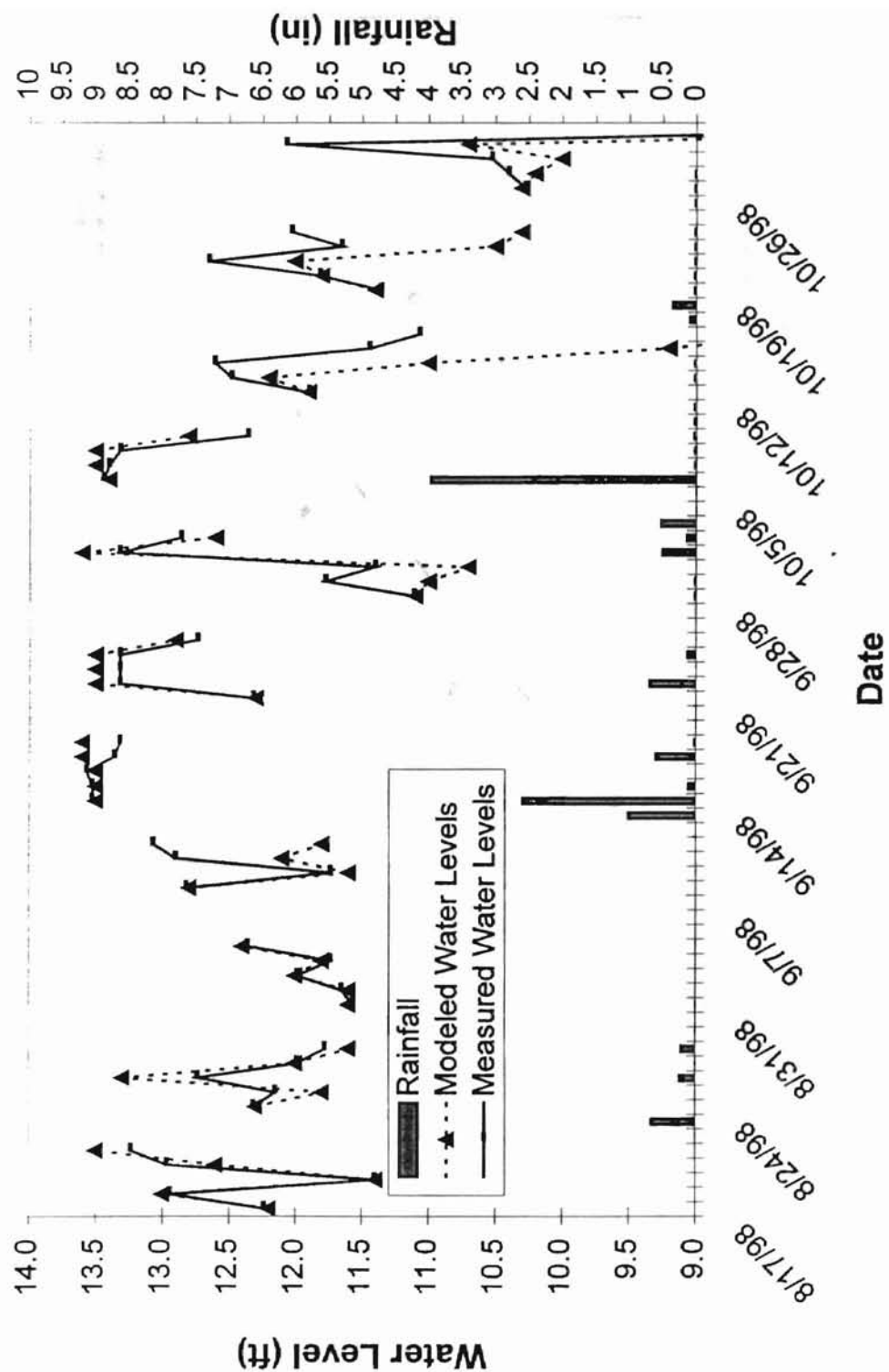
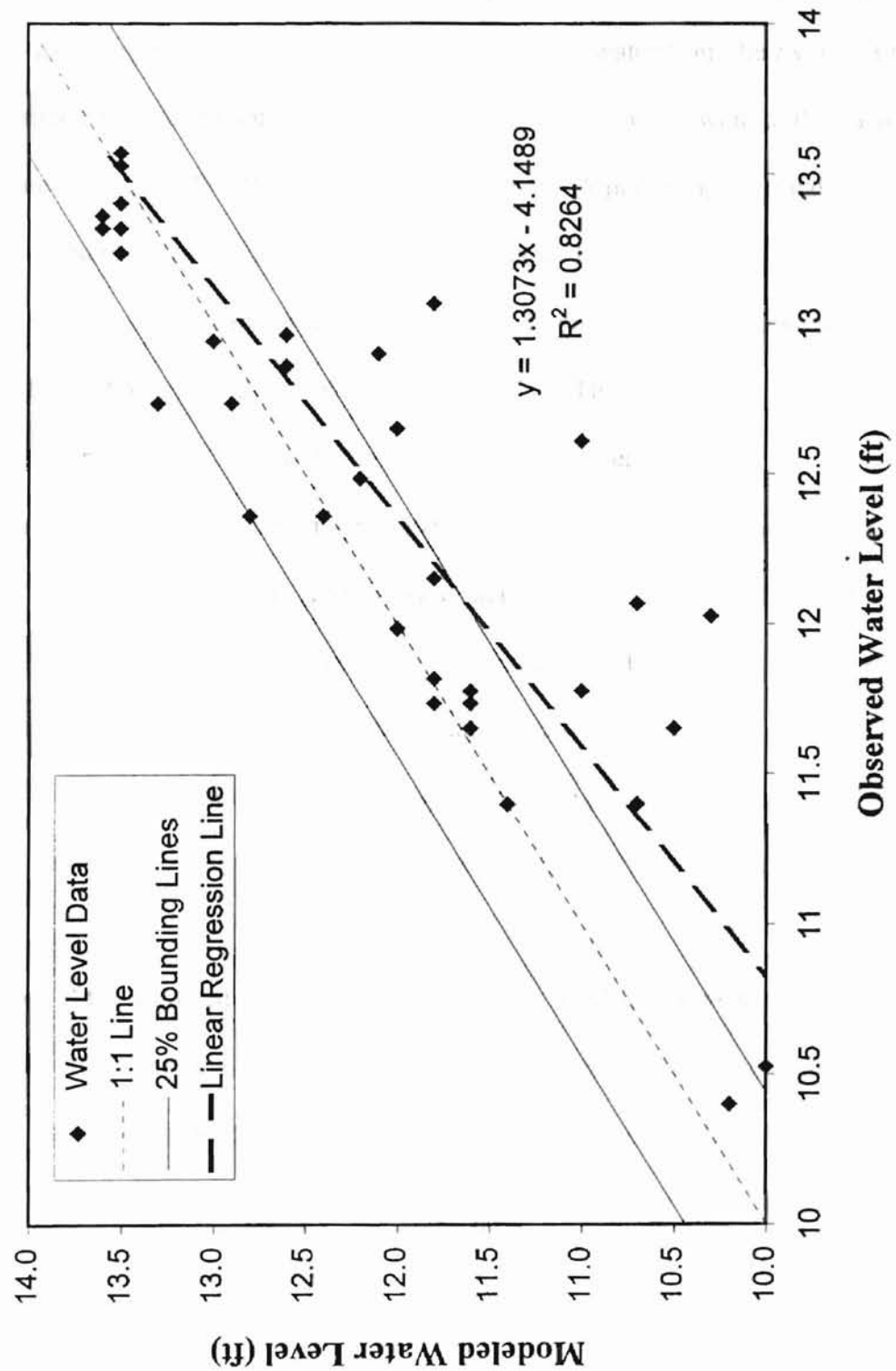


Figure 6. Time Series Plot of Modeled and Observed Water Levels for Basin 9D.

# Basin 9D



**Figure 7. Modeled versus Observed Water Levels for Basin 9D with Error Lines Representing 25% of the Average Daily Volume Pumped from Basin 9D.**

Basin 17D. Basin 17D was also one of the less complicated basins on the nursery, having only four irrigation pumps. This basin does receive water from the river, but the pump hour meter records do not allow one to separate the water that went to the basin from the water that went directly to the irrigation system. A percentage estimate was provided by nursery personnel as explained in Chapter 6. Even with the uncertainty in this estimate, the model performed surprisingly well. Figure 8 shows the time series plot of the modeled and observed water levels for Basin 17D. The model does a good job of predicting the same general trends shown in the observed water levels.

Over predictions in the second and seventh weeks are most likely due to less water being pumped into the basin from the river than indicated based on the estimate provided by nursery personnel. Rainfall also occurred during those two weekly modeling periods. When rainfall occurs, it is less likely that water would be pumped directly into this basin. However, the pump at the river must be used to provide irrigation water for some plants, and the 35% estimate for pumping directly to this basin was used under all conditions.

A plot of the modeled versus the observed water levels is shown in Figure 9. This plot shows that the water level was over predicted more often than under predicted. This was expected since, on some days, no water is pumped from the river to this basin. Although the data falls outside of the 25% bounding lines 20 times during the 42 modeling days, only four occurrences are due to under predictions. Knowing precisely how long and what days water is pumped into Basin 17D from the river would allow for a more strongly validated model.

