Effectiveness of Stormwater Treatment Systems in the Florida Keys

Final Report

Prepared for:

FLORIDA DEPARTMENT OF ENVIRONMENTAL PROTECTION

FDEP Contract No. WM797

"This project and the preparation of this report were funded by a Section 319 Nonpoint Source Management Program grant from the U.S. Environmental Protection Agency (US EPA) through a contract with the Stormwater/Nonpoint Source Management Section of the Florida Department of Environmental Protection. The total cost of the monitoring project was $167,994.92 which was provided by the US EPA."

December 2002

Prepared By:

Harvey H. Harper, Ph.D., P.E.
David Baker, P.E.
Chip Harper

Environmental Research & Design, Inc.

3419 Trentwood Blvd., Suite 102
Orlando, FL 32812

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ACKNOWLEDGEMENTS

The authors wish to thank the U.S. Environmental Protection Agency and the Stormwater/Nonpoint Source Management Section of the Florida Department of Environmental Protection for their assistance in funding and administration of this project. A special thank you is also given to the FDEP Project Manager, Mr. Eric Livingston, for his invaluable support throughout this project. As always, Eric is a pleasure to work with, and his technical expertise contributed heavily to the success of this project. The authors also wish to sincerely thank and acknowledge the city of Key Colony Beach and the Key Colony Beach Sewage Treatment Plant personnel for providing general assistance and use of the study sites utilized throughout this project.

SECTION 1

INTRODUCTION

One of the most common stormwater treatment methodologies used for pollution abatement in the Florida Keys today is dry detention. Dry detention systems are water storage areas which are designed to store a specified quantity of stormwater runoff which is slowly evacuated by a combination of groundwater infiltration and discharge through an outlet structure to adjacent receiving waters. The control elevation of the storage area is typically designed to be at or below the bottom elevation of the pond. As a result, after drawdown of the stored runoff has been completed, the storage basin does not contain any standing water, and the system maintains "dry" conditions between storm events. Dry detention systems are commonly used in high groundwater table areas where design criteria for retention type facilities cannot be met.

Traditional dry detention systems constructed outside the Florida Keys generally have limited infiltration capabilities. As a result, water column processes such as sedimentation, precipitation, and adsorption are the primary mechanisms responsible for pollutant removal. However, soil profiles in the Florida Keys often consist of a shallow layer of sandy soil overlying a highly permeable layer of lime rock and coral. Even though water table elevations may be near the surface, lateral groundwater seepage rates are often high, and a large portion of the runoff entering dry detention ponds percolates into shallow groundwater. Previous stormwater research (Harper, 1988) has indicated that surficial soils are extremely important in retaining pollutants in stormwater management systems and in minimizing impacts on shallow groundwater from infiltration of stormwater runoff. However, the research performed by Harper was conducted in the Central Florida area where soils are substantially less permeable and contain higher levels of organic matter than soils typically observed in the Florida Keys.

Although dry detention stormwater management systems have been commonly used in the Florida Keys, no previous research has been performed to evaluate the effectiveness of these systems for retaining stormwater pollutants and preventing downward migration of pollutants into shallow groundwater. In addition, drainage wells are also commonly used in the Florida Keys for disposal of both treated and untreated stormwater runoff. These drainage wells typically discharge to low quality aquifers which have little usefulness for drinking water or irrigation purposes. However, no previous research has been performed to evaluate the potential groundwater impacts resulting from the use of these wells for disposal of stormwater runoff.

1.1 History of Study Site

In 2001, the Florida Department of Environmental Protection (FDEP), as part of a Section 319(H) Grant from the U.S. Environmental Protection Agency (EPA) selected Environmental Research & Design, Inc. (ERD) to evaluate the hydraulic performance, pollutant removal effectiveness, and groundwater impacts of dry detention stormwater management systems constructed in porous, shallow soils typical of the Florida Keys area. The dry detention pond site selected for study is located in a single-family residential subdivision in the City of Key Colony Beach, located south of U.S. 1 and northeast of Marathon Shores in the Florida Keys. A location map for the Key Colony Beach project site is given in Figure 1-1. The dry detention pond was constructed during 2000-2001 as part of an FDEP Section 319(H) Grant to establish BMP stormwater treatment within the City of Key Colony Beach.

Prior to implementation of the FDEP Section 319(H) Grant, there were approximately 28 existing stormwater outfalls in the City of Key Colony Beach that discharged untreated stormwater runoff directly into canals or other surface waters adjacent to the City of Key Colony Beach (Greiner, Inc., 2000). Waters surrounding the City of Key Colony Beach have been designated as "Outstanding Florida Waters" (OFW), an "Area of Critical State Concern", a "National Marine Sanctuary", and an area of shellfish harvesting. Few areas within the City of Key Colony Beach had provisions for stormwater treatment, and untreated stormwater runoff discharged directly into adjacent marine waters.

During the period from 1995-2000, the City of Key Colony Beach installed an array of BMPs to minimize discharges of stormwater runoff into adjacent marine waters. BMPs, including vegetative swales, oil/grease skimmers, detention areas, and Class V stormwater injection wells, were used to demonstrate techniques to improve water quality in the coastal waters of the Florida Keys. Primary BMP elements included: (1) construction of seven new 61 cm (24-inch) diameter Class V injection wells; (2) installation of 427 m (1400 ft) of 20 cm (8-inch) CPE pipe to convey runoff between runoff swale segments; (3) elimination of seven existing direct outfalls to marine waters; (4) construction of 2740 m (9000 ft) of grassed swales; (5) installation of 2210 m (7250 ft) of exfiltration piping and trenching to enhance infiltration of runoff into the soils; and (6) a 0.59 ha (1.45 ac) shallow grassed dry detention pond, which is the primary subject of the evaluation presented in this report.

1.2 Scope of Work Efforts

This project is designed to evaluate the performance efficiency of a dry detention pond constructed in the Florida Keys, with particular emphasis on shallow groundwater impacts resulting from infiltration of runoff into the bottom of the detention basin, as well as deeper groundwater impacts resulting from the use of injection drainage wells for disposal of the treated runoff. The specific objectives of this project are to:

1. Evaluate the hydraulic performance of a dry detention system operated under high groundwater table conditions

2. Evaluate the pollutant removal effectiveness of a dry detention stormwater management system operated in an area of porous soils and high groundwater table conditions

3. Evaluate the shallow groundwater impacts resulting from infiltration of runoff through the pond bottom

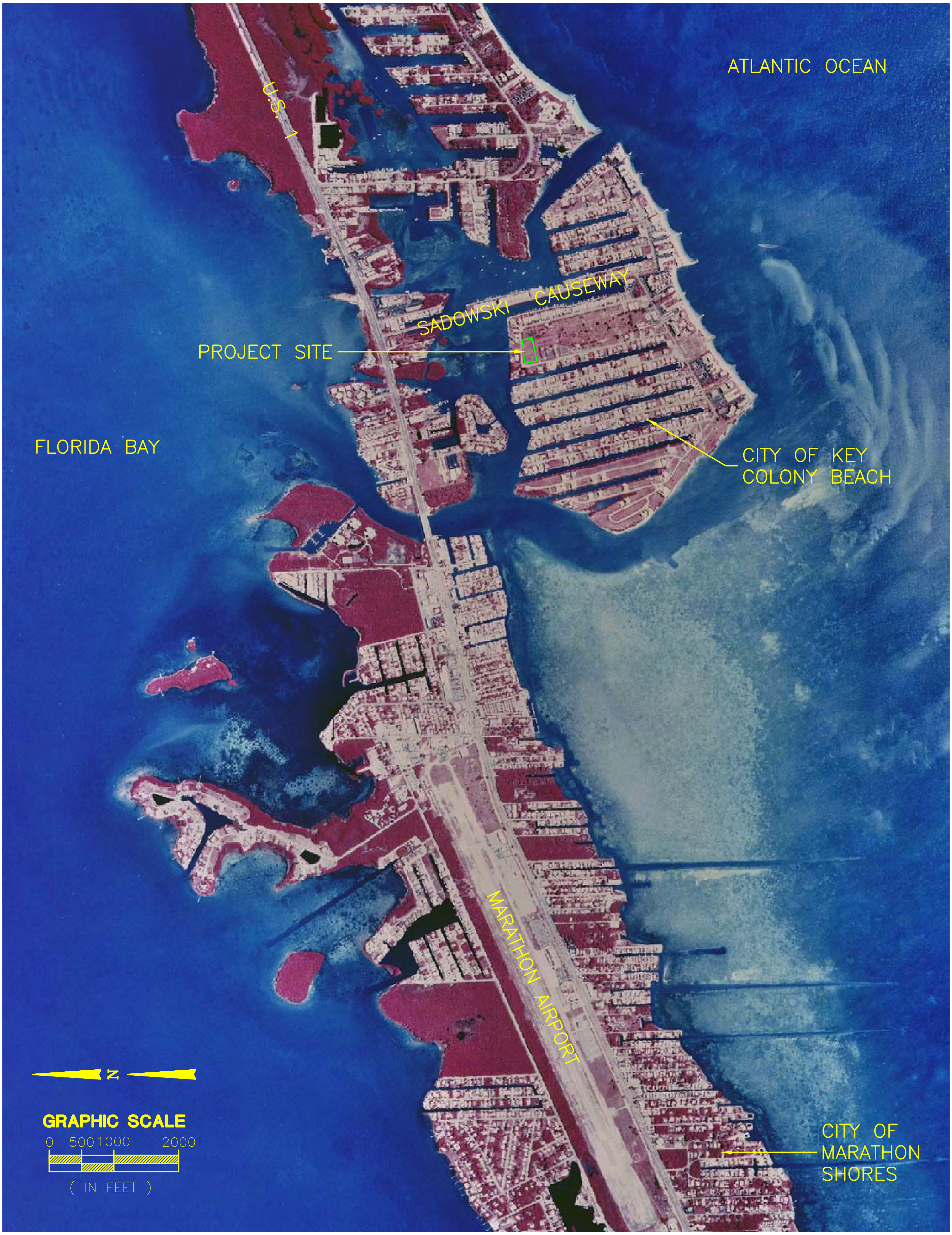


Figure 1-1. Location map for the Key Colony Beach research site.

4. Evaluate the deep groundwater impacts of using drainage/injection wells for disposal of treated runoff

5. Provide recommendations for improvement of the current design for dry detention systems to enhance the hydraulic and pollutant removal effectiveness of these systems and to minimize impacts on shallow and deep groundwater resources

Field monitoring was performed by ERD at the Key Colony Beach site from July 2001-November 2002. Work efforts included field instrumentation of the dry detention pond, followed by a 16-month period of field monitoring to define water quality and hydrologic characteristics of the system. A complete hydrologic budget was performed on the dry detention facility, including direct measurement of inputs from stormwater runoff and direct precipitation, with losses occurring as a result of infiltration into shallow groundwater, evaporation, and discharge into the drainage well. Chemical analyses were also performed on inputs into the pond from stormwater runoff and bulk precipitation, along with pond surface water and discharges into the injection wells. Shallow and deep groundwater characteristics were also evaluated to identify potential groundwater impacts. In excess of 280,000 separate hydrologic and laboratory measurements were generated during the course of this project.

This report is divided into five separate sections for presentation and discussion of project results. The first section provides an introduction to the report and includes a history of the site, along with a summary of work efforts performed by ERD. A detailed description of field and laboratory procedures performed by ERD is given in Section 2. The results of the field and laboratory investigations performed by ERD are summarized in Section 3. A summary, list of conclusions, and recommendations are given in Section 4. References are included in Section 5. Appendices are also attached which contain raw and summary data generated during the work efforts performed by ERD.

1.3 Units of Measurement

Project work efforts described in this report are presented using a combination of metric and English units of measurement. In general, all data related to chemical analyses and estimation of mass loading rates and removal efficiencies for the dry detention system are presented exclusively in metric units. However, elevation data referenced to mean sea level (NGVD) is given in terms of English units since this is the format utilized for engineering drawings and construction plans for the dry detention system. Units of measurement for evaluation of hydraulic inputs and losses into the dry detention system are presented in both metric and English units.

SECTION 2

FIELD AND LABORATORY PROCEDURES

2.1 Description of the Project Site

The detention pond site evaluated during this project is located in a single-family residential subdivision in the City of Key Colony Beach, Florida, located south of U.S. 1 and northeast of Marathon Shores in the Florida Keys. The project site is located within Monroe County and within the South Florida Water Management District (SFWMD).

In design documents for the pond, the pond system is alternatively referred to as both a retention and detention system. Based on SFWMD design criteria, the pond meets the definition of a dry retention/detention area which is defined as a "water storage area with bottom elevation at least one foot above the control elevation of the area". Therefore, for purposes of this report, the pond is referred to as a retention/detention pond.

An approximate delineation of the drainage basin boundary for the dry detention pond is given in Figure 2-1, based upon drainage maps prepared by Greiner, Inc. and field observations by ERD personnel. The overall drainage basin for the dry detention pond covers approximately 9.86 ha (24.34 ac) and includes portions of roadway with associated right-of-way, a 9-hole golf course, playground, sewage treatment plant, tennis courts, storage yard for boats and trailers, and commercial/public businesses. As seen in Figure 2-1, the majority of the site consists of open areas covered with grass in relatively good condition. Palm trees and isolated hardwoods are scattered throughout the basin.

Topography within the drainage basin is essentially flat, and no well-defined natural drainage features are present within the basin. Runoff is conveyed primarily by overland flow to a series of vegetated drainage swales located on the eastern and western boundaries of the basin. Due to the highly permeable characteristics of the on-site soils, overland flow into the swale system is generated only during long duration high-intensity rain events. The swale systems are also relatively flat, and a large portion of the runoff which enters the swales is retained and does not reach the dry detention pond. Due to the highly permeable nature of the on-site soils, the substantial retention within the drainage swales, and the small amount of impervious surfaces within the basin, rain events in excess of 2.5 cm (1.0 in) are typically required to contribute measurable runoff into the dry detention pond.

Since the drainage basin indicated on Figure 2-1 is relatively flat, the basin boundaries are difficult to define, and the boundaries indicated on Figure 2-1 should be viewed as approximate boundaries only. It is possible that under certain conditions, the commercial and institutional areas south of the drainage basin boundary may also contribute stormwater runoff to the dry detention pond. Under normal conditions, excess runoff generated in these areas discharges into a treatment

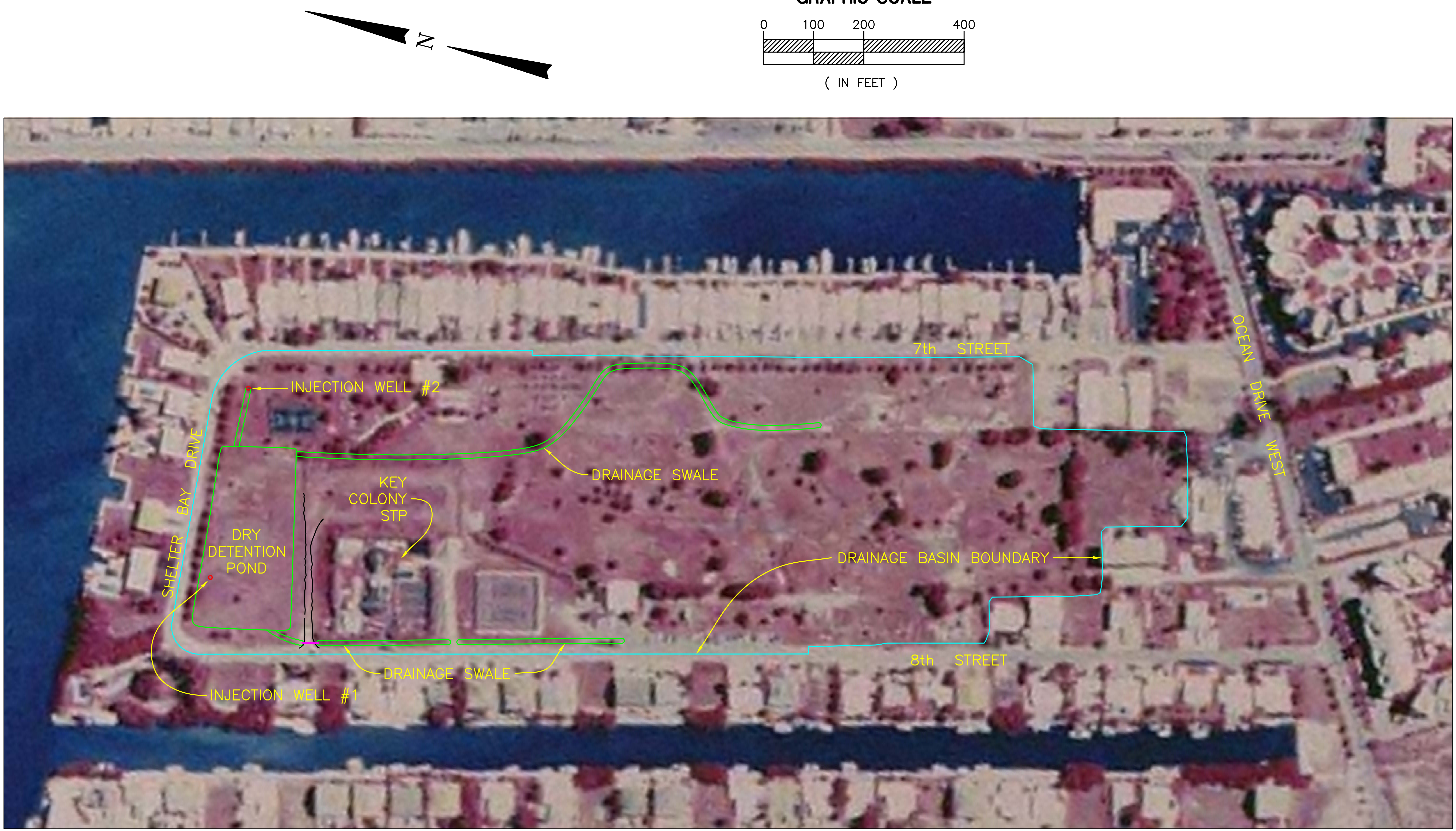


Figure 2-1. Drainage features for the dry detention pond site.

drain consisting of vegetated swales, perforated underdrains, and several Class V injection wells. If the capacity of this treatment train were to be exceeded as a result of an extreme rain event, it is possible that excess runoff from this area could also migrate into the dry detention basin. However, since this occurrence appears to be relatively rare, these areas have been excluded from the drainage basin boundaries indicated on Figure 2-1.

Excess runoff which reaches the dry detention pond begins to rapidly infiltrate through the pond bottom into the shallow surficial soils. When the storage capacity of the surficial soil layer has been exceeded, accumulation of water begins to occur within the pond. Drawdown of excess runoff within the pond occurs through two separate Class V injection wells. One of the injection wells is located along the northern perimeter of the pond, with the second injection well located on the northeast corner of the drainage basin. The intake inverts for each injection well are set near the bottom elevation of the pond so that excess runoff which fills the pond can rapidly be discharged into the groundwater. The injection well located on the northeast perimeter of the drainage basin is connected to the dry detention pond by a dense grassed swale. This injection well also receives a limited amount of direct surface runoff from road and right-of-way areas immediately adjacent to the injection well.

A typical schematic of the drainage/injection wells is given in Figure 2-2. Each of the actual drainage wells is located inside a manhole for safety and security purposes. Excess runoff discharges through a baffled grate inlet structure before entering the injection well. Each of the wells is approximately 24 m (140 ft) deep, with PVC well casing extending to a depth of approximately 12 m (30 ft). Runoff inputs into each well discharge into a groundwater layer extending from approximately 12-24 m (40-80 ft) below the ground surface.

Elevation contours for the dry detention pond are indicated on Figure 2-3 based upon field surveys conducted by ERD during February 2002. Spot elevations were collected at 7.6 m (25 ft) intervals over the entire pond site, and the contours indicated in Figure 2-3 were generated using AutoCAD. In general, the bottom of the pond appears to be relatively flat, with bottom elevations ranging from 2.1-2.6 ft (NGVD). Top-of-bank elevations range from 3.2-3.5 ft, with maximum water depths ranging from approximately 0.3-0.5 m (1-1.5 ft). Stage-storage relationships for the dry detention pond are indicated in Table 2-1 for surface elevations ranging from 2.05-3.05 ft (NGVD). At a surface elevation of 3.05 ft, which reflects top-of-bank conditions in many areas of the pond, the pond has a surface area of approximately 0.59 ha (1.45 ac) and a cumulative storage volume of approximately 992 m^3 (35,000 ft^3).

Based on as-built design drawings certified by Greiner, Inc., the invert of the inlet structure for Injection Well #1 is 2.40 ft (NGVD) and 2.46 ft (NGVD) for Injection Well #2. However, the swale leading to Injection Well #2 has a high spot which must be exceeded before water from the pond can flow toward the well. Based on field surveys conducted by ERD, the elevation of the high spot is approximately 2.98 ft (NGVD). As a result, the water level in the pond must rise to levels in excess of 2.98 ft (NGVD) before flow can reach Injection Well #2. Therefore, for hydrologic purposes, the invert elevation of Injection Well #2 is assumed to be 2.98 ft (NGVD).

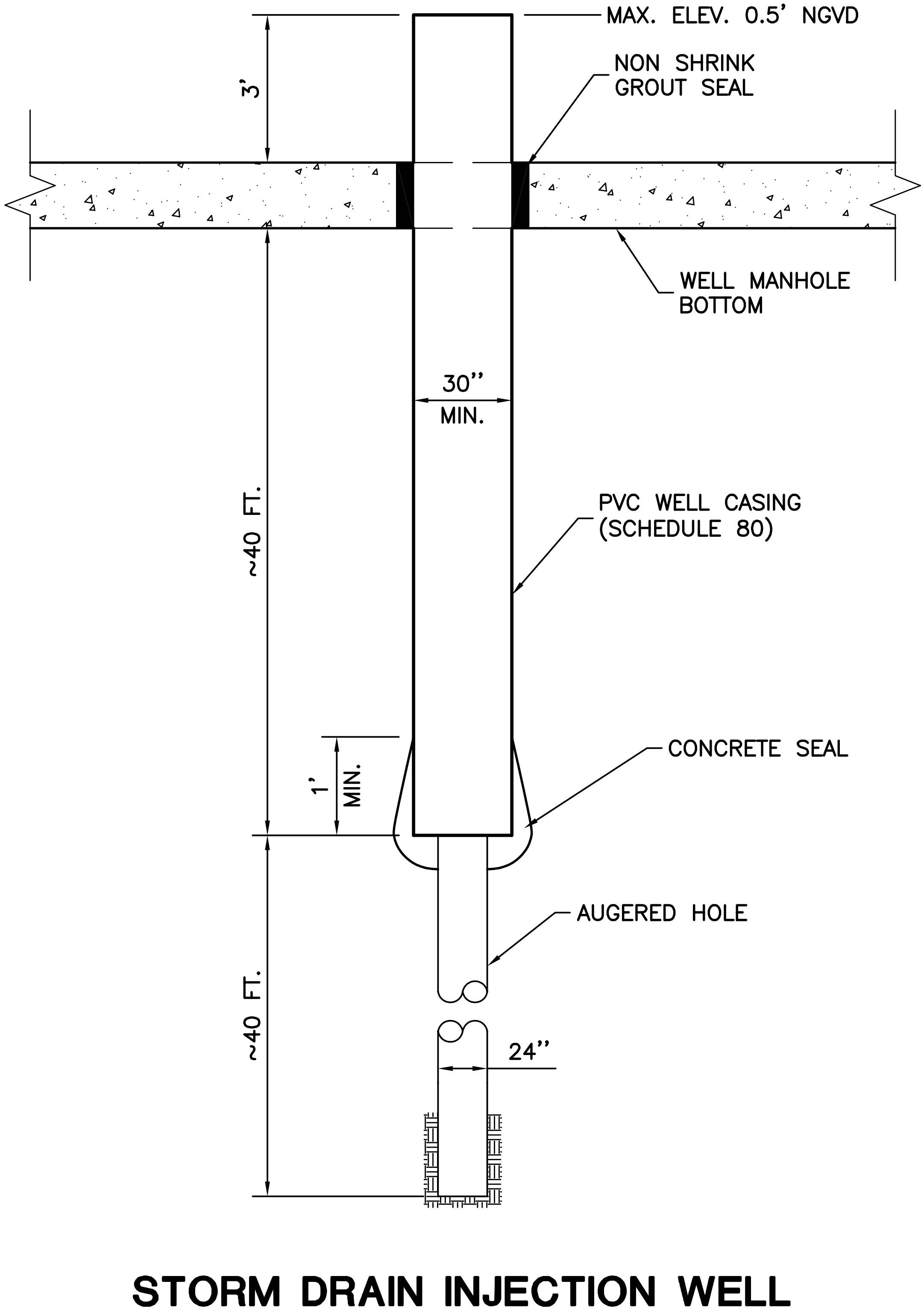


Figure 2-2. Typical Schematic of the Drainage/Injection Wells.

