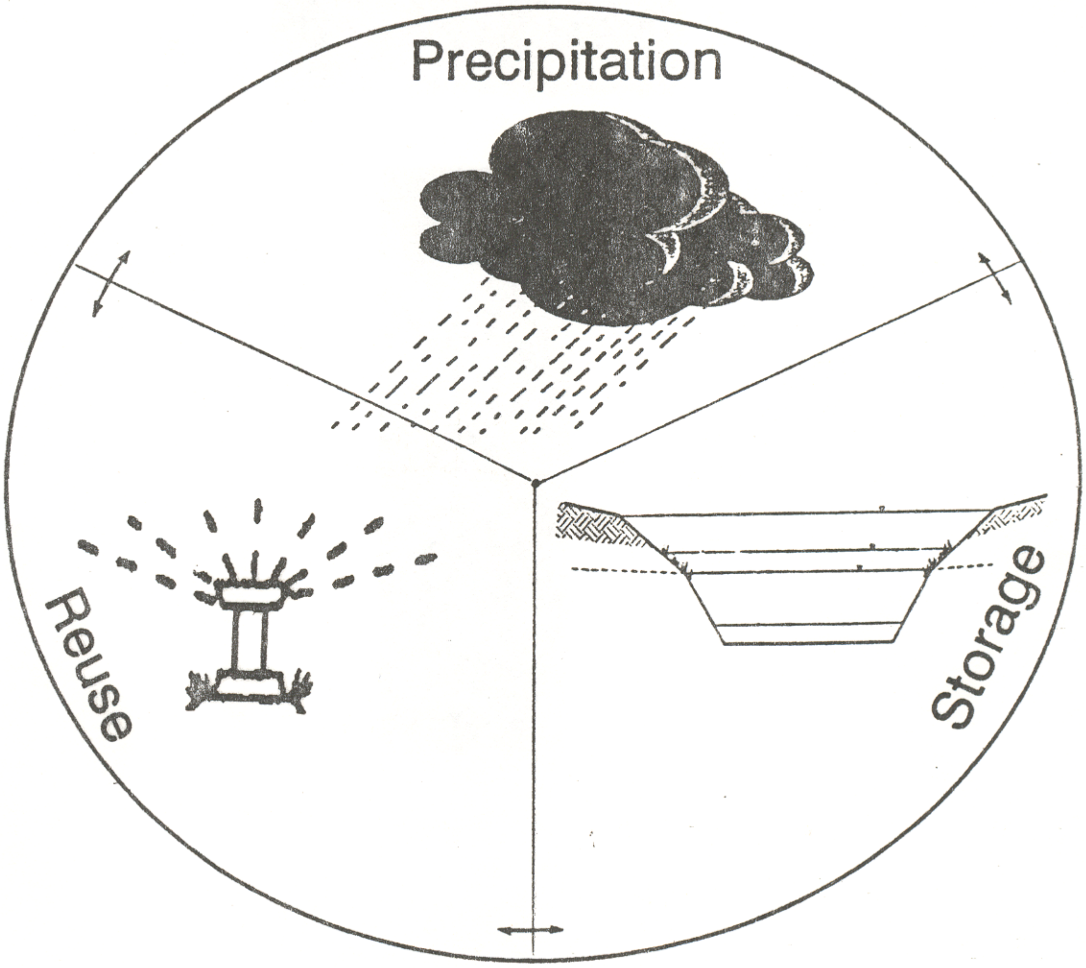
PROJECT SMART
A
RESTORATION/DEMONSTRATION



MAINTAINING THE BALANCE

By

Martin Paul Wanielista, PhD
&
James Nelson Bradner, MS

December, 1992

A HISTORICAL RESTORATION

PRE-CONDITION NEGLECT

RESTORATION-IN-PROGRESS
WATERSHED AREA AND POND

SHORELINE BEFORE
REVEGETATION

SHORELINE AFTER
REVEGETATION

A RESTORATION PROJECT THAT

COLLECTS RUNOFF WATER

CONTROLS POLLUTION

AND REUSES THE WATER

ACKNOWLEDGEMENTS

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Most of the work reported in this publication is from the thesis of James N. Bradner, M.S., an author of this report.

Continuous Modeling........................... 39
The Structure of a Reuse Pond.................. 40
The Behavior of a Reuse Pond................... 42
The Mass Balance............................... 43
Volume Units................................... 45
Mathematical Equations and a Computer Program.. 47
Watershed and Pond Design Details.............. 48
Watershed Data................................ 48
Removal of Debris and Muck.................... 51

5. PRESENTATION, CALCULATION, AND
INTERPRETATION OF DATA.......................... 53
Presentation of Data........................... 53
Methods of Calculation......................... 54
Interpretation of Data......................... 62
Precipitation Effects......................... 62
Pond Stage, Groundwater and Leakage Effects. 63
Backflow Conditions........................... 69
Reuse Operation............................... 72
Rainfall from the Watershed................... 72
Cost Analysis.................................. 74
Capital Cost.................................. 74
Reuse Economic Benefits....................... 75

6. CONCLUSIONS AND RECOMMENDATIONS................. 75
Research Objectives............................ 78
First Research Objective...................... 78
Second Research Objective..................... 79
Third Research Objective...................... 79
Fourth Research Objective..................... 80
Fifth Research Objective...................... 80
Project Objectives and Benefits................ 81
First Project Objective/Benefit............... 82
Second Project Objective/Benefit.............. 82
Third Project Objective/Benefit............... 82
Recommendations................................ 83
Closing Statement.............................. 84

APPENDICES.. 85
A. Reuse Pond Mass Balance........................ 86
B. Datalogger Programs............................ 96
C. Surface Water Inflow-Outflow Calculation Program.. 99
D. Notation......................................102

REFERENCES..105

LIST OF TABLES

5-1 Reuse Pond Elevation, Area, and Volume............ 58

5-2 Monthly Totals from Reuse Pond Mass Balance....... 68

LIST OF FIGURES

2-1 Project Area in 1956 and 1970.................... 7

3-1 Liquid Level Measuring Equipment.................. 23

4-1 Schematic of a Reuse Pond......................... 41

4-2 Reuse Rate-Efficiency-Pond Volume for Orlando..... 46

4-3 Watershed Detail.................................. 49

4-4 Reuse Pond Muck Depths............................ 52

5-1 Reuse Pond Elevations............................. 59

5-2 Precipitation During the Study Period............. 64

5-3 Reuse Pond Stage.................................. 66

5-4 Reuse Pond Volume................................. 67

5-5 Reuse Pond Stage November 24 - December 3......... 70

5-6 Reuse Pond Stage May 16 - May 27.................. 70

5-7 Reuse Rates....................................... 73

CHAPTER 1

INTRODUCTION

Stormwater runoff has been reused for many years by lakefront property owners who pump lake water through piping systems for lawn irrigation. However, until recently, a pond and reuse system designed to meet current regulations and theoretical design parameters (Wanielista, et.al., 1991) had not been constructed, nor had its operational effectiveness been documented. This thesis addresses the construction and operation of a stormwater reuse demonstration pond, in conjunction with the restoration of an altered lake-wetland area.

Research Objectives

The research objectives address measurement equipment and data collection for documentation of stormwater inputs to the reuse pond, irrigation quantities, rainfall, and pond discharge. Groundwater pond exchange and the watershed runoff as a function of the watershed are documented from the directly measured data. Research objectives are as follows:

1. Determine the reliability of equipment for direct measurement and data collection of water depth, flow rates, and rainfall.

2. Calculate the percentage of runoff volume not discharged from the pond.
3. Determine irrigation volumes and average weekly application rates.
4. Estimate the net ground water pond exchange from a mass balance based on collected data.
5. Estimate the fraction of annual rainfall entering the reuse pond through the stormwater collection pipes.

Project Objectives and Benefits

This research, restoration, and demonstration project was initiated and largely funded by the Florida Department of Environmental Regulation. The Department's mission is to "Protect, Conserve, and Restore the Air, Water and Natural Resources of the State." In keeping with this philosophy, the benefits of the project are as follows:

1. Protect the ground water by diverting and treating stormwater runoff which otherwise would discharge directly into the Floridan Aquifer through drainage wells.
2. Conserve the state's vital groundwater resources through a demonstration of the beneficial reuse of stormwater for irrigation.
3. Restore the ecology of a portion of an altered lake and urban wetland area.

In urban areas, impervious surfaces such as parking lots, streets, and roofs of buildings often channel stormwater runoff directly into rivers, lakes, streams, and drainage wells. Two drainage wells in Lake Mendsen, the site provided by the City of Winter Park for the project, have received untreated stormwater discharges from the surrounding watershed for over 35 years. The reuse demonstration pond has significantly reduced the discharge of untreated stormwater runoff to drainage wells from its 8.13-acre watershed, as indicated by the surface water inflow-outflow data. Overflow from the pond has been treated by the physical process of sediment removal, and pollutant uptake from restored aquatic vegetation. However, the discharge to the remainder of Lake Mendsen is only minimally treated. Restoration of the entire lake would further reduce discharge to the drainage wells, while providing treatment.

A reuse pond collects and stores water for irrigation, which helps simulate a natural, pre-development hydrologic balance, while preventing the direct discharge of untreated stormwater runoff. Reuse of stormwater for irrigation also provides a significant economic benefit. If potable water costs $1.00/1000 gallons, and the irrigation rate is 1"/week, the cost is $1,400/acre/year. This would be $140,000/year for a typical 18-hole golf course with 100 acres under irrigation. The amortized yearly cost for installation and operation of a reuse irrigation system would be about 20% of this cost, or 10% if the irrigation system is already in place.

Lake Mendsen has been significantly altered in the past 30 to 40 years. Re-establishing natural contours, removing invading exotic vegetation, and restoring natural littoral zone vegetation in the area restored for the reuse pond have endowed the project with significant ecological, environmental and educational values. Visitors to the Winter Park Civic Center, nearby recreation facilities, and a hotel located directly opposite the demonstration pond can directly compare the restored and unrestored areas. The project serves as a highly visible example of the positive results of cooperative efforts of the University, with state and local government.

Limitations

The scope of this research does not include quantification of anticipated water quality improvements in the pond. However, water quality is proposed to be studied in later experimental projects using the reuse demonstration pond.

Development of an overall mass balance in a natural ponded area is highly complex experimental situation in which the variables may be subject to unknown or unanticipated sources of error. Every effort was made to collect the most reliable data possible, and to account for all potential and identified sources of error.

The project restoration area is limited. It is hoped that further restoration, and possible creation of an urban wetland in the remainder of Lake Mendsen will be feasible in the future.

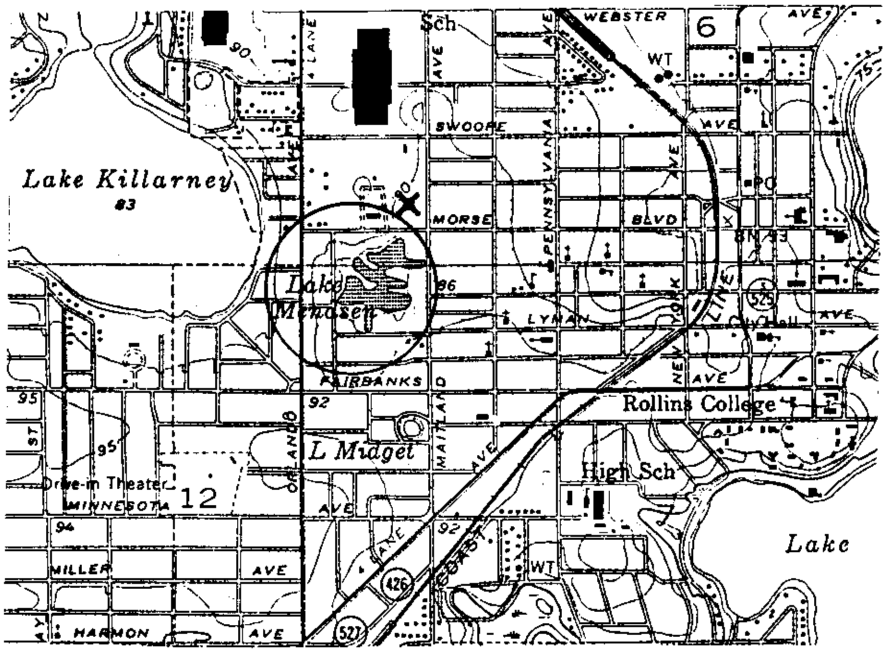
CHAPTER 2

RESTORATION

Background and History

The area known as Lake Mendsen is actually a borrow pit approximately six acres in size. Lake Mendsen was originally a small, approximately one-acre circular lake. Its appearance, as seen on the 1956 edition of the U. S. Geological Survey Orlando East Quadrangle 7.5-minute series topographic map, had become roughly crescent-shaped lake surrounding a wetland. The 1970 photorevised version of the same map showed the altered, irregularly-shaped Lake Mendsen as it exists today. These maps are shown in Figure 2-1.

Topographic maps show Lake Mendsen closely surrounded by an 85-foot contour line, with an elevation approximately five to ten feet lower than the surrounding, highly-developed watershed area. It was presumed that Lake Mendsen was altered to improve drainage during the several months of extremely wet weather following Hurricane Donna in the fall of 1960 and the winter of 1961. This was confirmed by Mr. Leroy Bass, a heavy-equipment operator employed by the City of Winter Park, who worked on the original excavation project in 1960, and also assisted during the reuse pond construction in 1990 and 1991.



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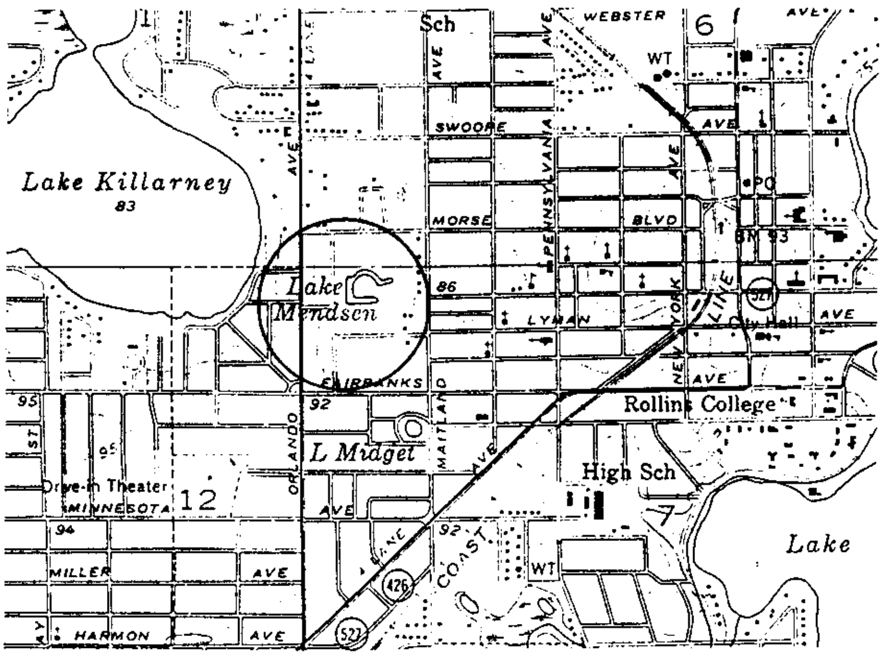

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Figure 2-1. Project Area in 1956 and 1970

Two drainage wells are used to dispose of stormwater from the watershed, much of which is directly connected and impervious. These wells were surveyed and placed on well schedule records by the U. S. Geological Survey in August 1974. According to these records, the larger well, which is also nearest the reuse pond, was drilled in 1957 to a total depth of 507 feet, with 131 feet of 20-inch diameter casing. The smaller well, located at the north end of Lake Mendsen, is constructed of 8-inch diameter casing, but the date of construction, cased depth and total depth are unknown. These wells allow stormwater to flow, by gravity, to the Upper Floridan aquifer, a major source of water for the City of Winter Park.

According to a geotechnical survey conducted as part of the pre-construction planning for the Winter Park Civic Center, the area surrounding Lake Mendsen contained significant quantities of "trash fill" and may have been used for a landfill at one time (Jammal and Associates, 1983).

During the intervening 30 years, the lake, or borrow pit, received little maintenance. Nuisance/exotic plant species such as Ludwigia spp. (water willow) and Typha spp. (cattails) flourished in the nutrient-rich runoff. The lake also developed a sediment layer up to five feet deep, from material carried in by the stormwater runoff (Jammal and Associates, Inc., 1990).

Proposal and Funding

In May 1989, representatives from the University of Central Florida, College of Engineering, Department of Civil and Environmental Engineering proposed to the Department of Environmental Regulation a restoration and demonstration project involving reuse of stormwater for irrigation. Through the efforts of Alex Alexander, P.E., Director of the Department's Central District office in Orlando, the project received an initial grant of $64,000 from the Pollution Recovery Trust Fund in 1990. In 1991, the project received an additional $15,000 from the trust fund for a total of $79,000. The Pollution Recovery Trust Fund is made up of monies collected as the result of enforcement actions against violators of the Department's regulations. The City of Winter Park and the University agreed to participate in the project by matching the original grant with $64,000 in money and in-kind services.

Planning, Design, and Permitting

The public golf course in Winter Park, which had originally been selected as the project site was found to be unsatisfactory, because much of the property was privately owned and leased to the City. The Lake Mendsen site was selected as an alternative, and preliminary design work began in May 1990. The watershed was defined by site visits during several storms of varying intensity. The watershed was plotted on a 1:2400 scale map and measured with a planimeter. The area set aside for the wet detention pond was drawn on a 1:1200 scale map. Water surface area at various depths was initially measured with a planimeter, and later digitized and refined using AutoCAD software (Jeppesen, 1992).

The St. Johns River Water Management District was contacted, and assumed permitting jurisdiction for the project. In June 1990, a preapplication conference was held with Water Management District staff members to discuss the information required for permitting. A District field biologist conducted an informal, on-site wetlands jurisdictional determination. It was the District's decision that a stormwater construction permit would be required, but a wetland resource management (dredge/fill) permit would not be required. The permit application with accompanying design calculations and other documentation was completed and submitted to the water management district in July 1990, and the permit was issued in September 1990. In the interim, the watershed boundaries were further refined by ground observation during several storms of varying intensity and duration.

Construction

Actual pond construction began in September 1990. Nuisance/exotic vegetation was mechanically removed, followed by excavation and re-contouring of the pond according to design specifications. Desirable aquatic vegetation was carefully removed and placed in holding ponds for later use in the re-vegetation phase of the project.

A berm was constructed along the east boundary of the pond to enclose a water area of approximately 0.7 acre at the discharge invert control elevation. Inlet structures were installed at the northwest and southwest corners where existing stormwater discharge pipes entered the pond. The original structures were aluminum boxes, with outside dimensions of approximately 4 by 8 feet and 4 feet deep, equipped with a 90° v-notch weir at the discharge end. Wooden decks were built over the structures for safety and security. This phase of the construction continued through December 1990. In December, measurements were made to develop an irrigation plan for the reuse demonstration portion of the project.

In January 1991, construction of the control structures began. The pond was de-watered sufficiently to allow access to the new berm without undue flooding. Dual rectangular weirs, 44 and 45 inches wide and supported with concrete pillars were placed side-by-side in a trench excavated in the new berm. The weirs were carefully leveled, at an elevation of 82.52 feet, then stabilized with rip-rap. Roughly fan-shaped aprons were constructed on both the approach and tailwater sides of the weirs, and the resulting excavations were stabilized with rip-rap. Additional concrete was poured into forms on top of the supporting pillars and around the bottom of the weir plates to further stabilize and protect the structure. A wooden platform or "bridge" was built across the weir structure for protection and to improve its appearance.

Construction of the irrigation system and pump house began in February. On two Saturdays, volunteers from the Florida Department of Environmental Regulation, the University of Central Florida, and the Florida Irrigation Society installed pipe, fittings, and controls for an irrigated area of approximately one and one-quarter acres immediately surrounding the pond. A 5-HP single phased pump was bolted to a poured concrete pad which also served as the foundation for the pump house. Individuals from the Florida Irrigation Society provided freely of their time to help design the irrigation system and they helped in obtaining necessary equipment and supplies. Construction of the pump house, and pump intake with controller continued and was completed in mid-March. After electrical power was installed, the pump was connected to the suction and discharge lines. A programmable automatic controller and electrically actuated zone valves were installed to independently operate the irrigation system's four zones. A fifth zone valve with partial piping was installed for possible future use. The system was tested before sod was placed in the cleared area around the pond.

The original inlet structures were modified following a mid-March storm during which more than five inches of precipitation occurred in a three-day period. The pond reached a level that completely submerged the v-notch weirs, making measurement impossible. Because the permanent pool established itself at a higher elevation than originally anticipated, the weirs were raised and modified. The new weirs were rectangular, with a discharge opening 24 inches wide and 16 inches high. The structures were raised 13 inches and equipped with sharp-crested rectangular weirs to make inflow measurement feasible at higher pond elevations. Raising the weirs further could have caused a backup in the stormwater collection piping, and possible street flooding. At the time the structures were modified, the inlet from a small stormwater detention pond serving the adjacent Civic Center parking lot was piped into the nearest inlet structure at the northwest end of the pond. This was done to assure that all possible inflow, including the overflow from the smaller pond, would be measured. The pond's overflow had previously flowed downhill over a grassed surface into the reuse pond.

Re-vegetation

Aquatic plants and sod were planted in May, and further aquatic plantings continued throughout the spring and summer. Sod was placed approximately 25 feet wide around the perimeter of the pond to prevent erosion. The aquatic plants are maintained by City of Winter Park's lake management personnel, and some control of primrose willow and cattails has been necessary. After some adjustments, the irrigation system was placed in automatic operation at a rate of about 1 inch per week over the irrigated area to keep the new sod alive and irrigate existing grassed areas

A major goal of the restoration effort was the re-creation of natural conditions through re-vegetation with appropriate aquatic plants. The following guidelines are excerpted from Beever, (1986), Mitigative Creation and Restoration of Wetland Systems, A Technical Manual for Florida, in the section dealing with ponds, larger lakes, and "lake"-borrow lake systems.

"The mitigation of pond-lake systems often takes two separate forms with similar final goals. Either a natural system is being mitigated by additional work in contact with or adjacent to a natural wetland or a de novo created lake or pond is to be furnished with native vegetative systems to provide enhances habitat and water quality, while precluding the establishment of nuisance species." In this case, the pond was a previously created, though altered, eutrophic lake and wetland system.

"Exotic and nuisance plant species, if present, should not be left to remain in or adjacent to the mitigation site. A buffer equivalent to the width of the mitigation area should be cleared of these species." The clearing and removal of nuisance species was accomplished during the excavation and re-grading of the pond. Primrose willow and cattails have reappeared, but are being controlled and managed.

"Critical to a successful lake/pond mitigation is the knowledge of hydroperiod, elevation, and the water quality incoming to the lake or pond system." If these factors are known, a plan profile can be drawn up specifying plantings for each of the vegetative bands around the mitigation site. In the reuse pond, the hydroperiod is not only known, but controlled by the regular withdrawal of water for irrigation. Although some trial and error has been necessary, the original plantings have flourished during the warm wet summer months, and recovered after the cool, dry winter months.