## Basin 17D

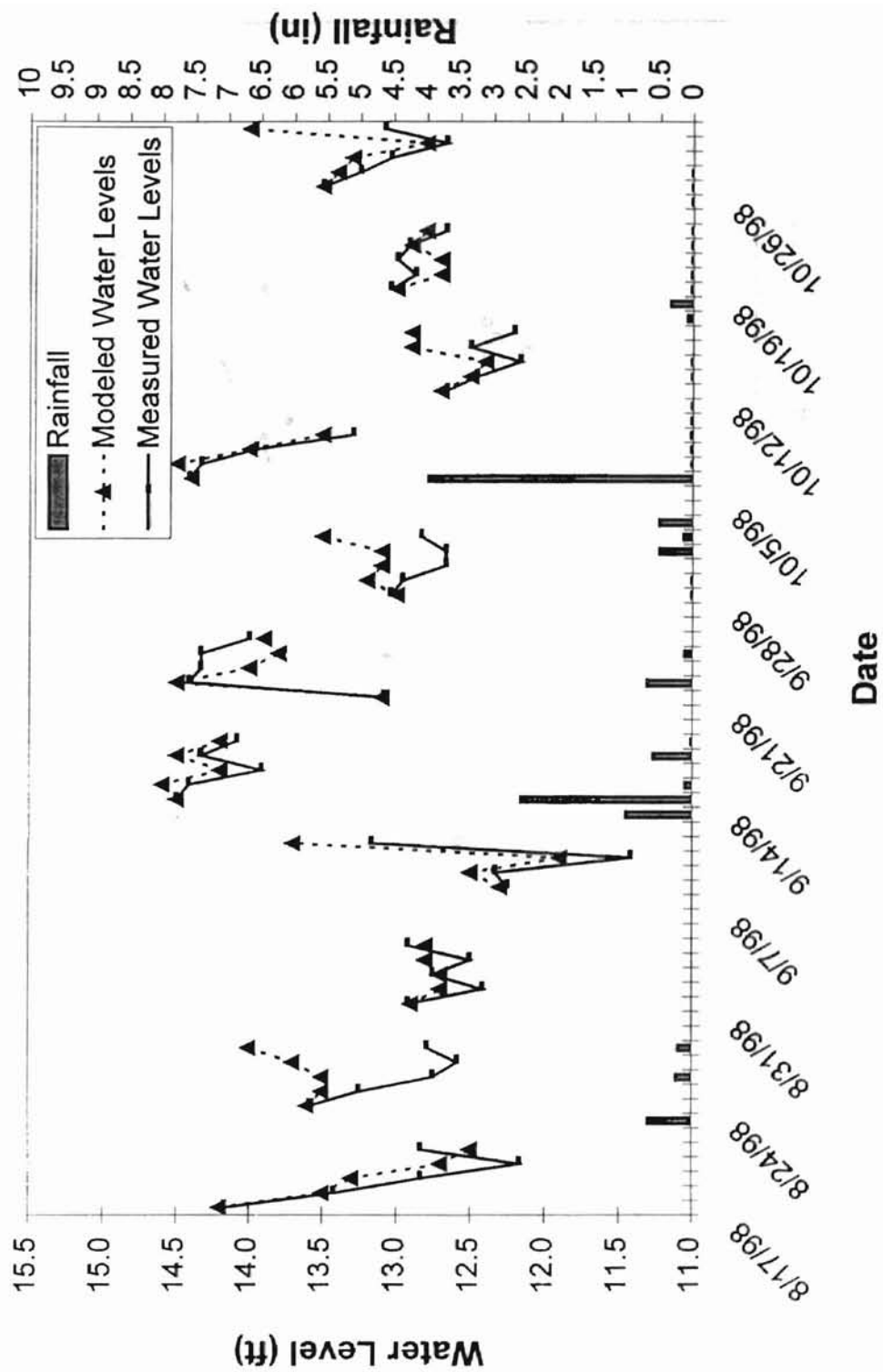
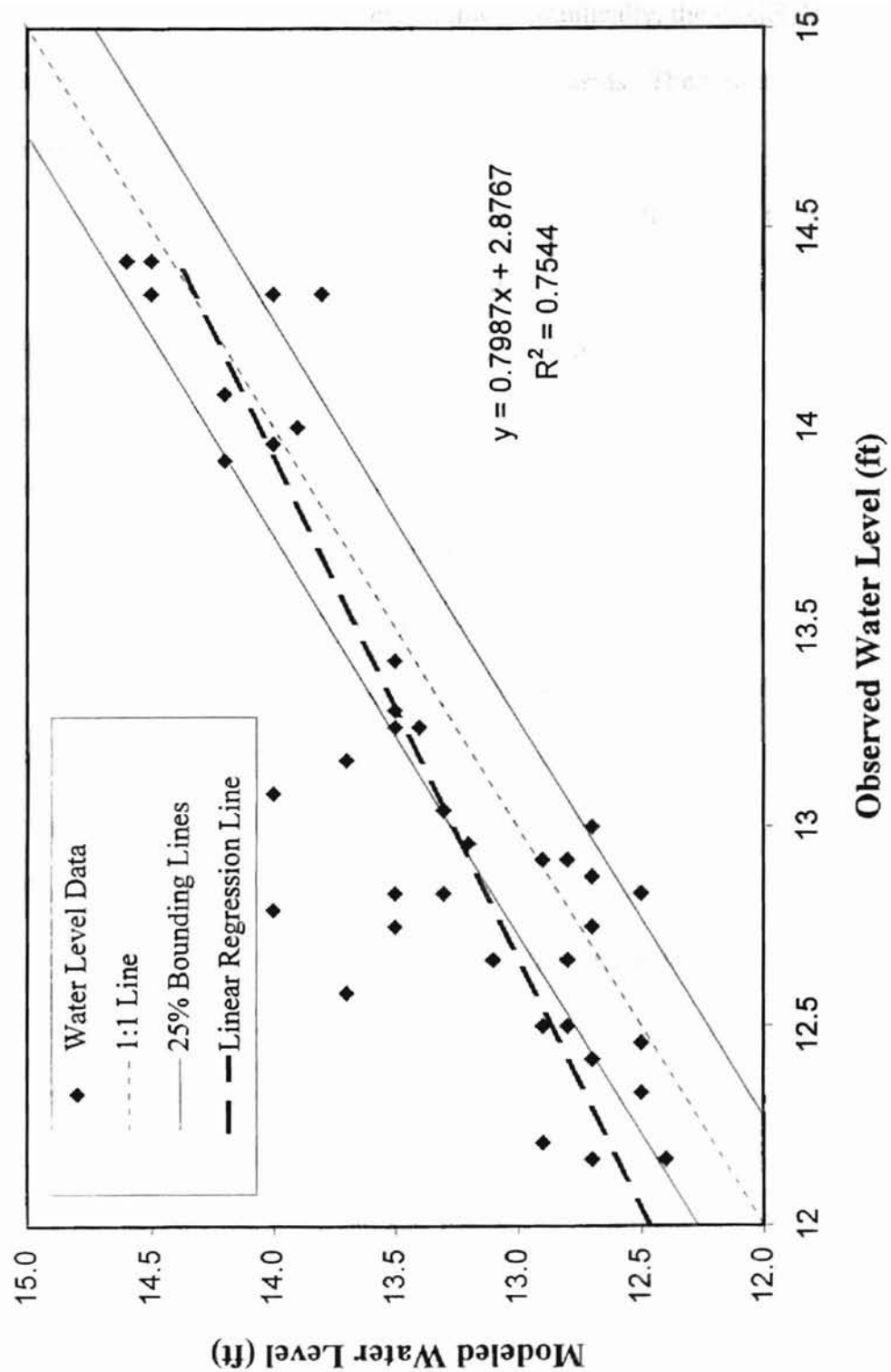


Figure 8. Time Series Plot of Modeled and Observed Water Levels for Basin 17D.

# Basin 17D



**Figure 9. Modeled versus Observed Water Levels for Basin 17D with Error Lines Representing 25% of the Average Daily Volume Pumped from Basin 17D.**

Basin 1H. Although Basin 1H is relatively simple hydraulically, the model does not perform as well as it does for the two previously discussed basins. The best explanation for this poor performance is that, like Basin 17D, this basin also receives water pumped directly from the river as discussed in Chapter 6. The estimated inflow from the river works well for some times, but not as well for other times. A time series plot of the modeled and observed water levels is shown in Figure 10. The two data sets follow many of the same trends.

The modeled water levels drop significantly lower than the observed levels for weeks three and eight. This is most likely due to water being pumped to the basin from the river more than the assumed 35% of the time that the pump operated. Another important consideration for this basin is its relatively small surface area. Although it has larger deviations in water levels, the volume deviations are much smaller than for other basins. For example, Basin 1H is approximately one-half the surface area of Basin 9D, so a water level deviation of one foot in Basin 1H is equivalent in volume to 0.5 feet in Basin 9D. Refer to Table 6 for the statistical analysis of the results data.

The plot of modeled versus observed water levels for Basin 1H (Figure 11) shows that the levels are under predicted more often than over predicted. There are many points scattered along the 1:1 line, but several points are clearly under predicted. One problem that is evident for this basin is that when the water level is markedly under predicted for day two of a model run, the error is included in days three and four, making the model performance seem worse than the actual performance. Less than 15% of the data points are outside of the 25% bounding lines for this basin, all as a result of the model under predicting the water level.