Figure 2-3. Elevation Contours for the Dry Detention Pond (Ft. NGVD).

TABLE 2-1

STAGE-STORAGE RELATIONSHIPS FOR THE KEY COLONY DRY DETENTION POND

ELEVATION (ft NGVD)	SURFACE AREA		CUMULATIVE VOLUME	
	ft^2	m^2	ft^3	m^3
2.0	0	0	0	0
2.1	655	61	66	2
2.2	4,520	420	517	15
2.3	13,720	1,275	1,889	54
2.4	25,730	2,392	4,463	126
2.5	40,130	3,730	8,476	240
2.6	47,261	4,393	13,202	374
2.7	53,272	4,952	18,529	525
2.8	56,295	5,233	24,158	685
2.9	57,652	5,359	29,924	848

1. Based on field measurements conducted by ERD during February 2002

Hydrologic characteristics of the contributing watershed area for the dry detention pond are summarized in Table 2-2 based upon field measurements and evaluations performed by ERD personnel. The total contributing watershed area for the detention pond is approximately 9.86 ha (24.34 ac), although additional areas may contribute to the detention pond during extreme rain events. Approximately 6.1% of the drainage basin is covered with impervious areas, with approximately 28% of these areas considered to be directly connected impervious areas, most of which consist of road and right-of-way areas adjacent to the pond.

According to the Soil Survey of Monroe County, Florida, published by the Soil Conservation Service, soils within the drainage basin consist primarily of Urban Land series which are soils that have been modified from the natural condition by fill activities. Based on soil samples collected by ERD during the project, soils in the drainage basin consist of a thin layer of sandy top soil approximately 5 cm (2 in) or less in thickness, with a subsoil consisting of sandy marl extending to approximately 25 cm (10 in) overlying a thick layer of sandy marine clay. Based on the observed rapid permeability and extremely low runoff potential, these soils would be classified in Hydrologic Soil Group A. Pervious areas within the drainage basin consist primarily of open spaces with grass cover in good condition. Based upon Technical Release 55 (June 1986) published by the Soil Conservation Services, the curve number (CN) value for open spaces with good grass cover in Hydrologic Group A soils is 39.

TABLE 2-2

HYDROLOGIC CHARACTERISTICS OF THE CONTRIBUTING WATERSHED AREA FOR THE DRY DETENTION POND SITE

PARAMETER	VALUE
Watershed Area	9.86 ha (24.34 ac)
Impervious Area	6.1% (0.60 ha, 1.49 ac)
Pervious Area	93.9% (9.26 ha, 22.85 ac)
Percent of Impervious Area Directly Connected	28%
Curve Number for Pervious Area	39
Time of Concentration	180-240 minutes

Time of concentration for the drainage basin area is difficult to estimate due to the relatively flat topography and the lack of well-defined conveyance channels throughout much of the area. The general travel path for surface runoff includes overland flow across the grassed areas into the drainage swale conveyance systems located on the eastern and western sides of the basin. In general, single rain events in excess of 1.5-1.75 inches of rainfall are required to generate measurable runoff from all portions of the drainage basin. However, based upon field observations performed by ERD personnel during rain events at the site, migration of excess runoff from the most remote areas of the drainage basin to the dry detention pond requires approximately 180-240 minutes, depending upon the intensity of the rain event.

2.2 Field Procedures and Instrumentation

A schematic of field instrumentation used at the dry detention pond site is given in Figure 2-4. Instrumentation was installed to conduct a complete hydrologic budget for the pond site, including a water level recorder, rainfall recorder, evaporimeter, and groundwater piezometers. Automatic sequential samplers were also installed to provide continuous records of inflow and outflow from the detention pond and to collect both inflow and outflow samples on a flow-weighted basis. Details on installation and routine operation for this equipment are provided in the following sections.

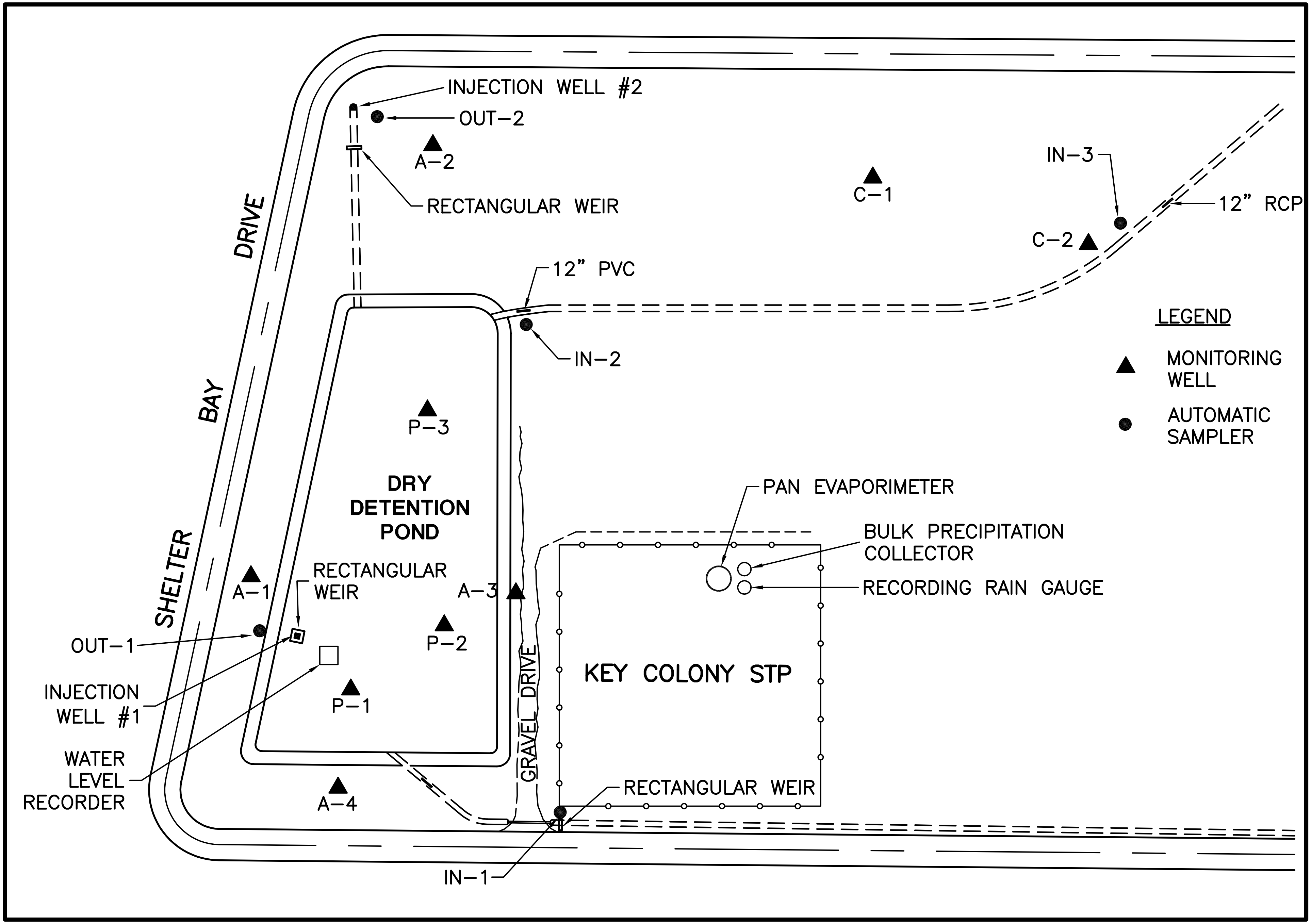


Figure 2-4. Field Instrumentation for the Dry Detention Pond Study Site.

2.2.1 Collection of Pond Inflow and Outflow

2.2.1.1 Collection of Pond Inflow

Runoff inputs into the pond were monitored using automatic sequential samplers with integral flow meters, manufactured by Sigma (Model No. 900MAX-AV), which were installed at three separate locations, as indicated on Figure 2-4, to provide a continuous hydrograph record of inputs into the detention pond system. One of the automatic samplers was installed in the drainage swale along the western perimeter of the pond and was designated as Inflow 1 (IN-1). An 81 cm (32 in) rectangular weir with end contractions was constructed inside the drainage swale, just upstream of the gravel driveway, to provide a control point for accurate measurement of stormwater inputs. The automatic sampler was housed inside an insulated aluminum equipment shelter with sensor cables and sample tubing extending through underground PVC conduit to the point of sample collection. The integral flow recorder was programmed to provide a continuous record of hydraulic inputs into the pond at this location, with measurements stored into internal memory at 10-minute intervals. A photograph of Inflow Monitoring Site 1 is given in Figure 2-5.

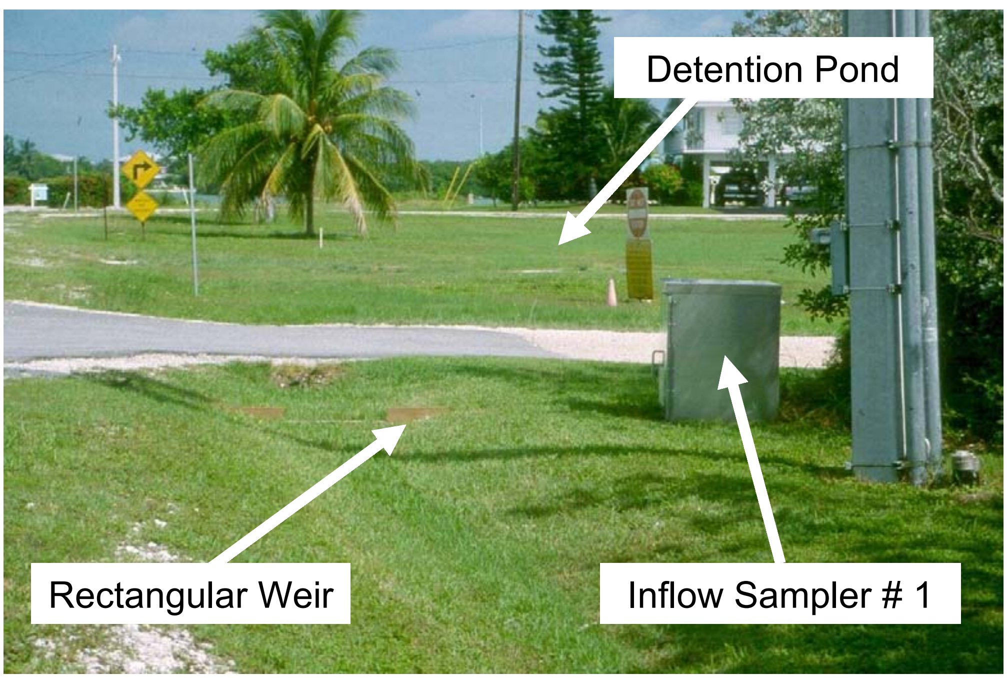


Figure 2-5. View of Inflow Monitoring Site 1.

The automatic stormwater sampler contained 24 one-liter polyethylene bottles and was programmed to collect stormwater samples in a flow-weighted sample mode. A single flow-weighted composite stormwater sample was generated from each monitored storm event by combining the flow-weighted samples to form a single composite sample. A total of nine separate flow-weighted composite samples of stormwater runoff was collected at this site during the 16-month monitoring program.

A second automatic sequential sampler with integral flow meter, manufactured by Sigma (Model No. 900MAX-AV), was installed to monitor runoff inputs through the swale which enters at the southeast corner of the pond, and was designated as Inflow 2 (IN-2). The automatic sampler was housed inside an insulated aluminum equipment shelter with sensor cables and sample tubing extending through underground PVC conduit to the point of sample collection. A 3 m (10 ft) section of 30 cm (12 in) PVC was installed inside the drainage swale to provide a control point for more accurate measurement of runoff inputs. After installation, the PVC pipe was backfilled with lime rock so that all water discharging through the swale would have to pass through the 30 cm (12 in) PVC control section. The integral flow meter was programmed to provide a continuous record of hydraulic inputs into the pond, with measurements stored into internal memory at 10-minute intervals. A photograph of Inflow Monitoring Site 2 is given in Figure 2-6.

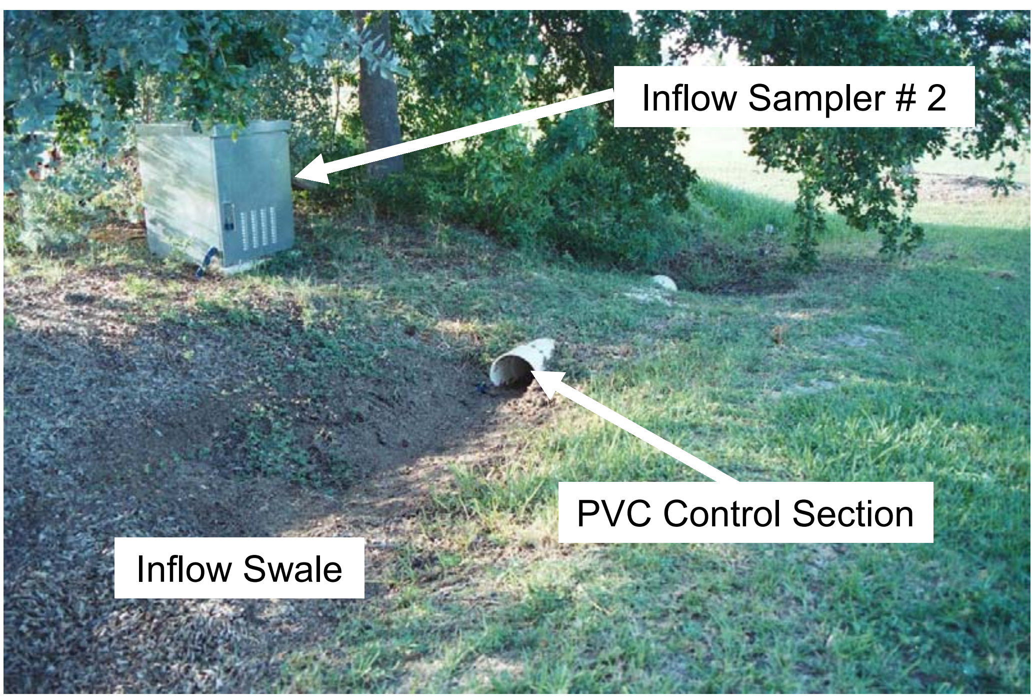


Figure 2-6. View of Inflow Monitoring Site 2.

The automatic stormwater collector at Inflow 2 contained 24 one-liter polyethylene bottles and was programmed to collect stormwater samples on a flow-weighted basis during rain events of sufficient rainfall depth to generate runoff flow. A single flow-weighted composite runoff sample was then generated from each rain event by combining the individual flow-weighted samples from the storm event to form a single composite. A total of six separate flow-weighted composite samples of runoff inflow was collected from this site and submitted for laboratory analyses during the 16-month monitoring program.

The southeastern inflow into the pond consists of a heavily vegetated swale, approximately 0.3-0.6 m (1-2 ft) deep, which conveys untreated runoff from areas adjacent to Seventh Street, as well as portions of the golf course, into the dry detention pond. The vegetated swale is designed to provide pre-treatment of stormwater runoff inputs prior to entering the pond. Since this swale is a component of the overall treatment train, the performance efficiency of this component was also evaluated. An additional automatic sampler, designated as Inflow 3 (IN-3), was installed in upstream portions of the swale, approximately 180 m (600 ft) upstream of Inflow 2, to monitor the quantity and quality of raw runoff entering the swale system. This monitoring location is used to evaluate the overall treatment efficiency of the swale system by comparing the quantity and quality of runoff inputs measured at Inflow 3 with the quantity and quality of runoff inputs measured at Inflow 2. A photograph of Inflow Monitoring Site 3 is given in Figure 2-7.

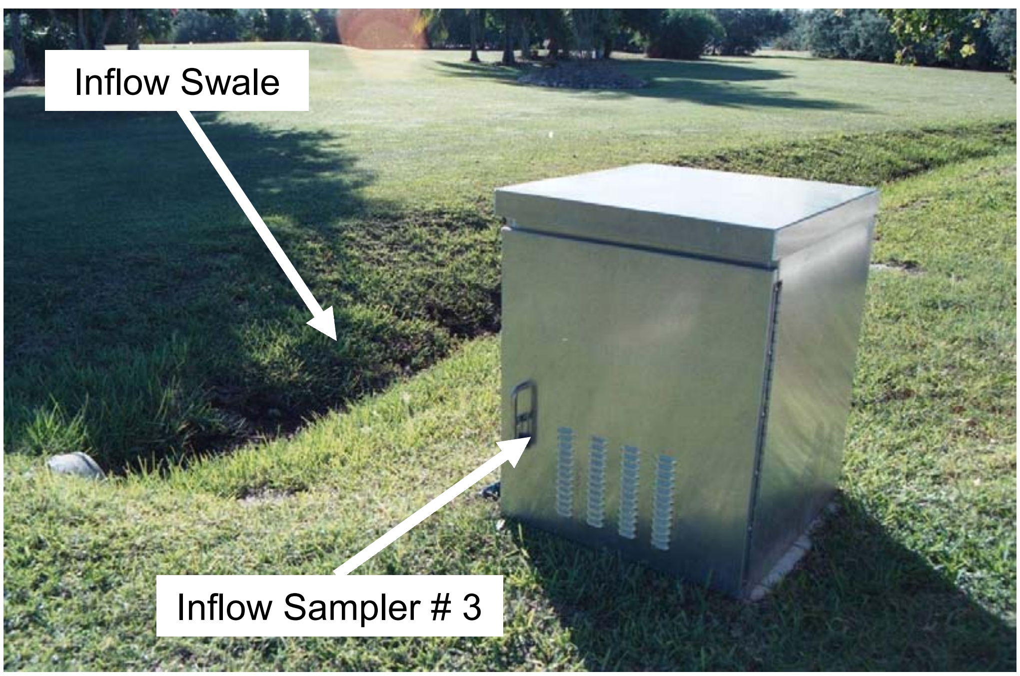


Figure 2-7. View of Inflow Monitoring Site 3.

An automatic sequential sampler with integral flow meter, manufactured by Sigma (Model No. 900MAX-AV) was installed inside an insulated aluminum equipment shelter and used to collect samples on a flow-weighted basis and to provide a continuous hydrograph of discharges through the swale system at this location. The flow sensor and stormwater intake were installed inside a 30 cm (12 in) CMP which is located within the drainage swale. Sensor cables and sample collection tubing were extended from the equipment shelter to the point of flow measurement and sample collection through underground PVC conduit. The internal flow recorder was programmed to provide a continuous record of discharges at this site which were stored into internal memory at 10-minute intervals. The automatic stormwater collector contained 24 one-liter polyethylene bottles and was programmed to collect stormwater samples in a flow-weighted sample mode. A single flow-weighted composite stormwater sample was generated from each rain event of sufficient rainfall depth to generate runoff flow. A total of six separate flow-weighted composite samples of stormwater runoff was collected at this site during the 16-month monitoring program.

2.2.1.2 Collection of Pond Outflow

Outflow from the dry detention pond to the two adjacent injection wells was also monitored on a continuous basis using two separate automatic sequential samplers. Each of the outflow samples was manufactured by Sigma (Model No. SL8000) and contained integral flow meters for flow measurement. One of the outflow samplers, designated as Outflow 1 (OUT-1), was installed to monitor discharge from the pond into injection well #1. A rectangular weir was installed around the perimeter of the grate inlet to the injection well to provide a control section for accurately monitoring discharges. A variable high V-notch weir was installed in the rectangular weir to accurately measure inflow rates during low pond level conditions. The weir invert was periodically adjusted as necessary to prevent weir submergence. Photographs of Outfall Monitoring Site 1 are given in Figures 2-8 and 2-9.

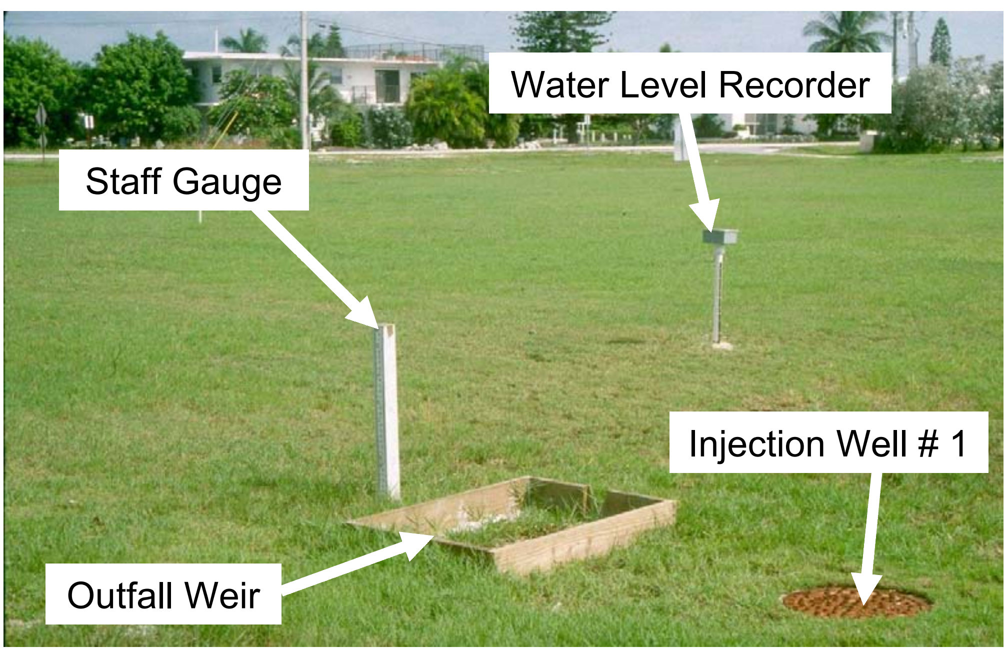


Figure 2-8. View of Outfall Monitoring Site 1.