"Generally, natural systems mitigation should provide similar grades and dominant species assemblage to the adjacent wetland areas. Particularly when the mitigation area is small relative to the remainder of the system, a 'donor' effect will dominate." The reuse pond comprises about 15 percent of Lake Mendsen. The remaining 85 percent remains altered and choked with nuisance species and sediment. Although the entire Lake Mendsen area is relatively small (approximately six acres) and isolated, with no discharge to surface waters, the 'donor' effect appears to be affecting the reuse pond by replenishing the nuisance species, which were removed. Unless the entire area is restored in the future, the need for periodic maintenance will continue.

Following is a brief description of each plant species chosen for the re-vegetation.

Pontederia spp. - Pickerelweeds: Pickerelweed is a hardy transplant. It survives from one foot above to two feet below the ordinary water level (OWL), doing best at one foot below OWL in organic peats and sands. Seasonal die-backs should be expected. This plant is a staple of freshwater mitigation projects.

Sagittaria spp. - Arrowheads: Arrowheads survive in a range of sandy organic substrates with lancifolia proving the hardiest in southwest Florida. Two to three foot centers at one foot above to two feet below OWL are recommended with best survival at OWL.

Canna indica - Canna lily: Canna propagates readily from bulb and potted nursery stocks. Several variants are escaped cultivars. Elevation should be from OWL to one foot below OWL planted during the winter dry season. Substrate optima is thickly organic.

Juncus effusus - Soft rush: Soft rush is found in large clumping stands along the edges of freshwater ponds, lakes, and low pasture lands. It grows equally well in wet soil or dry ground. Recruitment to restored sites is good. These plants were placed along the shoreline of the reuse pond at elevations ranging from OWL to one foot below OWL, and in clumps two to four feet above OWL.

Nymphaea odorata - Fragrant water lily: Fragrant water lily can be found in ponds, lakes, and sluggish streams in water from 0.1-2.5 meters deep. It has a wide pH tolerance and is able to grow in very acid to very alkaline water. Wood ducks (some of which inhabit the reuse pond) use this species as a secondary food source, and the roots and petioles are fed upon by certain rodents. Also, the underside of the leaves provide a surface for egg deposition by small invertebrates. (Tarver, et. al., 1979)

These species were considered highly desirable for the reuse pond re-vegetation, and have survived and proliferated during the past year.

CHAPTER 3

MEASUREMENT AND DATA COLLECTION

To formulate a mass balance for an actual operational reuse pond is more difficult than one for a bench-scale laboratory demonstration, because the pond requires data collection at all times. Although the in-situ data collection was found to have some unforseen, adverse characteristics and revealed some potential sources of error, the data are for the most part reliable and serve to validate the theoretical predictions. Two separate systems were designed and constructed; one for measurement of precipitation and one for measurement of liquid levels for flow into and out of the reuse pond and for pond storage. To complete the mass balance irrigation and evapotranspiration data are necessary.

Precipitation

Rain Gauge

A Texas Electronics Model 6118-1 electric rain gauge transmitter was chosen to measure precipitation. The transmitter consists of a collector and a series of funnels to divert the rain water into a tipping bucket mechanism. The collector and tipping bucket are designed so that each hundredth of an inch of rain causes the alternate fill and tip of the mechanism. A sealed glass enclosed mercury switch is attached to the mechanism to momentarily complete an electrical circuit with each tip of the bucket (Texas Electronics, Inc., 1991). An electrical impulse from a datalogger passes through a two-conductor cable, registering 0.01 inch of precipitation with each tip.

Datalogger for Recording Precipitation

A Campbell Scientific Model CR10 datalogger was used to record the precipitation data. A datalogger is actually a small programmable computer designed for field data collection applications. Dataloggers have the capability to accurately convert a sensor signal to a digital value, process measured data over time, and store processed results for later retrieval. The CR10 has 64K bytes of random access memory, with approximately 29,000 final storage locations available to record precipitation data (Campbell Scientific, Inc., 1986). The CR10 was programmed to accumulate bucket tips, and record the accumulated precipitation at each five-minute interval during which rainfall occurred. The program, which was adapted from programs developed by the U. S. Geological Survey, also calculates and records total daily precipitation, the five-minute interval of maximum precipitation, and the total accumulation since the program was initialized (German, 1991). Other useful information such as battery voltage, and maximum and minimum daily temperature are also stored.

Appendix B contains a listing of program instructions and parameters, with a brief description of each step.

Power Supply and Storage Modules

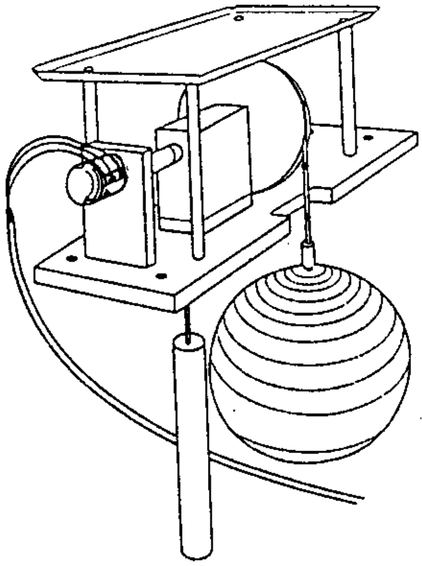
Two additional features were incorporated into the precipitation measurement and data collection system design to help increase data integrity and reliability. A 12-volt, rechargeable storage battery was chosen as the power supply for the datalogger to prevent interruptions in data collection during electrical storms. Batteries were exchanged when the voltage dropped below 12 volts, or every two months.

Two Campbell Scientific Model SM192 storage modules were obtained for use with the CR10 data logger. The storage modules have a self-contained power supply and a storage capacity of 192,896 bytes (Campbell Scientific, Inc., 1990). One of the storage modules was constantly connected to the datalogger to simultaneously record and store the precipitation data. This configuration provided a convenient means of transferring the data to a personal computer, and had the added advantage of providing a complete set of backup data. When all storage locations in the module have been used, the oldest data are written over as new data are stored; however, in the case the precipitation data, neither storage module ever reached its full capacity. If the datalogger or its power source were to be damaged, all its internal memory would be erased, but the data up to the point of failure would be preserved in the storage module. The storage modules were exchanged approximately every two weeks, and the data downloaded to ASCII text files in a personal computer using software provided with the datalogger and a serial interface.

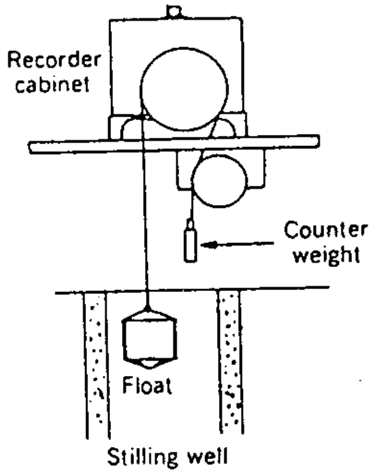
Rain Gauge Location and Physical Setup

By cooperative agreement, the rain gauge and datalogger were installed on the roof of the Orange County Environmental Protection Department's air monitoring building, located approximately 400 feet from the center of the reuse pond. This location was completely open to the atmosphere, free from interfering obstructions, and well protected from potential vandalism. The rain gauge was mounted on a heavy, secure base, carefully leveled, and connected to the data logger with signal wire. Approximately once a month the mechanism was checked for debris and bird droppings, and carefully cleaned if necessary. The datalogger was located inside the secure, locked building, which is temperature controlled and accessible only to specified individuals.

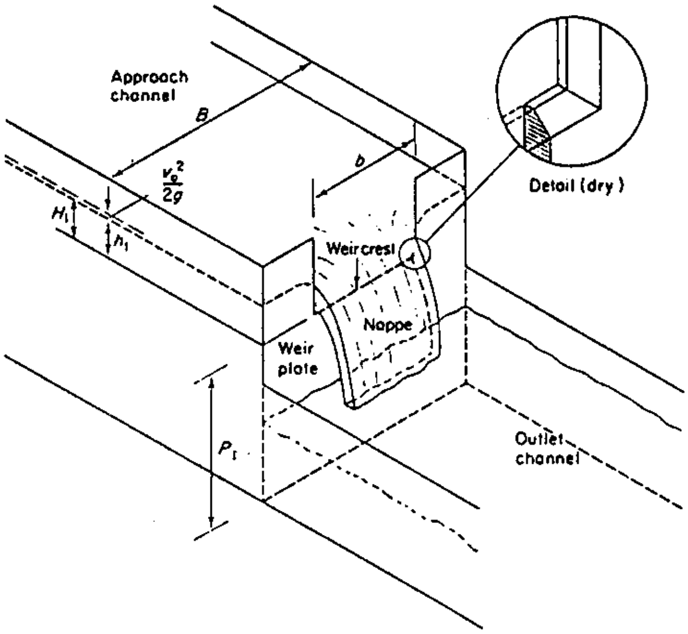
The original rain gauge proved to be defective, and data from June 26 through July 19, 1991, when the gauge was replaced, were considered unreliable. For this time period, precipitation data files were obtained from a U.S. Geological Survey rainfall collection station located approximately one mile from the reuse pond.



Level Sensor
(Omnidata, 1986)



Installation Detail
(Wanielista, 1990a)



Weir Structure Detail
(Ackers et. al., 1978)

Figure 3-1. Liquid Level Measuring Equipment mechanical shaft rotation into an electrical signal. A 5-volt (5000 millivolt) direct current input excitation voltage from a datalogger is applied to the potentiometer. As the potentiometer shaft turns, the output voltage varies directly with the change in resistance across the potentiometer. This output voltage is directly proportional to the measured water level. As the potentiometer is rotated through its full 10 turns, representing a change in elevation of 10 feet, its output voltage varies from 0 to 5000 millivolts. The relationship between change in height and change in voltage is linear to a tolerance of ± 0.1%. The slope of the line describing this relationship is 10 ft/5000 mv or 0.002 ft/mv. This slope is used in the measure subroutine of the datalogger program to translate the movements of the float and pulley to the stage reading recorded by the datalogger. The system resolution is 0.01 foot, resulting in extremely accurate stage measurements.

Signal Transfer

Transferring the relatively low-voltage signals to the datalogger from the remote level sensors presented some logistic problems. Wire runs of approximately 200 feet and 340 feet were required for the south and north inlet structures, respectively. Shielded 24-gauge signal wire with polyethylene or polypropylene insulation was required to eliminate the possibility of interference from electrical fields. Wire of the proper specifications was obtained, cut to length, and buried in trenches to protect it from traffic in parking areas, lawn maintenance equipment, and vandalism. Despite these precautions, the 340-foot signal wire failed in January 1992 after less than seven months of use. When it was determined that the loss of continuity could not easily be found, the wire was replaced. For ease of installation, the new wire was run across the pond rather than being buried in the ground. It has functioned reliably for the last four months.

The datalogger instructions recommend a signal delay to adjust for signal stabilization and transient voltage effects in wire runs greater than 100 feet. A technical representative from Campbell Scientific recommended a trial-and-error bench test to determine the optimum delay time (McHugh, 1991). This approach is easier, more practical, and at least as accurate as the rigorous method of calculation contained in the instructions. One of the level sensors was connected to a 1000-foot length of signal wire. The pulley was rotated through several precise one-foot increments at delay times of 5, 10, 20, and 100 milliseconds. The most accurate readings were obtained at 20 and 100 milliseconds, although all readings appeared to be within the 0.01-foot sensitivity specified for the level sensors. Based on this test, a 20-millisecond delay was specified in the measure subroutine of the datalogger program.

Level Sensor Location and Physical Setup

To provide protection from potential damage and damp the wave action resulting from short-period water surface disturbances, the level sensors were mounted over 10-inch diameter stilling wells made of Schedule 40 PVC pipe (Wanielista, 1990a). The steel tapes attached to the float and counterweight were cut to a length which would allow for maximum anticipated changes in stage without allowing the counterweight to contact the bottom of the stilling well. Each of the three potentiometers was set to its nominal halfway point, roughly five feet. An arbitrary datum was established for each sensor and compared to a known elevation, so weir crest elevation could be accurately determined.

Several holes were bored in each stilling well, and the pipe was firmly seated on the bottom of the weir structure or the pond bottom for the pond stage recorder. Sturdy wooden structures were constructed to protect the level-measuring equipment from weather and vandalism. One stilling well was located at each of the two inlet structures, and a third was placed at the end of a dock extending approximately 15 feet (depending on pond stage) into the pond.

The inlet weirs were designed for a calculated maximum flow rate of 8.8 cubic feet per second (cfs). High tailwater conditions occurred during times when the pond was at full temporary storage capacity. The effect on flow calculations is discussed in Chapter 5. The outflow structure was designed for a flow rate of up to 30 cfs; however, observations confirmed that the pond and adjacent watershed would reach a static or possible backflow condition during storms producing flows of a much smaller magnitude, as explained in Chapter 5.

Datalogger for Stage Recording

A Campbell Scientific Model 21X datalogger was used to record the stage measurements from which inflow and data were calculated. The 21X has 40K bytes of random access memory, with approximately 19,000 final storage locations available to record stage data (Campbell Scientific, Inc., 1987). The 21X was programmed to record the stage at each of the two inlet weirs and the pond stage every five minutes. The program, which was adapted from programs developed by the U. S. Geological Survey, also records battery voltage, and maximum and minimum daily temperature (German, 1991). Appendix B contains a listing of program instructions and parameters, with a brief description of each step.

The 21X is equipped with a self-contained, 12-volt, rechargeable battery pack. The datalogger was installed in the irrigation pump house, where 110-volt power was available to keep the batteries constantly charged in case of power failure. Two storage modules were used to store, back up, and transfer the stage data. One of the storage modules was connected to the datalogger at all times. Because of the high volume of data involved in the stage measurements (869 data points per day) some of the oldest files have been written over. However, at least three months of data files are still available in the storage modules, should they ever be needed.

Irrigation System Data

Irrigation system data were obtained from an in-line meter installed on the discharge side of the pump. Because of periodic problems with the pump and controller, the necessity for frequent testing, and sprinkler heads broken by vehicles using the irrigated areas for parking, the irrigation system had several periods of down time, as discussed in Chapter 5. Meter readings were taken when the storage module was exchanged, and when groundwater monitoring wells were measured. Data were manually listed and transferred to a spreadsheet for calculation.

Evapotranspiration Data

Evaporation data were obtained from records on file at the Citrus Experiment Station in Lake Alfred, Florida. Daily records were available for the months of June 1991 through April 1992. Since data for May and June 1992 were unavailable at the time of publication, 1991 records data were substituted. Although daily evapotranspiration rates would be expected to vary, it was assumed that the average evapotranspiration rates in May and June 1992 would be similar to those in May and June 1991.

Based on a technical report issued by the National Oceanic and Atmospheric Administration (U. S. Department of Commerce, 1982), a coefficient of 0.76 was used to convert the pan evaporation values provided by the Citrus Experiment Station to the lake evapotranspiration values used in the overall mass balance.

Data Integrity

The only losses of data during the past twelve months have been the result of the defective rain gauge and the signal wire failure. Of the data collected during the 358-day study period, 310,535 data points were considered for use in the overall mass balance for the reuse pond. Of these only 6071 data points were unusable as a result of equipment failure. This represents a 98% recovery rate of data during the study period.

CHAPTER 4

POND DESIGN

Department of Environmental Regulation Rule 17-40, Florida Administrative Code (F.A.C.), the State Water Policy (Cox, 1991) requires a stormwater pollutant annual average load reduction of 80% for discharges to most waters, Rule 17-40.420(4)(a)1., F.A.C., and 95% for those discharging into Outstanding Florida waters, Rule 17-40.420(4)(a)1., F.A.C. Of the currently used stormwater management methods, off-line retention can achieve the stated pollutant removal efficiencies for surface discharge only. However, wet detention ponds that discharge to adjacent surface waters are, in general, not designed to achieve even 80%. If some of the detained water can be used within the watershed and not discharged to surface waters, the pollutants discharged from the wet detention ponds will also be decreased and the pollution removal standards may be met.

Wet Detention Ponds

One of the more common stormwater management practices is the wet detention pond. These ponds are excavated areas with a pool of water (permanent pool) which usually exists throughout the year, a debris storage volume, and a temporary storage area. The ponds are used to attenuate peak discharges, reduce pollutant loading and pollutant concentrations, and most recently to store water for reuse purposes. The pond helps improve downstream water quality by sediment removal, uptake of nutrients from aquatic plants, chemical transformation, and runoff water reuse. Temporary storage volume designs vary depending on the use of the storage volume; however, the minimum size is calculated as one inch over the entire watershed. The total pond volume if used for peak attenuation is generally greater than the temporary storage volume. The maximum depth for the permanent pool has been specified by some water management districts as six feet to minimize recycling of pollutants stored in the bottom mud. Greater depths are allowed for the storage of sediment and debris in a small area of the pond. A vegetated area that leaves no more than 70 percent of the permanent pool in open water is recommended. Short-circuiting of flow should be minimized by locating pond inlets and outlets as far apart as possible. Wet detention systems are found throughout the State of Florida in areas where the water table is of sufficient height to maintain a permanent pool.

Reuse Ponds

Reuse pond design and operating specifications for pond depth, size of permanent pool, debris storage, and flood control are the same as those required for wet detention ponds. Although the temporary storage volume may differ, wet detention pond specifications for temporary storage may be used. The reuse rate is then calculated based on a percentage of the annual runoff. However, flexibility exists to use combinations of design temporary storage volumes and reuse rates.

Recycling or reuse of stormwater for irrigation will minimize the volume of discharge and reduce the pollutant load on downstream water bodies, while providing a beneficial use for the runoff and simulating pre-development hydrology (EPA, 1990).

A Possible Solution

The stormwater reuse pond was designed using the procedures recommended by Wanielista et. al. (1991). According to the proposed procedures, reuse ponds are designed to retain runoff water within a watershed and to reduce the mass of pollutants in the discharges to drainage wells and surface water bodies. The difference between a wet detention pond and a stormwater reuse pond is the operation of the temporary storage volume. A wet detention pond may be constructed and operated to discharge the runoff water and possibly some ground water to adjacent surface waters, while a reuse pond is designed to reuse rather than discharge a portion of the runoff volume.

The traditional design of pond temporary storage volume for a wet detention pond has been based on the consideration of water quality, and uses a design storm. The design storm; however, usually ignores the preceding rainfall record and assumes that there is an antecedent dry period long enough to ensure that the pond is at some control elevation. The usual assumption is a zero temporary storage.

To address the sensitivity of the temporary storage volume to inter-event dry periods, Wanielista, et. al. (1991) used long-term rainfall records from 25 Florida rainfall stations in a model that simulates the behavior of a reuse pond over time. A spreadsheet was used to build a 15-year mass balance for a theoretical reuse pond. After each rainfall event, surface runoff and reuse volumes were respectively added to and subtracted from the previous pond storage volume. If the temporary storage volume exceeded the available storage volume, discharge occurred. If the temporary storage volume was less than zero (the permanent pool volume was withdrawn for reuse), supplemental water was used to replenish the pond and maintain the permanent pool. Both the rate of reuse from the theoretical pond and the reuse volume were varied. The pond efficiency, (or percentage of the runoff not discharged) defined as one minus the total volume of surface discharge divided by the total volume of runoff times one hundred, was calculated for each combination.

The results of the simulation are presented in **Rate-Efficiency-Volume (REV)** charts. Curves reflecting several efficiencies track the appropriate combinations of reuse rates and reuse storage volumes. The **REV** charts are generalized for application to watersheds of any size or runoff coefficient. A computer program was developed to execute the design technique. Information about the theory behind the **REV** charts and their development was adapted from published research (Harper, 1991).

For an average annual pollutant mass removal of 80% in a wet detention pond, at least 50% of the runoff volume should be retained and not discharged from the pond, and available for reuse, when the **REV** charts are used for design. For a 95% annual pollutant mass removal, at least 90% of the runoff volume should not be discharged. The percentages assume a wet detention pond will remove an annual average 60% of the incoming runoff pollution mass before surface discharge, which may over-estimate the actual efficiency.

The Rainfall-Runoff Process

Upon receiving rainfall, a watershed will produce some degree of runoff. Development typically increases the amount of runoff, due to an increase in impervious areas that are directly connected to the point of discharge of the watershed. Stormwater management systems are constructed to control the amount of runoff and the rate at which runoff is discharged from the watershed. When designing a system to collect, transport, and treat stormwater, the runoff characteristics of the watershed must be determined. The runoff coefficient, designated C, is a most basic parameter for runoff. It is equal to the fraction of rainfall that flows overland to a discharge point, becoming runoff (Wanielista, 1990a).

$$C = \frac{R}{P} \tag{4.1}$$

where C = runoff coefficient
R = rainfall excess or runoff volume
P = rainfall volume

The runoff coefficient for a watershed varies depending on the quantity and rate of rainfall, the extent of pervious area, the water storage potential of the soil, the permeability and antecedent moisture conditions of the soil, and the degree to which runoff corridors are linked.

When designing stormwater systems, the runoff coefficient must be determined for an assumed specific rainfall event and antecedent conditions. Impervious areas that are directly connected to the point of discharge will contribute almost all of the rainfall that falls on them. For design purposes, the runoff coefficient for impervious areas is generally assumed to be one. Pervious areas may or may not contribute runoff, in which case the runoff coefficient may range from near zero for soils with high permeability and storage potential (low saturation) to near one for soils with low permeability and storage (high saturation).

The overall runoff coefficient for an area composed of different surfaces can be determined by weighting the runoff coefficients with respect to the total areas they encompass. This relationship is described in equation (4.2).

$$C = \frac{C_1 A_1 + C_2 A_2 + \cdots + C_N A_N}{A_1 + A_2 + \cdots + A_N} \tag{4.2}$$

where C_N = runoff coefficient for surface N
A_N = area of surface N

This value is termed the effective runoff coefficient of the watershed and is representative for the entire watershed.

The Equivalent Impervious Area

The equivalent impervious area (EIA) is equal to the product of the total area of the watershed and the effective, or weighted, runoff coefficient for the watershed.

$$EIA = C \times A \tag{4.3}$$

The area of the EIA is equal to the area of a completely impervious watershed that would produce the same volume of runoff as the actual watershed. As an example, a 20 acre watershed with an effective runoff coefficient of 0.50 would have an EIA of 10 acres. If one inch of rain fell on this 10-acre impervious area, the runoff volume would be 10 ac-in (10 ac x 1 in). If the same amount of rain fell on the actual watershed the runoff volume would not change (20 ac x 1 in x 0.50 = 10 ac-in). The EIA will be expressed in acres throughout this report. The use of the EIA serves to generalize the model so that it can be applied to a watershed of any size and runoff characteristics.