## Basin 1H

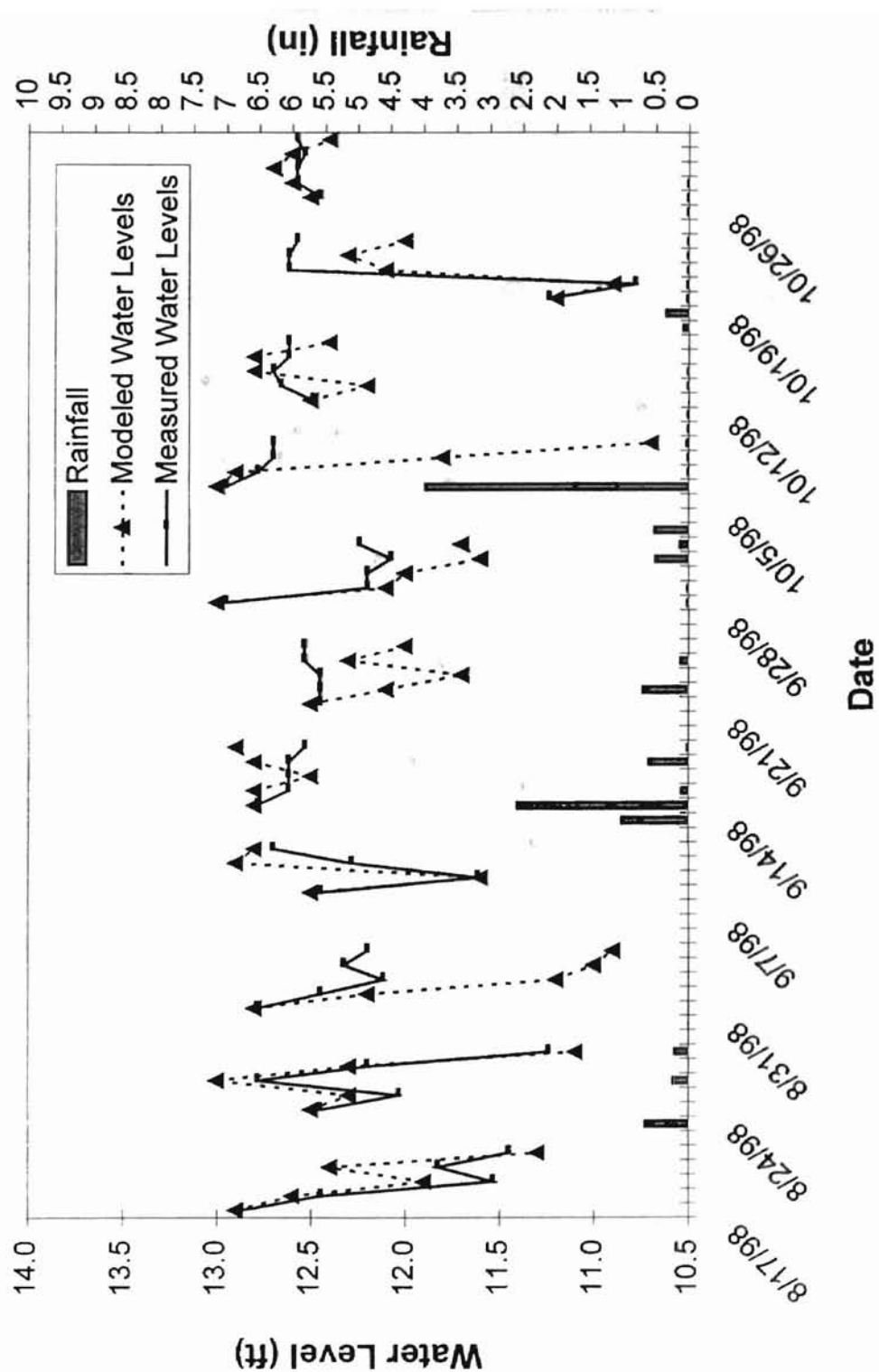
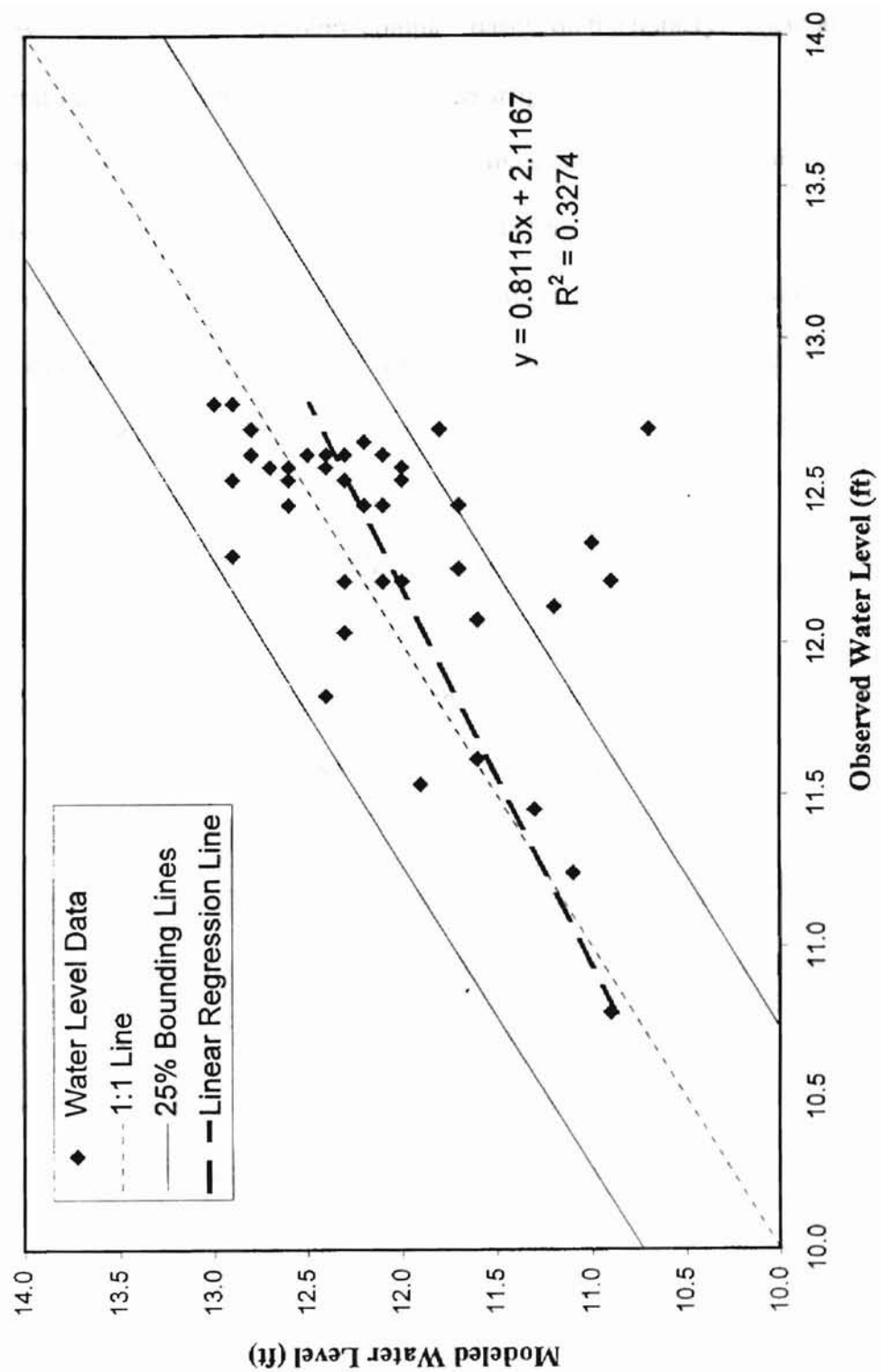


Figure 10. Time Series Plot of Modeled and Observed Water Levels for Basin 1H.

## Basin 1H



**Figure 11. Modeled versus Observed Water Levels for Basin 1H with Error Lines Representing 25% of the Average Daily Volume Pumped from Basin 1H.**



Basin 15E. Basin 15E is one of the more complex basins on the nursery. There are five pumps operating on the basin. This basin receives irrigation runoff from the largest area of any basin, and most of that irrigation water originates in other basins or the river. This basin is also used to irrigate a large area of plants. In terms of inflow and outflow, this is one of the most hydraulically active basins at the nursery. Figure 12 shows the time series plot of the modeled and observed water levels for this basin. The model and observed data follow the same trends for many of the eleven weeks, but the modeled data tends to vary from the observed more often than for the other basins.

According to nursery personnel, this basin is occasionally filled using the pumps from the "Float #2" station. This would explain why the model could have reported low water levels. One period where this appears to be the case is during the ninth modeling week where the water level was getting low and then the observed level increased significantly during a one day period.

Figure 13 shows a plot of modeled water level versus the observed water level. Although the  $r^2$  is slightly greater than that of Basin 1H, more of the data is scattered further from the 1:1 line. The water level prediction errors were much better in terms of the volume of water pumped on a daily basis. Of the 42 modeling days, only once did the error volume exceed 25% of the average volume pumped. The data are fairly evenly distributed in terms of over and under predicting the water level.