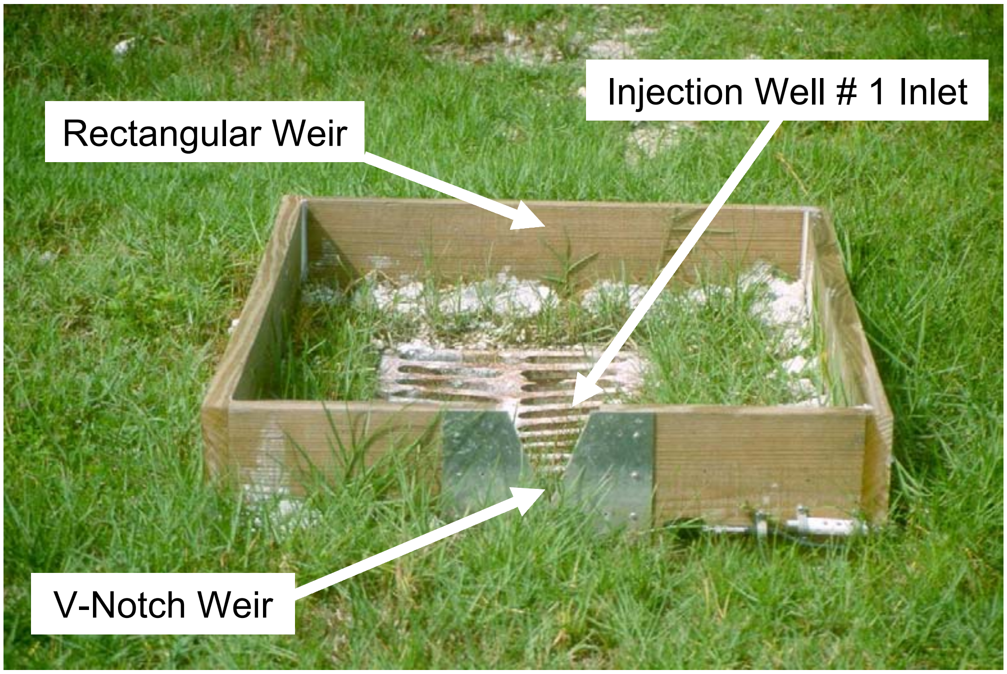


Figure 2-9. View of Outfall Weirs and Injection Well 1 Inlet.

The second outflow sampler, designated as Outflow 2 (OUT-2), was installed at the point of inflow to injection well #2. An 81 cm (32 in) rectangular weir with end contractions was installed across the shallow swale which discharges from the northeast side of the dry detention pond to the injection well. An automatic sequential sampler with integral flow meter, manufactured by Sigma (Model No. SL8000), was installed at this location to provide a continuous record of discharges from the pond into the injection well. A photograph of Outflow Monitoring Site 2 is given in Figure 2-10.

Each of the two outflow samplers was installed inside insulated aluminum equipment shelters, with sensor cables and sample tubing extending from the equipment shelter to the point of measurement through underground PVC conduits. Flow recorders in each of the outflow samplers were programmed to provide a continuous record of discharges from the pond with measurements stored into internal memory at 10-minute intervals. Each of the two samplers contained a single 4-gallon polyethylene bottle which was programmed to collect a continuous composite sample of pond discharges on a flow-weighted basis.

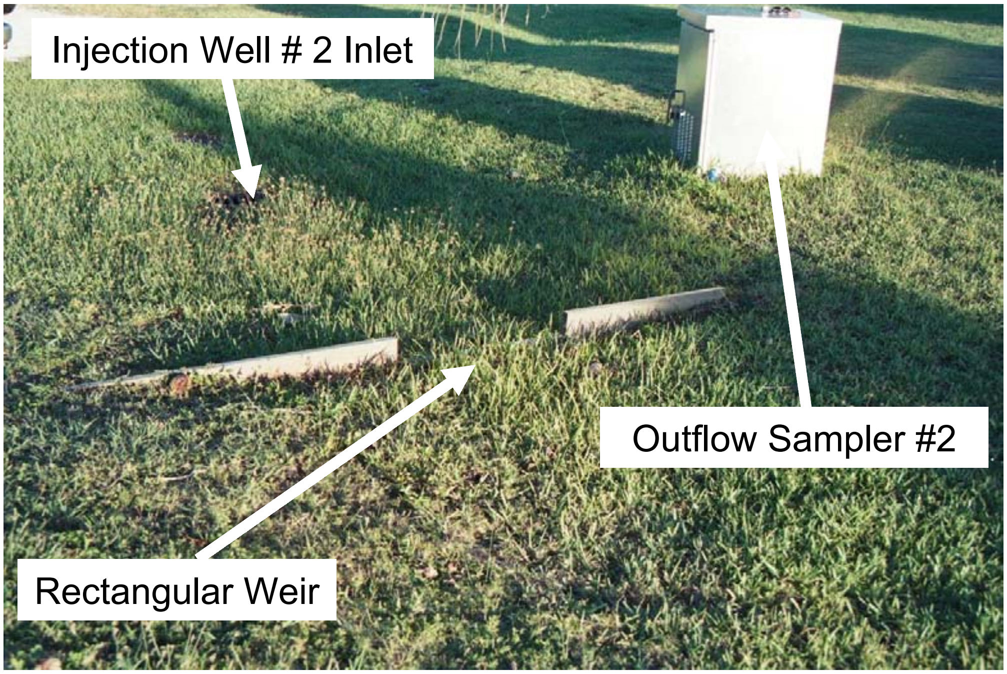


Figure 2-10. View of Outfall Monitoring Site 2.

2.2.1.3 Routine Sample Collection Procedures

ERD field personnel visited the dry detention pond site approximately once each week to retrieve samples and flow data from the stormwater and outflow collectors. The center compartment of each of the automatic samplers was filled with approximately 8-10 lbs of ice during each site visit. This amount of ice was generally sufficient to chill the collected samples between the collection dates. Data was retrieved from each sampler using a Data Transfer Unit (DTU) which produced a hard copy printout of hydrographs measured at each site.

2.2.2 Hydrologic Instrumentation

In addition to continuous measurements of inflow and outflow for the dry detention pond, additional instrumentation was installed to complete the hydrologic budget for the pond site. A sensitive pressure transducer type water level recorder (Global Water) was installed inside a perforated 5 cm (2 in) pipe which was extended approximately 1.5 m (5 ft) below the ground elevation. Electronics for the water level recorder were housed in a watertight housing mounted on top of the 5 cm (2 in) PVC. The water level recorder provided a continuous record of changes in both surface water and groundwater elevations at 10-minute intervals. Data was retrieved from the unit approximately once each month.

A recording rainfall gauge was installed inside the fenced perimeter of the Key Colony Sewage Treatment Plant (STP). This rainfall recorder (Texas Electronics, Inc., Model 1014-P) produced a digital record of all rainfall occurring at the site. This record was used to provide information on rainfall characteristics such as total rainfall amount, antecedent dry period, rainfall intensity, and total rainfall volume over the 16-month monitoring period.

A Class A pan evaporimeter was installed on a level wooden platform adjacent to the recording rain gauge. Evaporation losses were recorded during each visit to the site. Water from the pond was added to the evaporimeter as necessary for make-up purposes.

2.2.3 Piezometer/Monitoring Wells

A series of groundwater piezometers was also installed at the project site to provide information on horizontal groundwater gradients in the vicinity of the pond. Each piezometer was constructed of 3.2 cm (1.25 in) diameter solid PVC attached to a 0.9 m (3 ft) long section of 3.2 cm (1.25 in) diameter slotted PVC. Bore holes were augered for each piezometer which extended approximately 1.5 m (5 ft) below the ground surface at each site. The piezometers were then inserted into the open boreholes and backfilled with clean silica sand. The top 15 cm (6 in) was packed with bentonite clay to minimize downward migration of surface water through the permeable sand media.

Three separate piezometers were installed in the dry detention pond at locations indicated on Figure 2-4. These pond piezometers are identified as P-1, P-2, and P-3. An additional four piezometers were installed adjacent to the pond on each of the four sides. These piezometers are identified as A-1, A-2, A-3, and A-4. Piezometric elevations measured in these piezometers will be compared with pond piezometric levels to identify the direction of water movement throughout the study period. An additional two shallow piezometers, identified as C-1 and C-2, were installed in areas away from the pond for control purposes. Piezometric measurements were collected from each of the nine piezometers on approximately a weekly basis using a water level recorder manufactured by SoilTest.

Shallow groundwater samples were collected from each of the piezometers on a monthly basis over the 16-month monitoring period. Each of the wells was purged prior to sampling according to FDEP protocol, and a single sample for laboratory analyses was collected from each well using a battery-powered peristaltic pump. Each of the collected samples was field-filtered using a disposable 0.45 micron groundwater filter manufactured by Geotech. Field measurements of temperature, pH, dissolved oxygen, specific conductivity, salinity, and oxidation-reduction potential (ORP) were also measured in each monitoring well by pumping water through a flow-through cell attached to a Hydrolab H20 Water Quality Monitor.

In addition to the monitoring performed in the nine shallow groundwater monitoring wells, monitoring was also performed in the two drainage/injection wells indicated on Figure 2-4 on a monthly basis. Separate samples were collected from the surface (0.5 m), middle (12 m), and bottom (24 m) of the two drainage wells, for a total of six samples collected from the two wells during each monthly monitoring event. Sample collection was performed using a battery-powered peristaltic pump which was attached to individual dedicated teflon tubing which extended to each of the three monitoring depths. Each of the teflon tubes were purged for approximately 10 minutes prior to collection of a sample for laboratory analyses. Collected samples were pumped through a 0.45 micron disposal groundwater filter (Geotech) and placed directly into the sample collection bottle. In addition, water from each level was also pumped through a flow-through cell attached to a Hydrolab H20 Water Quality Monitor to obtain field measurements of temperature, pH, dissolved oxygen, conductivity, salinity, and ORP.

2.2.4 Collection of Pond Surface Water

Due to the high infiltration rate of the surficial soils of both the watershed and the pond, ponded water was rarely observed within the detention pond during the weekly visits performed by ERD personnel. Sufficient surface water for collection of samples was present on only three occasions during the 16-month monitoring program. In general, pond surface water was collected from depressional areas in the pond using a portable peristaltic pump. Field measurements of pH, temperature, conductivity, dissolved oxygen, and ORP were collected by pumping water through a flow-through cell attached to a Hydrolab H20 Water Quality Monitor. Water samples were also collected and returned to the ERD Laboratory for chemical analyses.

2.2.5 Bulk Precipitation

Water quality characteristics of bulk precipitation were estimated by collection and analysis of combined wet and dry fallout. A housing was placed inside the fenced Key Colony STP compound which contained a 30 cm (12 in) diameter polyethylene collection funnel. The discharge from the funnel was attached to a length of tygon tubing which was inserted into a 4-liter sample container inside an iced-filled cooler. Combined wet and dry fallout was collected and stored inside the sample container. Bulk precipitation samples were collected on approximately a weekly basis, depending on antecedent rainfall conditions, with the old sample container replaced with a new pre-cleaned bottle during each weekly visit.

2.2.6 Sediment Collection and Analysis

Sediment sampling was conducted in both pond and control areas to evaluate the potential of the pond soils for retaining stormwater pollutants. A total of 10 separate core samples was collected within the dry detention pond, with five additional core samples collected from areas outside of the pond which are unaffected by runoff inputs or other potential pollutant sources.

All sediment core samples were collected using an aluminum split-spoon type sampler. The sediment core collector was driven a minimum of 50 cm into the soil layers and then retrieved. In general, the sediment core samples provided an intact column of soil profiles at each site. Locations of soil sampling sites are indicated on Figure 2-11.

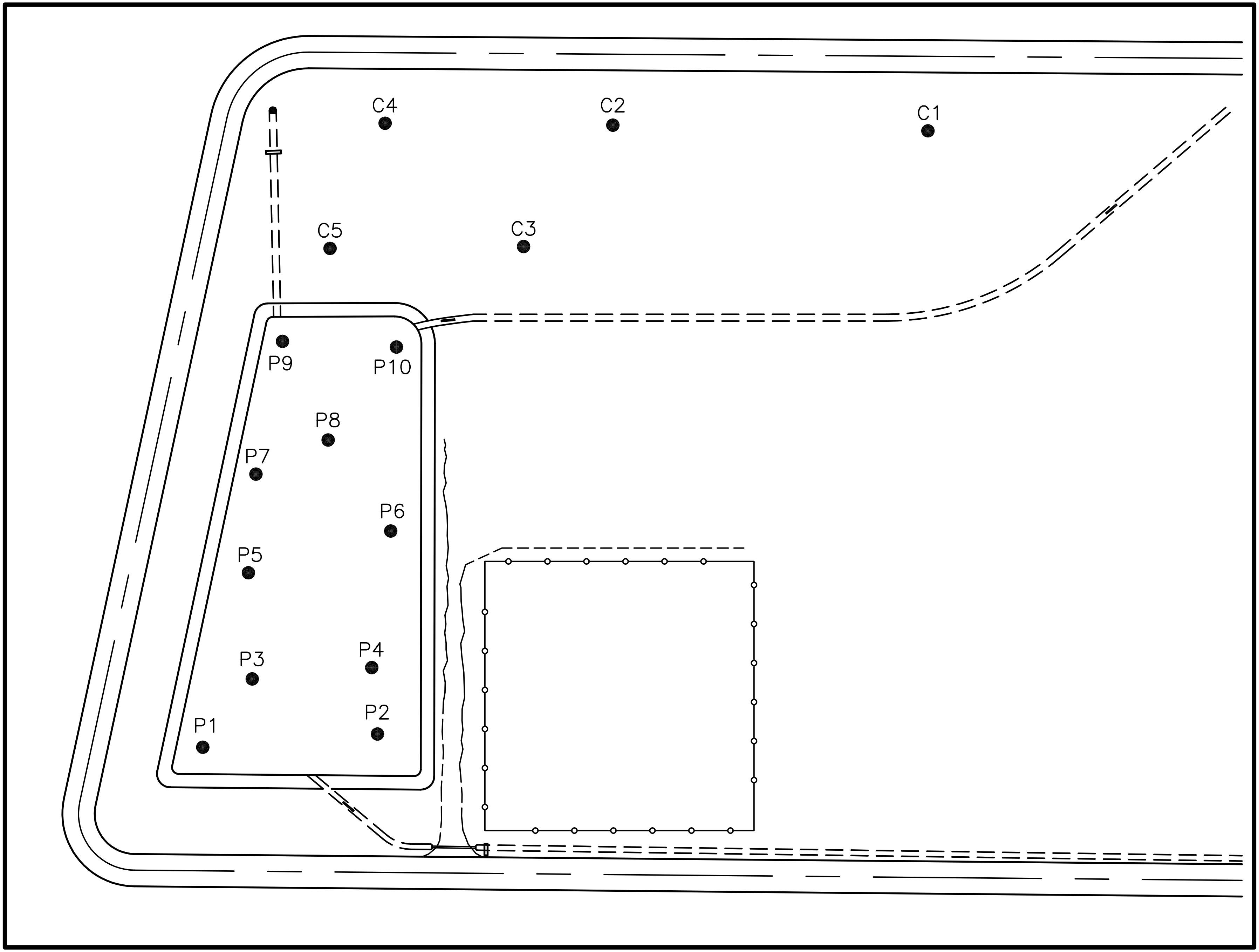


Figure 2-11. Soil Monitoring Sites for the Key Colony Detention Pond Study Site.

Duplicate core samples were collected at each site using the aluminum split-spoon core device. Following retrieval of each core sample, the sample was divided into the following four layers: 0-1 cm, 1-5 cm, 5-10 cm, and 10-25 cm. A single composite sample was formed for each depth layer at each site for both pond and control area samples, comprising a total of 60 separate soil samples submitted to the laboratory for analyses. Each of the pond and control area samples was returned to the ERD Laboratory and analyzed for the following parameters:

1. Organic Content
2. Total Phosphorus
3. Total Nitrogen
4. Total Cadmium
5. Total Chromium
6. Total Copper
7. Total Lead
8. Total Iron
9. Total Zinc
10. Total Aluminum
11. Total Manganese

In addition, composite samples of each of the four layers in both pond and control areas were submitted for analysis of particle size distribution.

2.3 Field and Laboratory Analyses

A summary of field and laboratory analyses conducted on water samples collected during this project is given in Table 2-3. Laboratory analyses performed on sediment samples are summarized in Table 2-4. Details on field operations, laboratory procedures and quality assurance methodologies are provided in the FDEP-approved Comprehensive Quality Assurance Plan No. 870322G/S for Environmental Research & Design, Inc. In addition, a Quality Assurance Project Plan, outlining the specific field and laboratory procedures to be conducted for the project efforts described in this report, was submitted for approval from FDEP prior to initiation of any field and laboratory activities.

TABLE 2-3
SUMMARY OF FIELD AND LABORATORY ANALYSES FOR WATER SAMPLES

PARAMETER	SCHEDULE OF ANALYSES					METHOD OF ANALYSIS
	RUNOFF INFLOW/ OUTFLOW	POND SURFACE WATER	BULK PRECIPITATION	SHALLOW MONITORING WELLS	INJECTION WELLS	
pH (lab/field)	lab	field	lab	field	field	EPA-83[1], Sec. 150-1
Conductivity (lab/field)	lab	field	lab	field	field	EPA-83, Sec. 120-1
Temperature (field)	-	field	-	field	field	EPA-83, Sec. 170-1
Diss. Oxygen (field)	-	field	-	field	field	SM-18[2], Sec. 421 F.
ORP (field)	-	field	-	field	field	Manf. Spec.
Alkalinity	x	x	x	x	x	EPA-83, Sec. 310.1
NH_3-N	x	x	x	x	x	EPA-83, Sec. 350.1
NO_x-N	x	x	x	x	x	EPA-83, Sec. 353.3
Dissolved Organic N	x	x	x	x	x	Alk. Persulfate[3]
Particulate N	x	x	x	x	x	Alk. Persulfate[3]
Total N	x	x	x	x	x	Alk. Persulfate[3]
Orthophosphorus	x	x	x	x	x	EPA-83, Sec. 365.1
Particulate P	x	x	x	x	x	Alk. Persulfate[4]
Total P	x	x	x	x	x	Alk. Persulfate[4]
Turbidity	x	x	x	--	--	EPA-83, Sec. 180.1
Chloride	x	x	x	x	x	EPA-83, Sec. 325.3
TSS	x	x	x	--	--	EPA-83, Sec. 160.2
BOD	x	x	x	x	x	SM-18, Sec. 5210 B.
Fecal Coliform	x	x	--	x	x	SM-18, Sec. 9222 D.
Cadmium (Total/Diss.)	x	x	Total	Total	Total	EPA-83, Sec. 213.1
Chromium (Total/Diss.)	x	x	Total	Total	Total	EPA-83, Sec. 218.1
Copper (Total/Diss.)	x	x	Total	Total	Total	EPA-83, Sec. 220.1
Lead (Total/Diss.)	x	x	Total	Total	Total	EPA-83, Sec. 239.1
Iron (Total/Diss.)	x	x	Total	Total	Total	EPA-83, Sec. 236.1
Zinc (Total/Diss.)	x	x	Total	Total	Total	EPA-83, Sec. 289.1

1. Methods for Chemical Analysis of Water and Wastes, EPA 600/4-79-020, Revised March 1983.
2. Standard Methods for the Examination of Water and Wastewater, 18th Ed., 1992.
3. Alkaline Persulfate Digestion: FDEP-approved alternate method for determination of TKN
4. Alkaline Persulfate Digestion: FDEP-approved alternate method for determination of Total P
5. Method 1664: N-Hexane Extractable Material (HEM) and Silica Gel Treated N-Hexane Extractable Material (SGT-HEM) by Extraction and Gravimetry (Oil and Grease and Total Petroleum Hydrocarbons), EPA-821-B-94-004b, April 1995.

TABLE 2-4

SUMMARY OF LABORATORY ANALYSES FOR SEDIMENT SAMPLES

PARAMETER	SAMPLES ANALYZED	METHOD OF ANALYSIS
Moisture Content	all	EPA/CE-81-1[1]; p. 3-54, p. 3-58
Organic Content	all	EPA/CE-81-1; pp. 3-59 and 3-60
Total P	all	EPA-83[2], Sec. 365.4
Total N	all	EPA/CE-81-1; p. 3-205
Cadmium	all	EPA[3] 7130
Chromium	all	EPA 7190
Copper	all	EPA 7210
Lead	all	EPA 7420
Iron	all	EPA 7380
Zinc	all	EPA 7950
Aluminum	all	EPA 7020
Manganese	all	EPA 7400
Particle Size	Composite Samples	EPA/CE-81-1; pp. 3-33 to 3-47

1. Procedures for Handling and Chemical Analysis of Sediments and Water Samples, EPA/Corps of Engineers, EPA/CE-81-1, 1981.

2. Methods for Chemical Analysis of Water and Wastes, EPA/4-79-020, Revised March 1983.

3. Best Methods for Evaluating Solid Wastes, Physical-Chemical Methods, 3rd Ed., EPA-SW-846, Updated November 1990.

2.4 Statistical Treatment of Data

A large number of statistical analyses were conducted during analysis of the experimental results from this project. All statistical procedures were performed using the Statistical Analysis System (SAS) and included PROC CORR for calculation of Pearson product-moment correlation coefficients; PROC PLOT to produce scatter diagrams of the values of one variable against the values of another variable for examination of relationships and functional forms; PROC MEANS to obtain simple univariate descriptive statistics such as means, standard deviation, minimum and maximum values; PROC UNIVARIATE to evaluate data distribution and to test for normality;

PROC GLM for analysis of variance procedures for unbalanced data sets; and PROC REG for regression analyses to provide least-square estimates to various linear regression models. All data sets were initially tested for normality of data distribution by examination of residuals. Some data sets required a log transformation to obtain a normally distributed probability distribution function. Subsequent statistical analyses were conducted using transformed data sets where appropriate.

Statistical analyses were conducted on data sets using the number of significant figures indicated in the raw data contained in the Appendices. Data indicated as less than the detection limit for a particular variable was entered into the data set as one-half of the detection limit presented.

SECTION 3

RESULTS

Field monitoring, sample collection, and laboratory analyses for stormwater, pond outflow, surface water, bulk precipitation, and groundwater were conducted at the Key Colony site over a 16-month period from July 2001-October 2002. A discussion of the results of these tasks is given in the following sections.

3.1 Site Hydrology

As discussed in Section 2, a wide range of hydrologic information was collected at the Key Colony site. This information is used to: (1) provide hydrologic characteristics of rain events used for characterization of stormwater runoff; (2) evaluate the hydraulic response of the pond to inputs of stormwater runoff; (3) assist in development of hydrologic and mass balance budgets for the pond site; and (4) evaluate the direction of shallow groundwater movement at the pond site.

3.1.1 Rainfall Characteristics

A continuous record of rainfall characteristics was collected at the Key Colony project site from July 18, 2001-October 31, 2002 using a tipping-bucket rainfall collector with a resolution of 0.03 cm (0.01 in) and a digital logging data recorder. Characteristics of individual rain events measured at the project site are given in Appendix A. A continuous record of rainfall characteristics was maintained throughout the entire study period. For each individual rain event, information is included for event start time, event end time, total rainfall, event duration, antecedent dry period, and average rainfall intensity. Average rainfall intensity is calculated as the total rainfall divided by the total event duration. For purposes of this analysis, periods of rainfall separated by a dry period of 3 hours or more are considered to be separate rain events.

A summary of rainfall characteristics measured at the Key Colony site from July 2001-October 2002 is given in Table 3-1. Total event rainfall ranged from 0.03-9.35 cm (0.01-3.68 in), with a mean of 0.79 cm (0.31 in) per rain event. A total of 160.2 cm (63.07 in) of rainfall was measured at the site during the 16-month monitoring period. Event durations ranged from 0.02-32.05 hours, with a mean event duration of 2.49 hours. Antecedent dry period ranged from 0.13-34.23 days, with a mean of 2.23 days.

TABLE 3-1

SUMMARY OF RAINFALL CHARACTERISTICS MEASURED AT THE KEY COLONY SITE FROM JULY 2001-OCTOBER 2002

PARAMETER	UNITS	MINIMUM VALUE	MAXIMUM VALUE	MEAN VALUE
Total Rainfall	cm in	0.03 0.01	9.35 3.68	0.80 0.31
Event Duration	hr	0.02	32.05	2.49
Average Intensity	cm/hr in/hr	0.03 0.01	9.13 3.59	0.66 0.26
Antecedent Dry Period	days	0.13	34.23	2.23

3.1.2 Fluctuations in Site Piezometric Elevations

Piezometric surface elevations in the pond were measured on a continuous basis from September 2001-October 2002 using a water level pressure transducer with digital data logger, manufactured by Global Water. Relationships between rainfall and pond piezometric surface elevations at the project site are illustrated in Figure 3-1. Several periods of missing piezometric data are present in Figure 3-1 due to equipment disturbance during pond maintenance activities, along with several instances of equipment malfunction.