Calculation of EIA

For watersheds in which all runoff is from directly connected impervious areas, the EIA is simply equal to the DCIA. The EIA is calculated as

$$EIA = DCIA = C \times A \tag{4.4}$$

when there is no contribution from other areas. The C x A term is commonly called the contributing area, and is referenced in hydrology literature (Mulvaney, 1851; Wanielista, 1990a).

When a watershed has pervious areas as well as a DCIA, the runoff or rainfall excess from the pervious areas can be calculated using one of following techniques. The runoff coefficients calculated separately for pervious and impervious areas can then be used to calculate the effective, overall runoff coefficient using Equation (4.2).

Rainfall Excess

Soil Conservation Service (SCS) Curve Number

The United States Soil Conservation Service compiles and publishes data concerning the hydrologic characteristics of soils. This information, combined with on-site observations, can be used to obtain a measure of the water storage capacity of the soil called the curve number (CN). The curve number ranges from 0 (no runoff) to 100 (complete runoff). The maximum storage of the soil, S′, is related to the curve number by the following equation (Kent, 1973):

$$S' = \frac{1000}{CN} - 10 \tag{4.5}$$

where S′ = maximum storage (inches).

The rainfall excess can then be calculated using

$$R_p = \frac{(P - 0.2S')^2}{(P + 0.8S')} \quad if\ P > 0.2S' \tag{4.6}$$

and

$$R_p = 0 \quad if\ P \leq 0.2S' \tag{4.7}$$

where P = rainfall (inches).

Irrigation Ponds in Florida

From a survey of members of the Florida Irrigation Society, at least 40 irrigation pond sites were identified within the state. Ten of the 40 sites serve golf courses, eight were built for commercial development, two provide water for a cemetery, and the others operate in apartment and multi-family developments. None of the pond volumes or irrigation rates were designed considering long-term historical rainfall and other hydrologic data. Essentially, the volumes were either fit to an area, or some rough calculations were done using a design storm, e.g., the runoff from 4 inches of rainfall. Also, many ponds have been constructed to provide water for agricultural uses.

Design Methods

The Design Storm

Historically, the sizing of detention ponds has been based on the concept of a design storm, a storm of particular volume that is associated with a specific recurrence interval and duration. The volumes vary with geographic location and are presented in Frequency-Intensity-Duration curves. A designed system is expected to fail only when a storm of greater magnitude occurs. For instance, a pond volume might be designed using the 25-year, 6-hour storm event which is equivalent to 6 inches of rainfall over a 6-hour period for Orlando. Ideally, the pond will properly function during this and any smaller storm, and will fail on the average of once every 25 years.

The certainty and completeness of using the design storm is being increasingly questioned (James, 1982). A major shortcoming is that the antecedent condition of the pond, specifically the level of water in the pond at the time of the design storm event, is not considered.

Continuous Modeling

As an alternative, increasing value is being placed on long-term continuous modeling. A continuous model of a reuse pond would use the complete rainfall record of a specific region and simulate the pond's reaction to this and other variables. The time distribution of storm events is known so that both the antecedent conditions and inter-event dry periods, which are being stressed by Wanielista and Yousef (1990b), are addressed. The cumulative effects of more frequently occurring storms are also considered. Thus with inexpensive but fast microcomputers, complex simulations are both time- and cost-effective. The results of the continuous model can be used to develop design criteria that meet discharge regulations.

The data collected as a result of this research can be used as a basis for future long-term modeling and analysis. The demonstration reuse pond's measurement and equipment has proven to be reliable and accurate, and can be used to continue data collection indefinitely.

The Structure of a Reuse Pond

Figure 4-1 is the cross-section of a typical reuse pond. The sediment storage volume lies at the bottom to receive settled matter. Above this, is the permanent pool volume, which provides a minimum residence time for stormwater. The reuse volume (temporary storage volume), is the volume above the permanent pool and below the flood control structure. The flood control volume includes the reuse volume and is the volume which lies above the permanent pool. The flood volume may exceed the reuse volume, at which time discharge would occur.

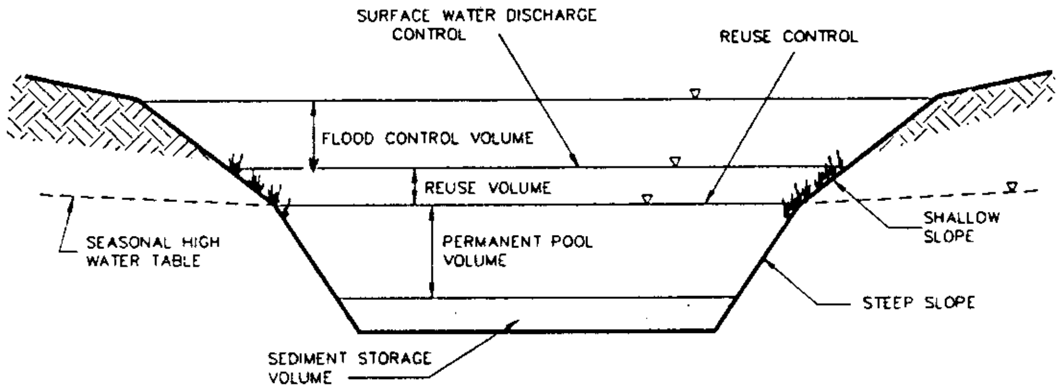


Figure 4-1 Schematic of a Reuse Pond

The reuse pond differs from a typical detention pond in that instead of the temporary storage volume being depleted by a discharge device (such as a bleed-down orifice in an outlet pipe) it is drawn down by a reuse system, and is thus called the reuse volume. A bleed-down orifice does not deplete the permanent pool because it lies at the top of this layer. A reuse system; however, could continue to deplete the pond volume below the permanent pool boundary, and may require a supplemental component to maintain this volume. A discharge structure is still necessary for flood control. Common practice should be used for the design of sediment storage, permanent pool, and flood control volumes, and their elevations and side slopes. This report provides design criteria for the reuse volume only.

The Behavior of a Reuse Pond

The response of a typical reuse pond to a rainfall event may be summarized. During and following a rainfall event, there is runoff into the pond and the water level rises to some depth above the permanent pool. If this new water level exceeds the level of the surface discharge control, there will be discharge at some rate until the water level drops back below the control structure. The reuse system is incrementally (daily) removing an amount of water from the reuse volume. If the reuse volume is expended, supplemental water, such as ground water, can be used to maintain the permanent pool volume. This could occur as seepage through the sides of the pond or by mechanical pumping using a controller. This scenario was simulated by creating a mass balance, monitoring the inputs and outputs, and recognizing assumptions.

The Mass Balance

The mass balance for the reuse demonstration pond was based on the model from which the **REV** curves were developed. This simplified model for the theoretical pond assumed two inputs, runoff and supplementary ground water, and two outputs, reuse and discharge. The reuse demonstration pond model was based on the mass balance equation (4.8), and expanded to include additional variables which were quantified through field measurement and data collection as noted in equations (4.9), (4.10), and (4.11).

$$INPUTS - OUTPUTS = \Delta S \tag{4.8}$$

The total of all inputs to the pond, minus the total of all outputs from the pond equals the change in storage. By considering all potential water movements, a complete, daily hydrologic balance may be expressed in volume units as:

Beginning Storage + Inputs - Outputs = Ending Storage, or

$$S_1 + RP + RI + RW + G_{in} - ET - D - RU - G_{out} = S_2 \tag{4.9}$$

Solving for unknown G terms (which include all unmeasured outflow):

$$S_1 - S_2 + RP + RI + RW - ET - D - RU = G_{out} - G_{in} \tag{4.10}$$

To express water into the pond as a positive value and water out of the pond as a negative value, as shown in the spreadsheet in Appendix A, the sign is reversed:

$$-(S_1 - S_2 + RP + RI + RW - ET - D - RU) = G_{in} - G_{out} \quad (4.11)$$

Thus:

If $G_{in} > G_{out}$, $G_{in} - G_{out} = (+)$ (water flowing into pond).

If $G_{in} < G_{out}$, $G_{in} - G_{out} = (-)$ (water flowing out of pond).

The variables are defined as follows:

RW = rainfall excess or runoff volume collected from the watershed and conveyed to the pond through pipes
RP = volume of precipitation falling into the pond
RI = indirect runoff from the area immediately surrounding the pond (not conveyed through pipes)
G = volume of water moving through the sides of the pond (subscript "in" or "out" indicates direction of movement as noted above)
D = discharge volume
ET = evapotranspiration volume
RU = reuse volume
S_1 = pond storage at the beginning of each day
S_2 = pond storage at the end of each day

The average evapotranspiration rate in the Winter Park area for a pond is generally equal to the average precipitation on the pond (approximately 50 inches). This was the assumption used to develop the reuse pond **REV** curves. However, published data were used to estimate evapotranspiration from the reuse pond, and all other variables in the mass balance except groundwater movement in and out of the pond were measured, as noted in Chapter 3. Because of its complexity, the flow of ground water through the sides of the pond was back-calculated based on the other known variables.

Volume Units

The runoff, discharge, reuse, ground water, and net storage are expressed as volumes of water. Volumes are frequently expressed as inches over a defined area, or in more common English units of cubic feet. Rates are merely volumes delivered over a period of time and thus can be expressed in the same manner. A unit area is the equivalent impervious area of the watershed. The volumetric unit of inches on the EIA is a way in which the charts are generalized for any runoff coefficient and contributing area. Once the EIA is known, the values can be converted to more practical units using simple conversions.

The ultimate functional product of the simplified, theoretical reuse pond model is the Rate-Efficiency-Volume (**REV**) chart. Individual **REV** charts are specific to geographical regions with similar meteorological characteristics.

The 358 days of data obtained from the reuse demonstration pond produced an overall efficiency of 55% (percentage of runoff not discharged), which compares favorably to the conservative 50% efficiency used to determine the reuse rate from the **REV** chart for Orlando, Figure 4-2. These efficiencies represent the percentage of runoff not discharged from the pond, not necessarily the total amount of water reused for irrigation.

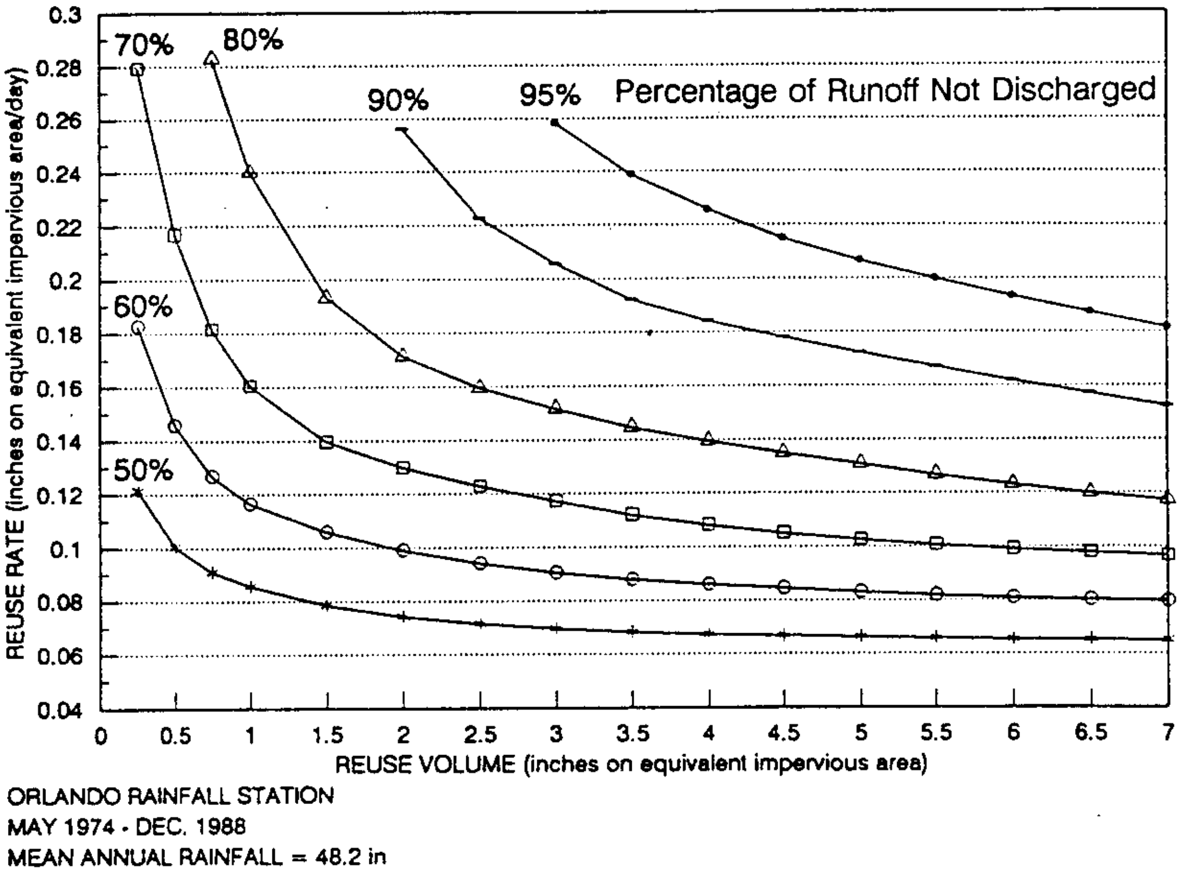


Figure 4-2. Reuse Rate-Efficiency-Pond Volume for Orlando, a (**REV**) Curve (Harper, 1991)

Mathematical Equations and a Computer Program

The efficiency curves of the **REV** charts were approximated with equations of best fit by the regression package of graphics software Lotus Freelance Plus. It was found that the power equation consistently estimated the curves most accurately. The "fit" was generally very good. Out of the 150 equations (6 for each station), only four had R-squared values of less than 0.90 and of the remaining, two-thirds were above 0.96.

The equation is of the form:

$$y = a \cdot x^{b} \tag{4.12}$$

or

$$R = a \cdot V^{b} \tag{4.13}$$

where R = reuse rate (inches on EIA/day)
V = reuse volume (inches on EIA)
a,b = descriptive variables

The variables vary for each geographic region and level of efficiency.

The equations were used in a computer program, written to execute the design calculations. Information concerning two of the three **REV** parameters (rate, efficiency, volume) is required. The input of watershed data (area, runoff coefficient, area for irrigation) is an option that allows the program to express the **REV** parameters in more meaningful units, ie., cubic feet and acre-inches as opposed to inches on the EIA.

Watershed and Pond Design Details

The **REV** curves for Orlando (Figure 4-2) were used for the design of the pond temporary storage, the irrigation area, and the irrigation rate in the demonstration reuse pond. The design was then submitted with a permit application to the St. John's River Water Management District. The data required by the District are also needed to use the **REV** curves in design, thus no additional work was required to complete the permit.

Watershed Data

The total area that could possibly contribute runoff water to the pond was estimated as 8.13 Acres, with approximately 6.84 impervious acres composed of roof tops, streets, and parking lots. Figure 4-3 shows the detailed outline of the watershed, and the location of pond inlets and outlets. The directly connected impervious area was estimated at about 3.42 Acres and consists primarily the streets and some of the parking area. However, some of the other impervious areas may contribute, because of small (less than about one-half inch) holding areas for their runoff. The area available for irrigation can be as large as 8.5 Acres and includes recreational areas adjacent to the watershed. The area within the watershed that is available for irrigation and adjacent to the pond is 1.25 Acres.

The area for irrigation was specified by knowing the maximum available pond temporary volume, the range for an

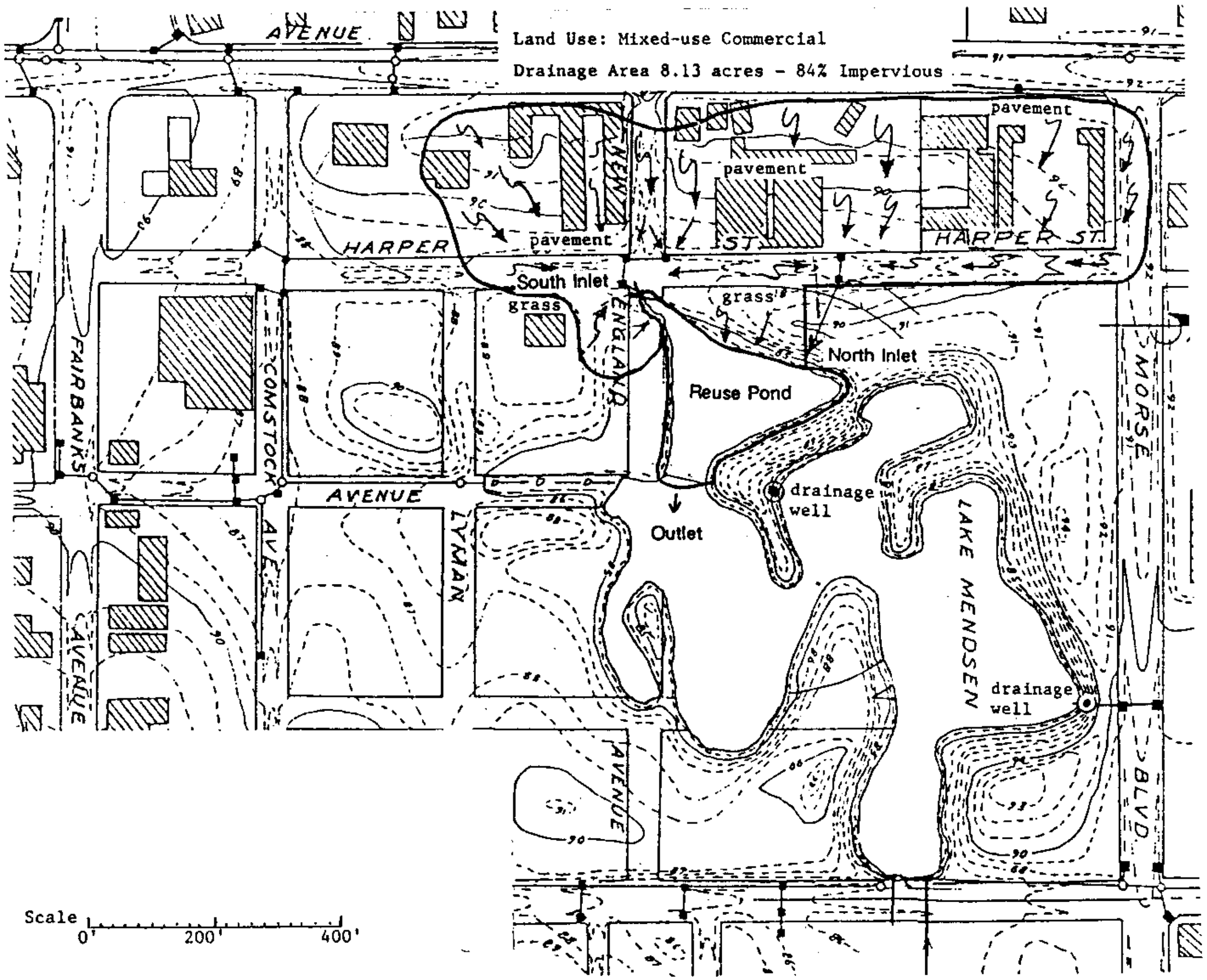


Figure 4-3. Watershed Detail

acceptable irrigation rate, and the percent reuse of runoff required. The maximum pond temporary storage was 1.0 acre-feet and was calculated by assuming the top of the permanent pool at elevation 81.00 feet with the discharge weir set at 82.52 feet. The range for an acceptable irrigation rate was 0.33 to 0.67 inches per irrigation period, with three irrigation periods per week, which is a volume of about 1 to 2 inches per week. The desired pond efficiency, or percent of runoff not discharged, was set at 50% which is the equivalent of an assumed pollutant mass loading reduction of 80%. Using the **REV** curves, the following two options were available, considering two different watershed conditions. One option would be that all impervious areas contribute and the other is that only the directly connected areas contribute:

Watershed EIA Condition	Irrigation Rate (inches/application)	Reuse Area (Acres)
6.84 Acres	0.50	2.50
3.42 Acres	0.44	1.25

Since the total watershed impervious area will most likely not contribute, it was decided to irrigate 1.25 Acres based on the directly connected impervious area and make provisions to increase the irrigation area if necessary based on pond monitored overflow frequencies.

The detention pond depth was set at a maximum of about 6 feet measured from the invert of the discharge weir to the pond bottom. A littoral zone was established using natural vegetation. Maintenance of the pond shoreline and control of unwanted vegetation was built into the normal grounds maintenance activities performed by the City of Winter Park.

Removal of Debris and Muck

As stated previously, the area of Lake Mendsen used for the reuse pond was filled with debris, overgrown with unwanted vegetation and neglected over the years. In addition, during the design phase, extensive silt and muck pockets were located at the site as shown in Figure 4-4. The depth of water and muck was documented, and the muck was substantially removed before the pond was contoured and re-vegetated.

It is important to document the muck depth because of the potential to degrade the pond from internal recycling of pollutants from the muck. Removal of the muck provides for a lasting restoration and more thorough treatment of runoff which is discharged from the pond.