## Basin 15E

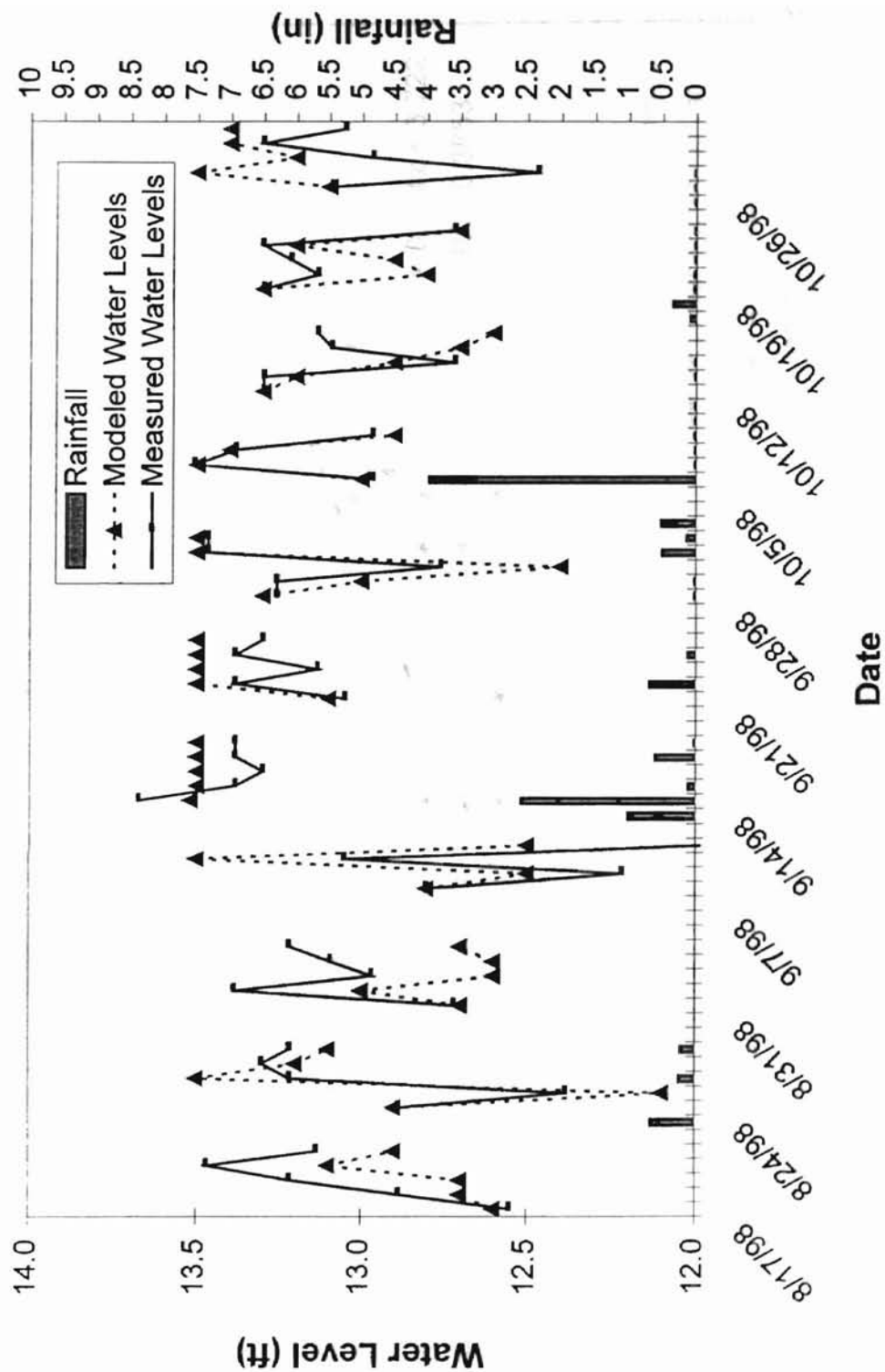


Figure 12. Time Series Plot of Modeled and Observed Water Levels for Basin 15E.

# Basin 15E

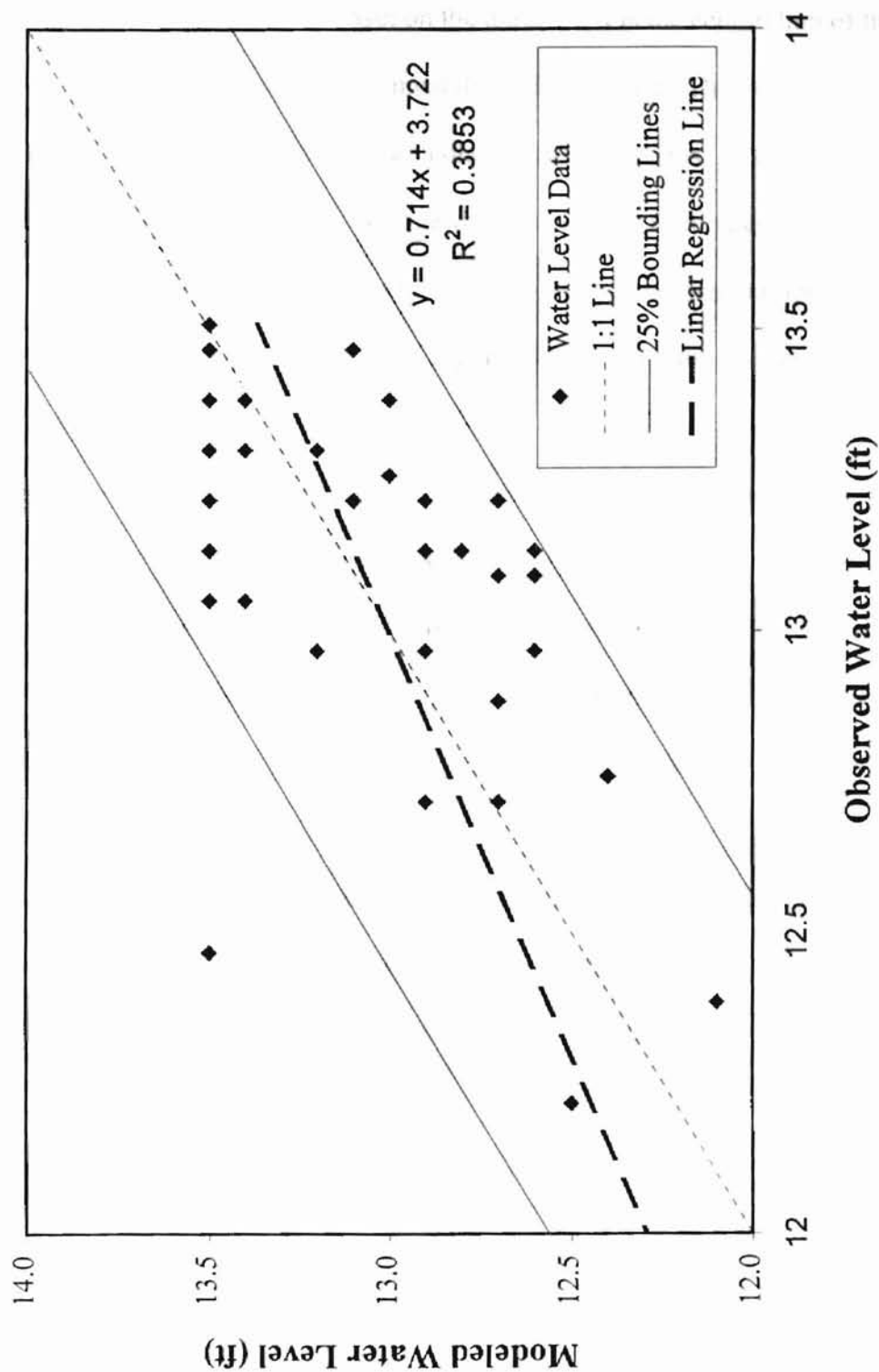


Figure 13. Modeled versus Observed Water Level for Basin 15E with Error Lines Representing 25% of the Average Daily Volume Pumped from Basin 15E.

Basin 26G. This is the most complex basin on the nursery. It is the central hub of the hydraulic system, and was expected to be the most difficult to model. This basin receives runoff from a large area, and water from the two concrete storage basins. It also receives overflow water from Basins 9D and 17D. A large volume of water is pumped into Basin 26G from Basin 15E, and from 26G into Basin 17D. The average volume pumped from Basin 26G is greater than for every other basin. Figure 14 shows the time series plot of the observed and modeled water levels.

The modeled water levels follow many of the general trends shown in the observed data. There are a few instances, such as week two and four, where the trends are not followed. Over the entire modeling period, the model performs reasonably well considering the high turnover rate for the basin. Since there is a lot of pumping activity in the basin, the timing for the hour meter and water level readings have a greater impact for this basin.

As seen in Figure 15, there is a great deal of scatter in the data, and the points are further from the 1:1 line than for any other basin. The  $r^2$  for this basin is 0.240, which is also lower than for any other basin. However, this is the only basin that had none of the data points outside the 25% bounding lines.

## Basin 26G

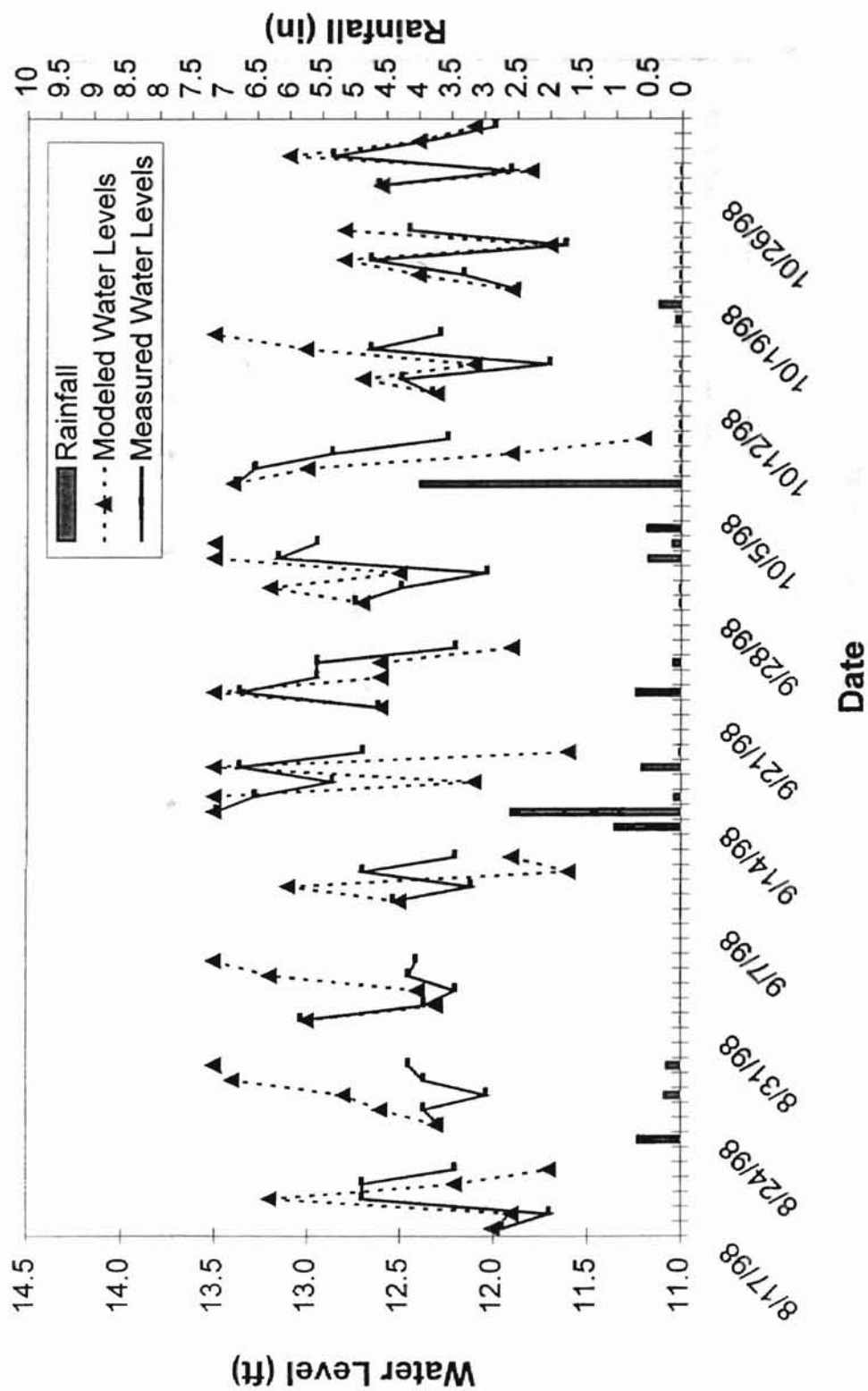


Figure 14. Time Series plot of Modeled and Observed Water Level for Basin 26G.