In general, piezometric elevations respond rapidly to rain events, with a rapid increase in piezometric surface. Drawdown of the piezometric surface following rain events also occurrs rapidly, although less rapidly than the initial increase in elevation. Measured minimum, maximum, and average piezometric levels during the project period are summarized in Table 3-2. Piezometric elevations within the pond exceeded the minimum pond ground level of 2.05 ft (NGVD) on only 11 occasions during periods for which piezometric data is available. During prolonged periods with little or no rainfall, pond piezometric elevations decreased substantially, approaching elevations less than 0.5 ft (NGVD). These minimum piezometric elevations are approximately 0.5 m (1.5 ft) lower than the minimum ground surface elevation of the pond. A majority of the rainfall events at the project site resulted in maximum piezometric elevations which were less than the average ground level within the pond.

The minimum piezometric elevation measured during the study period is 0.07 ft (NGVD). The maximum elevation of 3.09 ft (NGVD) measured at the site occurred following a 7.92 cm (3.12 in) rain event during September 2001. The water level achieved during this event exceeded the top-of-bank in several areas of the pond. The average piezometric level of 0.95 ft (NGVD) measured during the study period is approximately 0.3 m (1.1 ft) lower than the ground elevation of the pond.

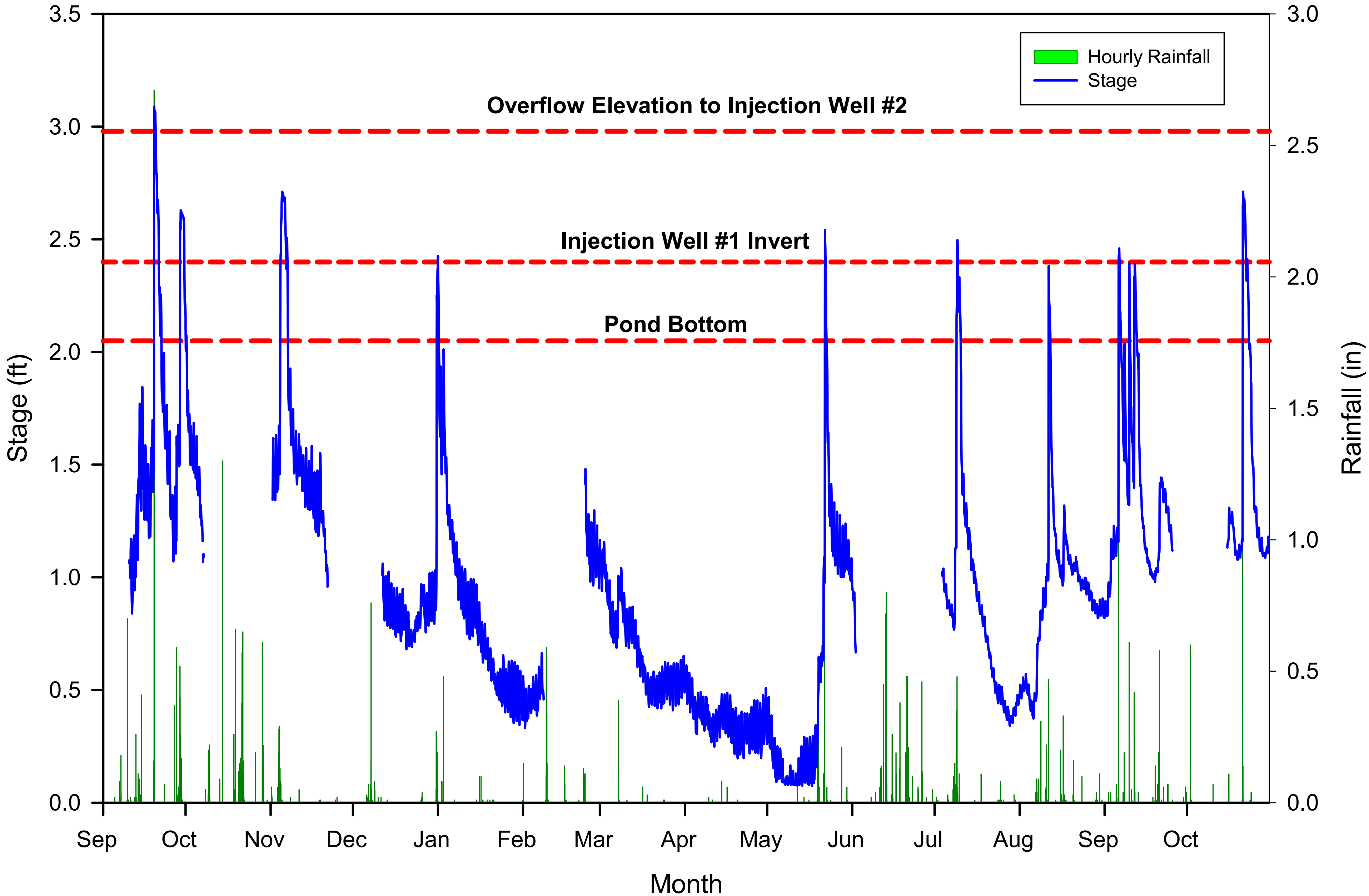


Figure 3-1. Relationship Between Rainfall and Pond Stage at the Key Colony Detention Pond Site.

TABLE 3-2

SUMMARY OF POND PIEZOMETRIC LEVELS AT THE KEY COLONY PROJECT SITE

PARAMETER	ELEVATION (ft, NGVD)
Measured Minimum Piezometric Elevation	0.07
Measured Maximum Piezometric Elevation	3.09
Mean Piezometric Elevation	0.95
Injection Well #1 Invert	2.40
Injection Well #2 Invert	2.98[1]

1. Invert of high spot in swale leading to Injection Well #2

Changes in piezometric elevations within the dry detention pond are provided in Figure 3-2 for 11 selected rain events with rainfall amounts ranging from 1.63-7.92 cm (0.64-3.12 in). Piezometric elevations are provided for a period of approximately 200 hours following initiation of the storm event. Prior to each of the storm events, the piezometric elevation within the pond was approximately 0.3-0.5 m (1-1.5 ft) below the ground surface elevation of the pond. Piezometric elevations within the pond responded rapidly to each storm event as rainfall initially fills the pore spaces within the soils beneath the pond. When the piezometric elevation reaches 2.05 ft, water begins to pond within the detention pond.

After reaching the peak elevation associated with each storm event, piezometric elevations within the pond begin to decline rapidly, with similar drawdown characteristics for each of the events summarized in Figure 3-2. When the piezometric levels exceeded an elevation of 2.40 ft (NGVD), the invert elevation for injection well #1, runoff into the pond was evacuated by a combination of infiltration through the pond bottom and discharges into injection well #1. When the piezometric surface dropped below an elevation of 2.40 ft (NGVD), drawdown occurred only as a result of infiltration through the pond bottom. After approaching a piezometric elevation of approximately 1.50 ft, the rate of drawdown appears to decrease rapidly as each of the drawdown curves begin to converge at an elevation of approximately 1.1-1.25 ft.

As the drawdown curve begins to recede below the ground level, the curves begin to exhibit a sinusoidal pattern, with alternating peaks and valleys, while still progressing in a general downward direction. As seen in Figure 3-2, these sinusoidal patterns appear to occur in approximately 12-24 hour intervals, suggesting that drawdown characteristics beneath the pond are impacted by tidal conditions in the adjacent marine waters. The fact that piezometric elevations actually increase periodically throughout the sinusoidal events suggests that marine water is moving freely through the porous sub-soil layers, causing the groundwater to rise and fall with the tides. This type of drawdown behavior suggests an extremely porous connection between the adjacent marine waters and areas beneath the pond.

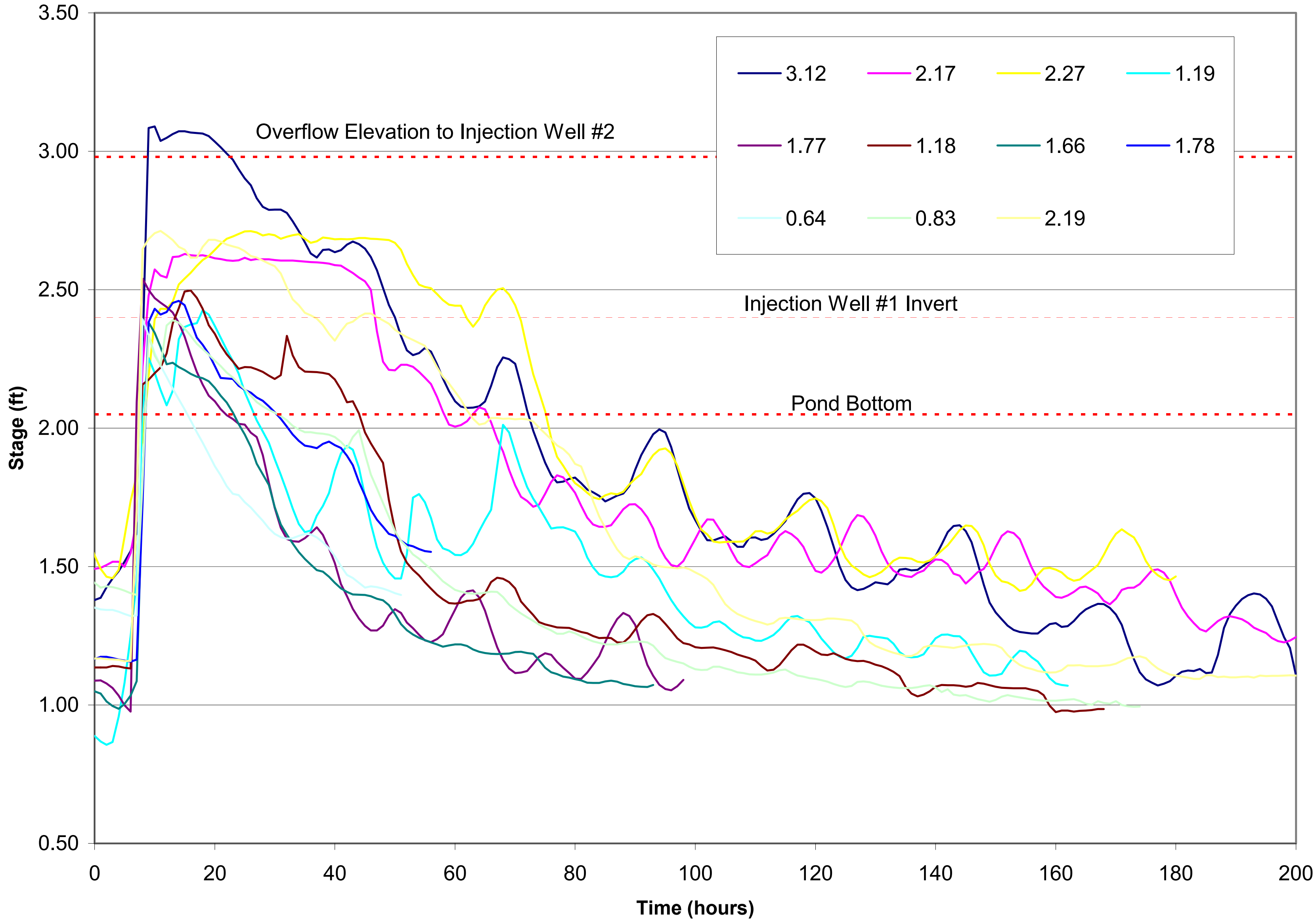


Figure 3-2. Drawdown Characteristics for Selected Storm Events at the Key Colony Detention Pond.

Relationships between rainfall and pond stage during January 2002 are given in Figure 3-3. The total rainfall at the site during January was only 1.85 cm (0.73 in), and no measurable runoff inputs were recorded entering the pond. The daily cyclic pattern of rise and fall in piezometric elevation is clearly visible in the recorded data.

The rate of drawdown was evaluated for each of the storm events summarized in Figure 3-2 by calculating the slope of the drawdown curve exhibited by each rain event after the pond had reached its peak elevation. The slope of each drawdown curve was calculated by examining the rate of change over the initial 48-hour period following initiation of the drawdown curve for each event. A summary of calculated drawdown rates for the evaluated storm events is given in Table 3-3. Drawdown rates are relatively constant for each of the 11 evaluated storm events, ranging from 0.33-0.89 cm/hr (0.13-0.35 in/hr), with a mean drawdown rate of 0.61 cm/hr (0.24 in/hr). Based upon these mean drawdown rates, a decrease in piezometric surface of 0.3 m (1 ft) would require approximately 50 hours to accomplish. It should be noted that the drawdown rates summarized in Table 3-3 reflect drawdown which occurs primarily as a result of lateral groundwater migration after the surficial soil layers have become saturated. Movement of water through the unsaturated layers is substantially more rapid than the values listed in Table 3-3.

TABLE 3-3

CALCULATED DRAWDOWN RATES FOR SELECTED STORM EVENTS AT THE KEY COLONY POND SITE

RAIN EVENT DATE	RAINFALL AMOUNT		DRAWDOWN RATE	
	(cm)	(in)	(cm/hr)	(in/hr)
9/19/01	7.92	3.12	0.66	0.26
9/28/01	5.51	2.17	0.48	0.19
11/3/01	5.77	2.27	0.53	0.21
12/31/01	3.02	1.19	0.41	0.16
5/21/02	4.50	1.77	0.89	0.35
7/8/02	3.00	1.18	0.76	0.30
8/11/02	4.22	1.66	0.79	0.31
9/6/02	4.52	1.78	0.61	0.24
9/9/02	1.63	0.64	0.64	0.25
9/11/02	2.11	0.83	0.61	0.24
10/21/02	5.56	2.19	0.33	0.13
		Mean:	0.61	0.24

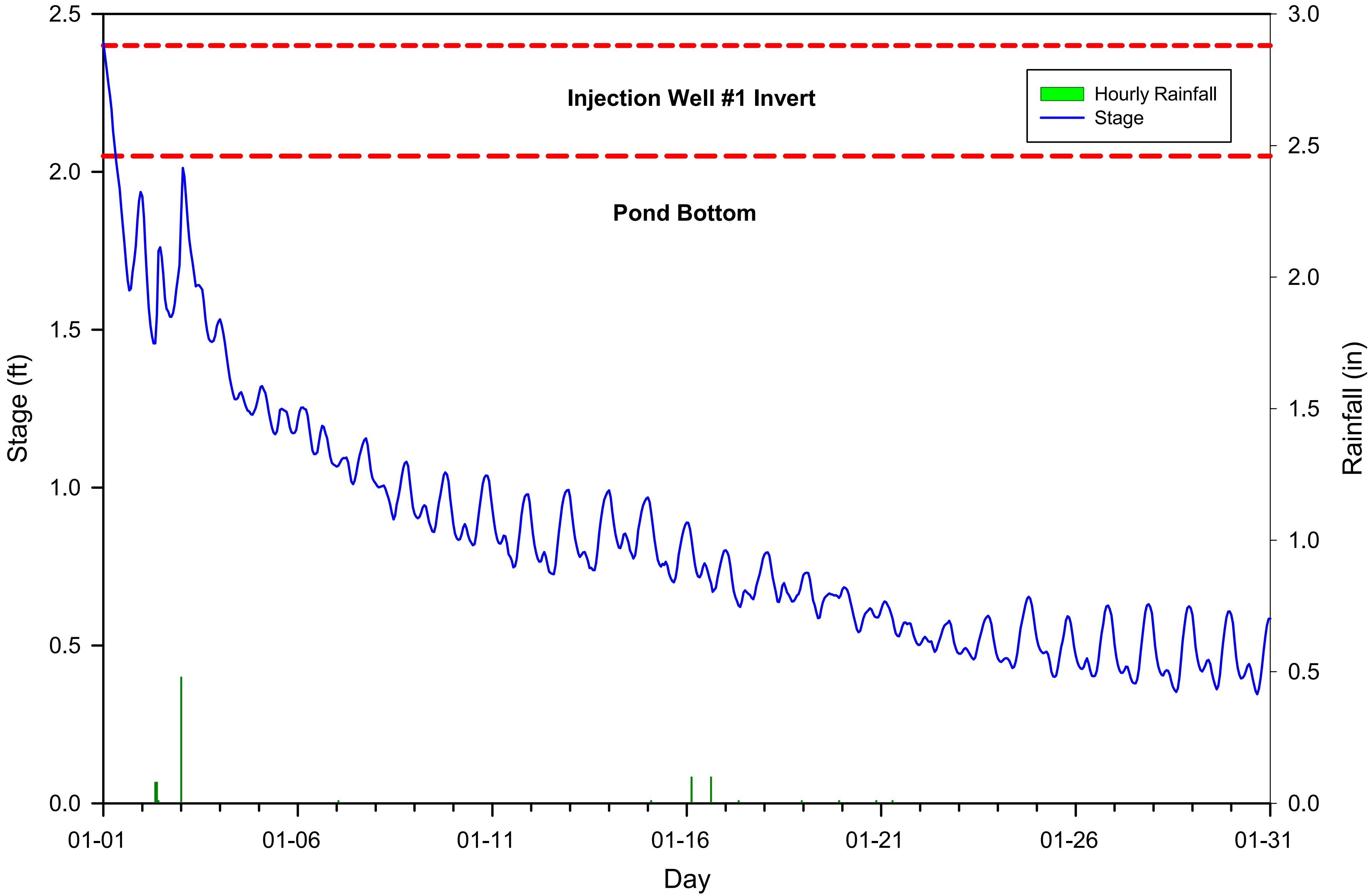


Figure 3-3. Relationship Between Rainfall and Pond Stage at the Key Colony Site during January 2002.

The rain events illustrated in Figure 3-2 represent the most significant rain events observed during the 16-month study period. As seen in Figure 3-2, eight of the 11 evaluated events resulted in piezometric elevations which exceeded the minimum ground elevation of the pond. These events constitute the only periods of time during which significant standing water was present within the pond. Approximately half of the runoff events which created standing water within the pond were evacuated from the pond in less than 20 hours. The remaining events required approximately 40-70 hours to remove the stored water within the pond. As a result, standing water was rarely present within the pond, and when present, existed for periods of less than 2-3 days.

A listing of individual groundwater piezometric elevations measured at the Key Colony project site from July 2001-October 2002 is given in Appendix B for piezometers located at the pond, adjacent, and control sites. A total of 31 separate piezometric measurements were performed at each of the nine monitoring sites. Mean piezometric elevations measured at each of the nine monitoring sites are given in Table 3-4. In general, mean piezometric elevations measured within the pond appear to be greater than mean piezometric elevations measured in the adjacent and control areas. Mean pond piezometric elevations vary by approximately 0.07 m (0.23 ft) throughout the pond, with the highest piezometric elevations measured in piezometer P-2, located adjacent to the Key Colony STP. The greatest mean piezometric elevations in the adjacent piezometers were observed in piezometer A-3 which is also adjacent to the Key Colony STP. Mean piezometric elevations measured in the control piezometer designated as C-1 are similar to elevations measured at the adjacent piezometric sites. However, substantially lower mean piezometric elevations were observed in piezometer C-2 which is located adjacent to upstream portions of the southeastern inflow swale.

TABLE 3-4

MEAN PIEZOMETRIC ELEVATIONS MEASURED AT POND, ADJACENT, AND CONTROL SITES

PIEZOMETER TYPE	PIEZOMETER SITE	MEAN ELEVATION (ft, NGVD)
Pond	P-1	1.12
	P-2	1.23
	P-3	1.00
Adjacent	A-1	1.01
	A-2	0.99
	A-3	1.07
	A-4	0.93
Control	C-1	1.01
	C-2	0.69

A graphical comparison of mean piezometric elevations in pond, adjacent, and control areas at the dry detention site from July 2001-October 2002 is given in Figure 3-4. Piezometric elevations presented on this table reflect the mean of all measurements performed in pond, adjacent, and control areas on each individual monitoring date. In general, piezometric elevations within the pond appear to be greater than elevations measured in adjacent or control areas. This suggests that the primary direction of lateral water movement at the study site is from the detention pond into the adjacent groundwater areas. Significant lateral influx of groundwater into the pond from other areas does not appear to occur at the dry detention site.

3.1.3 Estimates of Site Evaporation

As discussed in Section 2, a Class A pan evaporimeter was installed on a level wooden platform located inside the fenced compound of the Key Colony STP. Information from the evaporimeter was retrieved on each of the visits to the project site. A complete listing of evaporative losses measured during each monitoring period is given in Appendix C. Mean daily evaporative losses measured at the project site are summarized in Figure 3-5 on a monthly basis. Mean daily evaporative losses at the site ranged from a high of 0.61 cm/day in July to a low of 0.20 cm/day during January, June, and December.

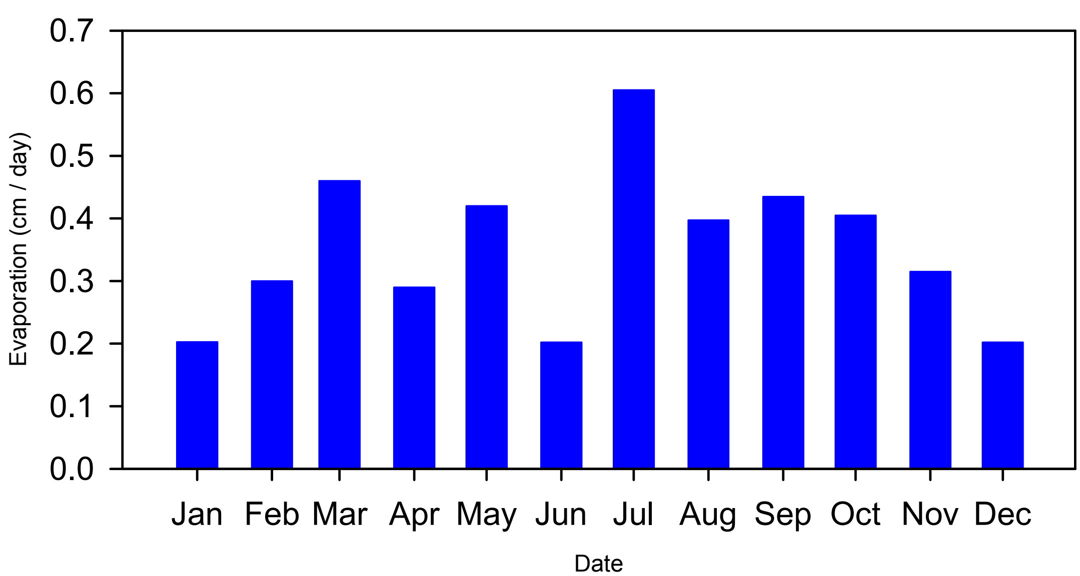


Figure 3-5. Mean Monthly Evaporation Rates at the Key Colony Detention Pond Site.