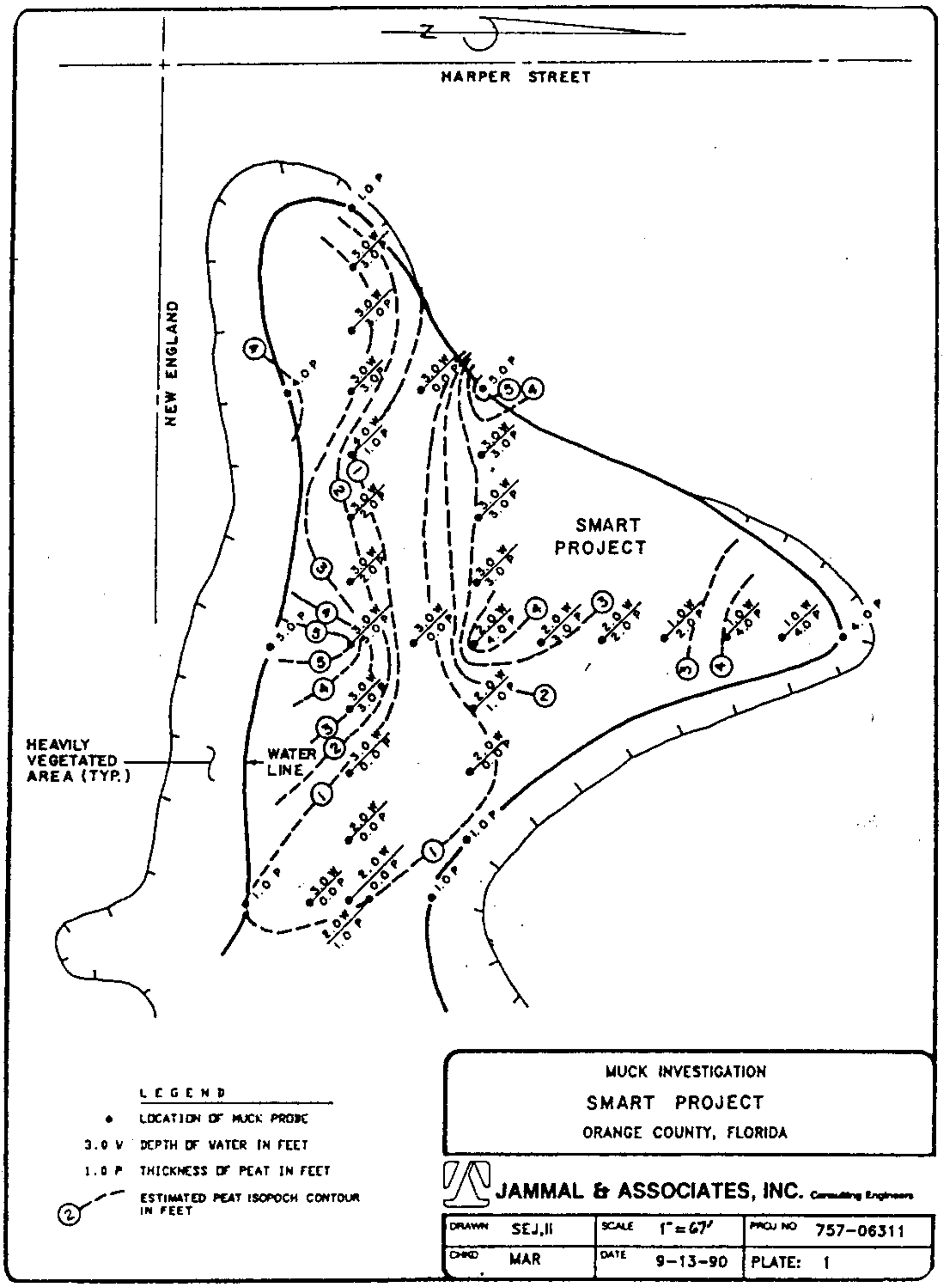


Figure 4-4. Reuse Pond Muck Depths

CHAPTER 5

PRESENTATION, CALCULATION, AND INTERPRETATION OF DATA

Presentation of Data

Rainfall and pond inflow and outflow data were collected on a continuous basis. All collected data were converted to units of cubic feet for consistency. The collected data representing inflow and outflow from the pond are tabulated for calculation purposes in the form of a spreadsheet (Appendix A). The 310,535 data points collected during the 358 days (51 weeks) and used in the spreadsheet were parsed and used in calculations by a computer program (Eaglin, 1992). A listing of the program logic is contained in Appendix C. Variables in each column heading of the spreadsheet are defined as follows:

Day of Year	The Julian date on which data were collected (ddd)
Date	The day on which data were collected (dd-mmm-yy)
Stage	Elevation of the pond surface above NGVD (ft)
S_1	Beginning daily storage in the pond (ft^3)
P	Depth of precipitation measured over the project area (in)
RP	Volume of precipitation in cubic feet falling directly into pond (ft^3)
RI	Volume of indirect runoff in cubic feet from the area immediately surrounding the pond (ft^3)

RW	Volume of runoff flowing into the pond from the watershed through the stormwater collection system (ft^3)
D	Discharge from the pond (ft^3)
dI	The net inflow to the pond (total inflow minus discharge) (ft^3)
EV	Evaporation rate (from published data) (in/day)
Area	Pond area based on stage (ft^2)
ET	Evapotranspiration over the pond area (calculated) (ft^3)
RU	Water reused for irrigation (gal and ft^3)
S_2	Ending storage (ft^3)
G	Net groundwater inflow-outflow and other unmeasured flow (ft^3)

Methods of Calculation

Calculated variables displayed in the spreadsheet columns, and values from the summary table, require a more detailed explanation. All data were carefully checked for input errors and for calculation accuracy.

The volume of precipitation falling directly into the pond was calculated in the spreadsheet by converting precipitation depth to feet and multiplying by the pond area, 34,064 ft^2, at the control elevation of 82.52 feet.

$$RP = (P\ in)(34064\ ft^2)/(12\ in/ft) \qquad (5.1)$$

The volume of indirect runoff was calculated in the spreadsheet by converting precipitation depth to feet and multiplying by the design area at the 85-foot contour, 45,346

ft^2, minus the pond area, 34,064 ft^2, at the control elevation of 82.52 feet. This quantity was then multiplied by a runoff coefficient C = 0.5.

$$RI = (P\ in)[(45346-34064)ft^2](0.5)/(12\ in/ft) \quad (5.2)$$

The runoff from the watershed was calculated using a standard rectangular weir equation and the measured depth above the weir crest (h_1) in two inlet weirs which received flow from the watershed conveyed through the stormwater collection system. The weir coefficient C_w was adjusted based on the depth above the weir crest (Wanielista, 1990a).

$$C_w = 3.15 + 0.0075(h_1/P_1) \quad (5.3)$$

The variable h_1 is defined as the depth above the weir crest, in feet, and P_1 is the depth of the approach channel, in this case two feet. Discharge Q in cubic feet per second was then calculated with the rectangular weir equation.

$$Q = C_w\ h_1^{3/2}\ (b-0.2h_1) \quad (5.4)$$

The variable b is defined as the base length of the weir(s), in this case 2 feet.

At the pond's design control elevation, the tailwater at the inlet weirs rose to within approximately two inches of their overflow or crest elevation. This compromise in the pond design was originally made to provide for maximum storage, while preventing street flooding during intense rainfall. Because ground water storage was greater than anticipated, the pond level stabilized near the control elevation for much of the wet season in 1991. To adjust for conditions under which the inlet weirs would be "drowned" or when the weir overflow would not be fully aerated, the following equation (Ackers, et. al. 1978) was used when the pond level was at, or above, the design control elevation.

$$Q_w = Q[1-(h_2/h_1)^{3/2}]^{0.385} \qquad (5.5)$$

The discharge under high tailwater conditions in cubic feet per second Q_w is corrected by applying the ratio of tailwater elevation to the depth above the weir crest (h_2/h_1) in the above equation.

A record of discharge was made every five minutes at each of the two inlet weirs. The total volume of inflow from the watershed was determined by multiplying each discharge increment (Q or Q_w) by 5 minutes (300 seconds) and summing the resulting volumes in cubic feet for the two inlet weirs at the north and south ends of the pond each day.

$$RW = \Sigma[300(Q_{north} + Q_{south})] \qquad (5.6)$$

A similar method was used to calculate overflow or discharge from the pond. Measurement was made with two side-by-side weirs with base lengths b_1 = 3.67 feet and b_2 = 3.75 feet respectively. The weir crest elevation h_1 is the same for both weirs. The standard rectangular weir coefficient (C_w) of 3.33 was used.

$$Q_{out} = 3.33h_1^{3/2}\ (b_1-0.2h_1) + 3.33h_1^{3/2}\ (b_2-0.2h_1) \qquad (5.7)$$

The two discharge values were separately calculated and added together to account for the effects of end contractions of the weirs. As with the inlet weirs, the total volume of inflow from the watershed was determined by multiplying each discharge increment Q_{out} by 5 minutes (300 seconds) and summing the resulting volumes in cubic feet each day.

$$D = \Sigma[300(Q_{out})] \tag{5.8}$$

There was no correction for tailwater elevation, since no measuring equipment was installed to record water elevation on the downstream side of the weirs. However, high tailwater conditions and backflows were observed during storms which were very intense or of long duration. The drainage wells that provide a means of stormwater disposal for the watershed area outside the demonstration area's boundaries could not provide sufficient drainage capacity to prevent backflow into the demonstration pond. On these occasions the pond level stabilized, and no measurement of either inflow or outflow was possible. Under these conditions, the inflow was calculated based on the depth of precipitation and reliable inflow measurements made when the pond elevation was significantly below the control elevation. Based on the collected data, the following precipitation-to-volume relationships were used:

$P > 3.0$ inches	$RW = 26{,}500$ ft^3/inch
$0.40 \leq P \leq 3.00$ inches	$RW = 16{,}000$ ft^3/inch
$0.20 \leq P \leq 0.39$ inch	$RW = 12{,}000$ ft^3/inch

It was assumed that the net inflow was equal to zero until the pond returned to near its design control elevation.

The net inflow to the pond is calculated in the spreadsheet by subtracting the daily discharge from the sum of the daily inflows.

$$dI = RP + RI + RW - D \tag{5.9}$$

The pond surface area is expressed as a function of stage, or water surface elevation. The pond dimensions were determined using land surveying techniques and transferred to an AutoCAD file, which was used to determine the area at seven different elevations between 78 and 84 feet above the NGVD (Jeppesen, 1992). Incremental volumes were calculated by multiplying change in elevation by the average area between elevation increments. Elevations, areas, and volumes are shown in Table 5-1, and contour lines are shown in Figure 5-1.

Table 5-1
Reuse Pond Elevation, Area, and Volume

Elevation (ft above NGVD)	Area (ft^2)	Volume (ft^3)
78.00	2924	2924
79.00	19602	14187
80.00	24811	36394
81.00	27328	62463
82.52	34064	104000
83.00	36020	120820
84.00	41200	159430

The function relating elevation to area was determined by linear regression. Elevations from 80.00 to 83.00 feet were used, since virtually all stage observations fell within this

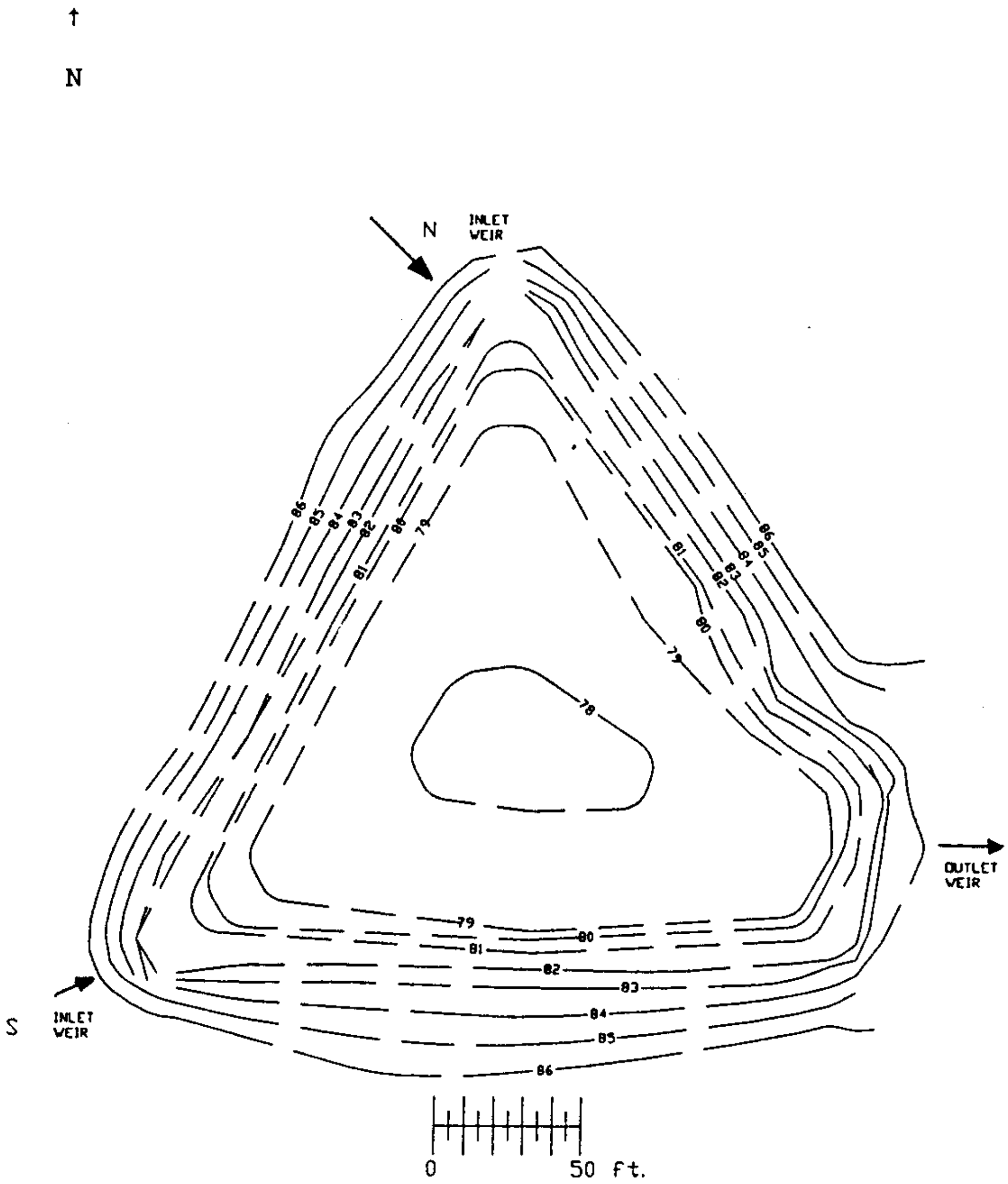


Figure 5-1. Reuse Pond Elevations

range. The regression resulted in Equation (5.10) which was used to calculate pond surface area in the spreadsheet.

$$\textbf{Area} = 3733.9\ (\textbf{Stage}) - 274{,}336 \qquad (5.10)$$

Evapotranspiration was then calculated from pan evaporation values, pond surface area, and the pan coefficient of 0.76.

$$ET = (EV\ in)(Area\ ft^2)(0.76)/(12\ in/ft) \qquad (5.11)$$

Reuse volumes in gallons were read directly from an in-line meter. Equation (5.12) is used to express reuse volumes in cubic feet.

$$RU\ ft^3 = RU\ gal/7.48\ (gal/ft^3) \qquad (5.12)$$

The same methodology used to develop Equation (5.10) was used for the elevation-volume, or stage-storage relationship. Note that S_1 and S_2 are calculated with the same equation, and S_2 becomes the next day's S_1.

$$S = 27855.2\ (Stage) - 2{,}192{,}900 \qquad (5.13)$$

Groundwater inflow or outflow is calculated from all other measured inputs and outputs. As noted in Chapter 4, a negative value of G indicates exfiltration or other unmeasured outflow of water from the pond, and a positive value of G indicates infiltration of water into the pond.

$$-(S_1 - S_2 + RP + RI + RW - D - ET - RU) = \pm G \qquad (5.14)$$

The percent of runoff discharged from the pond (%RD) is calculated by dividing pond surface discharge by the sum of inputs directly resulting from rainfall, and multiplying by 100.

$$\%RD = \frac{\Sigma Output}{\Sigma Input}(100) \tag{5.15}$$

or

$$\%RD = \frac{\Sigma D}{\Sigma RP + \Sigma RI + \Sigma RW}(100) \tag{5.16}$$

As calculated in the spreadsheet, the %RD = 45.

Similarly, the percent of runoff not discharged from the pond (%RND) is calculated as:

$$\%RND = \frac{\Sigma Input - \Sigma Output}{\Sigma Input}(100) \tag{5.17}$$

or

$$\%RND = \frac{(\Sigma RP + \Sigma RI + \Sigma RW) - \Sigma D}{\Sigma RP + \Sigma RI + \Sigma RW}(100) \tag{5.18}$$

As calculated in the spreadsheet, the %RND = 55.

The percent error is found by adding all inputs and outputs to the beginning storage and comparing the number to the ending storage. One output not included in the spreadsheet was pumped pond drawdown for maintenance purposes. The pumped drawdown was subtracted from the mass balance because it was a pond output. The maintenance activities occurred and resulted in the removal of 38,857 ft^3 of water from the pond. The difference between the calculated and actual ending storage, 932 ft^3, is divided by the total of the inputs, 1,114,001 ft^3, and multiplied by 100 to convert to percent. The result is 0.08% overall error.

The fraction annual rainfall entering the pond through stormwater collection pipes (FR) is found by dividing total runoff from the watershed by total precipitation, with the appropriate conversion constants.

$$FR = \frac{RW\ ft^3}{P\ inches\ (1\ ft/12\ inches)\ (43{,}560\ ft^2/ac)\ (8.13ac)} \tag{5.19}$$

Interpretation of Data

Precipitation Effects

The 51 weeks of data presented in this report demonstrate a significant seasonal variation in the frequency and intensity of storms, with accompanying changes in the water balance in the pond. In 1991, major rainfall events occurred on June 26, July 12 through 15, July 20, July 27 through July 29, August 24, September 20, and September 28. Rainfall decreased through the month of October, and the months of November and December were relatively dry. The next storm producing over one inch of precipitation occurred on February 5, 1992. Major rainfall events occurred again on February 25, March 25, April 11 and 12, and April 20 and 21. The severe hail that accompanied the March 25 and April 11 storms did not damage the reuse pond measuring equipment. A dry period followed these events, with moderate rainfall occurring on May 14 and May 27. Significant rainfall occurred on June 2 and 3, and inter-event dry periods became shorter through the end of the study period. Figure 5-2 shows the rainfall distribution during the study period.

During periods of no precipitation, some relatively small inflows through the stormwater collection system were recorded. This phenomenon was particularly noticeable during the dry season in February and March 1992. These flows were attributed to two possible sources. The first was groundwater seepage through cracks and improperly sealed joints in the stormwater collection pipes. The second was indicated by the raw data from the water level sensors, which frequently showed a small rise in stage in each of the inlet measuring structures between 4:30 and 5:30 a.m. This was attributed to water entering the stormwater collection system from irrigation systems serving the Winter Park Civic Center and nearby businesses.

Pond Stage, Groundwater and Leakage Effects

During the wet season, July through September, the pond stage showed little change as irrigation water was withdrawn and quickly replaced with stored ground water.

During dry periods, the irrigation withdrawals produced a general lowering of pond stage and ground water during the longer inter-event dry periods between storms. The pond's

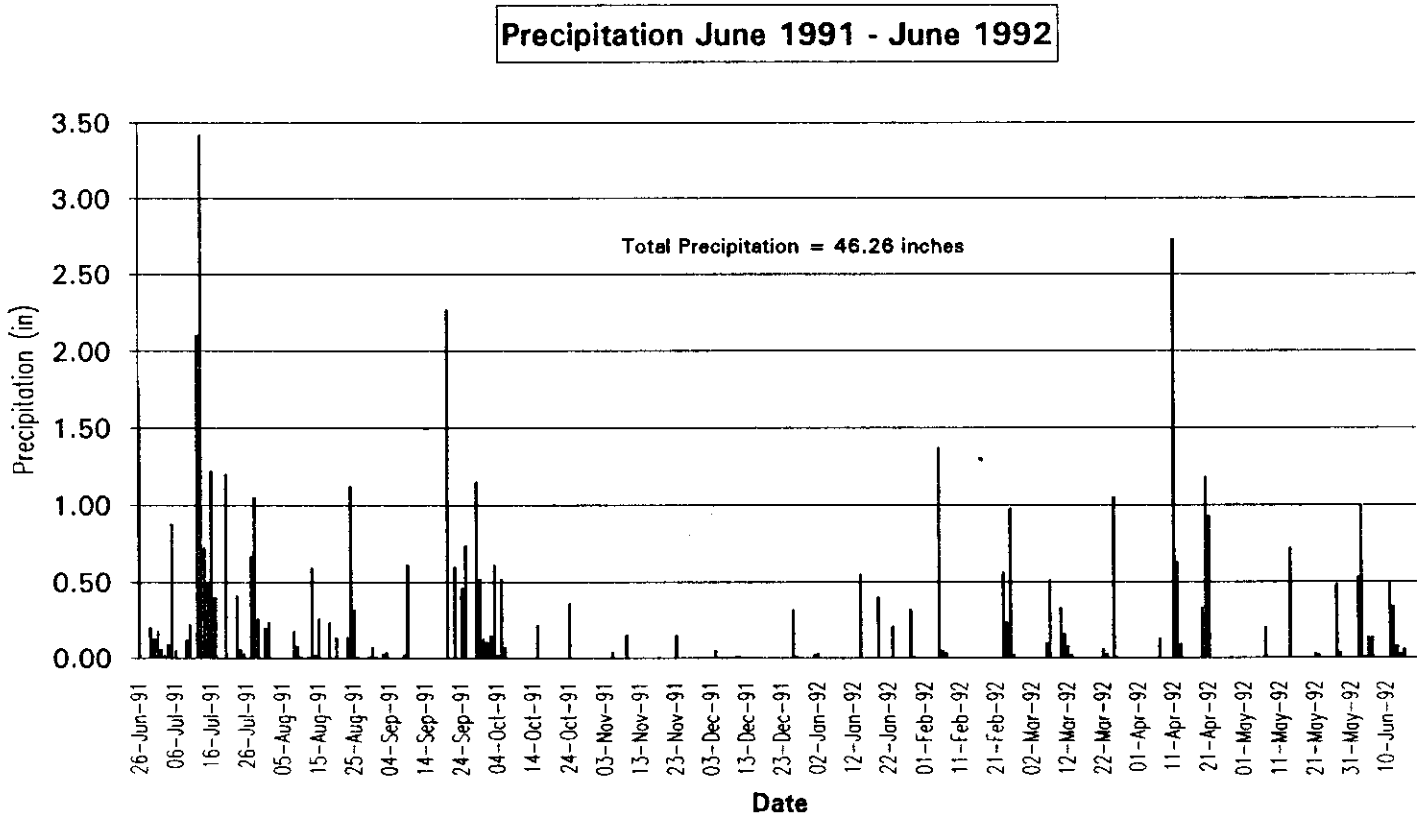


Figure 5-2. Precipitaton During the Study Period

storage capability continued to be adequate through the dry season, despite the reduced frequency of storms, and their lower intensity and volume. The effects of leakage and artificial drawdowns in the spring, coupled with some major precipitation events caused large, rapid fluctuations of the apparent groundwater inflow and outflow. These trends are shown in Figure 5-3 and Figure 5-4, representing pond stage and storage volume during the study period.