# Basin 26G

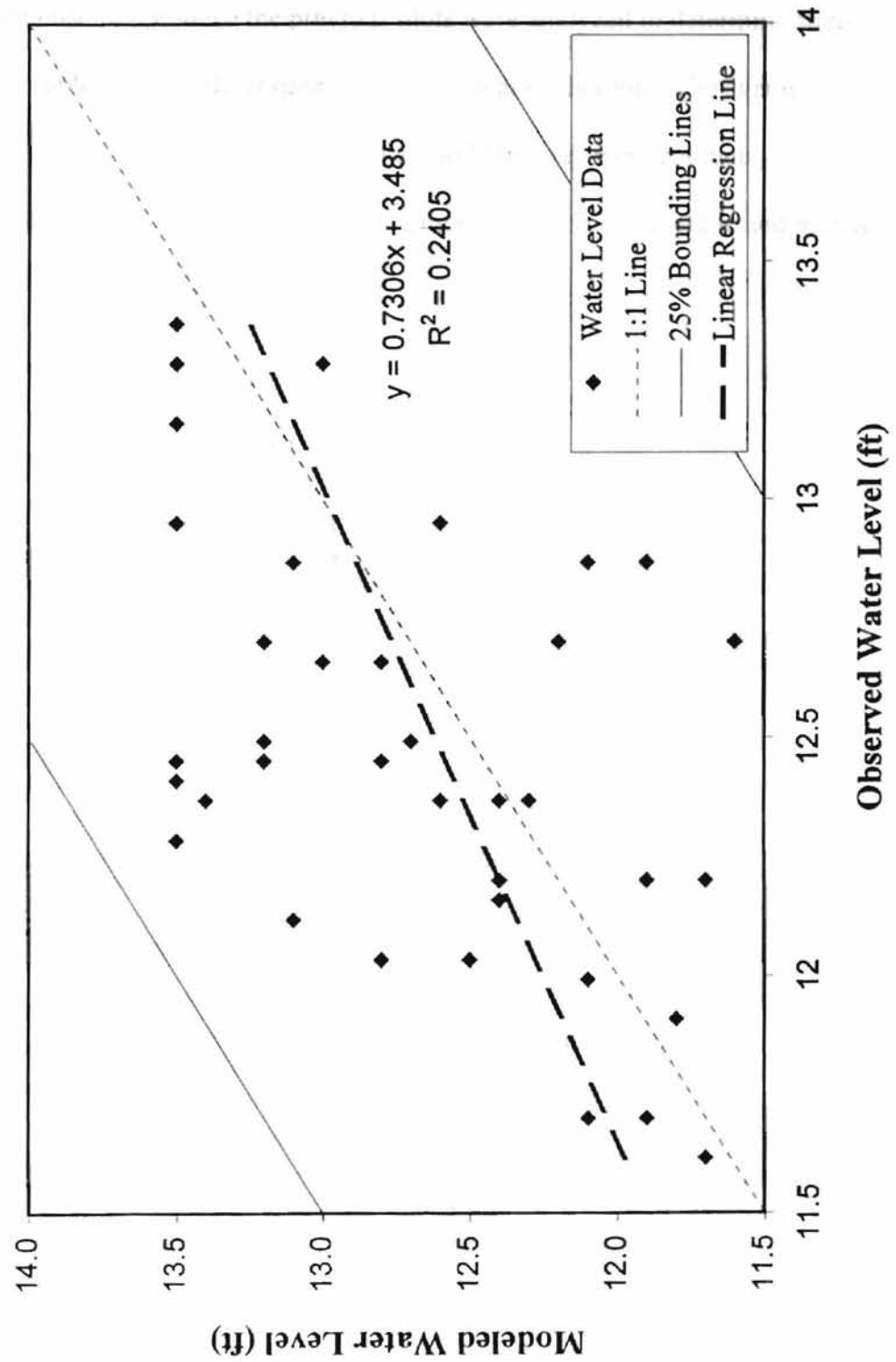


Figure 15. Modeled versus Observed Water Level for Basin 26G with Error Lines Representing 25% of the Average Daily Volume Pumped from Basin 26G.

The data used to produce the previous plots were analyzed to determine statistical relationships. Table 6 shows the results of the statistical evaluation. The average deviation for the second modeling day and final modeling day were computed to determine if the errors accumulated through the modeling period. Average and maximum errors were determined for each basin.

**Table 6. Results from Model Analysis.**

Basin	17D	1H	9D	26G	15E
Average Error (ft)	0.19	-0.16	-0.30	0.09	-0.02
Maximum Error (ft)	1.21	-2.0	-2.87	1.22	1.03
Average Volume Error (gal)	148,000	-14,235	-56,000	25,500	-12,100
Maximum Volume Error (gal)	924,000	-180,000	-535,000	333,000	587,000
Average Absolute Day 2 Error (ft)	0.17	0.18	0.20	0.31	0.28
Average Absolute Final Day Error (ft)	0.46	0.55	0.82	0.69	0.25
Average Volume Pumped (gal/day)	836,000	265,000	330,000	1,642,000	1,280,000

For all of the basins, the average deviations were significantly less than the average volumes of water pumped from each respective basin. The maximum deviations occurred on the final modeling day for each basin except Basin 15E. For the entire modeling period, the errors exceeded 25% of the average volume pumped only 41 times out of 210 water level predictions, less than 20% of the cases.

The average errors for day two and the final day were computed using the absolute value of the deviations of the modeled water levels from the observed water levels. The average errors for day two were lower than for the final day, except for Basin

15E. For that basin, the day two and final day errors were nearly equal, 0.28 and 0.25 respectively. This indicates that, in general, the errors from previous days increase the errors for following days.

Based on the statistical information, the model performs best for Basin 15E. It has the smallest maximum error, average error, average volume deviation, and final day error. This is one of the largest and most active basins, so the statistical data are very pleasing for this basin. The statistical results for Basin 9D are influenced greatly by a few days when the model under predicts the water level significantly. However, taking both the statistical and graphical information into consideration, and considering the hydraulic complexity of the recycling system, the overall model performance is good.

### **Additional Discussion**

For most weeks and for most basins the model was able to predict the water levels very well. There were a few weeks that the model diverged from the observed. The basins that receive water directly from the river performed well considering the shortcoming of the input data. For these basins, a percentage of time the pumps direct water to the basin was set for the overall period. It is very possible that this percentage would not be the same for the entire period. This source of error could be easily removed from the modeling process by having a more direct knowledge of how long the pumps direct water to the respective basins, which could be done by the nursery personnel. This should improve the results for Basin 1H and Basin 17D.

For the pumps that serve more than one purpose (irrigation and pumping directly to a basin), knowing specifically how long the pump operates in each function would



improve the input data. Knowing the specific times that the pumps operate would also improve the model. For example, less runoff would be likely to occur during the heat of the day, and more would occur during the early morning hours (everything else being equal). Taking the daily water level readings and pump operation times at a time when a minimal amount of water was being pumped would have improved the input data. However, that was the only time nursery personnel were available to do that work.

During the 11 weekly modeling periods, model predictions were determined for 42 days. A breakdown of the model error is shown in Table 7. This table shows how frequently the model error exceeded 25%, 50%, and 100% of the average water volume pumped daily (shown in Table 6). The daily error volume recorded in Basin 26G, Basin 15E, and Basin 1H never exceeded the average volume pumped from that basin. Basin 9D and Basin 17D only exceeded twice each. When the error volume was compared to one-half the average pumped volume, two basins still did not exceed. Basin 9D had eight days where the error exceeded one-half of the average pumped volume. Basin 17D exceeded six times and Basin 1H had one day where the error exceeded one-half of the average pumped volume.

The modeling error was also compared to 25% of the average volume pumped. In this comparison, the error volume was greater than 25% of the average pumped volume nearly half of the time for Basin 17D. Two basins, 15E and 26G, had a total of only one point exceeding the 25% limit. Overall, the model error was within 25% of the average volume pumped 80% of the modeling period.

In summary, only four modeled days had volume errors greater than the average volume pumped from each basin. Of the 210 modeling days, the error volume only

exceeded one-half the average pumping volume fifteen times, slightly more than 7% of the readings. Eighty percent of the time the model error was within 25% of the average volume pumped from each respective basin.