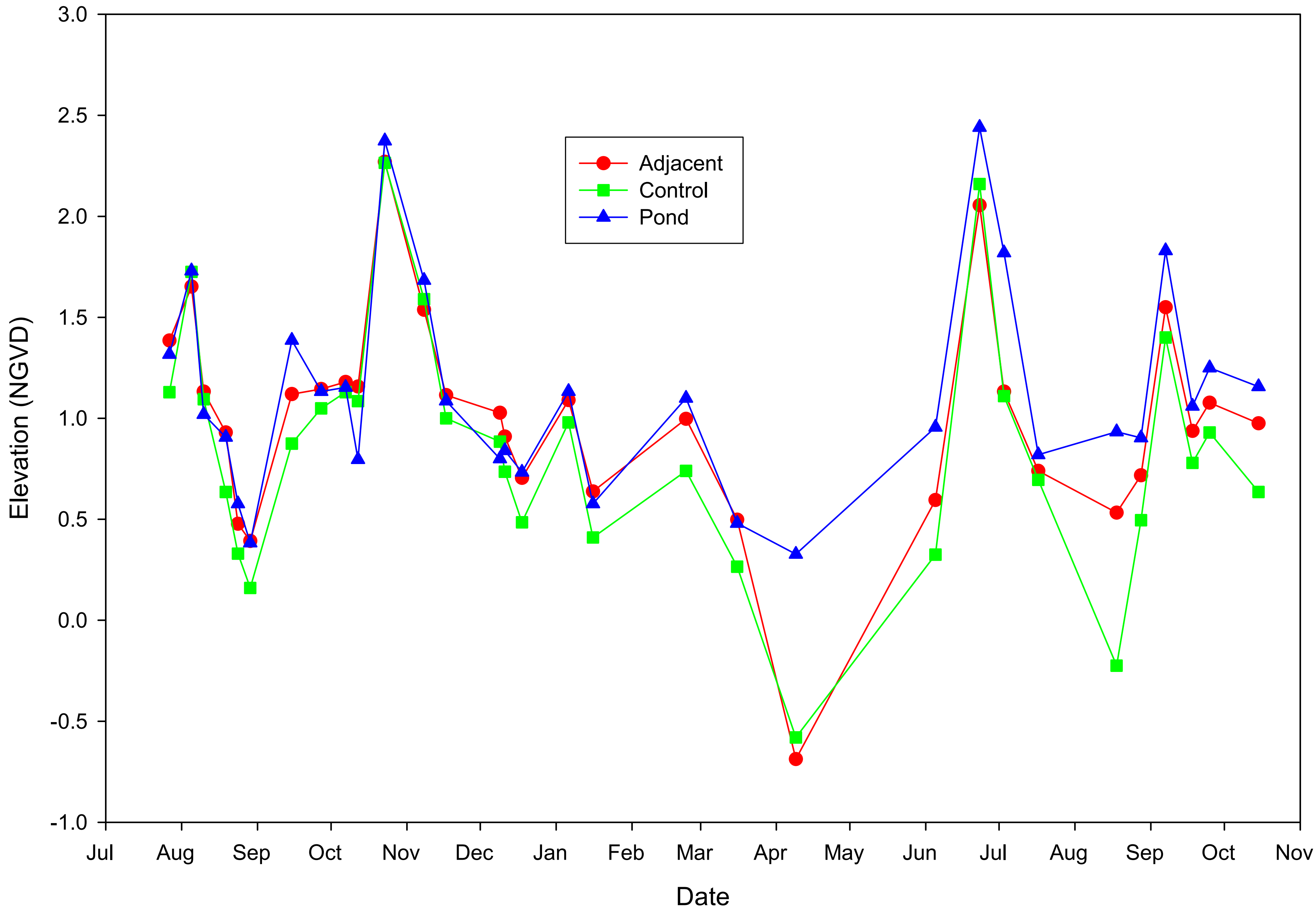


Figure 3-4. Comparison of Mean Piezometric Levels in Pond, Adjacent, and Control Areas at the Key Colony Site from July 2001 to October 2002.

Although evaporation was measured on a continuous basis as part of this project, it does not appear that evaporation is a significant component of the hydrologic budget for this site. Evaporation losses can only occur when standing water is present within the pond. As indicated on Figure 3-2, areas of standing water were only present on 11 separate occasions during the 16-month monitoring period. These areas of standing water were evacuated rapidly from the pond, with standing water present from periods ranging from 10-70 hours. The maximum evaporation rates indicated on Figure 3-5 are approximately 25 times less than the mean drawdown rates from groundwater infiltration and discharge through the drainage well structure indicated on Table 3-3. In addition, as the pond draws down, the area of standing water becomes smaller, further reducing the surface area available for evaporation. As a result, evaporative losses are assumed to be negligible at the pond site and are not included as part of the hydrologic budget developed for this project. The evaporation data presented in Appendix C and in Figure 3-5 are provided for information purposes only.

3.1.4 <u>Stormwater Inputs</u>

As described in Section 2, continuous inflow hydrographs were recorded at each of the three inflow monitoring sites indicated on Figure 2-4. Hydrograph information was recorded at 10-minute intervals at each of the three sites from July 18, 2001-October 31, 2002. The continuous inflow hydrographs provided information on total daily volume and cumulative total volume for the period of record. No baseflow was recorded at any of the three inflow monitoring sites during the 16-month study period.

A summary of total monthly hydrologic inputs measured at the three inflow sites from August 2001-October 2002 is given in Table 3-5. Inputs measured during July 2001 are not included in this summary since monitoring was performed only for a portion of the month. Direct runoff inputs into the pond occurred at the monitoring sites indicated as Inflow 1 and Inflow 2. Of these two sites, the largest volumetric inflow was contributed by Inflow 2, which enters at the southeastern corner of the pond. Direct inputs at Inflow 2 contributed approximately 14,997 m^3 (529,591 ft^3) which comprises 80% of the total direct runoff inputs into the pond.

Approximately two-thirds of the overall runoff inputs into the pond occurred during the period from August-December 2001. No measurable inputs of stormwater runoff were recorded at any of the three monitoring sites during the period from January-April 2002. The remaining one-third of the measured runoff inputs occurred from May-October 2002.

As indicated on Figures 2-1 and 2-4, the site designated as Inflow 3 was located approximately 180 m (600 ft) upstream of Inflow 2. As seen in Table 3-5, larger total inflow volumes were observed at Inflow 3, compared with inputs measured at Inflow 2, during nine of the 11 months for which measurable runoff was recorded, suggesting infiltration losses through the swale system during migration from Inflow 3 to Inflow 2. However, during two of the 11 months for which measurable runoff was recorded, a higher runoff volume as observed at Inflow 2, suggesting additional hydrologic inputs into the swale system between the two monitoring sites. Over the 16-month monitoring period, approximately 14,997 m^3 (529,591 ft^3) were measured at Inflow 2 compared with 15,547 m^3 (549,029 ft^3) measured at Inflow 3. The total runoff volume measured at Inflow 2 represents about 96% of the total runoff inflow measured at Inflow 3, suggesting a net loss of approximately 4% of the total runoff inputs within the swale system during migration from Inflow 3 to Inflow 2.

TABLE 3-5

SUMMARY OF TOTAL MONTHLY HYDROLOGIC INPUTS MEASURED AT THE KEY COLONY SITE FROM AUGUST 2001-OCTOBER 2002

MONTH	MONTHLY RAINFALL		MEASURED DISCHARGE					
			INFLOW 1		INFLOW 2		INFLOW 3	
	(cm)	(in)	(m^3)	(ft^3)	(m^3)	(ft^3)	(m^3)	(ft^3)
August	14.76	5.81	537	18,957	2,766	97,667	2,722	96,114
September	21.72	8.55	359	12,694	1,405	49,612	1,579	55,771
October	20.29	7.99	618	21,822	3,951	139,518	4,411	155,787
November	6.27	2.47	466	16,459	1,169	41,287	1,142	40,320
December	7.62	3.00	134	4,721	319	11,259	321	11,340
January	1.85	0.73	0	0	0	0	0	0
February	8.76	3.45	0	0	0	0	0	0
March	1.88	0.74	0	0	0	0	0	0
April	0.56	0.22	0	0	0	0	0	0
May	8.92	3.51	148	5,227	283	9,987	299	10,564
June	23.72	9.34	906	31,990	3,862	136,391	3,741	132,110
July	5.46	2.15	95	3,371	204	7,210	252	8,911
August	10.31	4.06	56	1,972	241	8,510	300	10,585
September	13.44	5.29	81	2,850	155	5,490	204	7,198
October	8.13	3.20	299	10,561	642	22,660	576	20,329
TOTALS:	**153.70**	**60.51**	**3,699**	**130,624**	**14,997**	**529,591**	**15,547**	**549,029**

A summary of rainfall-runoff relationships at the Key Colony detention pond site from August 2001-October 2002 is given in Table 3-6. Total monthly rainfall depth measured during each month of the monitoring program is given in both centimeters and inches. The total basin rainfall volume is calculated as the total monthly rainfall times the estimated watershed area of 9.86 ha (24.34 ac). This volume represents the total rainfall amount which fell within the watershed during each month of the monitoring program. Next, measured stormwater volumes entering the pond at Inflow 1 and Inflow 2 combined are indicated in units of m^3 and ft^3. Finally, an average runoff coefficient (C value) is calculated for each month by dividing the measured stormwater input volumes by the total rainfall volume which fell within the watershed.

TABLE 3-6

SUMMARY OF RAINFALL-RUNOFF RELATIONSHIP AT THE KEY COLONY SITE FROM AUGUST 2001-OCTOBER 2002

MONTH	TOTAL RAINFALL		TOTAL BASIN RAINFALL VOLUME		STORMWATER RUNOFF[1]		AVERAGE "C" VALUE
	(cm)	(in)	(m^3)	(ft^3)	(m^3)	(ft^3)	
August	14.76	5.81	14,536	513,338	3,302	116,624	0.227
September	21.72	8.55	21,391	755,428	1,764	62,306	0.082
October	20.29	7.99	19,990	705,950	4,569	161,340	0.229
November	6.27	2.47	6,180	218,235	1,635	57,746	0.265
December	7.62	3.00	7,506	265,063	453	15,980	0.060
January	1.85	0.73	1,826	64,499	0	0	0.000
February	8.76	3.45	8,632	304,822	0	0	0.000
March	1.88	0.74	1,851	65,382	0	0	0.000
April	0.56	0.22	550	19,438	0	0	0.000
May	8.92	3.51	8,782	310,123	431	15,214	0.049
June	23.72	9.34	23,368	825,228	4,768	168,381	0.204
July	5.46	2.15	5,379	189,962	300	10,581	0.056
August	10.31	4.06	10,158	358,718	297	10,482	0.029
September	13.44	5.29	13,235	467,394	236	8,340	0.018
October	8.13	3.20	8,006	282,733	941	33,221	0.117
TOTALS:	**153.70**	**60.51**	**151,391**	**5,346,313**	**18,695**	**660,215**	**0.123**

1. Sum of Inflow 1 and Inflow 2

Calculated runoff coefficients at the Key Colony project site range from a low of 0.000, during the period from January-April 2002 when no measurable runoff was observed at the site, to a high of 0.265 during November 2001. In general, calculated runoff coefficients at the Key Colony site are impacted more by rainfall depths occurring during individual events than by the total rainfall observed during a given month. As indicated previously, rainfall amounts in excess of approximately 2.5 cm (1 in) are required to generate measurable runoff at the site, depending upon antecedent moisture conditions. Therefore, during a month when all recorded rain events are substantially less than 1 inch, the calculated runoff coefficient for the site would be 0.00 since no runoff would be generated in spite of potentially high total monthly rainfall. In contrast, a month with only a few large storm events may generate a relatively high C value at the site in spite of a low total monthly rainfall depth.

3.1.5 Injection Well Losses

Continuous hydrographs of discharges from the dry detention pond to Injection Wells 1 and 2 were collected from mid-July 2001 to October 2002. Hydrograph measurements were recorded at 10-minute intervals at each of the two monitoring sites and contained information on total daily volume and cumulative total volume over the period of record.

A summary of measured total monthly discharges to the injection wells at the Key Colony detention pond site from August 2001-October 2002 is given in Table 3-7. Information for July 2001 is not included in Table 3-7 since data was collected for only a portion of the month.

Approximately 93% of the total discharges from the pond into injection wells occurred at Injection Well 1. As discussed in Section 2, the invert of the inlet structure for Injection Well 1 is 2.40 ft (NGVD). Due to a raised area in the swale leading to Injection Well 2, water within the pond must first reach an elevation of approximately 2.98 ft (NGVD) before discharges can begin occurring from the pond into the swale system leading to Injection Well 2. Therefore, overflow into Injection Well 2 can only occur during relatively extreme events at the site. Relationships between pond stage and the relative inverts for Injection Wells 1 and 2 is given in Figure 3-1. Measurable discharges to Injection Well 1 occurred during 10 of the 11 months for which measurable runoff inputs entered the pond system. However, discharges to Injection Well 2 were observed during only two of the 11 months for which pond inputs were recorded.

TABLE 3-7

SUMMARY OF TOTAL MONTHLY DISCHARGES TO THE INJECTION WELLS AT THE KEY COLONY SITE FROM AUGUST 2001-OCTOBER 2002

MONTH	MONTHLY RAINFALL		MEASURED DISCHARGE			
			INJECTION WELL 1		INJECTION WELL 2	
	(cm)	(in)	(m^3)	(ft^3)	(m^3)	(ft^3)
August	14.76	5.81	2,502	88,252	264	9,311
September	21.72	8.55	831	29,340	0	0
October	20.29	7.99	2,634	92,947	287	10,116
November	6.27	2.47	988	34,861	0	0
December	7.62	3.00	343	12,120	0	0
January	1.85	0.73	0	0	0	0
February	8.76	3.45	0	0	0	0
March	1.88	0.74	0	0	0	0
April	0.56	0.22	0	0	0	0
May	8.92	3.51	361	12,752	0	0
June	23.72	9.34	3,740	131,973	374	13,197
July	5.46	2.15	169	5,980	0	0
August	10.31	4.06	0	0	0	0
September	13.44	5.29	304	10,710	0	0
October	8.13	3.20	640	22,569	0	0
TOTALS:	**153.70**	**60.51**	**12,512**	**441,534**	**925**	**32,624**

3.1.6 Pond Hydrologic Budget

A monthly hydrologic budget for the Key Colony retention/detention pond is given in Table 3-8. Inputs into the pond are summarized for direct precipitation and stormwater runoff entering through Inflow 1 and Inflow 2. Based on the relative groundwater piezometric elevations in pond, adjacent, and control areas presented in Section 3.1.2, it is assumed that lateral inflow into the pond from groundwater is negligible.

TABLE 3-8

HYDROLOGIC BUDGET FOR THE KEY COLONY SITE FROM AUGUST 2001-OCTOBER 2002

MONTH	RAINFALL		POND INPUTS						POND OUTPUTS					
			Direct Precipitation		Inflow 1		Inflow 2		Outflow 1		Outflow 2		Groundwater	
	(cm)	(in)	(m^3)	(ft^3)	(m^3)	(ft^3)	(m^3)	(ft^3)	(m^3)	(ft^3)	(m^3)	(ft^3)	(m^3)	(ft^3)
August	14.76	5.81	866	30,581	537	18,957	2,766	97,667	2,500	88,282	264	9,311	1,405	49,612
September	21.72	8.55	1,274	45,003	359	12,694	1,405	49,612	831	29,340	0	0	2,208	77,969
October	20.29	7.99	1,191	42,055	618	21,822	3,951	139,518	2,632	92,947	286	10,116	2,841	100,332
November	6.27	2.47	368	13,001	466	16,459	1,169	41,287	987	34,861	0	0	1,016	35,886
December	7.62	3.00	447	15,791	134	4,721	319	11,259	343	12,120	0	0	556	19,651
January	1.85	0.73	109	3,842	0	0	0	0	0	0	0	0	109	3,842
February	8.76	3.45	514	18,159	0	0	0	0	0	0	0	0	514	18,159
March	1.88	0.74	110	3,895	0	0	0	0	0	0	0	0	110	3,895
April	0.56	0.22	33	1,158	0	0	0	0	0	0	0	0	33	1,158
May	8.92	3.51	523	18,475	148	5,227	283	9,987	361	12,752	0	0	593	20,937
June	23.72	9.34	1,392	49,161	906	31,990	3,862	136,391	3,737	131,973	374	13,197	2,049	72,372
July	5.46	2.15	320	11,317	95	3,371	204	7,210	169	5,980	0	0	451	15,918
August	10.31	4.06	605	21,370	56	1,972	241	8,510	0	0	0	0	902	31,852
September	13.44	5.29	788	27,844	81	2,850	155	5,490	303	10,710	0	0	721	25,474
October	8.13	3.20	477	16,843	299	10,561	642	22,660	639	22,569	0	0	779	27,495
TOTAL:	**153.70**	**60.51**	**9,019**	**318,495**	**3,699**	**130,624**	**14,996**	**529,591**	**12,503**	**441,534**	**924**	**32,624**	**14,287**	**504,552**

Outputs from the pond include discharges through Injection Wells 1 and 2 plus losses due to seepage into the surficial groundwater table. As discussed in Section 3.1.3, estimates of losses due to evaporation are assumed to be negligible since standing water was present within the pond for only short periods of time. Losses due to groundwater infiltration were determined as the difference between measured inputs and outputs, according to the following relationship:

Groundwater Loss = Rainfall + Stormwater - Injection Well Losses

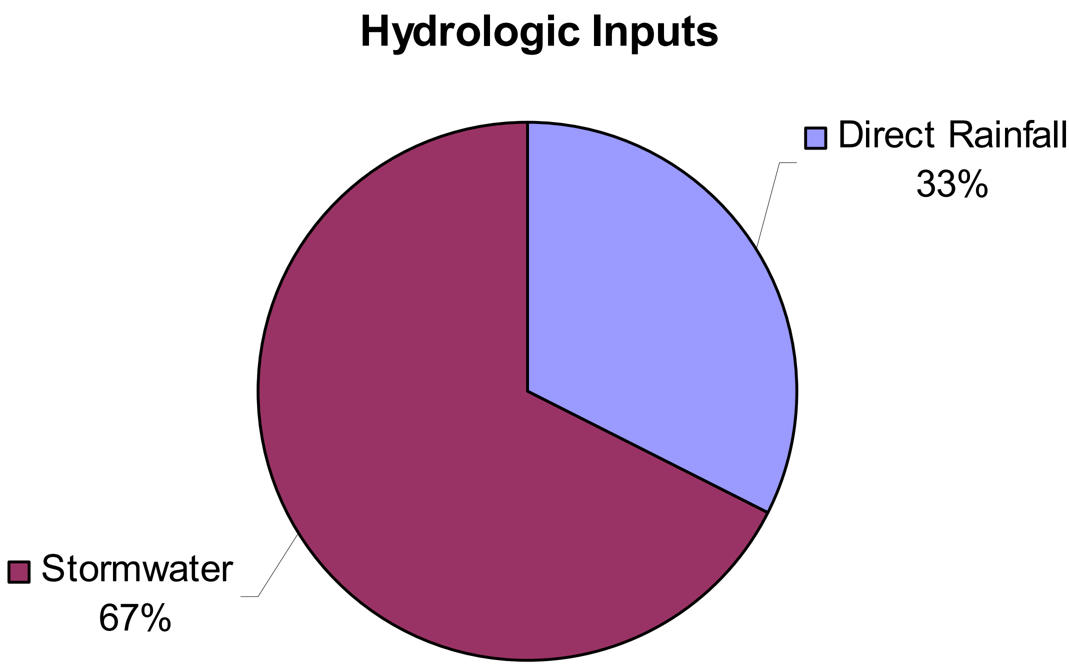
During the 16-month assessment period, the dominant input into the detention pond was stormwater runoff which contributed approximately 67% of the inputs into the system. Direct rainfall onto the pond surface contributed approximately 33% of the total measured inputs. Infiltration into shallow groundwater was the most significant source of losses from the pond, contributing approximately 52% of the overall hydrologic pond losses. Discharges from the pond through the two drainage well structures accounted for approximately 48% of the overall system losses. A graphical presentation of overall hydrologic inputs and losses at the Key Colony detention pond is given in Figure 3-6.

3.2 Characteristics of Bulk Precipitation

Water quality characteristics of combined wet and dry fallout (bulk precipitation) were measured at the Key colony detention pond site from July 2001 to October 2002. Bulk precipitation was measured by collecting all wet and dry fallout which fell into a funnel device located within the city of Key Colony Beach STP Complex. Bulk precipitation samples were collected over periods ranging from 5-81 days depending upon rainfall during the collection period. A total of 25 separate bulk precipitation samples were collected at the Key Colony project site during the 16-month monitoring period. A complete listing of chemical characteristics of each bulk precipitation sample collected at the Key Colony project site is given in Appendix D.

3.2.1 General Chemical Characteristics

A summary of mean characteristics of bulk precipitation measured at the Key Colony project site from July 2001-October 2002 is given in Table 3-9. In general, a high degree of variability is apparent in measured concentrations for many parameters. The range between minimum and maximum values for many parameters covers several orders of magnitude or more. The coefficient of variability (CV), defined as the standard deviation divided by the mean (expressed as a percentage), exceeded a value of 100 for many of the general chemical parameters measured in the precipitation. Coefficient of variation values in excess of 100 are typically used to indicate a high degree of variability within a data set. A particularly high degree of variability in chemical characteristics of bulk precipitation is apparent for pH, conductivity, alkalinity, ammonia, NO_X, dissolved organic nitrogen, particulate nitrogen, dissolved organic phosphorus, particulate phosphorus, total phosphorus, TSS, and total iron.



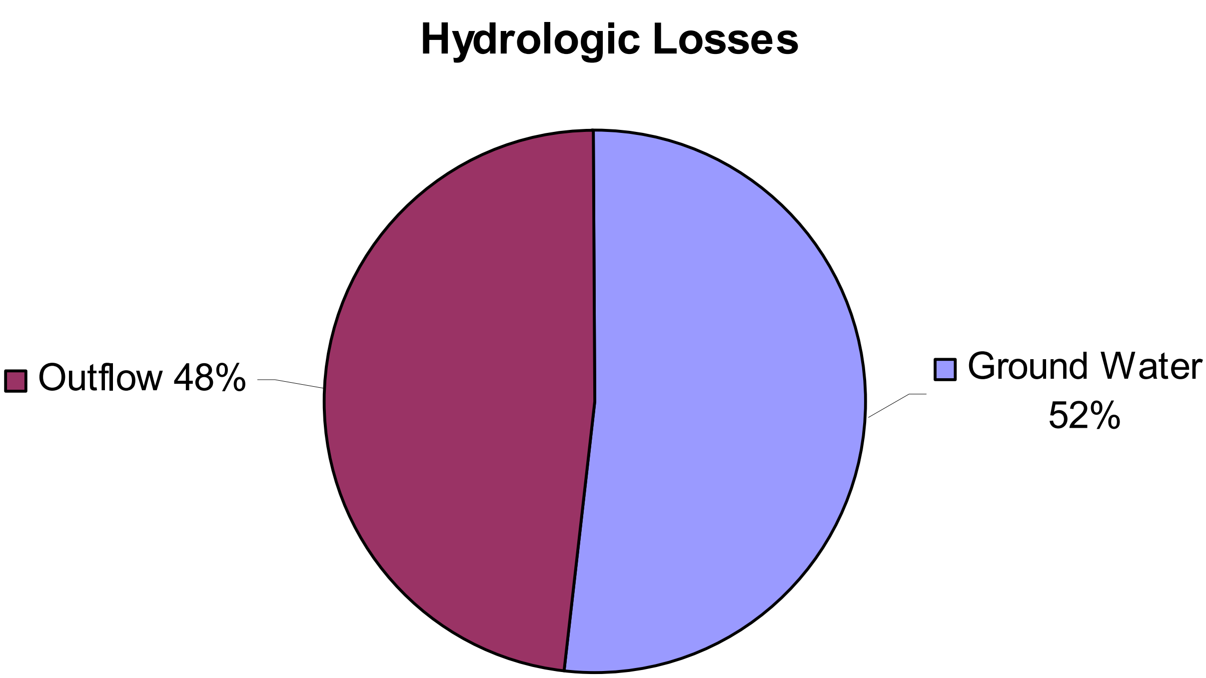


Figure 3-6. Comparison of Overall Hydrologic Inputs and Losses at the Key Colony Detention Pond.