During a routine visit to the reuse pond for data collection on March 29, significant leakage through the berm surrounding the outlet weir was noted. Some of the soil around the outside and underneath the concrete weir structure had been washed out, allowing a relatively free and constantly increasing flow of water through the resulting channels. From April 12 through 15, the pond was pumped down with a high-capacity portable pump, and soil cement was used to fill in the obviously channeled areas. While this somewhat reduced the unmeasured flow, it was not completely stopped. On May 10 through May 14, the pond was again drawn down for maintenance. A concrete apron was poured on both the pond and tailwater sides of the weir structure. Although this effectively sealed the structure from major leaks, a small amount of seepage, probably attributable to seepage underneath and around the sides of the structure, was still evident. Some indication of this leakage can be seen in the monthly trends shown in Table 5-2. Negative values in the "G" column during the months of

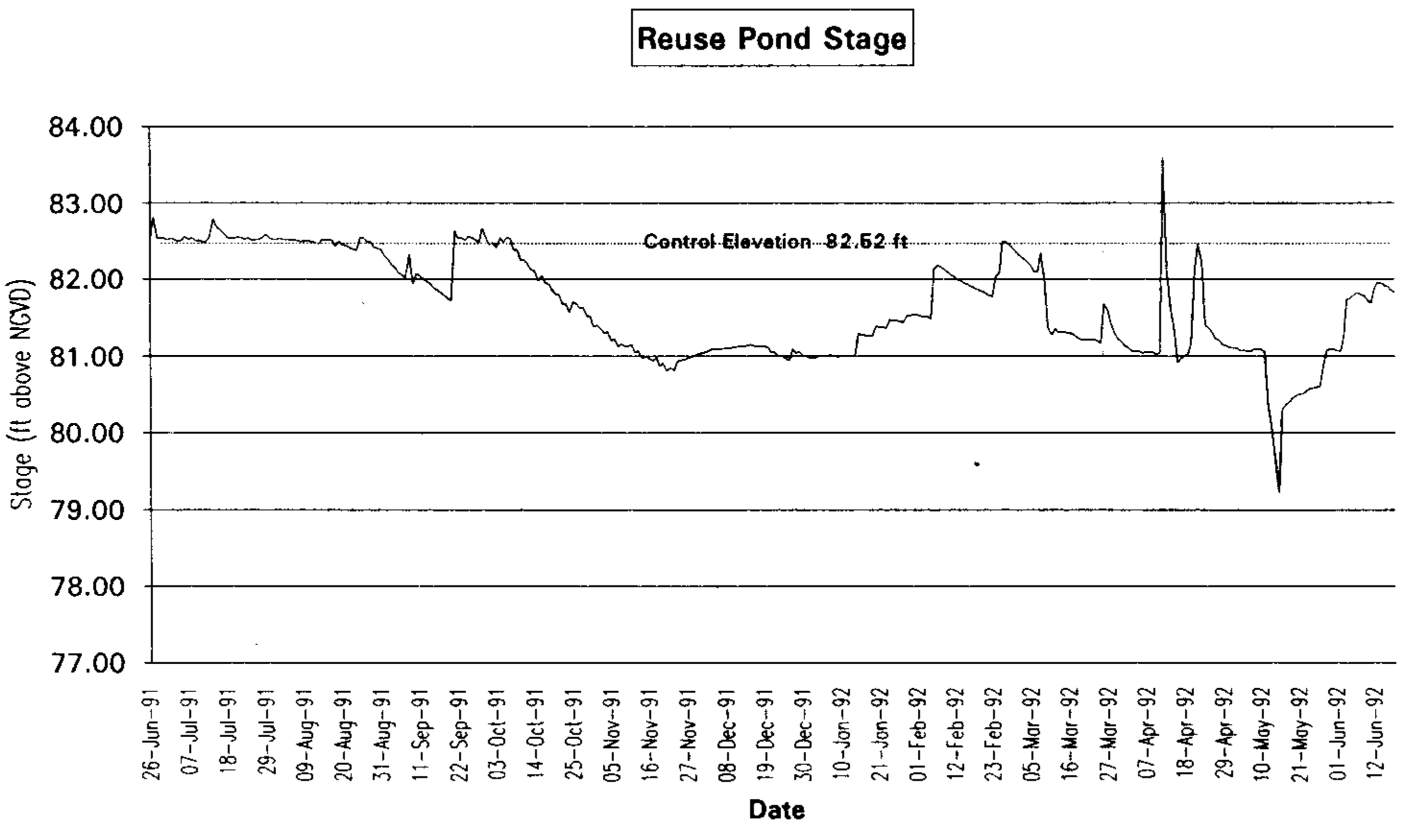


Figure 5-3. Reuse Pond Stage

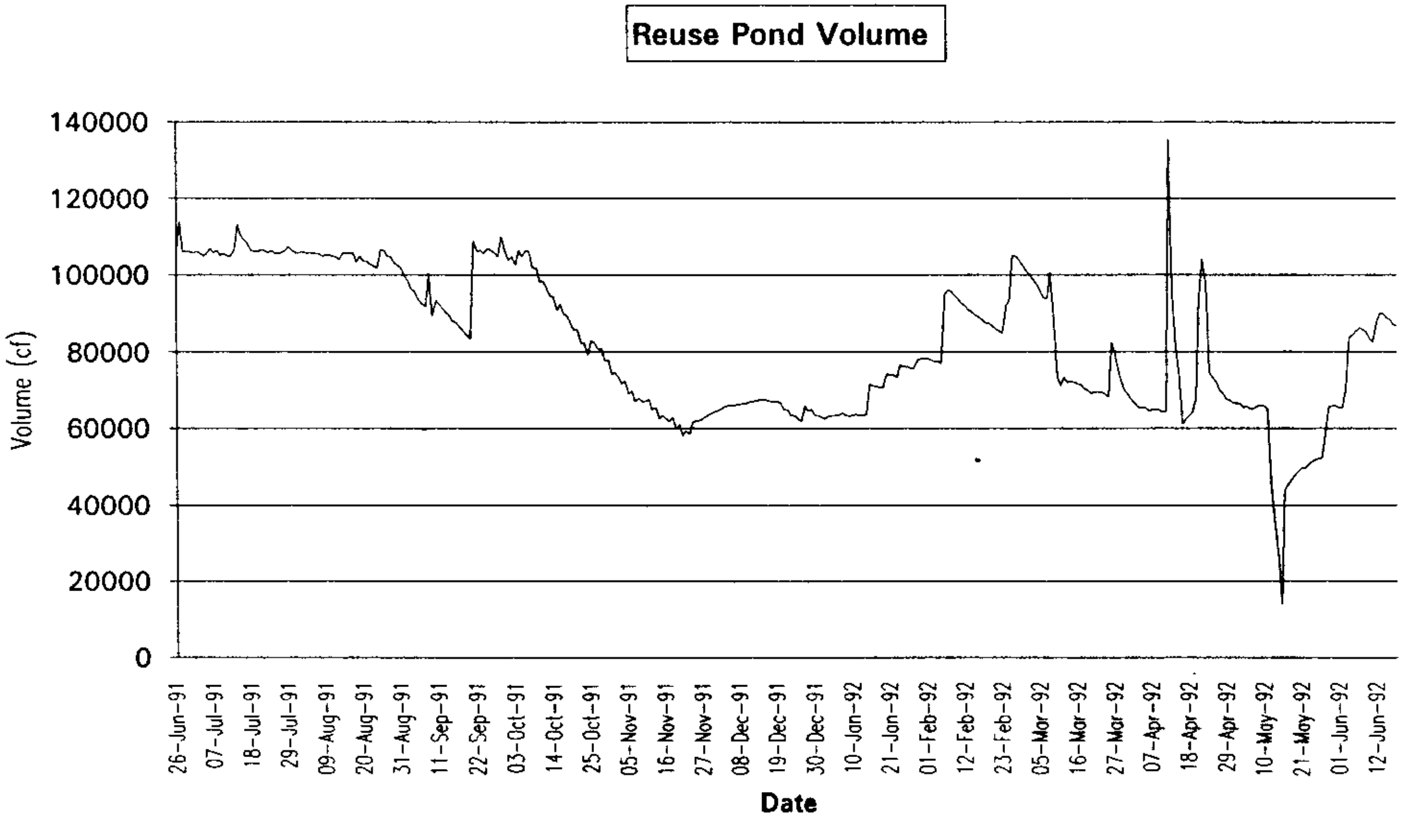


Figure 5-4. Reuse Pond Volume

July through October 1991 indicate the expected outflow of ground water, when the pond stage remained at or near its control elevation. During November and December, positive values of "G" indicate groundwater inflow at pond stages below the control elevation. However, beginning in February, or perhaps earlier, this trend was reversed and groundwater outflow (or other unmeasured outflow) was indicated by negative values, although the pond stage generally remained below the control elevation. This was interpreted as the effect of the unmeasured outflow through the outlet structure berm.

Table 5-2
Monthly Totals from Reuse Pond Mass Balance

Month	P (in)	RP (ft^3)	RI (ft^3)	RW (ft^3)	D (ft^3)	ET (ft^3)	RU (ft^3)	G (ft^3)
Jun 91[1]	2.09	5933	1394	35717	38614	2760	1290	-380
Jul 91	13.87	39372	9250	324881	318633	15239	11639	-27911
Aug 91	3.45	9793	2301	103060	22658	13587	7753	-77284
Sep 91	6.57	18650	4382	113450	88620	15155	15695	-12833
Oct 91	2.06	5848	1374	78835	9397	11268	59646	-34993
Nov 91	0.34	965	227	14047	0	7104	48172	30009
Dec 91	0.40	1135	267	3990	0	6550	12157	11644
Jan 92	1.54	4372	1027	22451	0	6754	7562	2066
Feb 92	3.26	9254	2174	50873	0	8713	1465	-29560
Mar 92	2.35	6671	1567	45471	0	11945	12994	-62475
Apr 92	6.02	17089	4015	103968	23022	13902	14477	-74507
May 92	1.49	4230	994	20675	0	14650	9791	-2572
Jun 92[2]	2.82	8005	1881	34415	0	10200	6733	-7547
Totals	46.26	131317	30851	951833	500945	137826	209374	-286425

[1] Data from June 26 - June 30, 1991
[2] Data from June 1 - June 18, 1992

Figures 5-5 and 5-6 show the pond level changes during non-rainfall conditions, and illustrate groundwater inputs to the pond at lower stages. They show the gradual effect of groundwater inflow when leakage from the pond was known to be minimal.

Preliminary data collected from monitoring wells indicate that the ground water table on the west side of the pond generally remained above the pond level, but sometimes fluctuated below the pond level on the south side. The outlet structure berm was constructed with soil from the pond containing muck and silt, and was subjected to occasional inundation. Water from the pond probably flowed outward through this berm whenever the pond stage was near the control elevation, even before the channeling and leakage occurred, and may have accounted for a significant portion of the total groundwater or unmeasured outflow.

Backflow Conditions

As previously mentioned, the inflow from the watershed, through the stormwater conveyance system and weir outflow measurement data were not always precise during the longest and most intense storms, because of backflow from the drainage well area. Reasonable estimates were made to provide discharge and input data during these periods. The overall pond balance during smaller storm events continued to conform the theoretical predictions. During these backflow events,

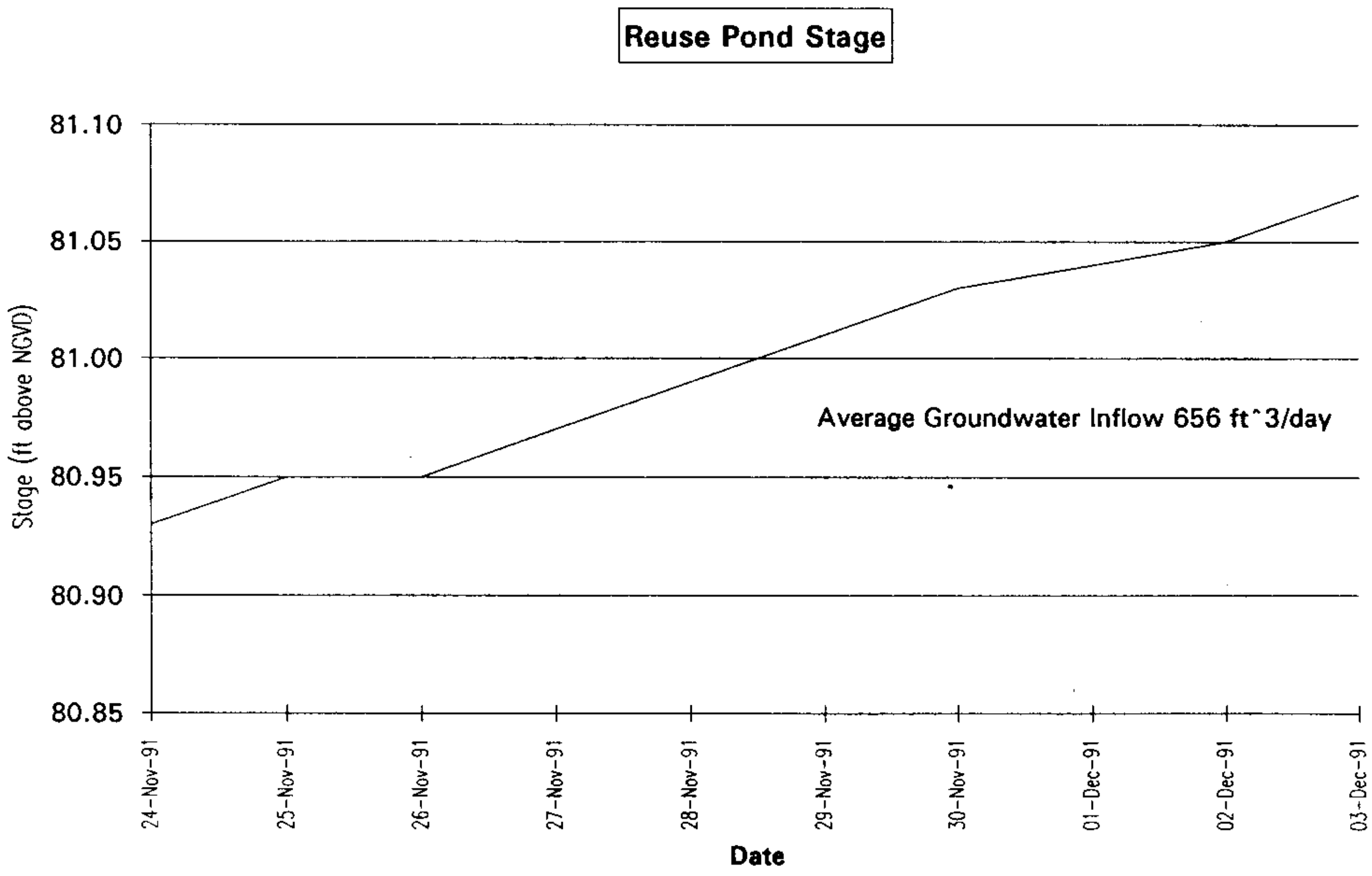


Figure 5-5. Reuse Pond Stage November 24 - December 3

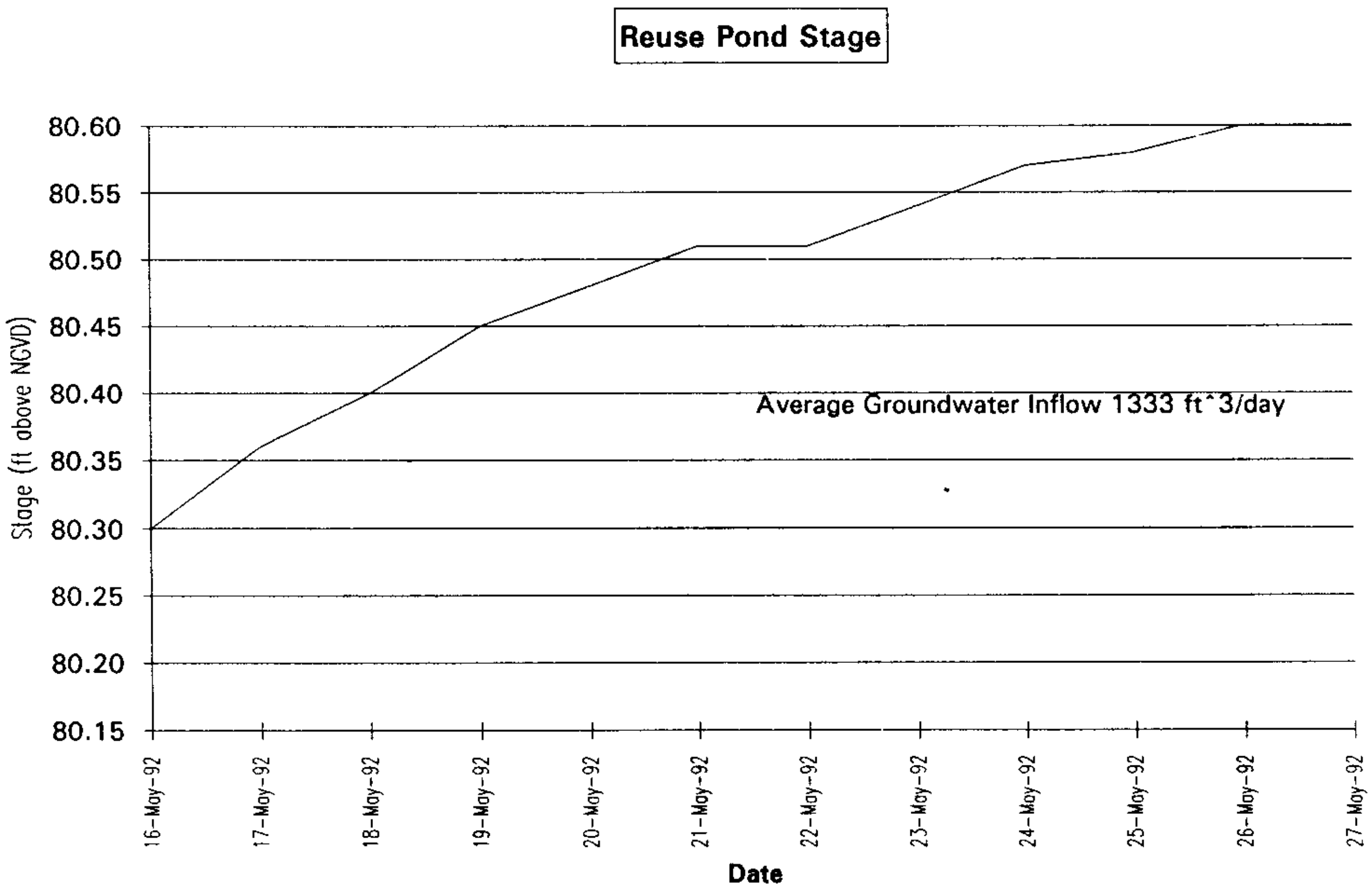


Figure 5-6. Reuse Pond Stage May 16 - May 27

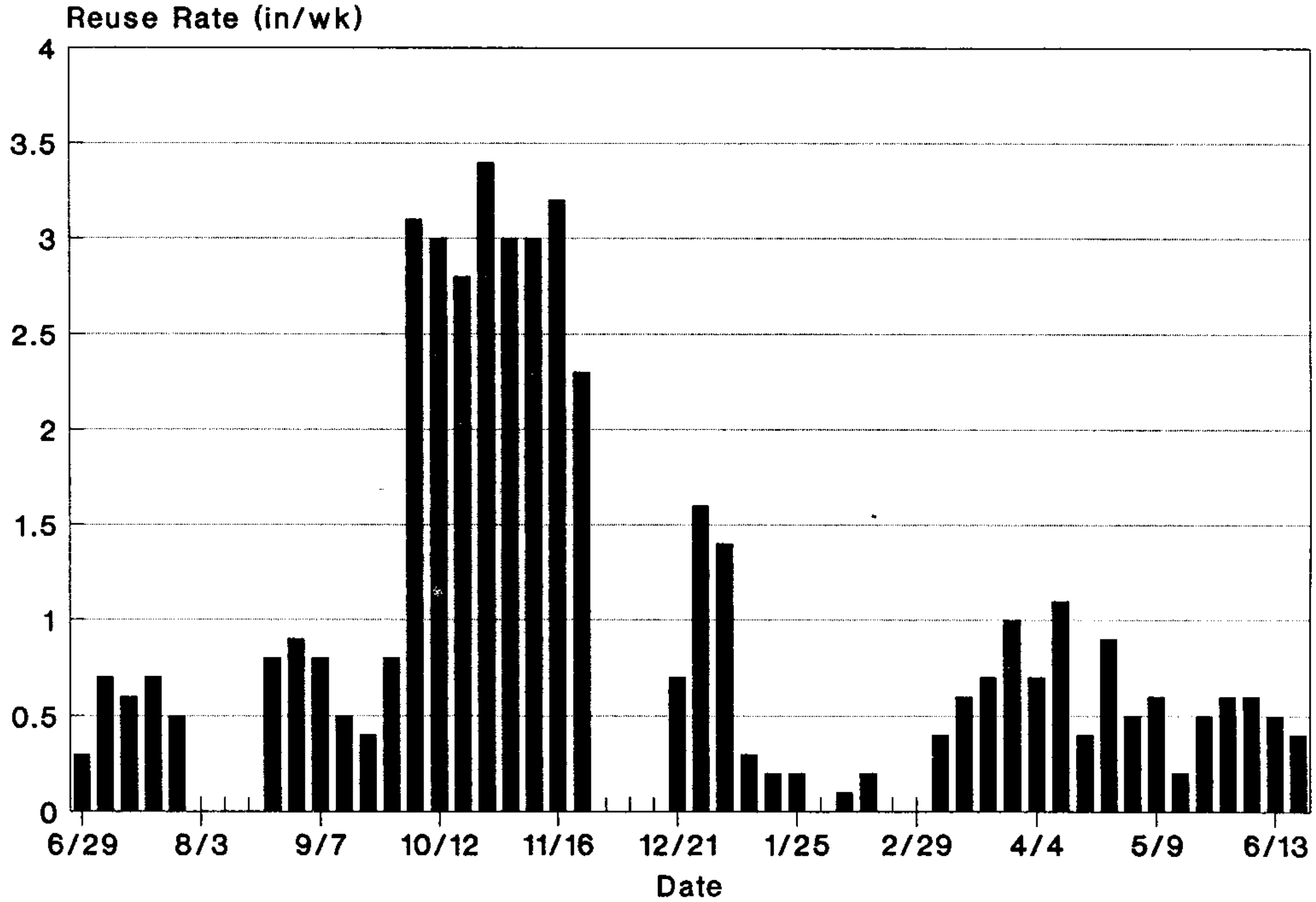
only about 4% of the discharge occurred. Thus, the resulting estimate of runoff water discharge is not effected by more than 4%. For more accurate data collection during these extreme events, a stage recorder located on the tailwater side of the pond's discharge weir would be necessary. With the additional data provided, flows under high-tailwater conditions, reverse flows, and static conditions could be quantified rather than estimated.

Reuse Operation

Reuse rates varied considerably during the study period, as illustrated in Figure 5-7. Although the system was purposely tested at different rates, some down time occurred as a result of malfunctioning equipment, broken sprinkler heads, and other operation and maintenance problems. The average reuse rate was 0.88 inches per week over the entire study period, or 1.07 inches per week if the down time is omitted. Even under dry weather conditions, the pond maintained a permanent pool which was sufficient for reuse irrigation without supplementary pumping.

Rainfall from the Watershed

The fraction of rainfall over the watershed which was conveyed to the pond was found to be a relatively high 0.7. However, this can be explained by the relatively high percentage of the watershed which is both impervious and directly connected.



Average Reuse 0.88 in/wk

Figure 5-7. Reuse Rates

Cost Analysis

Capital Cost

The approximate capital cost of the pump and the irrigation system was about $3910.00. This included the flow rate meter and pump controller. The cost of the pump and the controller was $710. The pond was constructed according to current stormwater detention pond construction details, and thus no additional cost would be incurred with the reuse pond design. The cost of operating the pump is about $3.00 per week or about $156.00 per year. This is calculated based on 8 hours of pumping per week at a cost of $0.10 per kilowatt hour. Annual costs consider amortization of the equipment over 20 years at 10% interest rate.