**Table 7. Model Error Analysis.**

Basin	Frequency of Error Exceeding 25% of the Average Pumping Volume	Frequency of Error Exceeding 50% of the Average Pumping Volume	Frequency of Error Exceeding 100% of the Average Pumping Volume
9D	14 (33%)	8 (19%)	2 (5%)
17D	20 (48%)	6 (14%)	2 (5%)
1H	6 (14%)	1 (2%)	0 (0%)
15E	1 (2%)	0 (0%)	0 (0%)
26G	0 (0%)	0 (0%)	0 (0%)
Overall Model	41 (20%)	15 (7%)	4 (2%)

The model was intended for possible use in making future water management judgements over a one to four day planning horizon. This validation shows that the model does simulate the hydraulics of the recycling system. The model results provide insights that can lend to more efficient use of the waters that are available to the nursery.

## **Chapter 9**

### **Summary and Conclusions**

#### **Summary**

The plant industry is important economically in Oklahoma. In 1997, the nursery industry was the fifth largest in grower receipts in Oklahoma, amounting to over \$250 million. Greenleaf Nursery Company is one of the five largest container nurseries in the United States. It plays a major role in the state economy, employing more than 600 people during the peak growing seasons.

Greenleaf anticipates continued growth, and has taken efforts to preserve the quality and quantity of water that is available for their daily irrigation practices. Recent environmental concerns have also played an important role in the changes made by Greenleaf. With legislative regulations focusing more and more on the nursery industry, Greenleaf took proactive steps to reduce their impact on the environment. They implemented a runoff recycling system that eliminates most off-site discharges while helping to reduce irrigation costs. The main focus of this project was to develop a computer based hydraulic model for the runoff recycling system for Greenleaf's container nursery.

A model was developed using an “off the shelf” software package, WaterCAD 3.1, that provides the necessary tools to simulate the hydraulics of the recycling system. A major consideration when developing this model was keeping it as simple as possible (without making unreasonable assumptions) in hopes that it would be utilized by the nursery as a water management tool upon completion of the project.

The first step in developing the model was to gather input data. This was done in several steps. The Global Positioning System (GPS) was used to gather location data for the hydraulically important points in the nursery. Daily data was also collected to record the operation of every pump used at the nursery, and the water levels in each basin. The computer model was developed by adding components until the model included each element at the nursery. Basins (tanks), reservoirs, pumps, and pipes made up the computer model. Extra reservoirs and pump systems were added to account for rainfall and irrigation runoff that enters the basins. With the model developed and the input data entered, the model was run for eleven weekly modeling periods. Each modeling period was three to four days in length.

The model runs produced output water levels for each basin. This output was recorded in Microsoft Excel and compared to observed water levels. The performance of the model was analyzed by comparing the modeled water levels to the observed water levels. Visual comparisons were made and statistical information was calculated for each basin. Comparisons were made between error volumes and percentages of the average volumes pumped from each basin. The average volume errors ranged from 12,100 to 148,000 gallons with the average pumping volumes ranging from 265,000 to 1,642,000

gallons per day. The charts shown in Chapter 9 show that for most weeks, the model accurately simulates the hydraulics of the nursery recycling system.

## **Conclusions**

The computer model has proven to do an adequate job of simulating the actions of the recycling system. The model could be improved, but not without making it much more complicated, reducing the possibility of Greenleaf using the model. One change that could be made to improve the model would be to use environmental factors to more accurately estimate the amount of irrigation runoff. Considering the desired end use of the model, as it is, the model provides very useful information and can be used by nursery personnel without a great deal of training on how to use the software and adjusting the model as the recycling system is changed.

There is one downfall for using WaterCAD on this project. Although it provides a nice user-interface, the method of entering pump controls is a time consuming process. This input requires a significant amount of time because there are so many pumps used in the model. Improvements in the method of entering pump controls would greatly increase the time efficiency of using WaterCAD.

The performance of the model, based on the statistical and graphical results from the model validation process, is very good. Overall, the average errors were less than 25% of the average pumping volumes greater than 80% of the modeling period. The error volumes were less than one-half of the average volume pumped 92% of the modeling period. The volumes entering and leaving the basins are much larger than the error most of the time.

Although there are a few drawbacks to using this software package for the modeling, it provides enough useful information to make it worthwhile. Using this model as a water management tool will enable the nursery to more efficiently utilize their irrigation system, save money on pumping costs, plan for and utilize rainfall more effectively, and provide information to the public regarding their water use. With this in mind, the model does what it was intended to do. With a little effort on the part of the nursery staff, this model can provide a great deal of valuable information to Greenleaf Nursery.

## Bibliography

- Arnold, M. and D.C. Wilkerson. 1994, January 15. A Thirst for Conservation. *American Nurseryman*. 56-61.
- Bonner, A.L., 1993, August. The Curtis Report, Illinois River Irrigation Tailwater Project, 1989-1992. Oklahoma Department of Agriculture Plant Industry and Consumer Services, 2800 N. Lincoln Blvd. Oklahoma City, Oklahoma 73105.
- Cole, J.C., V.L. Starnback, and C. Gray. 1993, September. Design for a Simulated Nursery for Water Runoff Research. *HortScience* Vol. 28(9): 952-953.
- Davidson, H., R. Mecklenburg, and C. Peterson. 1994. Nursery Management: Administration and Culture (3<sup>rd</sup> Ed.). New Jersey: Prentice Hall Career & Technology, Prentice Hall, Inc.
- Davis, T. (1998, January). Stewards of the Environment. *NMPro*. 40-46.
- Greenleaf Nursery Company. 1997, August. The History of Greenleaf Nursery Company. Rt.1, Box 163. Park Hill, Oklahoma 74451.
- Haan, C.T., Barfield, B.J., and Hayes, J.C. 1994. Design Hydrology and Sedimentology for Small Catchments. Academic Press, Inc.
- Hurn J., GPS - A Guide to the Next Utility. 1989. Trimble Navigation Ltd., 645 N. Mary Ave. Sunnyvale, CA 94088.
- Kabashima, J.N. 1993, April. Innovative Irrigation Techniques in Nursery Production to Reduce Water Usage. *HortScience* Vol. 28(4): 291-293.
- Oklahoma Department of Agriculture, 1997. 1997 Ag Facts.
- Oklahoma Department of Environmental Quality, 1997. Pollution Prevention in Oklahoma, DEQ, 1000 N.E.10<sup>th</sup> Street. Oklahoma City, OK 73117.
- Rackley, J. 1992, October 1. Harnessing Nursery Runoff. *American Nurseryman*. 30-37.
- Reaves, R.E. (1997, January). Greenleaf Nursery Makes Positive Environmental Impact. *Landscape & Irrigation*. 52-57.

Scenic Rivers Act, 82 O.S. 1991, Sections 1451 et seq.

Skimina, C.A.(1992, September). Recycling Water, Nutrients, and Waste in the Nursery Industry. *HortScience*, Vol. 27(9), 968-971.

United States Department of Agriculture, Economic Research Service. 1998. Size and Scope of the Nursery/Landscape Industry. Online. [http://www.anla.org/industryinfo/industry\\_profile.html](http://www.anla.org/industryinfo/industry_profile.html).

Urbano, C.C. (1989, April 15). The Environmental Debate: An Industry Issue. *American Nurseryman*. 69-85.

WaterCAD for Windows. 1998. On-line Help Text, Haestad Methods, Inc.

Wilson, S.K., von Broembsen, S.L., and Smolen, M.D., 1998. Pathogen Management in Capture and Recycle Irrigation Systems for Nurseries, ASAE Paper No. 987004, presented at the ASAE Annual International Meeting, Orlando, Florida, July 11-16.



## Appendices

## **Appendix A**

### **GPS and Model Coordinates**

# GPS Coordinates

Point ID	Latitude	Longitude	X (ft)	Y (ft)	Elevation (ft)
Benchmark	35°46'21.682290	-94°54'19.775060	2579	4257	617.4
Control Point #1	35°46'10.716393	-94°54'11.170302	3300	3125	504.5
Control Point #2	35°46'03.631333	-94°54'19.581673	2594	2422	518.9
Control Point #3	35°46'34.301093	-94°54'30.616582	1745	5540	666.0
Control Point #4	35°46'18.083216	-94°53'55.754976	4585	3845	533.3
Control Point #5	35°45'57.504205	-94°53'52.835701	4785	1760	540.4
Control Point #6	35°46'15.683890	-94°54'41.521062	1760	4785	628.9
Control Point #7	35°46'19.960137	-94°54'26.934151	2020	4085	553.3
Control Point #8	35°46'20.792800	-94°54'34.340604	1411	4181	588.3
Control Point #9	35°45'50.353700	-94°53'58.764426	4283	1047	525.1

1994

1995

1996

## **Appendix B**

### **Measured Rainfall Data**

# Daily Rainfall Data

Date	Rainfall (in)	Rainfall (cm)
8/17/98	0.00	0.00
8/18/98	0.00	0.00
8/19/98	0.00	0.00
8/20/98	0.00	0.00
8/21/98	0.00	0.00
8/22/98	0.65	1.65
8/23/98	0.00	0.00
8/24/98	0.00	0.00
8/25/98	0.00	0.00
8/26/98	0.23	0.58
8/27/98	0.00	0.00
8/28/98	0.20	0.51
8/29/98	0.00	0.00
8/30/98	0.00	0.00
8/31/98	0.00	0.00
9/1/98	0.00	0.00
9/2/98	0.00	0.00
9/3/98	0.00	0.00
9/4/98	0.00	0.00
9/5/98	0.00	0.00
9/6/98	0.00	0.00
9/7/98	0.00	0.00
9/8/98	0.00	0.00
9/9/98	0.00	0.00
9/10/98	0.00	0.00
9/11/98	0.00	0.00
9/12/98	0.24	0.61
9/13/98	2.41	6.12
9/14/98	1.85	4.70
9/15/98	0.04	0.10
9/16/98	0.00	0.00
9/17/98	0.00	0.00
9/18/98	0.02	0.05
9/19/98	0.00	0.00
9/20/98	0.00	0.00
9/21/98	0.20	0.51
9/22/98	0.76	1.93
9/23/98	0.11	0.28
9/24/98	0.00	0.00
9/25/98	0.00	0.00
9/26/98	0.00	0.00
9/27/98	0.00	0.00
9/28/98	0.00	0.00