TABLE 3-9

MEAN CHARACTERISTICS OF BULK PRECIPITATION AT THE KEY COLONY SITE FROM JULY 2001-OCTOBER 2002[1]

Parameter	Units	Range of Values		Mean	C.V.[2]
		Minimum	Maximum		
pH	s.u.	4.22	7.75	5.90	14
Spec. Cond.	µmho/cm	4	344	73	122
Alkalinity	mg/l	1	37	8	106
NH_3-N	µg/l	< 5	186	59	99
NO_2 + NO_3-N	µg/l	< 5	1,162	177	146
Diss. Organic N	µg/l	< 25	1,204	239	122
Particulate N	µg/l	< 25	1,393	377	116
Total N	µg/l	117	2,716	852	85
Diss. Ortho-P	µg/l	< 1	14	2	149
Diss. Organic P	µg/l	< 1	118	13	194
Particulate P	µg/l	2	209	33	148
Total P	µg/l	4	265	48	126
Turbidity	NTU	0.4	13.1	2.9	95
TSS	mg/l	< 0.7	36.5	6.0	127
BOD_5	mg/l	< 2	9.8	2.1	87
Chloride	mg/l	< 1	31	10	73
Total Cadmium	µg/l	< 1	< 1	< 1	---
Total Chromium	µg/l	< 5	< 5	< 5	---
Total Copper	µg/l	< 3	15	4	108
Total Iron	µg/l	< 2	203	25	170
Total Lead	µg/l	< 2	10	< 2	---
Total Zinc	µg/l	< 2	122	66	45

1. n = 25 samples
2. C.V.: coefficient of variation = standard deviation/mean, expressed as a percentage

Bulk precipitation measured at the site was found to be slightly acidic, with a mean pH of 5.90 and measured values ranging from 4.22-7.75. Bulk precipitation was also found to exhibit a moderate ionic strength with mean specific conductivity of 73 μmho/cm. Bulk precipitation was poorly buffered, with mean alkalinity of only 8 mg/l.

As seen in Table 3-9, measured concentrations of turbidity, TSS, and chloride were found to be highly variable in bulk precipitation measured at the Key Colony project site. These variabilities, particularly with respect to chloride concentrations, are at least partially related to the proximity of the pond to the adjacent marine environment.

3.2.2 Nutrients

A considerable degree of variability is apparent in measured concentrations of nitrogen species in bulk precipitation at the site. Relatively elevated concentrations of NO_X, dissolved organic nitrogen, particulate nitrogen and total nitrogen were observed at the site on several occasions. However, on an average basis, nitrogen concentrations in bulk precipitation appear to be moderate in value. The dominant nitrogen species present in bulk precipitation is particulate nitrogen, which comprises approximately 44% of the total nitrogen measured at the site. Dissolved organic nitrogen contributes approximately 28% of the nitrogen in bulk precipitation, with 21% contributed by NO_X and 7% by ammonia.

Similar to the trends observed for nitrogen species, elevated levels of phosphorus species were also observed in bulk precipitation at the site. Elevated concentrations were observed for dissolved organic phosphorus, particulate phosphorus, and total phosphorus during several of the monitoring periods. However, on an overall basis, total phosphorus species appear to be low to moderate in value at the project site. The dominant phosphorus species at the site is particulate phosphorus, which comprises approximately 69% of the total phosphorus measured. Dissolved organic phosphorus contributes approximately 27%, with the remaining 4% contributed by dissolved orthophosphorus.

3.2.3 Heavy Metals

In contrast to the trends observed for nitrogen and phosphorus, relatively low levels of heavy metals were observed in bulk precipitation for most parameters. Evidence of elevated concentrations during specific events are apparent only for total iron and total zinc. However, on an average basis, concentrations of heavy metals in bulk precipitation appear to be low in value and are lower than concentrations observed in stormwater inflow into the pond.

3.3 Characteristics of Stormwater Runoff

Runoff characteristics were monitored at each of the three inflow monitoring sites from August 2001-October 2002 over a wide range of rain event characteristics. A complete listing of the chemical characteristics of individual stormwater samples collected at the three sites is given in

Appendix E. All values in Appendix E represent event mean concentrations (emc) for each monitored event. Total event rainfall ranged from 4.52-9.35 cm (1.78-3.68 in), with rain event durations ranging from 1.48 to 14.04 hours and antecedent dry periods ranging from 0.06 to 4.83 days.

Characteristics of stormwater runoff collected at Inflow Monitoring Sites 1, 2 and 3 are given Tables 3-10, 3-11, and 3-12, respectively. In general, the degree of variability in runoff characteristics measured at each of the three sites is relatively low for many of the measured parameters. This relatively low degree of variability is probably related to the pre-treatment effects of the swale drainage system which appears to reduce the inherent variability in many stormwater constituents. However, relatively high levels of variability were observed at the inflow sites for conductivity, ammonia, dissolved organic phosphorus, turbidity, suspended solids and fecal coliform. Measured concentrations of these parameters varied by approximately one order of magnitude or more between minimum and maximum event mean concentrations for individual rain events.

3.3.1 General Parameters

A comparison of mean characteristics of stormwater runoff measured at the three inflow monitoring sites from August 2001-October 2002 is given in Table 3-13. Stormwater runoff measured at the Key Colony site was slightly alkaline in pH, with mean pH values at the three monitoring sites ranging from approximately 7.69-7.89. Runoff inputs were also relatively well buffered, with mean alkalinity values ranging from 68-189 mg/l. However, a large degree of variability was observed in measured conductivity values between the three sites, ranging from 186 μmho/cm at Inflow 1 to 2843 μmho/cm at Inflow 2. The mean specific conductivity at Inflow 3, located approximately 180 m (600 ft) upstream from Inflow 2, is only 603 μmho/cm, suggesting a significant input of dissolved ions during migration through the swale drainage system between the two monitoring sites.

Runoff inflow at the Key Colony site exhibited a wide range of measured turbidity values, ranging from a low of 2.9 NTU at Inflow 3 to high of 50.5 NTU at Inflow 1. However, concentrations of suspended solids between the sites were relatively similar, ranging from 14.4-37.7 mg/l. Mean BOD_5 concentrations at the three inflow sites were less than 2 mg/l. Measured chloride concentrations were found to be highly variable and exhibited a trend similar to that observed for specific conductivity. Relatively low chloride levels were observed at Inflow 1 with moderate levels at Inflow 3 and elevated levels observed at Inflow 2. Measured fecal coliform concentrations at the three sites appear to be relatively low compared with values typically observed in stormwater runoff, with mean concentrations ranging from 344-1063 organisms/100 ml.

TABLE 3-10

CHARACTERISTICS OF INFLOW 1 AT THE KEY COLONY SITE FROM JULY 2001-OCTOBER 2002[1]

Parameter	Units	Range of Values		Mean	C.V.[2]
		Minimum	Maximum		
pH	s.u.	7.23	8.33	7.69	4
Spec. Cond.	µmho/cm	76	732	186	111
Alkalinity	mg/l	40	137	77	37
NH_3-N	µg/l	< 5	113	39	104
NO_2 + NO_3-N	µg/l	20	885	198	135
Diss. Organic N	µg/l	68	899	361	96
Particulate N	µg/l	< 25	692	276	83
Total N	µg/l	399	1,642	874	52
Diss. Ortho-P	µg/l	22	182	90	64
Diss. Organic P	µg/l	9	74	25	78
Particulate P	µg/l	6	573	92	198
Total P	µg/l	75	646	206	85
Turbidity	NTU	3.1	125.0	50.5	92
TSS	mg/l	3.2	108.0	37.7	97
BOD_5	mg/l	< 2	3.5	< 2	---
Chloride	mg/l	< 1	8	4	58
Fecal Coliform	No./100 ml	1	1755	344	165
Diss. Cadmium	µg/l	< 1	< 1	< 1	---
Total Cadmium	µg/l	< 1	< 1	< 1	---
Diss. Chromium	µg/l	< 5	< 5	< 5	---
Total Chromium	µg/l	< 5	< 5	< 5	---
Diss. Copper	µg/l	< 3	13	3	122
Total Copper	µg/l	< 3	23	9	86
Diss. Iron	µg/l	< 2	18	8	73
Total Iron	µg/l	6	181	58	98
Diss. Lead	µg/l	< 2	< 2	< 2	---
Total Lead	µg/l	< 2	< 2	< 2	---
Diss. Zinc	µg/l	3	17	9	56
Total Zinc	µg/l	7	42	19	57

1. n = 9 samples
2. C.V.: coefficient of variation = standard deviation/mean, expressed as a percentage

TABLE 3-11

CHARACTERISTICS OF INFLOW 2 AT THE KEY COLONY SITE FROM JULY 2001-OCTOBER 2002[1]

Parameter	Units	Range of Values		Mean	C.V.[2]
		Minimum	Maximum		
pH	s.u.	7.43	8.35	7.89	4
Spec. Cond.	µmho/cm	579	5,723	2,843	64
Alkalinity	mg/l	59	343	189	54
NH_3-N	µg/l	5	989	237	162
NO_2 + NO_3-N	µg/l	29	778	372	96
Diss. Organic N	µg/l	309	952	557	50
Particulate N	µg/l	93	1,041	518	85
Total N	µg/l	802	3,101	1,685	47
Diss. Ortho-P	µg/l	20	201	111	71
Diss. Organic P	µg/l	15	441	117	141
Particulate P	µg/l	4	90	45	78
Total P	µg/l	41	660	272	85
Turbidity	NTU	1.6	38.9	14.5	124
TSS	mg/l	0.8	43.7	14.4	136
BOD_5	mg/l	< 2	4.0	< 2	---
Chloride	mg/l	495	2,024	1,151	55
Fecal Coliform	No./100 ml	36	4500	1063	161
Diss. Cadmium	µg/l	< 1	< 1	< 1	---
Total Cadmium	µg/l	< 1	< 1	< 1	---
Diss. Chromium	µg/l	< 5	< 5	< 5	---
Total Chromium	µg/l	< 5	< 5	< 5	---
Diss. Copper	µg/l	< 3	14	7	68
Total Copper	µg/l	3	33	15	74
Diss. Iron	µg/l	7	98	48	75
Total Iron	µg/l	22	267	119	72
Diss. Lead	µg/l	< 2	< 2	< 2	---
Total Lead	µg/l	< 2	< 2	< 2	---
Diss. Zinc	µg/l	8	19	13	30
Total Zinc	µg/l	15	35	24	32

1. n = 6 samples
2. C.V.: coefficient of variation = standard deviation/mean, expressed as a percentage

TABLE 3-12

CHARACTERISTICS OF INFLOW 3 AT THE KEY COLONY SITE FROM JULY 2001-OCTOBER 2002[1]

Parameter	Units	Range of Values		Mean	C.V.[2]
		Minimum	Maximum		
pH	s.u.	7.40	7.97	7.70	3
Spec. Cond.	µmho/cm	26	1,550	603	107
Alkalinity	mg/l	15	136	68	72
NH_3-N	µg/l	5	439	137	115
$NO_2 + NO_3$-N	µg/l	21	197	114	62
Diss. Organic N	µg/l	344	813	623	33
Particulate N	µg/l	< 25	1,320	316	157
Total N	µg/l	649	2,532	1,189	59
Diss. Ortho-P	µg/l	69	389	206	58
Diss. Organic P	µg/l	6	500	116	163
Particulate P	µg/l	16	150	79	69
Total P	µg/l	183	809	401	56
Turbidity	NTU	1.3	4.8	2.9	52
TSS	mg/l	1.6	122.0	23.1	210
BOD_5	mg/l	< 2	4.5	< 2	---
Chloride	mg/l	16	500	188	102
Fecal Coliform	No./100 ml	60	2300	1044	94
Diss. Cadmium	µg/l	< 1	< 1	< 1	---
Total Cadmium	µg/l	< 1	< 1	< 1	---
Diss. Chromium	µg/l	< 5	< 5	< 5	---
Total Chromium	µg/l	< 5	< 5	< 5	---
Diss. Copper	µg/l	< 3	5	< 3	---
Total Copper	µg/l	< 3	35	8	162
Diss. Iron	µg/l	4	34	14	80
Total Iron	µg/l	10	39	27	42
Diss. Lead	µg/l	< 2	< 2	< 2	---
Total Lead	µg/l	< 2	< 2	< 2	---
Diss. Zinc	µg/l	3	11	7	44
Total Zinc	µg/l	10	28	16	50

1. n = 6 samples
2. C.V.: coefficient of variation = standard deviation/mean, expressed as a percentage

TABLE 3-13

MEAN CHARACTERISTICS OF STORMWATER RUNOFF MEASURED AT THE INFLOW MONITORING SITES AT THE KEY COLONY SITE FROM JULY 2001-OCTOBER 2002

Parameter	Units	Inflow 1	Inflow 2	Inflow 3
pH	s.u.	7.69	7.89	7.70
Spec. Cond.	μmho/cm	186	2843	603
Alkalinity	mg/l	77	189	68
NH_3-N	μg/l	39	237	137
$NO_2 + NO_3$-N	μg/l	198	372	114
Diss. Organic N	μg/l	361	557	623
Particulate N	μg/l	276	518	316
Total N	μg/l	874	1685	1189
Diss. Ortho-P	μg/l	90	111	206
Diss. Organic P	μg/l	25	117	116
Particulate P	μg/l	92	45	79
Total P	μg/l	206	272	401
Turbidity	NTU	50.5	14.5	2.9
TSS	mg/l	37.7	14.4	23.1
BOD_5	mg/l	< 2	< 2	< 2
Chloride	mg/l	4.2	1151	188
Fecal Coliform	No./100 ml	344	1063	1044
Diss. Cadmium	μg/l	< 1	< 1	< 1
Total Cadmium	μg/l	< 1	< 1	< 1
Diss. Chromium	μg/l	< 5	< 5	< 5
Total Chromium	μg/l	< 5	< 5	< 5
Diss. Copper	μg/l	3	7	< 3
Total Copper	μg/l	9	15	8
Diss. Iron	μg/l	8	48	14
Total Iron	μg/l	58	119	27
Diss. Lead	μg/l	< 2	< 2	< 2
Total Lead	μg/l	< 2	< 2	< 2
Diss. Zinc	μg/l	9	13	7
Total Zinc	μg/l	19	24	16

3.3.2 Nutrients

In general, mean concentrations of nitrogen species measured at the three inflow site are typical of runoff which has received pre-treatment in a vegetated swale system. Concentrations of nitrogen species are relatively low in value at Inflow 1 and Inflow 3, with moderate concentrations observed at Inflow 2. The dominant nitrogen species at each of the three sites is dissolved organic nitrogen which comprises 33-52% of the total nitrogen present at the three sites. Particulate nitrogen, which is typically the largest contributor of total nitrogen in runoff, comprises only 27-32% of the total nitrogen present at each site. The remaining nitrogen measured at each site is comprised of inorganic species of ammonia and NO_X, both of which are present in relatively low concentrations, particularly at Inflows 1 and 3. It is interesting to note that mean concentrations of most nitrogen species increased during migration through the swale system from Inflow 3 to Inflow 2. This behavior, in combination with the observed increases in specific conductivity and chloride between Inflow 3 and Inflow 2, further suggests an influx into the swale system from another source between the two monitoring locations.

In general, measured concentrations of total phosphorus at the three inflow monitoring site are typical of values commonly observed in stormwater runoff. However, even though the total phosphorus concentrations are typical of values commonly observed, the distribution of concentrations among the measured phosphorus species is reflective of the pre-treatment which occurs during migration through swale drainage system. Normally, particulate phosphorus would comprise the largest fraction of total phosphorus in runoff which received no pre-treatment attenuation. However, at the Key Colony site, particulate phosphorus was the smallest species observed at two of the three monitoring sites. The dominant phosphorus species observed at the majority of the sites is dissolved orthophosphorus which comprises approximately 41-51% of the total phosphorus measured at each site. The second most dominant phosphorus species appears to be dissolved organic phosphorus, with relatively small contributions from particulate phosphorus. Unlike the trends observed for nitrogen species, phosphorus species appear to be lower in concentration at Inflow 2 compared with values measured at Inflow 3.

3.3.3 Heavy Metals

In general, measured concentrations of heavy metals at the three inflow monitoring sites are relatively low in value. Mean concentrations for dissolved and total cadmium, dissolved and total chromium, and dissolved and total lead are less than the applicable laboratory detection limits for these parameters. Low levels of dissolved and total copper, dissolved and total iron, and dissolved and total zinc were also observed, with mean concentrations substantially less than values typically measured in urban runoff. With the exception of copper, mean concentrations for all measured heavy metals are less than the applicable Class III marine criteria for heavy metals, outlined in Chapter 62-302 of the Florida Administrative Code (FAC).

In general, heavy metals measured at the three monitoring sites were found to exist primarily in a particulate form, although the percentage of particulates species is somewhat lower than typically observed in stormwater runoff. The relatively lower percentage of particulate species observed at the Key Colony site is likely related to the pre-treatment afforded by the swale drainage system.

3.3.4 Correlations Between Stormwater and Rain Event Characteristics

Correlation analyses were performed using the PROC CORR routine of the SAS statistical package to determine if significant relationships exist between the measured chemical characteristics of stormwater runoff at the three sites and rain event characteristics, such as total rainfall, event duration, average intensity, and antecedent dry period. Pearson correlations coefficients, along with level of significance values, were calculated for each combination of rain event characteristics and measured stormwater parameters. Chemical parameters which exhibit at least one significant correlation with a rain event characteristic are summarized in Table 3-14. Chemical parameters which do not exhibit significant relationships with rain event characteristics are not listed in Table 3-14.

TABLE 3-14

CORRELATIONS BETWEEN CHEMICAL CHARACTERISTICS OF STORMWATER RUNOFF AND RAIN EVENT CHARACTERISTICS

SITE	PARAMETER	PEARSON CORRELATION COEFFICIENT (LEVEL OF SIGNIFICANCE)			
		TOTAL RAINFALL	EVENT DURATION	RAINFALL INTENSITY	ANTECEDENT DRY PERIOD
Inflow 1	Total N	-0.857 (0.003)	N.S.C.	N.S.C.	N.S.C.
	Particulate P	N.S.C.[1]	N.S.C.	0.739 (0.023)	N.S.C.
	TSS	N.S.C.	-0.767 (0.016)	0.767 (0.016)	N.S.C.
Inflow 2	Alkalinity	N.S.C.	N.S.C.	N.S.C.	-0.838 (0.037)
	Chloride	N.S.C.	N.S.C.	N.S.C.	-0.929 (0.008)
Inflow 3	Conductivity	N.S.C.	0.865 (0.026)	N.S.C.	N.S.C.
	Alkalinity	N.S.C.	0.830 (0.041)	-0.854 (0.030)	N.S.C.
	Diss. Organic N	N.S.C.	N.S.C.	N.S.C.	-0.960 (0.002)
	Ortho-P	N.S.C.	0.918 (0.010)	N.S.C.	N.S.C.
	Particulate P	N.S.C.	N.S.C.	N.S.C.	-0.867 (0.025)
	Chloride	N.S.C.	0.896 (0.016)	N.S.C.	N.S.C.

1. N.S.C.: No significant correlation at the 0.05 level of significance

As seen in Table 3-14, only a few significant correlations were observed between runoff characteristics and rainfall characteristics. At Inflow 1, total nitrogen was found to be negatively correlated with total rainfall, suggesting that total nitrogen concentrations decrease as total rainfall amount increases. In addition, particulate phosphorus was found to be positively correlated with rainfall intensity, suggesting that particulate phosphorus species increase as rainfall intensity increases. Suspended solids concentrations at Inflow 1 were found to be negatively correlated with event duration and positively correlated with rainfall intensity, suggesting that suspended solids concentrations decrease as event duration increases and increase as rainfall intensity increases. Each of the correlations observed at Inflow 1 are consistent with relationships commonly observed between runoff and rain event characteristics.

At Inflow Monitoring Site 2, negative correlations with antecedent dry period were observed for both alkalinity and chloride, suggesting that measured concentrations of these parameters in stormwater runoff decrease with antecedent dry period.

At Inflow Monitoring Site 3, positive correlations were observed between event duration, conductivity, alkalinity, orthophosphorus, and chloride, suggesting that concentrations of each of these parameters increase at this site with increasing rainfall duration. A negative correlation was observed at Inflow 3 between alkalinity and rainfall intensity. Negative correlations with antecedent drought period were also observed for dissolved organic nitrogen and particulate phosphorus.

3.4 Characteristics of Pond Surface Water

As indicated Section 3.1, standing surface water was rarely present in the Key Colony dry detention pond. As a result, surface water samples were collected on only three separate occasions during the 16-month monitoring period. In addition, field measurements of pH, temperature, conductivity, dissolved oxygen, percent oxygen saturation, and oxidation reduction potential (ORP) were performed at the time of sample collection. A complete listing of the characteristics of individual surface water samples collected on the three separate monitoring dates is given in Appendix F. Mean characteristics of surface water samples are summarized in Table 3-15.

3.4.1 General Characteristics

In general, a relatively high degree of variability was observed in measured concentrations between the three collected surface water samples. High levels of variability are apparent for ammonia, particulate nitrogen, orthophosphorus, dissolved organic phosphorus, particulate phosphorus, TSS, BOD, chlorophyll-a, fecal coliform bacteria, dissolved iron, and total iron. Measured values for these parameters covered one order of magnitude or more between minimum and maximum values.

Surface water collected within the detention pond was slightly alkaline, with measured pH values ranging from 7.48-8.18. The water was also relatively well buffered, as indicated by alkalinity values in excess of 100 mg/l, and high in dissolved ions, with measured specific conductivity values ranging from 1910-3446 μmho/cm. Salinity of the surface water ranged from 1.0-1.9 ppt. Based upon the measured conductivity and salinity values, water within the detention pond would be characterized as brackish.

TABLE 3-15

CHARACTERISTICS OF SURFACE WATER COLLECTED AT THE KEY COLONY DETENTION POND FROM JULY 2001-OCTOBER 2002[1]

Parameter	Units	Range of Values		Mean	C.V.[2]
		Minimum	Maximum		
pH	s.u.	7.47	8.18	7.91	5
Temperature	°C	31.92	34.99	33.05	5
Spec. Cond.	µmho/cm	1,910	3,446	2,835	29
Salinity	ppt	1.0	1.9	1.5	29
Dissolved Oxygen	mg/l	3.7	4.3	3.9	7
D.O. Saturation	%	50	62	55	12
ORP	mV	345	454	407	14
Alkalinity	mg/l	130	247	202	31
NH_3-N	µg/l	101	1,089	436	130
$NO_2 + NO_3$-N	µg/l	< 5	19	8	119
Diss. Organic N	µg/l	1,024	4,998	2,414	93
Particulate N	µg/l	77	1,544	614	132
Total N	µg/l	1,222	7,650	3,473	104
Diss. Ortho-P	µg/l	2	302	170	90
Diss. Organic P	µg/l	6	1,279	440	165
Particulate P	µg/l	< 2	194	86	115
Total P	µg/l	303	1,475	696	97
Turbidity	NTU	3	10	6	72
TSS	mg/l	2	34	13	139
BOD_5	mg/l	4	25	11	112
Chlorophyll-a	mg/m^3	< 5	20	8	132
Chloride	mg/l	660	1,048	906	24
Fecal Coliform	No./100 ml	1	1,800	630	161
Diss. Cadmium	µg/l	< 3	< 3	< 3	---
Total Cadmium	µg/l	< 1	< 1	< 1	---
Diss. Chromium	µg/l	< 5	< 5	< 5	---
Total Chromium	µg/l	< 2	3	< 2	---
Diss. Copper	µg/l	< 2	< 2	< 2	---
Total Copper	µg/l	< 3	< 3	< 3	---
Diss. Iron	µg/l	< 2	45	20	116
Total Iron	µg/l	0	102	46	113
Diss. Lead	µg/l	0	1	1	87
Total Lead	µg/l	< 2	< 2	< 2	---
Diss. Zinc	µg/l	< 2	13	8	88
Total Zinc	µg/l	0	30	19	87

1. n = 3 samples
2. C.V.: coefficient of variation = standard deviation/mean, expressed as a percentage

Dissolved oxygen concentrations in the pond surface water are relatively low in value, particularly in view of the extremely shallow depth of water within the pond. Measured dissolved oxygen concentrations range from 3.7-4.3 mg/l, with an overall mean of 3.9 mg/l. These values represent dissolved oxygen saturation percentages ranging from 50-62%. However, surface waters within the pond appeared to be relatively well oxidized on each of the three monitoring dates, with measured redox potential values substantially in excess of 200 mV.