Based on pump, controller, and irrigation system cost:

$/yr = P ($3910, 10%, 20 yr) + $156

$/yr = ($3910 x .1175) + $156

$/yr = $615

Based on pump and controller cost only:

$/yr = P ($710, 10%, 20 yr) + $156

$/yr = ($710 x .1175) + $156

$/yr = $239

Based on irrigation system cost only:

$/yr = P ([$3910 - $710], 10%, 20 yr)

$/yr = ([$3910 - $710] x .1175)

$/yr = $376

Reuse Economic Benefits

During the 51-week study period, the volume of water reused for irrigation was approximately 1,566,000 gallons. Over the 51-week period the average use was roughly 30,700 gallons per week, or 130,500 gallons per month. However there were approximately nine weeks of irrigation system down time during the study period, or 42 weeks of actual operation. The average irrigation rate for the 42-week period was 37,300 gallons per week, or 162,000 gallons per month. The more realistic figures, based on actual operating time, and the City of Winter Park's are used to calculate the reuse economic benefits.

Based on City of Winter Park monthly rates within the City:

$3.60 + $1.00/1000 gallons for the first 6000 gallons

+ $1.45/1000 gallons for all over 6000 gallons.

$3.60 + $1.00 x 6 + $1.45 x 156 = $236/month

or $2830/year + 376 (irrigation system) = $3206/year

Based on City of Winter Park monthly rates outside the City:

$4.50 + $1.25/1000 gallons for the first 6000 gallons

+ $1.82/1000 gallons for all over 6000 gallons

$4.50 + $1.25 x 6 + $1.82 x 156 = $296/month

or $3552/year + $376 (irrigation system) = $3928/year

The cost savings can be calculated by subtracting the annualized cost of the reuse system from the yearly cost of potable water to irrigate the same area. In the City of Winter Park, the savings would be: $3206 - $615 = $2591. Outside the city, the savings would be: $3928 - $615 = $3313.

The cost of potable water can be substantially higher in some locations, making the yearly cost significantly greater, and making reuse more economically desirable.

If the cost savings realized from the 1.25-acre irrigation demonstration area are extrapolated to a typical 18-hole golf course that has about 100 acres of irrigation area, the cost savings would range from about $207,000 to $265,000 using the City of Winter Park's rate structures.

The metered irrigation volume within the City of Winter Park during 1991 was about 370 million gallons per year (Briggs, 1992). This does not include many residential users, and the total irrigation use may at least doubled. Using stormwater to supplement only half this volume (185 million gallons), would result in significant cost savings.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

The subject of this thesis involves an intensive study of a stormwater reuse pond. Observations were recorded every five minutes on three liquid level sensors in the reuse pond, and precipitation volumes were accumulated each five minutes during rain storms. Irrigation volumes were metered, and evapotranspiration data were obtained from a published source. These data were used to develop an overall mass balance for the reuse pond over a study period of 358 days. All known inputs and outputs were balanced. The remaining volume was attributed to groundwater infiltration and exfiltration, and some unmeasurable outflow near the end of the study period. The unmeasured flow, which was the result of channeling around the outlet weir structure of the reuse pond, provided the opportunity to observe the recovery of pond stage after a pumped drawdown for maintenance and repair of the weir structure.

This study has achieved both the research objectives and the objectives and benefits of the concurrent project funded, in part, by the Department of Environmental Regulation, as noted in the following discussion.

Research Objectives

First Research Objective

The first objective was to determine the reliability of equipment for direct measurement and data collection of water depth, flow rates, and rainfall.

The rainfall and liquid level sensing equipment used for measurement and data collection proved to be extremely reliable and effective during the study period, recovering 98% of the data from four sensors. Of the 310,535 data points used in the development of the overall mass balance, only 6071, or 2%, were unusable as a result of equipment failure on two separate occasions. When problems with the equipment occurred, they were easy to find and repair. It is notable that one of the level sensors continued to operate even while being completely submerged during a period of prolonged, intense rainfall.

The dataloggers and storage modules which recorded the data were 100% effective. Although, as a precaution, all data files were automatically backed up during collection and file transfer, these backup files were never needed.

The reliability of the measurement and data equipment has been firmly established in this study, and can serve as a model for future projects.

Second Research Objective

The second objective was to calculate the percentage of runoff volume not discharged from the reuse pond. In the overall mass balance this value, called the %RND, was determined by evaluating all known inputs and outputs. A value of 50% is needed to reduce the pollutant mass in the incoming runoff by 80% to achieve water quality standards mandated by the State of Florida. The overall mass balance demonstrated that 55% of the incoming runoff was not discharged into the remainder of Lake Mendsen and the drainage wells which provide a means of stormwater disposal for the surrounding watershed.

Third Research Objective

The third objective was to determine irrigation volumes and average weekly application rates. Operation of the irrigation system was studied, and the resulting data were used in the development of the overall mass balance. The volume of water reused during the study period was 45 inches over the 1.25-acre irrigation demonstration area. This represented an average rate of 0.88 inch per week over the entire study period. If total irrigation system down time is considered, the average rate becomes 1.07 inches per week. This form of reuse produces the multiple benefits of protecting the environment, saving ground water, saving the cost of providing treated ground water for irrigation, and possibly producing a source of revenue.

Fourth Research Objective

The fourth objective was to estimate the net groundwater pond exchange from a mass balance based on collected data. Groundwater pond exchange represented the unknown value in the overall mass balance. For the first seven to eight months of the study period, ground water exfiltration occurred during periods when the pond remained full or nearly full, and was replenished by frequent precipitation. Infiltration occurred when the pond was drawn down for reuse, and was not frequently replenished with precipitation.

During the last four to five months of the study, unmeasurable outflows occurred. This affected the unknown term for groundwater inflow-outflow in the mass balance during this period. The unmeasured flows were accounted for in the calculations, but could not be fully verified with the measuring equipment in place during the study period. However the reliable data indicate that ground water can be relied upon to help restore the temporary storage volume when water is withdrawn for reuse.

Fifth Research Objective

The fifth objective was to estimate the fraction of annual rainfall entering the reuse pond through the stormwater collection pipes. The reuse pond's watershed area is highly developed with roads, buildings and parking lots. The impervious area of the watershed was found to be 84% of the total area, and the directly connected impervious area was estimated at 42% of the total area. Given these ratios, it would be assumed that the fraction of rainfall entering the pond would be relatively high, since little initial abstraction, infiltration, or evaporation would occur before the runoff was conveyed to the pond.

The overall mass balance showed this fraction to be 0.70, which is a relatively high value, and supports the assumptions. In this case the higher value is beneficial, because an average of 55% of the incoming water will not be discharged from the pond. Some of this water can be beneficially reused for irrigation.

Project Objectives and Benefits

In conjunction with the research, the Department of Environmental Regulation provided some of the funds, with contributions by the University and the City of Winter Park, which were used to construct the pond and restore a more natural ecological balance to the project area. The project served to fulfill the Department's mission, which is to "Protect, Conserve, and Restore the Air, Water and Natural Resources of the State."

First Project Objective/Benefit

The first objective was to protect the ground water by diverting and treating stormwater runoff which otherwise would discharge directly into the Upper Floridan aquifer through drainage wells. During the study period, it was found that 55% of the runoff entering the pond was not discharged. The application of a portion of the retained water to the irrigation demonstration area helped to restore a more natural hydrologic balance to the project area.

Second Project Objective/Benefit

The second objective was to conserve the state's vital groundwater resources through a demonstration of the beneficial reuse of stormwater for irrigation. The overall mass balance demonstrates that stormwater can effectively and efficiently be collected and reused for irrigation, while producing significant economic benefits. Extrapolating the data from the limited study area demonstrates that significant volumes of ground water and potable water could be conserved.

Third Project Objective/Benefit

The third objective was to restore the ecology of an a portion of an altered lake and urban wetland area. The re-contouring and re-vegetation of the reuse pond were done according to guidelines published by the Department of Environmental Regulation. The study site is an ideal location for an urban wetland, and the restored area can be used as an

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Recommendations

During the study period, and as a result of analyzing the collected data some facts became evident which could be used to help make the present experimental setup more effective, or which could be used to benefit future research projects.

Placing a level sensor on the downstream side of the outlet weirs would allow for measurement of backflows into the pond which occurred under extreme conditions.

Reconstructing or retrofitting the outlet structure and berm with longer lasting and more impermeable materials would considerably reduce the volume of unmeasurable flow. Monitoring wells could also be placed in the berm and in other areas surrounding the pond to measure groundwater elevations and quantify flows.

For future demonstration ponds, a greater difference in elevation between the inlet and outlet weirs would reduce the possibility of measurement error resulting from weirs operating under "drowned" conditions.

In any future experiment, the irrigation system should be thoroughly tested under a variety of operating conditions, before being placed in service. Once in service, the system should be operated as closely as possible to the application rate specified in the design. A rain switch to prevent operation of the irrigation system during periods of heavy rainfall, and a low-level cutoff switch to prevent damage to the pump during prolonged dry periods could be installed.

The present experimental setup, could be used to compare the detention time in a reuse pond with the detention time of a standard wet detention pond, since the percentage of runoff discharged would be expected to decrease with reuse operation.

Closing Statement

This project has achieved its stated objectives involving the demonstration of the beneficial reuse of stormwater and the protection, conservation and restoration of the environment. The project serves as a highly visible example of the positive results of cooperative efforts of the University, with state and local government.

APPENDICES

APPENDIX A

REUSE POND MASS BALANCE

REUSE POND MASS BALANCE

Day of Year	Date	Stage (ft)	S1 (ft^3)	P (in)	RP (ft^3)	RI (ft^3)	RW (ft^3)	D (ft^3)	dI (ft^3)	EV (in/day)	Area (ft^2)	ET (ft^3)	RU (gal)	RU (ft^3)	RU (in/wk)	S2 (ft^3)	G (ft^3)
177	26-Jun-91	82.52	105711	1.76	4996	1174	21823	27993	0	0.26	33785	556	4823	645		113789	9279
178	27-Jun-91	82.81	113789	0.00	0	0	3975	3975	0	0.28	34868	618	0	0		105990	-7181
179	28-Jun-91	82.53	105990	0.00	0	0	1955	1373	582	0.23	33823	493	4823	645		105990	555
180	29-Jun-91	82.53	105990	0.20	568	133	5113	3739	2075	0.23	33823	493	0	0	0.3	105990	-1582
181	30-Jun-91	82.53	105990	0.13	369	87	2852	1535	1773	0.28	33823	600	0	0		105711	-1451
182	01-Jul-91	82.52	105711	0.18	511	120	5870	3915	2586	0.24	33785	514	0	0		105990	-1794
183	02-Jul-91	82.53	105990	0.06	170	40	2976	1367	1820	0.10	33823	214	7783	1041		105711	-844
184	03-Jul-91	82.52	105711	0.02	57	13	2025	0	2095	0.22	33785	471	0	0		104875	-2460
185	04-Jul-91	82.49	104875	0.09	255	60	3075	0	3390	0.25	33673	533	7783	1041		105433	-1259
186	05-Jul-91	82.51	105433	0.88	2498	587	13978	14880	2183	0.19	33748	406	0	0		106825	-384
187	06-Jul-91	82.56	106825	0.05	142	33	3499	1689	1985	0.31	33935	666	7783	1041	0.7	105711	-1393
188	07-Jul-91	82.52	105711	0.00	0	0	4214	2066	2148	0.24	33785	514	0	0		106268	-1077
189	08-Jul-91	82.54	106268	0.00	0	0	2612	795	1817	0.36	33860	772	7234	967		105154	-1192
190	09-Jul-91	82.50	105154	0.12	341	80	3122	0	3543	0.32	33711	683	0	0		105433	-2581
191	10-Jul-91	82.51	105433	0.22	625	147	3150	0	3921	0.22	33748	470	7234	967		104875	-3041
192	11-Jul-91	82.49	104875	0.00	0	0	2636	0	2636	0.14	33673	299	0	0		104875	-2337
193	12-Jul-91	82.49	104875	2.10	5961	1401	55840	63202	0	0.00	33673	0	7234	967		106547	2638
194	13-Jul-91	82.55	106547	3.42	9708	2281	90630	102619	0	0.00	33897	0	0	0	0.6	113232	6685
195	14-Jul-91	82.79	113232	0.73	2072	487	11680	14239	0	0.24	34794	529	0	0		110168	-2535
196	15-Jul-91	82.68	110168	0.50	1419	333	8000	9753	0	0.25	34383	544	0	0		109054	-570
197	16-Jul-91	82.64	109054	1.22	3463	814	19520	23797	0	0.16	34233	347	8428	1127		107940	359
198	17-Jul-91	82.60	107940	0.40	1135	267	6988	8391	0	0.22	34084	475	0	0		106268	-1197
199	18-Jul-91	82.54	106268	0.00	0	0	4014	4014	0	0.26	33860	558	8428	1127		105990	1405
200	19-Jul-91	82.53	105990	0.00	0	0	3460	3460	0	0.31	33823	664	0	0		105990	664
201	20-Jul-91	82.53	105990	1.20	3406	800	19456	23187	476	0.29	33823	621	8428	1127	0.7	106547	1829
202	21-Jul-91	82.55	106547	0.00	0	0	4024	4024	0	0.13	33897	279	0	0		106268	0
203	22-Jul-91	82.54	106268	0.00	0	0	3937	997	2940	0.34	33860	729	8364	1118		105711	-1649
204	23-Jul-91	82.52	105711	0.41	1164	273	6561	3679	4319	0.25	33785	535	0	0		106268	-3227
205	24-Jul-91	82.54	106268	0.06	170	40	3953	1035	3128	0.23	33860	493	8364	1118		105433	-2352
206	25-Jul-91	82.51	105433	0.03	85	20	2772	0	2877	0.26	33748	556	0	0		105711	-2043
207	26-Jul-91	82.52	105711	0.00	0	0	2364	0	2364	0.21	33785	449	0	0		105711	-1914
208	27-Jul-91	82.52	105711	0.67	1902	447	8487	8046	2790	0.20	33785	428	0	0	0.5	106268	-1805
209	28-Jul-91	82.54	106268	1.05	2981	700	11972	13021	2632	0.31	33860	665	0	0		107382	-853
210	29-Jul-91	82.58	107382	0.26	738	173	6087	6292	707	0.38	34009	818	0	0		106268	-1002
211	30-Jul-91	82.54	106268	0.00	0	0	3358	2746	612	0.30	33860	643	0	0		105711	-526
212	31-Jul-91	82.52	105711	0.20	568	133	4623	1422	3902	0.17	33785	364	0	0		105711	-3538
213	01-Aug-91	82.52	105711	0.24	681	160	4711	1628	3924	0.10	33785	214	0	0		105990	-3432
214	02-Aug-91	82.53	105990	0.00	0	0	3401	1676	1725	0.11	33823	236	0	0		105711	-1768
215	03-Aug-91	82.52	105711	0.00	0	0	3225	207	3018	0.49	33785	1048	0	0	0	105711	-1969
216	04-Aug-91	82.52	105711	0.00	0	0	3356	300	3057	0.04	33785	86	0	0		105711	-2971
217	05-Aug-91	82.52	105711	0.00	0	0	3338	0	3338	0.30	33785	642	0	0		105433	-2974
218	06-Aug-91	82.51	105433	0.00	0	0	2775	0	2775	0.17	33748	363	0	0		105433	-2411
219	07-Aug-91	82.51	105433	0.00	0	0	936	0	936	0.30	33748	641	0	0		104875	-852

REUSE POND MASS BALANCE

Day of Year	Date	Stage (ft)	S1 (ft^3)	P (in)	RP (ft^3)	RI (ft^3)	RW (ft^3)	D (ft^3)	dI (ft^3)	EV (in/day)	Area (ft^2)	ET (ft^3)	RU (gal)	RU (ft^3)	RU (in/wk)	S2 (ft^3)	G (ft^3)
220	08-Aug-91	82.49	104875	0.18	511	120	1806	0	2437	0.13	33673	277	0	0		105154	-1881
221	09-Aug-91	82.50	105154	0.08	227	53	2228	0	2508	0.21	33711	448	0	0		105154	-2060
222	10-Aug-91	82.50	105154	0.01	28	7	2009	0	2044	0.21	33711	448	0	0	0	104875	-1874
223	11-Aug-91	82.49	104875	0.00	0	0	2072	0	2072	0.27	33673	576	0	0		104597	-1775
224	12-Aug-91	82.48	104597	0.01	28	7	2077	0	2112	0.30	33636	639	0	0		104040	-2030
225	13-Aug-91	82.46	104040	0.59	1675	393	4858	0	6926	0.24	33561	510	0	0		105711	-4745
226	14-Aug-91	82.52	105711	0.02	57	13	2361	0	2431	0.21	33785	449	0	0		105433	-2260
227	15-Aug-91	82.51	105433	0.26	738	173	3526	0	4437	0.21	33748	449	0	0		105711	-3710
228	16-Aug-91	82.52	105711	0.00	0	0	2617	0	2617	0.21	33785	449	0	0		105433	-2447
229	17-Aug-91	82.51	105433	0.00	0	0	2357	0	2357	0.23	33748	492	0	0	0	103204	-4094
230	18-Aug-91	82.43	103204	0.24	681	160	4223	0	5064	0.38	33449	805	0	0		104875	-2588
231	19-Aug-91	82.49	104875	0.00	0	0	2126	0	2126	0.15	33673	320	9051	1210		103483	-1989
232	20-Aug-91	82.44	103483	0.14	397	93	2997	0	3487	0.18	33487	382	0	0		103483	-3106
233	21-Aug-91	82.44	103483	0.00	0	0	2793	0	2793	0.00	33487	0	9051	1210		102647	-2419
234	22-Aug-91	82.41	102647	0.00	0	0	2229	0	2229	0.25	33375	528	0	0		102090	-2258
235	23-Aug-91	82.39	102090	0.14	397	93	2764	0	3254	0.22	33300	464	9051	1210		101533	-2138
236	24-Aug-91	82.37	101533	1.12	3179	747	14025	11447	6504	0.16	33225	337	0	0	0.8	106268	-1432
237	25-Aug-91	82.54	106268	0.32	908	213	5833	6082	872	0.15	33860	322	0	0		106268	-551
238	26-Aug-91	82.54	106268	0.01	28	7	3776	1319	2492	0.15	33860	322	0	0		104875	-3563
239	27-Aug-91	82.49	104875	0.00	0	0	3191	0	3191	0.21	33673	448	10279	1374		104597	-1647
240	28-Aug-91	82.48	104597	0.00	0	0	2943	0	2943	0.19	33636	405	0	0		102926	-4209
241	29-Aug-91	82.42	102926	0.01	28	7	2918	0	2953	0.12	33412	254	10279	1374		102368	-1882
242	30-Aug-91	82.40	102368	0.07	199	47	3066	0	3311	0.23	33337	486	0	0		101811	-3382
243	31-Aug-91	82.38	101811	0.01	28	7	2525	0	2560	0.26	33263	548	10279	1374	0.9	99583	-2866
244	01-Sep-91	82.30	99583	0.00	0	0	1773	0	1773	0.26	32964	543	0	0		98469	-2344
245	02-Sep-91	82.26	98469	0.03	85	20	1323	0	1428	0.30	32815	623	9285	1241		96240	-1792
246	03-Sep-91	82.18	96240	0.04	114	27	1050	0	1190	0.23	32516	474	0	0		95405	-1552
247	04-Sep-91	82.15	95405	0.00	0	0	449	0	449	0.29	32404	595	9285	1241		93455	-562
248	05-Sep-91	82.08	93455	0.00	0	0	467	0	467	0.24	32143	489	0	0		92619	-814
249	06-Sep-91	82.05	92619	0.00	0	0	106	0	106	0.26	32030	527	9285	1241		91784	827
250	07-Sep-91	82.02	91784	0.00	0	0	174	0	174	0.17	31918	344	0	0	0.8	100140	8527
251	08-Sep-91	82.32	100140	0.02	57	13	222	0	292	0.30	33039	628	0	0		89277	-10528
252	09-Sep-91	81.93	89277	0.61	1732	407	4903	0	7041	0.34	31582	680	0	0		93176	-2461
253	10-Sep-91	82.07	93176	0.00	0	0	374	0	374	0.19	32105	386	5690	761		92341	-63
254	11-Sep-91	82.04	92341	0.00	0	0	124	0	124	0.22	31993	446	0	0		91226	-793
255	12-Sep-91	82.00	91226	0.00	0	0	238	0	238	0.23	31844	464	5690	761		90112	-127
256	13-Sep-91	81.96	90112	0.00	0	0	136	0	136	0.22	31694	442	0	0		89277	-530
257	14-Sep-91	81.93	89277	0.00	0	0	189	0	189	0.21	31582	420	5690	761	0.5	87884	-401
258	15-Sep-91	81.88	87884	0.00	0	0	122	0	122	0.28	31396	557	0	0		87327	-123
259	16-Sep-91	81.86	87327	0.00	0	0	212	0	212	0.29	31321	575	4123	551		86212	-200
260	17-Sep-91	81.82	86212	0.00	0	0	740	0	740	0.23	31172	454	0	0		85377	-1122
261	18-Sep-91	81.79	85377	0.00	0	0	408	0	408	0.27	31060	531	4123	551		84263	-440
262	19-Sep-91	81.75	84263	0.00	0	0	1078	0	1078	0.14	30910	274	0	0		83427	-1639