Date	Rainfall (in)	Rainfall (cm)
9/29/98	0.02	0.05
9/30/98	0.43	1.09
10/1/98	0.21	0.53
10/2/98	0.24	0.61
10/3/98	0.15	0.38
10/4/98	0.00	0.00
10/5/98	3.87	9.83
10/6/98	0.18	0.46
10/7/98	0.02	0.05
10/8/98	0.02	0.05
10/9/98	0.02	0.05
10/10/98	0.01	0.03
10/11/98	0.01	0.03
10/12/98	0.00	0.00
10/13/98	0.01	0.03
10/14/98	0.01	0.03
10/15/98	0.00	0.00
10/16/98	0.08	0.20
10/17/98	0.34	0.86
10/18/98	0.00	0.00
10/19/98	0.02	0.05
10/20/98	0.02	0.05
10/21/98	0.01	0.03
10/22/98	0.01	0.03
10/23/98	0.01	0.03
10/24/98	0.00	0.00
10/25/98	0.01	0.03
10/26/98	0.01	0.03
10/27/98	0.01	0.03
10/28/98	0.00	0.00
10/29/98	0.00	0.00
10/30/98	0.08	0.20
Total	12.51	31.77

## **Appendix C**

### **Ultrasonic Flow Measurements**

Flow Meter Measurements.

Pump ID	Flow Rate (gpm)	Delivery Location
1 - #1 - 125	950	Basin 17D
1 - #1 - 125	950	Irrigation
1 - #2 - 60	825	Irrigation
1 - #3 - 60	825	Irrigation Backup
2 - #1 - 125	1180	Irrigation
2 - #2 - 125	1180	Irrigation
2 - #3 - 60	825	Irrigation
2 - #4 - 60	1120	Basin 1H
3 - #1 - 60	850	Irrigation
3 - #1 & #2 - 60	1175	Irrigation
4 - #1 & #2 - 60	1100	Irrigation
5 - #1 & #2 - 60	1450	Irrigation
6 - #1 - 25	1050	Basin 17D
7 - #1 - 30	1250	Basin 26G
8 - #1 - 15	575	Basin 26G
9 - #1 & #2 - 60	1600	Irrigation
10 - #1 - 20	1475	Basin 15E
10 - #2 & #3 - 60	1100	Irrigation
10 - #4 - 75	1600	Basin 17D
11 - #1 & #2 - 60	1100	Irrigation
11 - #3 & #4 - 60	1475	Irrigation
11 - #5 - 20	1300	Basin 26G



1

2

## **Appendix D**

### **Stage-Storage Relationships**

### Basin 1H

Stage	Total Irrigation Volume	Total Storage
(ft)	Available (gal)	Remaining (gal)
13.0	781000	0
12.5	732000	49000
12.0	683000	98000
11.5	634000	147000
11.0	586000	195000
10.5	537000	244000
10.0	488000	293000

### Basin 9D

Stage	Total Irrigation Volume	Total Storage
(ft)	Available (gal)	Remaining (gal)
13.6	1608000	0
13.5	1590000	18000
13.0	1496000	112000
12.5	1403000	205000
12.0	1309000	299000
11.5	1216000	392000
11.0	1122000	486000

### Basin 17D

Stage	Total Irrigation Volume	Total Storage
(ft)	Available (gal)	Remaining (gal)
15.0	7630000	0
14.5	7248000	382000
14.0	6867000	763000
13.5	6485000	1145000
13.0	6104000	1526000
12.5	5722000	1908000
12.0	5341000	2289000

### Basin 15E

Stage	Total Irrigation Volume	Total Storage
(ft)	Available (gal)	Remaining (gal)
13.5	5498000	0
13.0	5236000	262000
12.5	4974000	524000
12.0	4712000	786000
11.5	4451000	1047000
11.0	4189000	1309000
10.5	3927000	1571000

### Basin 26G

Stage	Total Irrigation Volume	Total Storage
(ft)	Available (gal)	Remaining (gal)
13.5	3163000	0
13.0	3025000	138000
12.5	2888000	275000
12.0	2750000	413000
11.5	2613000	550000
11.0	2475000	688000
10.5	2338000	825000
10.0	2200000	963000

## Appendix E

### Regression Analysis

Basin 9D  
SUMMARY OUTPUT

<i>Regression Statistics</i>	
Multiple R	0.9090
R Square	0.8264
Standard Error	0.6865
Observations	42

ANOVA					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	1	89.726	89.726	190.4	8.52E-17
Residual	40	18.854	0.471		
Total	41	108.58			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>
Intercept	-4.1489	1.1680	-3.55	0.001	-6.5096	-1.788
X Variable 1	1.3073	0.0948	13.80	8.5E-17	1.1158	1.499

Additional Slope Test

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>
X	1.3073	0.0948	3.24

The critical t-value at the 95% confidence level is 2.02. Since the t Stat is greater than 2.02, it is concluded that the slope is significantly different from one.

Basin 17D  
SUMMARY OUTPUT

<i>Regression Statistics</i>	
Multiple R	0.8686
R Square	0.7544
Standard Error	0.3394
Observations	42

ANOVA

	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	1	14.153	14.153	122.9	9.14E-14
Residual	40	4.608	0.115		
Total	41	18.761			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>
Intercept	2.8767	0.9442	3.05	0.004	0.9685	4.785
X Variable 1	0.7987	0.0721	11.08	9.1E-14	0.6531	0.944

Additional Slope Test

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>
X	1.3073	0.0948	2.79

The critical t-value at the 95% confidence level is 2.02. Since the t Stat is greater than 2.02, it is concluded that the slope is significantly different from one.

Basin 1H  
SUMMARY OUTPUT

<i>Regression Statistics</i>	
Multiple R	0.5722
R Square	0.3274
Standard Error	0.5244
Observations	42

ANOVA					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	1	5.355	5.355	19.5	7.530E-05
Residual	40	11.001	0.275		
Total	41	16.356			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>
Intercept	2.1167	2.2694	0.93	0.357	-2.4699	6.7033
X Variable 1	0.8115	0.1839	4.41	0.000	0.4398	1.1833

Additional Slope Test

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>
X	1.3073	0.0948	1.03

The critical t-value at the 95% confidence level is 2.02. Since the t Stat is less than 2.02, it is concluded that the slope is not significantly different from one.

Basin 15E  
SUMMARY OUTPUT

<i>Regression Statistics</i>	
Multiple R	0.6207
R Square	0.3853
Standard Error	0.3176
Observations	42

ANOVA					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	1	2.529	2.529	25.1	1.157E-05
Residual	40	4.035	0.101		
Total	41	6.565			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>
Intercept	3.7220	1.8698	1.99	0.053	-0.0569	7.5010
X Variable 1	0.7140	0.1426	5.01	0.000	0.4258	1.0021

Additional Slope Test

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>
X	1.3073	0.0948	2.00

The critical t-value at the 95% confidence level is 2.02. Since the t Stat is less than 2.02, it is concluded that the slope is not significantly different from one.



Basin 26G  
SUMMARY OUTPUT

<i>Regression Statistics</i>	
Multiple R	0.4904
R Square	0.2405
Standard Error	0.5919
Observations	42

ANOVA					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	1	4.437	4.437	12.7	0.0009
Residual	40	14.015	0.350		
Total	41	18.451			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>
Intercept	3.4850	2.5671	1.36	0.182	-1.7034	8.6734
X Variable 1	0.7306	0.2053	3.56	0.001	0.3156	1.1455

Additional Slope Test

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>
X	1.3073	0.0948	1.31

The critical t-value at the 95% confidence level is 2.02. Since the t Stat is less than 2.02, it is concluded that the slope is not significantly different from one.

## **Appendix F**

### **Results Data**

# Basin 1H Water Level Data

Date	Observed Water Levels (ft)	Modeled Water Levels (ft)
8/17/98	12.9	12.9
8/18/98	12.5	12.6
8/19/98	11.5	11.9
8/20/98	11.8	12.4
8/21/98	11.5	11.3
8/22/98		
8/23/98		
8/24/98	12.5	12.5
8/25/98	12.0	12.3
8/26/98	12.8	13.0
8/27/98	12.2	12.3
8/28/98	11.2	11.1
8/29/98		
8/30/98		
8/31/98	12.8	12.8
9/1/98	12.5	12.2
9/2/98	12.1	11.2
9/3/98	12.3	11.0
9/4/98	12.2	10.9
9/5/98		
9/6/98		
9/7/98		
9/8/98	12.5	12.5
9/9/98	11.6	11.6
9/10/98	12.3	12.9
9/11/98	12.7	12.8
9/12/98		
9/13/98		
9/14/98	12.8	12.8
9/15/98	12.6	12.8
9/16/98	12.6	12.5
9/17/98	12.6	12.8
9/18/98	12.5	12.9
9/19/98		
9/20/98		
9/21/98	12.5	12.5
9/22/98	12.5	12.1
9/23/98	12.5	11.7
9/24/98	12.5	12.3
9/25/98	12.5	12.0

9/26/98		
9/27/98		
9/28/98	13.0	13.0
9/29/98	12.2	12.1
9/30/98	12.2	12.0
10/1/98	12.1	11.6
10/2/98	12.2	11.7
10/3/98		
10/4/98		
10/5/98		
10/6/98	13.0	13.0
10/7/98	12.8	12.9
10/8/98	12.7	11.8
10/9/98	12.7	10.7
10/10/98		
10/11/98		
10/12/98	12.5	12.5
10/13/98	12.7	12.2
10/14/98	12.7	12.8
10/15/98	12.6	12.8
10/16/98	12.6	12.4
10/17/98		
10/18/98		
10/19/98	11.2	11.2
10/20/98	10.8	10.9
10/21/98	12.6	12.1
10/22/98	12.6	12.3
10/23/98	12.6	12
10/24/98		
10/25/98		
10/26/98	12.5	12.5
10/27/98	12.6	12.6
10/28/98	12.6	12.7
10/29/98	12.5	12.6
10/30/98	12.6	12.4