Measured turbidity values within the pond were also found to be low in value, ranging from 2.8-10.2 NTU. However, a relatively wide variability was observed for suspended solids concentrations, which ranged from 2.4-33.9 mg/l. A similar degree of variability was observed for BOD concentrations which ranged from 3.8-25.2 mg/l. Chloride concentrations in the surface water were found to be elevated, with a mean chloride concentration of 906 mg/l. A high degree of variability was observed in fecal coliform counts, which ranged 1-1800 organisms/100 ml.

3.4.2 Nutrients

Measured concentrations of nitrogen species in the detention pond surface water were found to be somewhat elevated, particularly for ammonia and dissolved organic nitrogen. Dissolved organic nitrogen is clearly the dominant nitrogen species present within the surface water, comprising 70% of the total nitrogen measured. Approximately 18% of the total nitrogen is comprised of particulate nitrogen, with 13% contributed by ammonia. Measured concentrations of NO_X were found to be relatively low in value. Nitrogen species exhibited a high degree of variability between the three monitoring dates, with total nitrogen concentrations ranging from 1222-7650 µg/l. The mean total nitrogen concentration of 3473 µg/l measured within the pond is higher than total nitrogen concentrations measured at any of the three runoff inflow sites.

Elevated concentrations of phosphorus species were also observed in some of the surface water collected from the pond. The dominant phosphorus species is dissolved organic phosphorus, which comprises 63% of the total phosphorus measured. Dissolved orthophosphorus concentrations within the surface water were highly elevated compared with values commonly observed in detention pond water, and comprised 24% of the total phosphorus measured. The measured phosphorus concentrations were found to be highly variable between the three monitoring events, ranging from 303-1475 µg/l. The mean total phosphorus concentration of 696 µg/l is substantially greater than phosphorus concentrations measured at any of the three runoff inflow monitoring sites.

3.4.3 Microbiological Parameters

Measured concentrations of fecal coliform bacteria were highly variable between the three monitoring dates. Concentrations measured on two of the three monitoring dates were less than the Class III criterion of 200 organisms/100 ml outlined in Chapter 62-302 FAC. A fecal coliform count of 1800 organisms/100 ml was measured on the remaining date which substantially exceeds the Class III criterion. A similar variability was observed in measured concentrations of chlorophyll-a, with concentrations less than 3 mg/m^3 on two of the three monitoring dates and a value of 19.5 mg/m^3 on the remaining date.

3.4.4 Heavy Metals

In general, measured concentrations of heavy metals in the pond surface water were found to be relatively low in value. Heavy metal concentrations measured within the pond appear to be less than or equal to values measured at the three runoff inflow monitoring sites. No exceedances of the Class III marine criteria were observed for heavy metals in any of the three pond surface water samples.

3.5 Characteristics of Pond Outflow

As discussed in section 2.2.1.2 outflow from the dry detention pond into the two injection wells was monitored on a continuous basis from August 2001 to October 2002. However, due to the rapid infiltration characteristics of the on-site soils, combined with attenuation within the vegetated swales used for conveyance, discharges from the pond into the two injection wells occurred on an infrequent basis. A total of 10 separate pond outflow samples were collected entering Injection Well 1 during the 16-month monitoring program, while only four separate outflow samples were collected entering Injection Well 2. A complete listing of the chemical characteristics of the monitored discharges to Injection Well 1 and Injection Well 2 is given in Appendix G. A summary of the characteristics of discharges to Injection Wells 1 and 2 is given in Tables 3-16 and 3-17, respectively.

3.5.1 General Parameters

A high degree of variability is apparent in the chemical characteristics of discharges to both Injection Wells 1 and 2 for virtually all measured parameters. For many of the measured parameters, the range between minimum and maximum values covers one order of magnitude or more. A particularly high degree of variability is apparent for measured concentrations of ammonia, NO_X, total nitrogen, orthophosphorus, dissolved organic phosphorus, particulate phosphorus, total phosphorus, TSS, and chloride.

In general, discharges to the two injection wells were slightly alkaline with the majority of measurements exhibiting pH values in excess of 7.0. Discharges to the injection wells also exhibited moderate to high levels of dissolved ions as indicated by mean specific conductivity values ranging from 528-1011 μmho/cm.

Mean concentrations of turbidity and suspended solids discharging to the two injection wells appear to be low to moderate in value, particularly in view of the high variability in measured concentrations for these parameters between the individual samples. Mean turbidity values discharging into the injection wells range from approximately 6-7 NTU, with mean suspended solids concentrations ranging from approximately 16-27 mg/l.

Measured BOD concentrations in discharges to the two injection wells appear to be somewhat elevated, with mean concentrations ranging from approximately 7-8 mg/l. Measured chloride concentrations in discharges to the two injection wells were also found to be somewhat

TABLE 3-16

CHARACTERISTICS OF DISCHARGES TO INJECTION WELL NO. 1 AT THE KEY COLONY DETENTION POND FROM AUGUST 2001-OCTOBER 2002[1]

Parameter	Units	Range of Values		Mean	C.V.[2]
		Minimum	Maximum		
pH	s.u.	6.73	7.90	7.31	5
Spec. Cond.	μmho/cm	237	2,796	1,011	87
Alkalinity	mg/l	20	233	92	72
NH_3-N	μg/l	< 5	909	184	151
$NO_2 + NO_3$-N	μg/l	< 5	7,520	965	246
Diss. Organic N	μg/l	192	2,623	1,238	67
Particulate N	μg/l	< 25	2,322	1,001	96
Total N	μg/l	808	11,770	3,387	93
Diss. Ortho-P	μg/l	82	1,583	448	100
Diss. Organic P	μg/l	1	142	41	109
Particulate P	μg/l	5	266	89	95
Total P	μg/l	97	1,991	578	96
Turbidity	NTU	0.5	23.9	6.2	140
TSS	mg/l	< 0.7	200	26.6	233
BOD_5	mg/l	< 2	48.4	6.7	219
Chloride	mg/l	42	704	272	80
Fecal Coliform	No./100 ml	1	1700	308	169
Diss. Cadmium	μg/l	< 1	< 1	< 1	---
Total Cadmium	μg/l	< 1	< 1	< 1	---
Diss. Chromium	μg/l	< 5	< 5	< 5	---
Total Chromium	μg/l	< 5	< 5	< 5	---
Diss. Copper	μg/l	< 3	11	6	66
Total Copper	μg/l	< 3	34	13	79
Diss. Iron	μg/l	< 2	45	17	85
Total Iron	μg/l	3	57	27	64
Diss. Lead	μg/l	< 2	< 2	< 2	---
Total Lead	μg/l	< 2	< 2	< 2	---
Diss. Zinc	μg/l	8	73	26	80
Total Zinc	μg/l	12	132	43	85

1. n = 10 samples
2. C.V.: coefficient of variation = standard deviation/mean, expressed as a percentage

TABLE 3-17

CHARACTERISTICS OF DISCHARGES TO INJECTION WELL NO. 2 AT THE KEY COLONY DETENTION POND FROM AUGUST 2001-OCTOBER 2002[1]

Parameter	Units	Range of Values		Mean	C.V.[2]
		Minimum	Maximum		
pH	s.u.	7.37	7.50	7.42	1
Spec. Cond.	µmho/cm	143	1,565	528	131
Alkalinity	mg/l	46	204	106	68
NH_3-N	µg/l	11	1,387	377	179
NO_2 + NO_3-N	µg/l	30	432	174	108
Diss. Organic N	µg/l	112	3,394	1,183	127
Particulate N	µg/l	< 25	2,208	938	111
Total N	µg/l	590	6,573	2,672	102
Diss. Ortho-P	µg/l	80	1,096	389	123
Diss. Organic P	µg/l	14	86	45	70
Particulate P	µg/l	2	162	53	139
Total P	µg/l	123	1,344	487	119
Turbidity	NTU	1.3	14.0	7.9	80
TSS	mg/l	0.8	46.0	15.9	130
BOD_5	mg/l	< 2	25.2	7.6	156
Chloride	mg/l	8	765	321	117
Fecal Coliform	No./100 ml	170	3000	1123	116
Diss. Cadmium	µg/l	< 1	< 1	< 1	---
Total Cadmium	µg/l	< 1	< 1	< 1	---
Diss. Chromium	µg/l	< 5	< 5	< 5	---
Total Chromium	µg/l	< 5	< 5	< 5	---
Diss. Copper	µg/l	< 3	28	11	114
Total Copper	µg/l	4	33	15	84
Diss. Iron	µg/l	< 2	127	46	120
Total Iron	µg/l	3	192	108	73
Diss. Lead	µg/l	< 2	< 2	< 2	---
Total Lead	µg/l	< 2	< 2	< 2	---
Diss. Zinc	µg/l	9	42	22	67
Total Zinc	µg/l	14	66	34	67

1. n = 4 samples
2. C.V.: coefficient of variation = standard deviation/mean, expressed as a percentage

elevated, with mean values ranging from approximately 270-320 mg/l. Measured fecal coliform counts in discharges to the injection wells also appear to be somewhat elevated with higher concentrations measured at Outflow 2 compared with Outflow 1.

3.5.2 Nutrients

In general, measured nutrient concentrations in discharges to the two injection wells appear to be somewhat elevated, particularly for runoff which has migrated through a stormwater treatment train. Measured concentrations of inorganic nitrogen species were found to be relatively low in value in discharges to the two injection wells, with the exception of measured NO_X concentrations in discharges to Injection Well 1. The mean NO_x concentration at this site for the collected samples is 965 µg/l. The dominant nitrogen species measured at each of the two sites appears to be dissolved organic nitrogen, which comprises approximately 35-40% of the total nitrogen measured at each site. The second most abundant nitrogen species is particulate nitrogen, which comprises approximately 30-35% of the nitrogen measured.

Relatively elevated levels of phosphorus species were measured in discharges to each of the injection wells with mean total phosphorus concentrations ranging from 487 µg/l entering Injection Well 2 to 578 µg/l entering Injection Well 1. The dominant phosphorus species in discharges to the injections wells is clearly orthophosphorus, which comprises approximately 80% of the total phosphorus present at each site. Dissolved organic phosphorus and particulate phosphorus make up relatively small components of phosphorus discharges to the two injection wells.

3.5.3 Heavy Metals

In general, measured concentrations of dissolved and total cadmium, dissolved and total chromium, and dissolved and total lead were extremely low in value in discharges to the two injection wells, with all measured values less than applicable detection limits for these parameters. Measurable levels of dissolved and total copper, dissolved and total iron, and dissolved and total zinc were observed in many of the collected discharge samples. In general, concentrations for these parameters in discharges to the two injection wells are similar to the characteristics for these parameters in stormwater runoff measured at Inflow Monitoring Sites 1 and 2.

3.5.4 Comparison of Mean Discharge Characteristics

A comparison of mean characteristics in discharges to Injection Wells 1 and 2 is given in Table 3-18. In general, chemical characteristics of discharges to the injection wells appear to be relatively similar for the majority of the measured parameters. However, exceptions to this generality are present for NO_x, based upon the elevated value for this parameter observed in Injection Well 1, as well as for fecal coliform which exhibits somewhat higher concentrations in discharges to Injection Well 2. Elevated levels of total iron were also observed in discharges to Injection Well 2 compared with the mean value for Injection Well 1. However, chemical characteristics for the remaining parameters appear to be relatively similar.

TABLE 3-18

COMPARISON OF MEAN CHARACTERISTICS OF DISCHARGES TO INJECTION WELLS 1 AND 2

Parameter	Units	Injection Well 1	Injection Well 2
pH	s.u.	7.31	7.42
Spec. Cond.	µmho/cm	1,011	528
Alkalinity	mg/l	92	106
NH3-N	µg/l	184	377
NO2 + NO3-N	µg/l	965	174
Diss. Organic N	µg/l	1,238	1,183
Particulate N	µg/l	1,001	938
Diss. Total N	µg/l	2,386	1,734
Total N	µg/l	3,387	2,672
Diss. Ortho-P	µg/l	448	389
Diss. Organic P	µg/l	41	45
Particulate P	µg/l	89	53
Diss. Total P	µg/l	489	434
Total P	µg/l	578	487
Turbidity	NTU	6.2	7.9
TSS	mg/l	26.6	15.9
BOD5	mg/l	6.7	7.6
Chlorophyll-a	mg/m3	< 1	< 1
Chloride	mg/l	272	321
Fecal Coliform	No./100 ml	308	1123
Diss. Cadmium	µg/l	< 1	< 1
Total Cadmium	µg/l	< 1	< 1
Diss. Chromium	µg/l	< 5	< 5
Total Chromium	µg/l	< 5	< 5
Diss. Copper	µg/l	6	11
Total Copper	µg/l	13	15
Diss. Iron	µg/l	17	46
Total Iron	µg/l	27	108
Diss. Lead	µg/l	< 2	< 2
Total Lead	µg/l	< 2	< 2
Diss. Zinc	µg/l	26	22
Total Zinc	µg/l	43	34

TABLE 3-19

MEAN CHARACTERISTICS OF SHALLOW GROUNDWATER SAMPLES COLLECTED AT THE POND MONITORING SITES

Parameter	Units	P-1	P-2	P-3	Overall
Ph	s.u.	6.76	6.80	6.81	6.79
Temperature	°C	27.43	27.53	27.99	27.65
Spec. Cond.	µmho/cm	26,662	28,537	21,985	25,728
Salinity	Ppt	16.4	17.6	13.2	15.7
ORP	MV	23	40	48	37
Alkalinity	mg/l	668	573	602	614
NH_3-N	µg/l	16,811	18,982	12,857	16,217
$NO_2 + NO_3$-N	µg/l	< 5	< 5	13	13
Diss. Organic N	µg/l	8,360	8,559	4,812	7,243
Total N	µg/l	25,175	27,546	17,682	23,468
Diss. Ortho-P	µg/l	113	155	99	122
Diss. Organic P	µg/l	121	121	104	116
Total P	µg/l	234	276	203	238
BOD_5	mg/l	97	116	94	103
Chloride	mg/l	6,605	8,566	9,843	8,338
Fecal Coliform	No./100 ml	160	17	3	60
Total Cadmium	µg/l	< 1	< 1	< 1	< 1
Total Chromium	µg/l	3	3	3	3
Total Copper	µg/l	20	30	22	24
Total Iron	µg/l	54	90	82	75
Total Lead	µg/l	< 2	4	4	4
Total Zinc	µg/l	10	15	9	11

3.6 Characteristics of Shallow Groundwater

As discussed in Section 2.2.3, a series of groundwater piezometers was installed in pond, adjacent, and control areas to evaluate potential impacts of the pond on shallow groundwater. Three shallow piezometers/monitoring wells were installed in the pond area, with an additional four piezometers/monitoring wells installed in adjacent areas, and two in control areas. Each of the shallow monitoring wells extended to a depth of approximately 1.5 (5 ft) below the ground surface at each site. Shallow groundwater samples were collected from each of the piezometers on a monthly basis during the 16-month monitoring period. A complete listing of the chemical characteristics of shallow groundwater samples collected at the pond, adjacent, and control sites is given in Appendix H.

A statistical summary of the chemical characteristics of shallow groundwater in pond, adjacent, and control areas is given in Appendix I. In general, an extremely high degree of variability is apparent in concentrations for measured parameters at each of the nine sites. A high degree of variability is apparent in measured values for specific conductivity, alkalinity, ammonia, dissolved organic nitrogen, total nitrogen, dissolved orthophosphorus, dissolved organic phosphorus, total phosphorus, BOD, and chloride. Measured values for many of these parameters covered one order of magnitude or more between minimum and maximum values measured during the 16-month monitoring period. In general, it appears that the highest degree of variability was observed in groundwater connected beneath the pond and adjacent areas with substantially lower variability in groundwater characteristics observed in the two control areas. A summary of mean characteristics of shallow groundwater samples collected at pond, adjacent, and control sites is given in the following sections.

3.6.1 Pond Area

Mean characteristics of shallow groundwater samples collected at three pond monitoring sites are summarized in Table 3-19. In general, chemical characteristics are relatively similar in groundwater samples collected at the three separate monitoring sites. Mean pH values of groundwater samples were found to be slightly less than neutral, with an overall mean pH of 6.79. Shallow groundwater samples in the pond area also contained high levels of dissolved ions, as indicated by the elevated specific conductivity values. The mean conductivity value of 25,728 µmho/cm indicates brackish conditions and is equivalent to a salinity of approximately 15.7 ppt. Groundwater beneath the pond area is also highly buffered, with mean alkalinity in excess of 600 mg/l.

Shallow groundwater beneath the pond was found to contain extremely elevated levels of ammonia, with an overall mean in excess of 16 µg/l. Ammonia is clearly the dominant nitrogen species present, comprising approximately 69% of the mean nitrogen concentration of 23,498 µg/l measured at the site. Extremely low levels of NO_X were observed in the shallow groundwater, with most samples exhibiting concentrations less than 10 µg/l. The remaining nitrogen is contributed by dissolved organic nitrogen.

In contrast to the trends exhibited by nitrogen species, phosphorus concentrations beneath the pond are similar to values measured in runoff, with an overall mean phosphorus concentration of 238 µg/l. Dissolved organic phosphorus is the dominant phosphorus species beneath the pond, comprising approximately 68% of the total phosphorus measured, with the remaining contributed by dissolved organic phosphorus.

Elevated levels of BOD were observed beneath the detention pond with a mean value in excess of 100 mg/l. Substantially elevated levels of chloride were also observed beneath the pond. In general, concentrations of fecal coliform bacteria were relatively low in value in shallow groundwater.

Measured heavy metal concentrations beneath the pond appear to be relatively low in value for each of the six measured metals. Concentrations of total cadmium and total chromium were below applicable detection limits for these parameters. Concentrations of the remaining parameters appear to be equal to or less than values measured in runoff inputs into the pond.

3.6.2 Adjacent Areas

A summary of mean characteristics of shallow groundwater samples collected at the monitoring sites adjacent to the pond is given in Table 3-20. In general, chemical characteristics of groundwater samples collected from the adjacent areas are similar to values measured beneath the pond. Groundwater beneath the adjacent areas are characterized by approximately neutral pH values, with elevated levels of specific conductivity and chloride. Groundwater in adjacent areas was also found to be relatively well buffered, with a mean alkalinity of approximately 840 mg/l. Elevated concentrations of BOD were also observed with a mean in excess of 100 mg/l.

Measured concentrations of nitrogen species beneath the adjacent areas are similar to those observed beneath the detention pond. Ammonia concentrations in groundwater appear to be extremely elevated, with an overall mean of approximately 14.5 mg/l. Ammonia is the dominant nitrogen species in shallow groundwater comprising 63% of the total nitrogen present. Concentrations of NO_X appear to be extremely low in value, with the remaining nitrogen contributed by dissolved organic nitrogen. Total phosphorus concentrations beneath the adjacent areas appear to be slightly lower than those measured beneath the pond, with an overall mean of 179 µg/l. Dissolved organic phosphorus is the dominant phosphorus species in the adjacent areas, contributing approximately 72% of the total phosphorus measured.

In general, measured heavy metal concentrations beneath the adjacent areas are similar to values measured beneath the pond with the exception of a slightly higher mean value for total iron observed in the adjacent areas.

TABLE 3-20

MEAN CHARACTERISTICS OF SHALLOW GROUNDWATER SAMPLES COLLECTED AT THE ADJACENT MONITORING SITES

Parameter	Units	A-1	A-2	A-3	A-4	Overall
pH	s.u.	6.73	6.66	6.97	6.87	6.81
Temperature	°C	27.26	27.25	27.93	28.01	27.61
Spec. Cond.	μmho/cm	30,652	33,452	25,853	18,529	27,121
Salinity	Ppt	19.2	21.0	16.0	11.0	16.8
ORP	MV	21	29	45	41	34
Alkalinity	mg/l	763	1,308	631	659	840
NH_3-N	μg/l	14,867	22,230	11,142	9,812	14,513
NO_2 + NO_3-N	μg/l	29	17	12	12	17
Diss. Organic N	μg/l	8,556	12,281	4,166	9,483	8,622
Total N	μg/l	23,453	34,528	15,320	19,307	23,152
Diss. Ortho-P	μg/l	97	157	70	70	98
Diss. Organic P	μg/l	97	99	55	72	81
Total P	μg/l	194	256	125	142	179
BOD_5	mg/l	114	133	78.9	96.9	106
Chloride	mg/l	10,662	10,287	5,445	5,642	8,009
Fecal Coliform	No./100 ml	8	3	86	9	26
Total Cadmium	μg/l	< 1	< 1	< 1	< 1	< 1
Total Chromium	μg/l	3	3	3	3	3
Total Copper	μg/l	34	32	21	23	27
Total Iron	μg/l	124	102	173	65	116
Total Lead	μg/l	3	5	< 2	< 2	4
Total Zinc	μg/l	13	12	10	10	11

3.6.3 Control Areas

A summary of mean characteristics of shallow groundwater samples collected at the control monitoring sites is given in Table 3-21. Groundwater in the control area was found to be approximately neutral in pH, with elevated values of specific conductivity and chloride. Control area groundwater was found to be well buffered, with a mean alkalinity in excess of 500 mg/l. BOD concentrations were also somewhat elevated beneath control areas, with a mean of 62.6 mg/l.

Similar to the trends observed in the pond and adjacent sites, elevated levels of ammonia were observed beneath the control areas. Ammonia is clearly the dominant nitrogen species beneath the control areas, comprising approximately 66% of the mean total nitrogen concentration of 11,544 µg/l measured at the site. Mean concentrations of NO_X are extremely low in value, with the remaining nitrogen contributed primarily by dissolved organic nitrogen.

Measured total phosphorus concentrations beneath the control areas were found to be somewhat lower in value than observed under pond or adjacent areas. Dissolved organic phosphorus appears to be the dominant phosphorus species in the control areas, followed by dissolved orthophosphorus.

In general, heavy metal concentrations collected in groundwater samples beneath the control area are similar to values measured beneath pond and adjacent areas. Measured concentrations of total cadmium and total chromium were found at below detectable limits in all collected samples.

3.6.4 Comparison of Shallow Groundwater Characteristics in Pond, Adjacent and Control Areas

A comparison of mean characteristics of shallow groundwater samples collected in pond, adjacent, and control areas is given in Table 3-22. In general, the chemical characteristics measured beneath pond and adjacent areas appear to be relatively similar for the majority of the measured parameters. The most notable exception to this generality appears to be the slightly lower phosphorus concentrations observed beneath the adjacent areas compared with concentrations measured beneath the pond.

In contrast, the control area appears to have lower concentrations for most measured parameters than observed in either pond or adjacent sites. Groundwater collected beneath the control area was found to exhibit lower concentrations of specific conductivity, alkalinity, ammonia, dissolved organic nitrogen, total nitrogen, dissolved orthophosphorus, dissolved organic phosphorus, total phosphorus, BOD, chloride, and fecal coliform bacteria compared with values measured at the other monitoring sites. Mean concentrations of heavy metals appear to be similar at each of the three general areas.