REUSE POND MASS BALANCE

Day of Year	Date	Stage (ft)	S1 (ft^3)	P (in)	RP (ft^3)	RI (ft^3)	RW (ft^3)	D (ft^3)	dI (ft^3)	EV (in/day)	Area (ft^2)	ET (ft^3)	RU (gal)	RU (ft^3)	RU (in/wk)	S2 (ft^3)	G (ft^3)
263	20-Sep-91	81.72	83427	2.27	6444	1514	35243	43201	0	0.26	30798	507	4123	551		108775	26407
264	21-Sep-91	82.63	108775	0.00	0	0	4108	4108	0	0.28	34196	606	0	0	0.4	105990	-2179
265	22-Sep-91	82.53	105990	0.60	1703	400	7145	5430	3818	0.25	33823	536	0	0		106268	-3004
266	23-Sep-91	82.54	106268	0.00	0	0	3342	384	2957	0.20	33860	429	0	0		105433	-3364
267	24-Sep-91	82.51	105433	0.46	1306	307	6229	1810	6031	0.24	33748	513	8524	1140		106825	-2986
268	25-Sep-91	82.56	106825	0.74	2101	494	11535	13808	321	0.26	33935	559	0	0		106268	-319
269	26-Sep-91	82.54	106268	0.00	0	0	3666	2682	983	0.17	33860	365	8524	1140		105711	-36
270	27-Sep-91	82.52	105711	0.00	0	0	2934	0	2934	0.27	33785	578	0	0		104597	-3471
271	28-Sep-91	82.48	104597	1.15	3264	767	11978	6007	10003	0.24	33636	511	8524	1140	0.8	109889	-3059
272	29-Sep-91	82.67	109889	0.52	1476	347	8954	10571	206	0.22	34346	479	0	0		105990	-3627
273	30-Sep-91	82.53	105990	0.13	369	87	4229	619	4065	0.29	33823	621	34533	4617		103761	-1055
274	01-Oct-91	82.45	103761	0.11	312	73	3274	0	3659	0.09	33524	191	0	0		104597	-2632
275	02-Oct-91	82.48	104597	0.15	426	100	4233	0	4759	0.04	33636	85	34533	4617		102647	-2007
276	03-Oct-91	82.41	102647	0.61	1732	407	8656	3018	7776	0.12	33375	254	0	0		106268	-3901
277	04-Oct-91	82.54	106268	0.02	57	13	4095	431	3735	0.15	33860	322	34533	4617		104597	-468
278	05-Oct-91	82.48	104597	0.52	1476	347	8656	2836	7643	0.15	33636	320	0	0	3.1	106268	-5652
279	06-Oct-91	82.54	106268	0.07	199	47	4239	3007	1478	0.19	33860	407	0	0		105990	-1349
280	07-Oct-91	82.53	105990	0.00	0	0	2946	106	2841	0.31	33823	664	0	0		101811	-6355
281	08-Oct-91	82.38	101811	0.00	0	0	2484	0	2484	0.18	33263	379	33518	4481		101811	2376
282	09-Oct-91	82.38	101811	0.00	0	0	2600	0	2600	0.22	33263	463	0	0		98190	-5758
283	10-Oct-91	82.25	98190	0.00	0	0	2238	0	2238	0.11	32777	228	33518	4481		98190	2472
284	11-Oct-91	82.25	98190	0.00	0	0	2578	0	2578	0.17	32777	353	0	0		96519	-3896
285	12-Oct-91	82.19	96519	0.00	0	0	2388	0	2388	0.16	32553	330	33518	4481	3.0	94569	473
286	13-Oct-91	82.12	94569	0.00	0	0	2140	0	2140	0.25	32292	511	0	0		94290	-1907
287	14-Oct-91	82.11	94290	0.00	0	0	2119	0	2119	0.21	32255	429	31414	4200		90669	-1111
288	15-Oct-91	81.98	90669	0.22	625	147	3807	0	4579	0.21	31769	423	0	0		92341	-2485
289	16-Oct-91	82.04	92341	0.00	0	0	2684	0	2684	0.18	31993	365	31414	4200		89834	-626
290	17-Oct-91	81.95	89834	0.00	0	0	2122	0	2122	0.25	31657	501	0	0		89277	-2178
291	18-Oct-91	81.93	89277	0.00	0	0	1809	0	1809	0.15	31582	300	31414	4200		87327	741
292	19-Oct-91	81.86	87327	0.00	0	0	1875	0	1875	0.20	31321	397	0	0	2.8	85655	-3149
293	20-Oct-91	81.80	85655	0.00	0	0	1064	0	1064	0.18	31097	355	0	0		85655	-709
294	21-Oct-91	81.80	85655	0.00	0	0	1450	0	1450	0.24	31097	473	0	0		82313	-4319
295	22-Oct-91	81.68	82313	0.00	0	0	763	0	763	0.12	30649	233	37962	5075		82313	4545
296	23-Oct-91	81.68	82313	0.00	0	0	1384	0	1384	0.22	30649	427	0	0		79249	-4021
297	24-Oct-91	81.57	79249	0.36	1022	240	4033	0	5295	0.22	30238	421	37962	5075		82870	3823
298	25-Oct-91	81.70	82870	0.00	0	0	1058	0	1058	0.18	30724	350	0	0		82313	-1265
299	26-Oct-91	81.68	82313	0.00	0	0	1051	0	1051	0.21	30649	408	37962	5075	3.4	80641	2760
300	27-Oct-91	81.62	80641	0.00	0	0	440	0	440	0.18	30425	347	0	0		80920	185
301	28-Oct-91	81.63	80920	0.00	0	0	1145	0	1145	0.24	30462	463	34201	4572		77856	826
302	29-Oct-91	81.52	77856	0.00	0	0	220	0	220	0.14	30052	266	0	0		77856	46
303	30-Oct-91	81.52	77856	0.00	0	0	837	0	837	0.13	30052	247	34201	4572		74235	362
304	31-Oct-91	81.39	74235	0.00	0	0	448	0	448	0.19	29566	356	0	0		74513	186
305	01-Nov-91	81.40	74513	0.00	0	0	550	0	550	0.17	29603	319	34201	4572		73399	3227

REUSE POND MASS BALANCE

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306	02-Nov-91	81.36	73399	0.00	0	0	325	0	325	0.17	29454	317	0	0	3.0	71728	-1679
307	03-Nov-91	81.30	71728	0.00	0	0	208	0	208	0.05	29230	93	0	0		72285	442
308	04-Nov-91	81.32	72285	0.00	0	0	604	0	604	0.22	29305	408	0	0		68942	-3538
309	05-Nov-91	81.20	68942	0.04	114	27	541	0	681	0.12	28857	219	33975	4542		69778	4916
310	06-Nov-91	81.23	69778	0.00	0	0	1791	0	1791	0.04	28969	73	0	0		66992	-4503
311	07-Nov-91	81.13	66992	0.00	0	0	1223	0	1223	0.12	28595	217	33975	4542		67828	4372
312	08-Nov-91	81.16	67828	0.00	0	0	463	0	463	0.13	28707	236	0	0		66992	-1063
313	09-Nov-91	81.13	66992	0.15	426	100	1395	0	1921	0.19	28595	344	33975	4542	3.0	66992	2966
314	10-Nov-91	81.13	66992	0.00	0	0	269	0	269	0.14	28595	254	0	0		67549	541
315	11-Nov-91	81.15	67549	0.00	0	0	614	0	614	0.11	28670	200	36105	4827		64764	1627
316	12-Nov-91	81.05	64764	0.00	0	0	495	0	495	0.19	28297	341	0	0		65321	402
317	13-Nov-91	81.07	65321	0.00	0	0	1509	0	1509	0.16	28371	287	36105	4827		62536	820
318	14-Nov-91	80.97	62536	0.00	0	0	1926	0	1926	0.13	27998	231	0	0		63371	-860
319	15-Nov-91	81.00	63371	0.00	0	0	655	0	655	0.14	28110	249	36105	4827		62536	3586
320	16-Nov-91	80.97	62536	0.00	0	0	0	0	0	0.12	27998	213	0	0	3.2	61700	-623
321	17-Nov-91	80.94	61700	0.00	0	0	0	0	0	0.08	27886	141	0	0		62814	1255
322	18-Nov-91	80.98	62814	0.00	0	0	0	0	0	0.19	28035	337	0	0		59750	-2727
323	19-Nov-91	80.87	59750	0.00	0	0	0	0	0	0.12	27624	210	38628	5164		60864	6488
324	20-Nov-91	80.91	60864	0.00	0	0	0	0	0	0.16	27774	281	0	0		58079	-2504
325	21-Nov-91	80.81	58079	0.00	0	0	0	0	0	0.13	27400	226	38629	5164		59193	6504
326	22-Nov-91	80.85	59193	0.00	0	0	0	0	0	0.17	27550	297	0	0		58357	-539
327	23-Nov-91	80.82	58357	0.15	426	100	1373	0	1899	0.11	27438	191	38629	5164	2.3	61421	6521
328	24-Nov-91	80.93	61421	0.00	0	0	107	0	107	0.08	27849	141	0	0		61978	592
329	25-Nov-91	80.95	61978	0.00	0	0	0	0	0	0.19	27923	336	0	0		61978	336
330	26-Nov-91	80.95	61978	0.00	0	0	0	0	0	0.10	27923	177	0	0		62536	734
331	27-Nov-91	80.97	62536	0.00	0	0	0	0	0	0.10	27998	177	0	0		63093	734
332	28-Nov-91	80.99	63093	0.00	0	0	0	0	0	0.05	28073	89	0	0		63650	646
333	29-Nov-91	81.01	63650	0.00	0	0	0	0	0	0.13	28147	232	0	0		64207	789
334	30-Nov-91	81.03	64207	0.00	0	0	0	0	0	0.15	28222	268	0	0	0	64485	547
335	01-Dec-91	81.04	64485	0.00	0	0	0	0	0	0.14	28259	251	0	0		64764	529
336	02-Dec-91	81.05	64764	0.00	0	0	0	0	0	0.15	28297	269	0	0		65321	826
337	03-Dec-91	81.07	65321	0.00	0	0	0	0	0	0.15	28371	270	0	0		65878	827
338	04-Dec-91	81.09	65878	0.05	142	33	71	0	246	0.10	28446	180	0	0		65878	-66
339	05-Dec-91	81.09	65878	0.00	0	0	34	0	34	0.13	28446	234	0	0		65878	200
340	06-Dec-91	81.09	65878	0.00	0	0	0	0	0	0.08	28446	144	0	0		66157	423
341	07-Dec-91	81.10	66157	0.00	0	0	0	0	0	0.10	28483	180	0	0	0	66157	180
342	08-Dec-91	81.10	66157	0.00	0	0	0	0	0	0.08	28483	144	0	0		66435	423
343	09-Dec-91	81.11	66435	0.00	0	0	0	0	0	0.14	28521	253	0	0		66435	253
344	10-Dec-91	81.11	66435	0.01	28	7	0	0	35	0.12	28521	217	0	0		66992	739
345	11-Dec-91	81.13	66992	0.01	28	7	0	0	35	0.15	28595	272	0	0		66992	237
346	12-Dec-91	81.13	66992	0.00	0	0	0	0	0	0.11	28595	199	0	0		67271	478
347	13-Dec-91	81.14	67271	0.00	0	0	0	0	0	0.13	28633	236	0	0		67271	236
348	14-Dec-91	81.14	67271	0.00	0	0	0	0	0	0.09	28633	163	0	0	0	67549	442

REUSE POND MASS BALANCE

Day of Year	Date	Stage (ft)	S1 (ft^3)	P (in)	RP (ft^3)	RI (ft^3)	RW (ft^3)	D (ft^3)	dI (ft^3)	EV (in/day)	Area (ft^2)	ET (ft^3)	RU (gal)	RU (ft^3)	RU (in/wk)	S2 (ft^3)	G (ft^3)
349	15-Dec-91	81.15	67549	0.00	0	0	0	0	0	0.17	28670	309	0	0		67271	30
350	16-Dec-91	81.14	67271	0.00	0	0	0	0	0	0.18	28633	326	0	0		66992	48
351	17-Dec-91	81.13	66992	0.00	0	0	0	0	0	0.15	28595	272	0	0		66992	272
352	18-Dec-91	81.13	66992	0.00	0	0	0	0	0	0.11	28595	199	11189	1496		66992	1695
353	19-Dec-91	81.13	66992	0.00	0	0	0	0	0	0.13	28595	235	0	0		66714	-43
354	20-Dec-91	81.12	66714	0.00	0	0	0	0	0	0.12	28558	217	11189	1496		64764	-237
355	21-Dec-91	81.05	64764	0.00	0	0	0	0	0	0.12	28297	215	0	0	0.7	64764	215
356	22-Dec-91	81.05	64764	0.00	0	0	0	0	0	0.10	28297	179	0	0		63371	-1214
357	23-Dec-91	81.00	63371	0.00	0	0	0	0	0	0.11	28110	196	0	0		63371	196
358	24-Dec-91	81.00	63371	0.00	0	0	0	0	0	0.11	28110	196	17546	2346		62536	1706
359	25-Dec-91	80.97	62536	0.00	0	0	0	0	0	0.11	27998	195	0	0		61700	-641
360	26-Dec-91	80.94	61700	0.32	908	213	3103	0	4225	0.07	27886	124	17546	2346		65878	2423
361	27-Dec-91	81.09	65878	0.01	28	7	438	0	473	0.05	28446	90	0	0		64485	-1776
362	28-Dec-91	81.04	64485	0.00	0	0	247	0	247	0.13	28259	233	17546	2346	1.6	65043	2889
363	29-Dec-91	81.06	65043	0.00	0	0	97	0	97	0.06	28334	108	0	0		63371	-1661
364	30-Dec-91	81.00	63371	0.00	0	0	0	0	0	0.14	28110	249	15922	2129		63371	2378
365	31-Dec-91	81.00	63371	0.00	0	0	0	0	0	0.11	28110	196	0	0		62814	-361
1	01-Jan-92	80.98	62814	0.02	57	13	0	0	70	0.04	28035	71	15922	2129		62536	1851
2	02-Jan-92	80.97	62536	0.03	85	20	0	0	105	0.04	27998	71	0	0		63093	523
3	03-Jan-92	80.99	63093	0.00	0	0	0	0	0	0.11	28073	196	15922	2129		63371	2603
4	04-Jan-92	81.00	63371	0.00	0	0	0	0	0	0.27	28110	481	0	0	1.4	63371	481
5	05-Jan-92	81.00	63371	0.00	0	0	0	0	0	0.08	28110	142	0	0		63371	142
6	06-Jan-92	81.00	63371	0.00	0	0	0	0	0	0.12	28110	214	0	0		63928	771
7	07-Jan-92	81.02	63928	0.00	0	0	0	0	0	0.14	28185	250	3566	477		63371	170
8	08-Jan-92	81.00	63371	0.00	0	0	0	0	0	0.12	28110	214	0	0		63093	-65
9	09-Jan-92	80.99	63093	0.00	0	0	0	0	0	0.13	28073	231	3566	477		63371	986
10	10-Jan-92	81.00	63371	0.00	0	0	0	0	0	0.11	28110	196	0	0		63650	474
11	11-Jan-92	81.01	63650	0.00	0	0	0	0	0	0.19	28147	339	3566	477	0.3	63371	537
12	12-Jan-92	81.00	63371	0.00	0	0	0	0	0	0.08	28110	142	0	0		63371	142
13	13-Jan-92	81.00	63371	0.00	0	0	0	0	0	0.13	28110	231	2726	364		63650	874
14	14-Jan-92	81.01	63650	0.55	1561	367	8737	0	10665	0.15	28147	267	0	0		71449	-2598
15	15-Jan-92	81.29	71449	0.00	0	0	0	0	0	0.23	29193	425	2726	364		71171	511
16	16-Jan-92	81.28	71171	0.00	0	0	0	0	0	0.12	29155	222	0	0		70892	-57
17	17-Jan-92	81.27	70892	0.00	0	0	0	0	0	0.13	29118	240	2726	364		70892	604
18	18-Jan-92	81.27	70892	0.00	0	0	0	0	0	0.09	29118	166	0	0	0.2	70614	-113
19	19-Jan-92	81.26	70614	0.40	1135	267	6400	0	7802	0.09	29081	166	0	0		74235	-4015
20	20-Jan-92	81.39	74235	0.00	0	0	0	0	0	0.02	29566	37	0	0		73956	-241
21	21-Jan-92	81.38	73956	0.00	0	0	0	0	0	0.12	29529	224	1948	260		73956	485
22	22-Jan-92	81.38	73956	0.00	0	0	0	0	0	0.10	29529	187	0	0		73399	-370
23	23-Jan-92	81.36	73399	0.21	596	140	3474	0	4210	0.15	29454	280	1948	260		76463	-606
24	24-Jan-92	81.47	76463	0.00	0	0	0	0	0	0.15	29865	284	0	0		76185	5
25	25-Jan-92	81.46	76185	0.00	0	0	0	0	0	0.14	29827	264	1948	260	0.2	76185	525
26	26-Jan-92	81.46	76185	0.00	0	0	0	0	0	0.08	29827	151	0	0		75906	-127

REUSE POND MASS BALANCE

Day of Year	Date	Stage (ft)	S1 (ft^3)	P (in)	RP (ft^3)	RI (ft^3)	RW (ft^3)	D (ft^3)	dI (ft^3)	EV (in/day)	Area (ft^2)	ET (ft^3)	RU (gal)	RU (ft^3)	RU (in/wk)	S2 (ft^3)	G (ft^3)
27	27-Jan-92	81.45	75906	0.00	0	0	0	0	0	0.12	29790	226	0	0		75627	-52
28	28-Jan-92	81.44	75627	0.32	908	213	3840	0	4962	0.09	29753	170	0	0		77856	-2564
29	29-Jan-92	81.52	77856	0.01	28	7	0	0	35	0.12	30052	228	0	0		78134	472
30	30-Jan-92	81.53	78134	0.00	0	0	0	0	0	0.10	30089	191	0	0		78413	469
31	31-Jan-92	81.54	78413	0.00	0	0	0	0	0	0.13	30126	248	0	0		78413	248
32	01-Feb-92	81.54	78413	0.00	0	0	0	0	0	0.14	30126	267	0	0	0	77856	-290
33	02-Feb-92	81.52	77856	0.00	0	0	0	0	0	0.24	30052	457	0	0		77577	178
34	03-Feb-92	81.51	77577	0.00	0	0	0	0	0	0.11	30014	209	0	0		77577	209
35	04-Feb-92	81.51	77577	0.00	0	0	0	0	0	0.12	30014	228	0	0		77020	-329
36	05-Feb-92	81.49	77020	1.37	3889	914	21290	0	26093	0.22	29940	417	0	0		94848	-7848
37	06-Feb-92	82.13	94848	0.05	142	33	0	0	175	0.12	32329	246	1916	256		95962	1441
38	07-Feb-92	82.17	95962	0.04	114	27	0	0	140	0.20	32479	411	0	0		95683	-7
39	08-Feb-92	82.16	95683	0.00	0	0	0	0	0	0.07	32441	144	1916	256	0.1	94569	-714
40	09-Feb-92	82.12	94569	0.00	0	0	0	0	0	0.20	32292	409	0	0		93733	-427
41	10-Feb-92	82.09	93733	0.00	0	0	0	0	0	0.10	32180	204	2376	318		92619	-593
42	11-Feb-92	82.05	92619	0.00	0	0	0	0	0	0.14	32030	284	0	0		92062	-273
43	12-Feb-92	82.03	92062	0.00	0	0	0	0	0	0.12	31956	243	2376	318		90948	-554
44	13-Feb-92	81.99	90948	0.00	0	0	0	0	0	0.08	31806	161	0	0		90391	-396
45	14-Feb-92	81.97	90391	0.00	0	0	0	0	0	0.10	31732	201	2376	318		89555	-317
46	15-Feb-92	81.94	89555	0.00	0	0	0	0	0	0.10	31620	200	0	0	0.2	88998	-357
47	16-Feb-92	81.92	88998	0.00	0	0	13	0	13	0.22	31545	440	0	0		88441	-130
48	17-Feb-92	81.90	88441	0.00	0	0	276	0	276	0.13	31470	259	0	0		87605	-853
49	18-Feb-92	81.87	87605	0.00	0	0	289	0	289	0.16	31358	318	0	0		87327	-249
50	19-Feb-92	81.86	87327	0.00	0	0	329	0	329	0.09	31321	179	0	0		86770	-708
51	20-Feb-92	81.84	86770	0.00	0	0	343	0	343	0.12	31246	237	0	0		85934	-941
52	21-Feb-92	81.81	85934	0.00	0	0	304	0	304	0.25	31134	493	0	0		85377	-368
53	22-Feb-92	81.79	85377	0.00	0	0	252	0	252	0.08	31060	157	0	0	0	84820	-652
54	23-Feb-92	81.77	84820	0.56	1590	373	6795	0	8758	0.06	30985	118	0	0		92062	-1398
55	24-Feb-92	82.03	92062	0.24	681	160	1871	0	2712	0.19	31956	385	0	0		93176	-1213
56	25-Feb-92	82.07	93176	0.98	2782	654	11589	0	15024	0.14	32105	285	0	0		104875	-3041
57	26-Feb-92	82.49	104875	0.02	57	13	3415	0	3485	0.14	33673	299	0	0		104875	-3186
58	27-Feb-92	82.49	104875	0.00	0	0	1647	0	1647	0.21	33673	448	0	0		103761	-2313
59	28-Feb-92	82.45	103761	0.00	0	0	1453	0	1453	0.22	33524	467	0	0		102368	-2378
60	29-Feb-92	82.40	102368	0.00	0	0	1009	0	1009	0.26	33337	549	0	0	0	100976	-1853
61	01-Mar-92	82.35	100976	0.00	0	0	766	0	766	0.23	33151	483	0	0		99862	-1397
62	02-Mar-92	82.31	99862	0.00	0	0	441	0	441	0.17	33001	355	0	0		98747	-1200
63	03-Mar-92	82.27	98747	0.00	0	0	760	0	760	0.23	32852	479	0	0		97633	-1396
64	04-Mar-92	82.23	97633	0.00	0	0	474	0	474	0.18	32703	373	0	0		95962	-1773
65	05-Mar-92	82.17	95962	0.00	0	0	503	0	503	0.07	32479	144	6124	819		94012	-1491
66	06-Mar-92	82.10	94012	0.10	284	67	1513	0	1863	0.24	32217	490	0	0		93733	-1652
67	07-Mar-92	82.09	93733	0.51	1448	340	7354	0	9142	0.11	32180	224	6124	819	0.4	100419	-1414
68	08-Mar-92	82.33	100419	0.00	0	0	1893	0	1893	0.23	33076	482	0	0		89834	-11997
69	09-Mar-92	81.95	89834	0.00	0	0	688	0	688	0.25	31657	501	0	0		73399	-16621