# Basin 17D Water Level Data

Date	Measured Water Levels (ft)	Modeled Water Levels (ft)
8/17/98	14.2	14.2
8/18/98	13.4	13.5
8/19/98	12.8	13.3
8/20/98	12.2	12.7
8/21/98	12.8	12.5
8/22/98		
8/23/98		
8/24/98	13.6	13.6
8/25/98	13.3	13.5
8/26/98	12.8	13.5
8/27/98	12.6	13.7
8/28/98	12.8	14
8/29/98		
8/30/98		
8/31/98	12.9	12.9
9/1/98	12.4	12.7
9/2/98	12.8	12.7
9/3/98	12.5	12.8
9/4/98	12.9	12.8
9/5/98		
9/6/98		
9/7/98		
9/8/98	12.3	12.3
9/9/98	12.3	12.5
9/10/98	11.4	11.9
9/11/98	13.2	13.7
9/12/98		
9/13/98		
9/14/98	14.5	14.5
9/15/98	14.4	14.6
9/16/98	13.9	14.2
9/17/98	14.3	14.5
9/18/98	14.1	14.2
9/19/98		
9/20/98		
9/21/98	13.1	13.1
9/22/98	14.4	14.5
9/23/98	14.3	14
9/24/98	14.3	13.8
9/25/98	14.0	13.9
9/26/98		

9/27/98		
9/28/98	13.0	13
9/29/98	13.0	13.2
9/30/98	12.7	13.1
10/1/98	12.7	13.1
10/2/98	12.8	13.5
10/3/98		
10/4/98		
10/5/98		
10/6/98	14.4	14.4
10/7/98	14.3	14.5
10/8/98	14.0	14
10/9/98	13.3	13.5
10/10/98		
10/11/98		
10/12/98	12.7	12.7
10/13/98	12.5	12.5
10/14/98	12.2	12.4
10/15/98	12.5	12.9
10/16/98	12.2	12.9
10/17/98		
10/18/98		
10/19/98	13.0	13
10/20/98	12.9	12.7
10/21/98	13.0	12.7
10/22/98	12.9	12.9
10/23/98	12.7	12.8
10/24/98		
10/25/98		
10/26/98	13.5	13.5
10/27/98	13.3	13.4
10/28/98	13.0	13.3
10/29/98	12.7	12.8
10/30/98	13.1	14

# Basin 9D Water Level Data

Date	Measured Water Levels (ft)	Modeled Water Levels (ft)
8/17/98	12.2	12.2
8/18/98	12.9	13
8/19/98	11.4	11.4
8/20/98	13.0	12.6
8/21/98	13.2	13.5
8/22/98		
8/23/98		
8/24/98	12.3	12.3
8/25/98	12.2	11.8
8/26/98	12.7	13.3
8/27/98	12.0	12
8/28/98	11.8	11.6
8/29/98		
8/30/98		
8/31/98	11.6	11.6
9/1/98	11.7	11.6
9/2/98	12.0	12
9/3/98	11.7	11.8
9/4/98	12.4	12.4
9/5/98		
9/6/98		
9/7/98		
9/8/98	12.8	12.8
9/9/98	11.7	11.6
9/10/98	12.9	12.1
9/11/98	13.1	11.8
9/12/98		
9/13/98		
9/14/98	13.5	13.5
9/15/98	13.5	13.5
9/16/98	13.6	13.5
9/17/98	13.4	13.6
9/18/98	13.3	13.6
9/19/98		
9/20/98		
9/21/98	12.3	12.3
9/22/98	13.3	13.5
9/23/98	13.3	13.5
9/24/98	13.3	13.5
9/25/98	12.7	12.9
9/26/98		

9/27/98		
9/28/98	11.1	11.1
9/29/98	11.8	11
9/30/98	11.4	10.7
10/1/98	13.3	13.6
10/2/98	12.9	12.6
10/3/98		
10/4/98		
10/5/98		
10/6/98	13.4	13.4
10/7/98	13.4	13.5
10/8/98	13.3	13.5
10/9/98	12.4	12.8
10/10/98		
10/11/98		
10/12/98	11.9	11.9
10/13/98	12.5	12.2
10/14/98	12.6	11
10/15/98	11.4	9.2
10/16/98	11.1	8.2
10/17/98		
10/18/98		
10/19/98	11.4	11.4
10/20/98	11.8	11.8
10/21/98	12.7	12
10/22/98	11.7	10.5
10/23/98	12.0	10.3
10/24/98		
10/25/98		
10/26/98	10.275	10.3
10/27/98	10.4	10.2
10/28/98	10.5	10
10/29/98	12.1	10.7
10/30/98	7.4	5.9



# Basin 26G Water Level Data

Date	Measured Water Levels (ft)	Modeled Water Levels (ft)
8/17/98	12.0	12
8/18/98	11.7	11.9
8/19/98	12.7	13.2
8/20/98	12.7	12.2
8/21/98	12.2	11.7
8/22/98		
8/23/98		
8/24/98	12.3	12.3
8/25/98	12.4	12.6
8/26/98	12.0	12.8
8/27/98	12.4	13.4
8/28/98	12.5	13.5
8/29/98		
8/30/98		
8/31/98	13.0	13
9/1/98	12.4	12.3
9/2/98	12.2	12.4
9/3/98	12.5	13.2
9/4/98	12.4	13.5
9/5/98		
9/6/98		
9/7/98		
9/8/98	12.5	12.5
9/9/98	12.1	13.1
9/10/98	12.7	11.6
9/11/98	12.2	11.9
9/12/98		
9/13/98		
9/14/98	13.5	13.5
9/15/98	13.3	13.5
9/16/98	12.9	12.1
9/17/98	13.4	13.5
9/18/98	12.7	11.6
9/19/98		
9/20/98		
9/21/98	12.6	12.6
9/22/98	13.4	13.5
9/23/98	13.0	12.6
9/24/98	13.0	12.6
9/25/98	12.2	11.9
9/26/98		
9/27/98		

9/28/98	12.7	12.7
9/29/98	12.5	13.2
9/30/98	12.0	12.5
10/1/98	13.2	13.5
10/2/98	13.0	13.5
10/3/98		
10/4/98		
10/5/98		
10/6/98	13.4	13.4
10/7/98	13.3	13
10/8/98	12.9	11.9
10/9/98	12.2	11.2
10/10/98		
10/11/98		
10/12/98	12.3	12.3
10/13/98	12.5	12.7
10/14/98	11.7	12.1
10/15/98	12.7	13
10/16/98	12.3	13.5
10/17/98		
10/18/98		
10/19/98	11.9	11.9
10/20/98	12.2	12.4
10/21/98	12.7	12.8
10/22/98	11.6	11.7
10/23/98	12.5	12.8
10/24/98		
10/25/98		
10/26/98	12.6	12.6
10/27/98	11.9	11.8
10/28/98	12.9	13.1
10/29/98	12.4	12.4
10/30/98	12.0	12.1

# Basin 15E Water Level Data

Date	Measured Water Levels (ft)	Modeled Water Levels (ft)
8/17/98	12.6	12.6
8/18/98	12.9	12.7
8/19/98	13.2	12.7
8/20/98	13.5	13.1
8/21/98	13.1	12.9
8/22/98		
8/23/98		
8/24/98	12.9	12.9
8/25/98	12.4	12.1
8/26/98	13.2	13.5
8/27/98	13.3	13.2
8/28/98	13.2	13.1
8/29/98		
8/30/98		
8/31/98	12.7	12.7
9/1/98	13.4	13
9/2/98	13.0	12.6
9/3/98	13.1	12.6
9/4/98	13.2	12.7
9/5/98		
9/6/98		
9/7/98		
9/8/98	12.8	12.8
9/9/98	12.2	12.5
9/10/98	13.1	13.5
9/11/98	12.0	12.5
9/12/98		
9/13/98		
9/14/98	13.7	13.52
9/15/98	13.4	13.5
9/16/98	13.3	13.5
9/17/98	13.4	13.5
9/18/98	13.4	13.5
9/19/98		
9/20/98		
9/21/98	13.1	13.1
9/22/98	13.4	13.5
9/23/98	13.1	13.5
9/24/98	13.4	13.5
9/25/98	13.3	13.5
9/26/98		
9/27/98		

9/28/98	13.3	13.3
9/29/98	13.3	13
9/30/98	12.8	12.4
10/1/98	13.5	13.5
10/2/98	13.5	13.5
10/3/98		
10/4/98		
10/5/98		
10/6/98	13.0	13
10/7/98	13.5	13.5
10/8/98	13.4	13.4
10/9/98	13.0	12.9
10/10/98		
10/11/98		
10/12/98	13.3	13.3
10/13/98	13.3	13.2
10/14/98	12.7	12.9
10/15/98	13.1	12.7
10/16/98	13.1	12.6
10/17/98		
10/18/98		
10/19/98	13.3	13.3
10/20/98	13.1	12.8
10/21/98	13.2	12.9
10/22/98	13.3	13.2
10/23/98	12.7	12.7
10/24/98		
10/25/98		
10/26/98	13.1	13.1
10/27/98	12.5	13.5
10/28/98	13.0	13.2
10/29/98	13.3	13.4
10/30/98	13.1	13.4

## VITA<sup>2</sup>

Heath Ashton Sand

Candidate for the Degree of

Master of Science

Thesis: HYDRAULIC MODELING OF A RUNOFF RECYCLING SYSTEM FOR A  
CONTAINER NURSERY

Major Field: Biosystems Engineering

### Biographical:

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