REUSE POND MASS BALANCE

Day of Year	Date	Stage (ft)	S1 (ft^3)	P (in)	RP (ft^3)	RI (ft^3)	RW (ft^3)	D (ft^3)	dI (ft^3)	EV (in/day)	Area (ft^2)	ET (ft^3)	RU (gal)	RU (ft^3)	RU (in/wk)	S2 (ft^3)	G (ft^3)
70	10-Mar-92	81.36	73399	0.33	937	220	2813	0	3970	0.24	29454	448	7100	949		71171	-4801
71	11-Mar-92	81.28	71171	0.16	454	107	3094	0	3655	0.22	29155	406	0	0		73399	-1020
72	12-Mar-92	81.36	73399	0.08	227	53	1344	0	1625	0.20	29454	373	7100	949		72006	-1695
73	13-Mar-92	81.31	72006	0.02	57	13	1307	0	1377	0.05	29267	93	0	0		72285	-1006
74	14-Mar-92	81.32	72285	0.00	0	0	738	0	738	0.21	29305	390	7100	949	0.6	72006	323
75	15-Mar-92	81.31	72006	0.00	0	0	626	0	626	0.15	29267	278	0	0		71449	-905
76	16-Mar-92	81.29	71449	0.00	0	0	441	0	441	0.26	29193	481	0	0		71449	40
77	17-Mar-92	81.29	71449	0.00	0	0	406	0	406	0.25	29193	462	7568	1012		70335	-47
78	18-Mar-92	81.25	70335	0.00	0	0	361	0	361	0.21	29043	386	0	0		69778	-532
79	19-Mar-92	81.23	69778	0.00	0	0	369	0	369	0.18	28969	330	7568	1012		69221	416
80	20-Mar-92	81.21	69221	0.00	0	0	397	0	397	0.25	28894	457	0	0		69499	339
81	21-Mar-92	81.22	69499	0.00	0	0	506	0	506	0.36	28931	660	7568	1012	0.7	69499	1165
82	22-Mar-92	81.22	69499	0.06	170	40	903	0	1113	0.19	28931	348	0	0		69499	-765
83	23-Mar-92	81.22	69499	0.03	85	20	723	0	828	0.10	28931	183	0	0		68942	-1202
84	24-Mar-92	81.20	68942	0.00	0	0	428	0	428	0.21	28857	384	11042	1476		68107	597
85	25-Mar-92	81.17	68107	1.05	2981	700	11876	0	15557	0.23	28745	419	0	0		82313	-932
86	26-Mar-92	81.68	82313	0.01	28	7	2120	0	2155	0.18	30649	349	11042	1476		80084	-2558
87	27-Mar-92	81.60	80084	0.00	0	0	937	0	937	0.30	30350	577	0	0		75070	-5374
88	28-Mar-92	81.42	75070	0.00	0	0	673	0	673	0.29	29678	545	11042	1476	1.0	72006	-1715
89	29-Mar-92	81.31	72006	0.00	0	0	374	0	374	0.16	29267	297	0	0		69778	-2306
90	30-Mar-92	81.23	69778	0.00	0	0	331	0	331	0.12	28969	220	0	0		68664	-1225
91	31-Mar-92	81.19	68664	0.00	0	0	311	0	311	0.18	28819	329	7814	1045		67271	-331
92	01-Apr-92	81.14	67271	0.00	0	0	251	0	251	0.31	28633	562	0	0		66435	-524
93	02-Apr-92	81.11	66435	0.00	0	0	258	0	258	0.23	28521	415	7814	1045		65321	88
94	03-Apr-92	81.07	65321	0.00	0	0	164	0	164	0.33	28371	593	0	0		65321	429
95	04-Apr-92	81.07	65321	0.00	0	0	104	0	104	0.05	28371	90	7814	1045	0.7	65321	1031
96	05-Apr-92	81.07	65321	0.00	0	0	125	0	125	0.31	28371	557	0	0		64485	-403
97	06-Apr-92	81.04	64485	0.00	0	0	84	0	84	0.33	28259	591	0	0		64764	785
98	07-Apr-92	81.05	64764	0.13	369	87	1242	0	1697	0.18	28297	323	12112	1619		65043	523
99	08-Apr-92	81.06	65043	0.00	0	0	367	0	367	0.11	28334	197	0	0		64764	-448
100	09-Apr-92	81.05	64764	0.00	0	0	210	0	210	0.20	28297	358	12112	1619		64207	1211
101	10-Apr-92	81.03	64207	0.00	0	0	210	0	210	0.26	28222	465	0	0		64485	534
102	11-Apr-92	81.04	64485	2.73	7750	1821	41023	10263	40330	0.00	28259	0	12112	1619	1.1	135516	32320
103	12-Apr-92	83.59	135516	0.63	1788	420	10800	12759	250	0.26	37781	622	0	0		95126	-40018
104	13-Apr-92	82.14	95126	0.09	255	60	3236	0	3551	0.13	32367	266	0	0		80363	-18048
105	14-Apr-92	81.61	80363	0.00	0	0	1571	0	1571	0.24	30388	462	7520	1005		73956	-6510
106	15-Apr-92	81.38	73956	0.00	0	0	687	0	687	0.21	29529	393	0	0		61143	-13108
107	16-Apr-92	80.92	61143	0.00	0	0	243	0	243	0.27	27811	476	7520	1005		62536	2630
108	17-Apr-92	80.97	62536	0.00	0	0	34	0	34	0.25	27998	443	0	0		63371	1245
109	18-Apr-92	81.00	63371	0.00	0	0	34	0	34	0.28	28110	498	0	0	0.4	64207	1300
110	19-Apr-92	81.03	64207	0.33	937	220	2917	0	4074	0.33	28222	590	0	0		68107	416
111	20-Apr-92	81.17	68107	1.18	3350	787	18042	0	22179	0.13	28745	237	0	0		94290	4242
112	21-Apr-92	82.11	94290	0.93	2640	620	12259	0	15519	0.24	32255	490	10209	1365		104040	-3915

REUSE POND MASS BALANCE

Day of Year	Date	Stage (ft)	S1 (ft^3)	P (in)	RP (ft^3)	RI (ft^3)	RW (ft^3)	D (ft^3)	dI (ft^3)	EV (in/day)	Area (ft^2)	ET (ft^3)	RU (gal)	RU (ft^3)	RU (in/wk)	S2 (ft^3)	G (ft^3)
113	22-Apr-92	82.46	104040	0.00	0	0	3917	0	3917	0.26	33561	553	0	0		97355	-10049
114	23-Apr-92	82.22	97355	0.00	0	0	2856	0	2856	0.25	32665	517	10209	1365		74513	-23815
115	24-Apr-92	81.40	74513	0.00	0	0	1897	0	1897	0.22	29603	412	0	0		73399	-2599
116	25-Apr-92	81.36	73399	0.00	0	0	386	0	386	0.20	29454	373	10209	1365	0.9	72006	-41
117	26-Apr-92	81.31	72006	0.00	0	0	563	0	563	0.29	29267	538	0	0		69778	-2254
118	27-Apr-92	81.23	69778	0.00	0	0	227	0	227	0.43	28969	789	0	0		68942	-274
119	28-Apr-92	81.20	68942	0.00	0	0	94	0	94	0.36	28857	658	5329	712		67549	-116
120	29-Apr-92	81.15	67549	0.00	0	0	167	0	167	0.26	28670	472	0	0		67271	26
121	30-Apr-92	81.14	67271	0.00	0	0	0	0	0	0.53	28633	961	5329	712		66435	838
122	01-May-92	81.11	66435	0.00	0	0	0	0	0	0.31	28521	560	0	0		66435	560
123	02-May-92	81.11	66435	0.00	0	0	0	0	0	0.22	28521	397	5329	712	0.5	66435	1110
124	03-May-92	81.11	66435	0.00	0	0	0	0	0	0.33	28521	596	0	0		65321	-518
125	04-May-92	81.07	65321	0.00	0	0	0	0	0	0.30	28371	539	0	0		65600	818
126	05-May-92	81.08	65600	0.00	0	0	0	0	0	0.32	28409	576	7247	969		65043	987
127	06-May-92	81.06	65043	0.00	0	0	0	0	0	0.36	28334	646	0	0		65043	646
128	07-May-92	81.06	65043	0.20	568	133	1889	0	2590	0.27	28334	485	7247	969		65878	-301
129	08-May-92	81.09	65878	0.00	0	0	0	0	0	0.30	28446	540	0	0		65878	540
130	09-May-92	81.09	65878	0.00	0	0	0	0	0	0.35	28446	631	7247	969	0.6	65878	1599
131	10-May-92	81.09	65878	0.00	0	0	0	0	0	0.25	28446	450	0	0		65043	-385
132	11-May-92	81.06	65043	0.00	0	0	0	0	0	0.29	28334	520	0	0		46380	-18143
133	12-May-92	80.39	46380	0.00	0	0	0	0	0	0.31	25832	507	6019	805		36630	-8437
134	13-May-92	80.04	36630	0.00	0	0	0	0	0	0.33	24525	513	0	0		26324	-9794
135	14-May-92	79.67	26324	0.72	2044	480	7161	0	9685	0.40	23144	586	0	0		14067	-21355
136	15-May-92	79.23	14067	0.00	0	0	0	0	0	0.19	21501	259	0	0		43873	30064
137	16-May-92	80.30	43873	0.00	0	0	0	0	0	0.22	25496	355	0	0	0.2	45544	2027
138	17-May-92	80.36	45544	0.00	0	0	0	0	0	0.43	25720	700	0	0		46658	1815
139	18-May-92	80.40	46658	0.00	0	0	0	0	0	0.28	25870	459	0	0		48051	1852
140	19-May-92	80.45	48051	0.00	0	0	82	0	82	0.32	26056	528	0	0		48886	1282
141	20-May-92	80.48	48886	0.00	0	0	0	0	0	0.28	26168	464	0	0		49722	1300
142	21-May-92	80.51	49722	0.03	85	20	228	0	333	0.15	26280	250	9301	1243		49722	1160
143	22-May-92	80.51	49722	0.02	57	13	136	0	207	0.17	26280	283	0	0		50558	912
144	23-May-92	80.54	50558	0.00	0	0	0	0	0	0.09	26392	150	9301	1243	0.5	51393	2230
145	24-May-92	80.57	51393	0.00	0	0	0	0	0	0.10	26504	168	0	0		51672	446
146	25-May-92	80.58	51672	0.00	0	0	0	0	0	0.28	26542	471	0	0		52229	1028
147	26-May-92	80.60	52229	0.00	0	0	0	0	0	0.29	26616	489	7181	960		52229	1449
148	27-May-92	80.60	52229	0.48	1363	320	5264	0	6947	0.28	26616	472	0	0		59193	489
149	28-May-92	80.85	59193	0.04	114	27	5915	0	6055	0.28	27550	489	7181	960		65600	1800
150	29-May-92	81.08	65600	0.00	0	0	0	0	0	0.31	28409	558	0	0		65878	836
151	30-May-92	81.09	65878	0.00	0	0	0	0	0	0.31	28446	558	7181	960	0.6	65878	1519
152	31-May-92	81.09	65878	0.00	0	0	0	0	0	0.25	28446	450	0	0		65321	-107
153	01-Jun-92	81.07	65321	0.00	0	0	0	0	0	0.24	28371	431	0	0		65321	431
154	02-Jun-92	81.07	65321	0.53	1504	353	5510	0	7368	0.22	28371	395	6811	911		70614	-769
155	03-Jun-92	81.26	70614	1.00	2839	667	10357	0	13863	0.18	29081	332	0	0		83705	-439

REUSE POND MASS BALANCE

Day of Year	Date	Stage (ft)	S1 (ft^3)	P (in)	RP (ft^3)	RI (ft^3)	RW (ft^3)	D (ft^3)	dI (ft^3)	EV (in/day)	Area (ft^2)	ET (ft^3)	RU (gal)	RU (ft^3)	RU (in/wk)	S2 (ft^3)	G (ft^3)
156	04-Jun-92	81.73	83705	0.01	28	7	1580	0	1615	0.33	30836	644	6811	911		84263	497
157	05-Jun-92	81.75	84263	0.14	397	93	1702	0	2192	0.35	30910	685	0	0		85377	-393
158	06-Jun-92	81.79	85377	0.14	397	93	1763	0	2254	0.33	31060	649	6811	911	0.6	86212	142
159	07-Jun-92	81.82	86212	0.00	0	0	635	0	635	0.09	31172	178	0	0		85655	-1014
160	08-Jun-92	81.80	85655	0.00	0	0	0	0	0	0.29	31097	571	0	0		85098	14
161	09-Jun-92	81.78	85098	0.00	0	0	0	0	0	0.32	31022	629	5814	777		83427	-265
162	10-Jun-92	81.72	83427	0.00	0	0	0	0	0	0.36	30798	702	0	0		82591	-133
163	11-Jun-92	81.69	82591	0.49	1391	327	5835	0	7553	0.35	30686	680	5814	777		87605	-1082
164	12-Jun-92	81.87	87605	0.34	965	227	3230	0	4422	0.34	31358	675	0	0		89834	-1518
165	13-Jun-92	81.95	89834	0.08	227	53	1033	0	1313	0.33	31657	662	5814	777	0.5	89834	126
166	14-Jun-92	81.95	89834	0.03	85	20	1120	0	1225	0.32	31657	642	0	0		88719	-1698
167	15-Jun-92	81.91	88719	0.06	170	40	992	0	1203	0.33	31508	659	0	0		88441	-823
168	16-Jun-92	81.90	88441	0.00	0	0	660	0	660	0.24	31470	478	6245	835		87048	-739
169	17-Jun-92	81.85	87048	0.00	0	0	0	0	0	0.34	31284	674	0	0		86491	117
170	18-Jun-92	81.83	86491	0.00	0	0	0	0	0	0.26	31209	514	6245	835	0.4		
Totals	358 Days			46.26 in	131317 ft^3	30851 ft^3	951832 ft^3	500945 ft^3	613056 ft^3	70.81 in		137826 ft^3		209374 ft^3	45.0 in		-286425 ft^3

Summary Table
(All values are in units of ft^3 unless otherwise noted)

Efficiencies		Inputs		Outputs		Out-In	Storage		Maintenance Pumping	
% RD =	45.0	RP	131317	D	500945					
		RI	30851	ET	137826		Begin	105711	Calculated	39789
% RND =	55.0	RW	951832	RU	209374		End	86491	Recorded	38857
				G	286425		Difference	19220	Difference	932
	Totals		1114001		1134570	20569				

Overall % Error = 0.08

Fraction of collected rainfall entering pond = 0.70

APPENDIX B

DATALOGGER PROGRAMS

EVENT-ONLY PRECIPITATION RECORDING PROGRAM

STEP	INSTRUCTION	PARAMETERS	DESCRIPTION
	*1	300	PGM TABLE 1, 5-MIN (300 SEC) INTERVAL
1.	P03	1, 1, 2, 1, 0.01, 0	READ TIPS, STORE IN LOCATION 1
2.	P33	2, 1, 2	ADD INTO ACCUMULATOR: LOCATION 2
3.	P10	3	STORE BATTERY VOLTAGE IN LOCATION 3
4.	P17	4	STORE PANEL TEMPERATURE IN LOCATION 4
5.	P89	1, 1, 0, 30	IF L1 = 0 THEN: STEP 6
6.	P86	20	KEEP OUTPUT FLAG RESET
7.	P94		ELSE
8.	P86	10	SET OUTPUT FLAG
9.	P95		END
10.	P77	10	OUTPUT TIME (HR:MIN)
11.	P70	1, 1	TIPS IN LOCATION 1
12.	P92	0, 1440, 10	OUTPUT END OF EACH DAY
13.	P77	100	JULIAN DAY
14.	P72	1, 1	TOTALIZE RAIN
15.	P70	2, 2	ACCUMULATED RAIN AND BATTERY VOLTAGE
16.	P74	1, 10, 4	MINIMUM TEMPERATURE AND TIME OCCURRING
17	P73	1, 10, 4	MAXIMUM TEMPERATURE AND TIME OCCURRING
18.	P73	1, 10, 1	MAXIMUM INTERVAL RAINFALL
19.	P96	71	DUMP DATA TO STORAGE MODULE

STAGE RECORDING PROGRAM

STEP	INSTRUCTION	PARAMETERS	DESCRIPTION
	*1	300	PGM TABLE 1, 5-MIN (300 SEC) INTERVAL
1.	P86	1	CALL MEASURE SUBROUTINE
2.	P10	4	STORE BATTERY VOLTAGE IN LOCATION 4
3.	P17	5	STORE TEMPERATURE IN LOCATION 5
4.	P30	XXXX, 6	STORE STATION ID (XXXX) IN LOCATION 6
5.	P92	0, 5, 10	SET OUTPUT FOR EVERY 5 MINUTES
6.	P77	10	OUTPUT TIME (HR:MIN)
7.	P71	3, 1	OUTPUT 3 LEVEL SENSOR READINGS

DAY-END OUTPUT

STEP	INSTRUCTION	PARAMETERS	DESCRIPTION
8.	P92	0, 1440, 10	SET FLAG FOR END-OF-DAY OUTPUT
9.	P77	100	OUTPUT JULIAN DATE
10.	P70	1, 6	OUTPUT THE STATION ID
11.	P70	1, 4	OUTPUT THE BATTERY VOLTAGE
12.	P74	1, 10, 5	OUTPUT THE MINIMUM TEMPERATURE AND TIME
13.	P73	1, 10, 5	OUTPUT THE MAXIMUM TEMPERATURE AND TIME

****

MEASURE SUBROUTINE

STEP	INSTRUCTION	PARAMETERS	DESCRIPTION
	*3		PGM TABLE 3
1.	P85	1	SUBROUTINE LABEL
2.	P4	1, 5, 1, 1, 2, 5000, 1, 0.002, 0	SOUTHWEST INLET LEVEL SENSOR
3.	P4	1, 5, 2, 2, 2, 5000, 2, 0.002, 0	NORTHWEST INLET LEVEL SENSOR
4.	P4	1, 5, 3, 3, 2, 5000, 3, 0.002, 0	POND (OUTLET) LEVEL SENSOR
5.	P95		END SUBROUTINE

APPENDIX C

SURFACE WATER INFLOW-OUTFLOW CALCULATION PROGRAM

SURFACE WATER INFLOW-OUTFLOW CALCULATION PROGRAM

```
PRINT "This program is written to parse flow level data for the "
PRINT "Smart Pond project. It accepts .LVL files and outputs two"
PRINT "types of text files: *.TOT files which contain the total"
PRINT "inflow and outflow data for each of the weirs on the pond"
PRINT "and *.FLW files which contain the incremental flows in cfs"
PRINT "for each 5 minute increment - Time , South , North , Pond"
PRINT " The FLW files will also contain"
PRINT "The Julian date at the bottom of each day flagged with a -1"
PRINT
PRINT "for current directory"
FILES "*.LVL"
INPUT "Input filename you wish to parse (without .LVL extension)"; filename$
infile$ = filename$ + ".LVL"


SouthBaseElev! = 4.99
NorthBaseElev! = 5.18
PondBaseElev! = 5.04
SouthBase! = 2!
NorthBase! = 2!
PondBase1! = 44! / 12!
PondBase2! = 45! / 12!
TotalOutFile$ = filename$ + ".TOT"
FlowOutFile$ = filename$ + ".FLW"
OPEN infile$ FOR INPUT AS #1
OPEN TotalOutFile$ FOR OUTPUT AS #2
OPEN FlowOutFile$ FOR OUTPUT AS #3
startloop:
        WHILE NOT EOF(1)
        INPUT #1, code%
        IF code% = 105 THEN
                INPUT #1, time%, SouthElev!, NorthElev!, PondElev!

                ' Calculations of Height above weir

                SouthHeight! = SouthElev! - SouthBaseElev!
                NorthHeight! = NorthElev! - NorthBaseElev!
                PondHeight! = PondElev! - PondBaseElev!

                IF ABS(SouthHeight! - NorthHeight!) > 3! / 12! THEN GOSUB correctweir

                ' Calculation of weir coefficients

                SouthC! = 3.15 + .075 * SouthHeight! / 2!
                NorthC! = 3.15 + .075 * NorthHeight! / 2!
                PondC! = 3.33

                ' Calculation of Flowrates

                        IF SouthHeight! > 0 THEN SouthQ! = SouthC! * SouthHeight! ^ (3! / 2!) *
                        (SouthBase! - .2 * SouthHeight!)
                        IF NorthHeight! > 0 THEN NorthQ! = NorthC! * NorthHeight! ^ (3! / 2!) *
                        (NorthBase! - .2 * NorthHeight!)
                        IF PondHeight! > 0 THEN PondQ! = PondC! * PondHeight! ^ (3! / 2!) *
                        ((PondBase1! - .2 * PondHeight!) + (PondBase2! - .2 * PondHeight!))
```

(continued next page)

SURFACE WATER INFLOW-OUTFLOW CALCULATION PROGRAM (Continued)

```
            ' Correction for Tailwater Condition

            IF PondHeight! > 3! / 12! THEN
                    H2! = PondHeight! - 3! / 12!
                    IF SouthHeight! > H2! THEN
                            SouthQ! = SouthQ! * (1 - (H2! / SouthHeight!) ^ 1.5) ^ .385
                    ELSE
                            SouthQ! = 0
                    END IF
                    IF NorthHeight! > H2! THEN
                            NorthQ! = NorthQ! * (1 - (H2! / NorthHeight!) ^ 1.5) ^ .385
                    ELSE
                            NorthQ! = 0
                    END IF
                    TailWaterFlag = -1
            END IF

            IF SouthQ! < 0 THEN SouthQ! = 0
            IF NorthQ! < 0 THEN NorthQ! = 0
            IF PondQ! < 0 THEN PondQ! = 0

            IF SouthQ! > .01 OR NorthQ! > .01 OR PondQ! > .01 THEN
            PRINT #3, USING "#####   ##.####  ###.####   ##.####"; time%; SouthQ!; NorthQ!; PondQ!
            END IF
            VolumeIn! = VolumeIn! + 5 * 60 * (SouthQ! + NorthQ!)
            VolumeOut! = VolumeOut! + 5 * 60 * (PondQ!)
        ELSEIF code% = 108 THEN
            INPUT #1, date%, x!, x!, x!, x!, x!, x!
            PRINT "Outputting Julian Date "; date%
            PRINT #3, -1, date%
            PRINT #2, USING " #####  #.#####^^^^   #.#####^^^^"; date% - 1; VolumeIn!; VolumeOut!;
            IF TailWaterFlag = -1 THEN PRINT #2, "  *" ELSE PRINT #2,
            PRINT "Total Inflow = "; VolumeIn!; "    Total Outflow = "; VolumeOut!
            VolumeIn! = 0: VolumeOut! = 0
            TailWaterFlag = 0
        END IF
        WEND
        PRINT "End of file was reached Continue with new file? (Y or N)"
        x$ = "": WHILE x$ = "": x$ = INKEY$: WEND
        IF x$ = "Y" OR x$ = "y" THEN
            FILES "*.lvl"
            INPUT "Input Continuation file"; confile$
            CLOSE #1
            OPEN confile$ + ".lvl" FOR INPUT AS #1
            GOTO startloop
        END IF

END
correctweir:
IF SouthHeight! < NorthHeight! THEN
        MinHeight! = SouthHeight!
ELSE
        MinHeight! = NorthHeight!
END IF

NorthHeight! = MinHeight!
SouthHeight! = MinHeight!

RETURN
```

APPENDIX D

NOTATION

NOTATION

A Area of the watershed

b Width of rectangular fully-contracted weir discharge

C Runoff Coefficient - the fraction of a rainfall that will result in rainfall excess

cfs Cubic feet per second

C_w Weir coefficient adjusted for crest height

D Discharge of stormwater over control structure in cubic feet per second (cfs)

DCIA Directly connected impervious area of a watershed

dI The net inflow to the pond in cubic feet (total inflow minus discharge)

EIA Equivalent Impervious Area of the watershed - the size of an impervious area which would produce the same amount of runoff as the actual watershed (acres)

ET Evapotranspiration

EV Evaporation

G Net groundwater inflow/outflow

h_1 Depth of water above weir crest

h_2 Tailwater elevation relative to water depth above weir crest

mv millivolts

NGVD The National Geodetic Vertical Datum of 1929 (mean sea level)

P Precipitation in inches measured over the project area

P_1 Depth of weir approach channel

Q Discharge in cfs under normal tailwater conditions (subscripts "north," "south," and "out" refer to the discharge measurement from the appropriate weir).

Q_w Discharge in cfs under high tailwater conditions

%RD Percent of runoff discharged from the pond

REV Rate-Efficiency-Pond Volume Chart

RI Volume of indirect runoff in cubic feet from the area surrounding the pond

%RND Percent of runoff not discharged from the pond

R_p Rainfall excess for a pervious area

RP Volume of precipitation in cubic feet falling directly into pond

RU Volume of reuse water delivered to the irrigation demonstration area

RW Volume of runoff in cubic feet flowing into the pond from the watershed through the stormwater collection system

S' Maximum storage of soil

S_1 Beginning of day pond storage

S_2 End of day pond storage

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