TABLE 3-21

MEAN CHARACTERISTICS OF SHALLOW GROUNDWATER SAMPLES COLLECTED AT THE CONTROL MONITORING SITES

Parameter	Units	C-1	C-2	Overall
pH	s.u.	6.88	6.94	6.91
Temperature	°C	27.74	28.32	28.03
Spec. Cond.	µmho/cm	22,139	25,626	23,882
Salinity	ppt	13.4	15.7	14.6
ORP	mV	47	76	62
Alkalinity	mg/l	526	492	509
NH_3-N	µg/l	7,898	7,349	7,623
$NO_2 + NO_3$-N	µg/l	19	12	16
Diss. Organic N	µg/l	4,860	2,951	3,905
Total N	µg/l	12,777	10,312	11,544
Diss. Ortho-P	µg/l	53	40	46
Diss. Organic P	µg/l	66	60	64
Total P	µg/l	119	100	110
BOD_5	mg/l	72	53	63
Chloride	mg/l	6,096	8,415	7,255
Fecal Coliform	No./100 ml	9	4	6
Total Cadmium	µg/l	< 1	< 1	< 1
Total Chromium	µg/l	3	3	3
Total Copper	µg/l	20	29	25
Total Iron	µg/l	150	69	109
Total Lead	µg/l	9	< 2	9
Total Zinc	µg/l	10	9	10

TABLE 3-22

COMPARISON OF MEAN SHALLOW GROUNDWATER CHARACTERISTICS IN POND, ADJACENT, AND CONTROL AREAS

PARAMETER	UNITS	POND	ADJACENT	CONTROL
pH	s.u.	6.79	6.81	6.91
Temperature	□C	27.65	27.61	28.03
Spec. Conductivity	µmho/cm	25,728	27,121	23,882
Salinity	ppt	15.7	16.8	14.6
ORP	mV	37	34	62
Alkalinity	mg/l	614	840	509
NH_3-N	µg/l	16,217	14,513	7,623
$NO_2 + NO_3$-N	µg/l	6	17	16
Diss. Organic N	µg/l	7,243	8,622	3,905
Total N	µg/l	23,468	23,152	11,544
Diss. Ortho-P	µg/l	122	98	46
Diss. Organic P	µg/l	116	81	64
Total P	µg/l	238	179	110
BOD_5	mg/l	103	106	62.6
Chloride	mg/l	8,338	8,009	7,255
Fecal Coliform	No./100 ml	60	26	6
Total Cadmium	µg/l	< 1	< 1	< 1
Total Chromium	µg/l	< 5	< 5	< 5
Total Copper	µg/l	24	27	25
Total Iron	µg/l	75	116	109
Total Lead	µg/l	3	3	5
Total Zinc	µg/l	11	11	10

An analysis of variance (ANOVA) comparison was conducted to determine if measured differences in groundwater characteristics in pond, adjacent, and control areas are statistically significant at the 0.05 level of significance. For parameters which exhibit significant differences between the groundwater characteristics in the three areas, Tukey's multiple comparison technique is used to evaluate similarities and differences between the three data sets.

The results of an ANOVA comparison of shallow groundwater characteristics in pond, adjacent, and control areas is given in Table 3-23. No statistically significant differences were observed in chemical characteristics between the three general areas for the majority of measured parameters, including temperature, salinity, conductivity, alkalinity, NO_X, chloride, fecal coliform bacteria, total cadmium, total chromium, total copper, total iron, total lead, and total zinc. However, statistically significant differences were observed for many species of nitrogen and phosphorus, along with BOD. For each parameter which exhibited a statistically significant difference, the highest measured concentrations were observed in pond and adjacent areas, which were determined to be statistically similar for each of these parameters.

3.7 Characteristics of Injection Wells

Water samples were collected from each of the two Class V drainage/injection wells on a monthly basis throughout the 16-month monitoring period. Separate samples were collected from the surface (0.5 m), middle (12 m), and bottom (24 m) of the two drainage wells for a total of six samples collected from the two wells for each monthly monitoring event. A listing of the chemical characteristics of injection well samples collected from July 2001-October 2002 is given in Appendix J. A statistical summary of samples collected from Injection Well 1 and 2 is given in Appendix K.

3.7.1 Injection Well 1

As seen in Appendix K.1, a high degree of variability was observed in injection well samples collected at the surface monitoring location. A high degree of variability in measured values is particularly apparent for alkalinity, ammonia, dissolved organic nitrogen, particulate nitrogen, orthophosphorus, dissolved organic phosphorus, particulate phosphorus, chloride, fecal coliform bacteria, and total iron. Many of the measured values for these parameters cover one order of magnitude or more between minimum and maximum values.

A high degree of variability is also apparent in samples collected at the middle monitoring location from Injection Well 1. A high level of variability was observed for conductivity, ammonia, dissolved organic nitrogen, particulate nitrogen, orthophosphorus, dissolved organic phosphorus, particulate phosphorus, total phosphorus, turbidity, TSS, chloride, and total iron. In general, the variability observed in samples collected at the middle monitoring location appears to be greater than variability observed at the surface location.

High levels of variability were also observed in groundwater samples collected at the deep monitoring location. High levels of variability are apparent for a number of parameters including dissolved organic nitrogen, particulate nitrogen, total nitrogen, orthophosphorus, dissolved organic phosphorus, particulate phosphorus, total phosphorus, and total iron.

TABLE 3-23

ANOVA COMPARISON OF SHALLOW GROUNDWATER CHARACTERISTICS IN POND, ADJACENT, AND CONTROL AREAS

PARAMETER	PROB. OF UNEQUAL MEANS	WELL AREA[1]	MEAN CONCENTRATION	NUMBER OF OBSERVATIONS	TUKEY'S MULTIPLE COMPARISON
pH	99.5	C	6.91	32	A
(s.u.)		A	6.81	64	B
		P	6.79	48	B
Temperature	76.9	C	28.03	32	NSD[2]
(□C)		P	27.65	48	
		A	27.61	64	
Salinity	81.5	A	16.8	64	NSD
(ppt)		P	15.7	48	
		C	14.5	32	
Diss. O_2	99.9	C	1.1	32	A
(mg/l)		A	0.9	64	B
		P	0.7	48	B
ORP	99.9	C	62	32	A
(mV)		P	38	48	B
		A	34	64	B
Conductivity	77.3	A	27,121	64	NSD
(µmho/cm)		P	25,728	48	
		C	23,882	32	
Alkalinity	88.3	A	840	64	NSD
(mg/l)		P	615	48	
		C	509	32	
NH_3	99.8	P	16,217	48	A
(µg/l)		A	14,513	64	A
		C	7,623	32	B
NO_x	82.2	A	17	64	NSD
(µg/l)		C	16	32	
		P	7	48	
Diss. Organic N	97.2	A	8,622	64	A
(µg/l)		P	7,243	48	A
		C	3,905	32	B
Total N	99.9	P	23,468	48	A
(µg/l)		A	23,152	64	A
		C	11,544	32	B
Ortho-P	99.6	P	122	48	A
(µg/l)		A	98	64	A
		C	46	32	B
Diss. Organic P	98.2	P	116	48	A
(µg/l)		A	80	64	A
		C	63	32	B

1. Well Area: A = Adjacent, C = Control, and P = Pond
2. NSD: No significant difference at the 0.05 level

TABLE 3-23 -- CONTINUED

ANOVA COMPARISON OF SHALLOW GROUNDWATER CHARACTERISTICS IN POND, ADJACENT, AND CONTROL AREAS

PARAMETER	PROB. OF UNEQUAL MEANS	WELL AREA[1]	MEAN CONCENTRATION	NUMBER OF OBSERVATIONS	TUKEY'S MULTIPLE COMPARISON
Total P (µg/l)	99.9	P A C	238 179 110	48 64 32	A A B
BOD (mg/l)	99.5	A P C	106 103 63	64 48 32	A A B
Chloride (mg/l)	31.2	P A C	8,338 8,009 7,255	48 64 32	NSD
Fecal Coliform (# organisms/ 100 ml)	47.1	P A C	60 26 6	48 64 32	NSD
Total Cd (µg/l)	0.00	A C P	< 1 < 1 < 1	64 32 48	NSD
Total Cr (µg/l)	0.00	A C P	< 5 < 5 < 5	64 32 48	NSD
Total Cu (µg/l)	70.7	A C P	27 25 24	64 32 48	NSD
Total Fe (µg/l)	72.6	A C P	116 109 75	64 32 48	NSD
Total Pb (µg/l)	52.9	C P A	5.1 2.9 2.6	32 48 64	NSD
Total Zn (µg/l)	31.5	P A C	11 11 10	48 64 32	NSD

1. Well Area: A = Adjacent, C = Control, and P = Pond
2. NSD: No significant difference at the 0.05 level

3.7.1.1 General Parameters

A comparison of mean chemical characteristics of shallow, middle, and deep samples collected from Injection Well 1 is given Table 3-24. In general, pH values within Injection Well 1 are slightly alkaline with measured values ranging from 7.61-8.02. A slight trend of decreasing pH with increasing depth is apparent. Measured temperatures within Injection Well 1 also appear to decrease slightly with increasing water depth. The measured ORP values suggest borderline oxic and anoxic conditions at the shallow monitoring site, with reduced conditions observed at the middle and deep monitoring sites. Redox potentials in excess of 200 mV typically indicate oxidized conditions, while ORP readings less that 200 mV are indicative of reduced conditions.

A trend of increasing specific conductivity with increasing depth is also apparent within Injection Well 1. This trend is also apparent in measurements of salinity which increase from approximately 2.9 ppt near the surface to 31.1 ppt toward the bottom. Based on the measured salinity values, the well exhibits brackish water characteristics at all depths. Water within the injection well appears to be well buffered with a general trend of decreasing alkalinity with increasing water depth. Measured concentrations of TSS and BOD appear to be similar in shallow and deep samples, with a slight increase in these parameters observed at the middle monitoring location. A fecal coliform count of approximately 197 organisms/100 ml at the shallow monitoring location with values of approximately 1 organism/100 ml at the middle and deep sites.

3.7.1.2 Nutrients

In general, measured concentrations of nitrogen species appear to be moderate to low in value within Injection Well 1. A general trend of decreasing nitrogen concentration with increasing depth is apparent for the majority of the measured nitrogen parameters. The dominant nitrogen species at the shallow depth is dissolved organic nitrogen, which comprises approximately 47% of the total nitrogen present. However, ammonia is the dominant species present in the middle samples with particulate nitrogen comprising the dominant nitrogen species in deep samples. Measured concentrations of NO_X are extremely low in value at each of the three monitoring sites. The lower nitrogen concentrations observed at the middle and deep monitoring sites may be a result of dilution at these depths or possibly a result of nitrogen loss occurring as a result of denitrification in the reduced environment present at these depths. Total nitrogen concentrations decrease by approximately 57% between the shallow and the deep samples.

Similar to the trend observed for nitrogen species, species of phosphorus also decrease with increasing depth in the injection well. At the shallow monitoring location, orthophosphorus is the dominant phosphorus species, comprising 63% of the phosphorus measured. Orthophosphorus is still the dominant phosphorus species in the middle samples, although the mean concentration is less than half that observed at the shallow depth. At the deep monitoring location, particulate phosphorus becomes the dominant phosphorus species, followed closely by dissolved orthophosphorus. Orthophosphorus concentrations decrease by a approximately 85% between the shallow and the deep monitoring sites, with a corresponding decrease of approximately 74% for total phosphorus.

TABLE 3-24

COMPARISON OF MEAN CHEMICAL CHARACTERISTICS OF SHALLOW, MIDDLE, AND DEEP SAMPLES COLLECTED FROM INJECTION WELL 1

PARAMETER	UNITS	SHALLOW	MIDDLE	DEEP
pH	s.u.	8.02	8.00	7.61
Temperature	□C	27.75	26.89	26.53
Spec. Conductivity	µmho/cm	5,159	42,624	48,682
Salinity	ppt	2.9	28.0	31.9
ORP	mV	208	110	142
Alkalinity	mg/l	241	178	119
NH_3-N	µg/l	865	703	144
$NO_2 + NO_3$-N	µg/l	< 5	6	6
Diss. Organic N	µg/l	1,280	596	450
Particulate N	µg/l	596	659	569
Total N	µg/l	2,746	1,964	1,169
Diss. Ortho-P	µg/l	383	170	59
Diss. Organic P	µg/l	118	80	34
Particulate P	µg/l	111	79	65
Total P	µg/l	612	329	158
Turbidity	NTU	7.8	21.9	1.6
TSS	mg/l	3.9	24.8	3.4
BOD_5	mg/l	3.5	5.8	3.1
Chloride	mg/l	1,257	15,174	21,198
Fecal Coliform	No./100 ml	197	1	1
Total Cadmium	µg/l	< 1	< 1	< 1
Total Chromium	µg/l	< 5	< 5	< 5
Total Copper	µg/l	12	40	55
Total Iron	µg/l	1,031	1,543	258
Total Lead	µg/l	< 2	< 2	12
Total Zinc	µg/l	11	13	10

3.7.1.3 Heavy Metals

In general, measured concentrations of cadmium, chromium, and lead were found at below detectable limits in virtually all of the injection well samples. Detectable levels of copper and zinc were observed, although the measured concentrations appear to be low to moderate in value. Somewhat elevated levels of total iron were observed, particularly at the shallow and middle monitoring locations where total iron concentrations exceeded 1 μg/l.

3.7.2 Injection Well 2

A statistical summary of samples collected from Injection Well 2 is given in Appendix K.2. In general, a relatively high degree of variability was observed in measured parameters collected from shallow, middle, and deep portions of Injection Well 2. A high degree of variability is particularly apparent for specific conductivity in the shallow and middle samples, with a relatively small degree of variability present in specific conductivity collected in the deep sample. A relatively high degree of variability is also apparent in measured concentrations for alkalinity, ammonia, dissolved organic nitrogen, particulate nitrogen, total nitrogen, orthophosphorus, dissolved organic phosphorus, particulate phosphorus, total phosphorus, chloride, fecal coliform, and total iron. Measured values for each of these parameters cover approximately one order of magnitude or more between minimum and maximum values.

3.7.2.1 General Characteristics

A comparison of mean chemical characteristics of shallow, middle, and deep samples collected from Injection Well 2 is given in Table 3-25. In general, trends of many measured parameters in Injection Well 2 are similar to the trends observed in Injection Well 1. Measured pH values appear to be slightly alkaline within Injection Well 2, with a trend of decreasing pH with increasing sample depth. A reverse trend is apparent for specific conductivity, which exhibits a trend of increasing concentration with increasing depth. Measured alkalinity values exhibit a trend of increasing value, with increasing depth in Injection Well 2, while the opposite trend is apparent in Injection Well 1. Measured turbidity and suspended solids values in Injection Well 2 appear to be slightly lower than observed in Injection Well 1, particularly at the middle monitoring depth. Measured BOD was found at below detectable limits at each of the three monitoring depths in Injection Well 2. Similar to the trend observed in Injection Well 1, fecal coliform concentrations in Injection Well 2 decrease rapidly with increasing sample depth.

A slight trend of decreasing temperature with increasing sample depth is apparent in Injection Well 2 similar to the trend exhibited in Injection Well 1. Salinity and chloride concentrations increase rapidly with increasing depth, similar to the pattern observed in Injection Well 1. Mean ORP values suggest an oxidized environment in the shallow portions of Injection Well 2, with predominantly reduced conditions at the middle and deep monitoring depths.

TABLE 3-25

COMPARISON OF MEAN CHEMICAL CHARACTERISTICS OF SHALLOW, MIDDLE, AND DEEP SAMPLES COLLECTED FROM INJECTION WELL 2

PARAMETER	UNITS	SHALLOW	MIDDLE	DEEP
pH	s.u.	8.24	7.82	7.47
Temperature	°C	27.18	26.32	25.76
Spec. Conductivity	µmho/cm	11,106	39,378	51,186
Salinity	ppt	6.93	25.73	33.70
ORP	mV	291	183	180
Alkalinity	mg/l	131	137	149
NH_3-N	µg/l	117	146	149
$NO_2 + NO_3$-N	µg/l	31	14	8
Diss. Organic N	µg/l	621	301	390
Particulate N	µg/l	654	385	425
Total N	µg/l	1,424	846	972
Diss. Ortho-P	µg/l	72	29	10
Diss. Organic P	µg/l	53	35	23
Particulate P	µg/l	32	50	30
Total P	µg/l	157	114	63
Turbidity	NTU	4.8	10.8	2.2
TSS	mg/l	4.5	13.5	3.5
BOD_5	mg/l	< 2	< 2	< 2
Chloride	mg/l	1,766	15,409	19,680
Fecal Coliform	No./100 ml	5,021	51	9
Total Cadmium	µg/l	< 1	< 1	< 1
Total Chromium	µg/l	< 5	< 5	< 5
Total Copper	µg/l	17	39	42
Total Iron	µg/l	542	664	142
Total Lead	µg/l	< 2	10	8
Total Zinc	µg/l	11	8	6

3.7.2.2 Nutrients

In general, measured concentrations of nitrogen species appear to be relatively low in value in Injection Well 2 compared with values measured in Injection Well 1. The vast majority of nitrogen in Injection Well 2 is comprised of dissolved organic nitrogen and particulate nitrogen, with relatively small contributions from ammonia and NO_X. A slight trend of increase in ammonia concentrations with increasing depth is apparent in Injection Well 2, while the reverse trend is apparent for Injection Well 1.

Measured total phosphorus concentrations in Injection Well 2 are also substantially lower than values measured in Injection Well 1. The dominant phosphorus species observed in Injection Well 2 are dissolved orthophosphorus at the shallow depth, and particulate phosphorus at the deeper depths.

3.7.2.3 Heavy Metals

Measured concentrations of total cadmium, total chromium, and total lead appear to be extremely low in value at all monitoring depths in Injection Well 2. Measured total copper concentrations appear to increase with increasing sample depth with mean values, similar to those observed in Injection Well 1. Total iron concentrations increase slightly from the shallow to the middle sample, followed by a rapid decrease in the deep sample. This same trend is also present for Injection Well 1.

3.7.3 Comparison of Drainage Well Characteristics by Depth

ANOVA comparisons were performed to examine differences in chemical characteristics between Injection Well 1 and Injection Well 2 at each of the three monitored depths. As indicated in Table 3-8, Injection Well 1 received approximately 93% of the total discharges to the two injection wells, with only 7% of the total injection well inputs discharging to Injection Well 2. As a result, Injection Well 2 can be used as a quasi-control site since it was largely unaffected by runoff inputs during the majority of the monitoring period.

The results of an ANOVA comparison of injection well characteristics collected at the shallow monitoring depth is given in Table 3-26. No statistically significant differences between the two injection wells were observed for pH, temperature, conductivity, salinity, alkalinity, dissolved organic phosphorus, BOD, chloride, fecal coliform, cadmium, chromium, copper, iron, lead, and zinc. However, statistically significant differences were observed between measured concentrations of dissolved oxygen, ORP, ammonia, NO_X, dissolved organic nitrogen, total nitrogen, orthophosphorus, and total phosphorus. With the exceptions of dissolved oxygen, ORP, and NO_X, statistically higher concentrations were observed in Injection Well 1 compared with values measured in Injection Well 2 for all species exhibiting statistically significant differences.

TABLE 3-26

ANOVA COMPARISON OF INJECTION WELL CHARACTERISTICS COLLECTED AT THE "SHALLOW" MONITORING DEPTH

PARAMETER	PROB. OF UNEQUAL MEANS	WELL SITE[1]	MEAN CONCENTRATION	NUMBER OF OBSERVATIONS	TUKEY'S MULTIPLE COMPARISON
pH (s.u.)	81.4	2 1	8.24 8.02	16 16	NSD[2]
Temperature (°C)	52.6	1 2	27.75 27.18	16 16	NSD
Salinity (ppt)	84.9	2 1	6.94 2.85	16 16	NSD
Diss. O_2 (mg/l)	99.2	2 1	1.20 0.80	16 16	A B
ORP (mV)	99.9	2 1	291 208	16 16	A B
Conductivity (µmho/cm)	82.6	2 1	11,106 5,159	16 16	NSD
Alkalinity (mg/l)	94.8	1 2	241 131	16 16	NSD
NH_3 (µg/l)	99.9	1 2	865 117	16 16	A B
NO_x (µg/l)	96.7	2 1	31 5	16 16	A B
Diss. Organic N (µg/l)	97.9	1 2	1,280 621	16 16	A B
Total N (µg/l)	99.2	1 2	2,746 1,424	16 16	A B
Ortho-P (µg/l)	99.9	1 2	383 72	16 16	A B
Diss. Organic P (µg/l)	90.8	1 2	118 53	16 16	NSD

1. Well Area: 1 = Injection Well 1 and 2 = Injection Well 2
2. NSD: No significant difference at the 0.05 level

TABLE 3-26 -- CONTINUED

ANOVA COMPARISON OF INJECTION WELL CHARACTERISTICS COLLECTED AT THE "SHALLOW" MONITORING DEPTH

PARAMETER	PROB. OF UNEQUAL MEANS	WELL SITE[1]	MEAN CONCENTRATION	NUMBER OF OBSERVATIONS	TUKEY'S MULTIPLE COMPARISON
Total P (µg/l)	99.9	1 2	612 160	16 16	A B
BOD (mg/l)	76.3	1 2	3.5 1.8	16 16	NSD
Chloride (mg/l)	27.5	2 1	1,766 1,257	16 16	NSD
Fecal Coliform (# organisms/100 ml)	78.4	2 1	5,021 197	16 16	NSD
Total Cd (µg/l)	0.0	1 2	< 1 < 1	16 16	NSD
Total Cr (µg/l)	0.0	1 2	< 5 < 5	16 16	NSD
Total Cu (µg/l)	53.1	2 1	17 12	16 16	NSD
Total Fe (µg/l)	94.5	1 2	1,031 542	16 16	NSD
Total Pb (µg/l)	0.0	1 2	< 2 < 2	16 16	NSD
Total Zn (µg/l)	21.4	2 1	11 11	16 16	NSD

1. Well Area: 1 = Injection Well 1 and 2 = Injection Well 2
2. NSD: No significant difference at the 0.05 level

The results of an ANOVA comparison of injection well characteristics collected at the middle monitoring depth are given in Table 3-27. No statistically significant differences were observed between the two wells for measured values of pH, temperature, salinity, dissolved oxygen, conductivity, alkalinity, NO_X, dissolved organic nitrogen, dissolved organic phosphorus, chloride, cadmium, chromium, copper, lead, and zinc. However, statistically significant differences were observed in measured concentrations of ORP, ammonia, total nitrogen, orthophosphorus, total phosphorus, BOD, fecal coliform, and total iron between middle samples collected in the two wells. In each case where statistically significant differences were observed, the highest measured concentrations for these statistically significant parameters were observed at Injection Well 1, with the exceptions of ORP and fecal coliform which were higher in Injection Well 2.

The results of an ANOVA comparison of injection well characteristics collected at the deep monitoring depth are given in Table 3-28. In the deep monitoring well samples, statistically significant differences were observed for temperature, ORP, total phosphorus and BOD, all of which, with the exception of ORP, were higher in value at Injection Well 1 than Injection Well 2. No statistically significant differences were observed in any of the other measured parameters between the two injection wells.

TABLE 3-27

ANOVA COMPARISON OF INJECTION WELL CHARACTERISTICS COLLECTED AT THE "MIDDLE" MONITORING DEPTH

PARAMETER	PROB. OF UNEQUAL MEANS	WELL SITE[1]	MEAN CONCENTRATION	NUMBER OF OBSERVATIONS	TUKEY'S MULTIPLE COMPARISON
pH (s.u.)	68.5	1 2	8.00 7.82	16 16	NSD[2]
Temperature (□C)	76.3	1 2	26.89 26.32	16 16	NSD
Salinity (ppt)	37.5	1 2	28.01 25.73	16 16	NSD
Diss. O_2 (mg/l)	86.0	2 1	0.83 0.66	16 16	NSD
ORP (mV)	99.9	2 1	183 110	16 16	A B
Conductivity (µmho/cm)	35.7	1 2	42,624 39,378	16 16	NSD
Alkalinity (mg/l)	62.2	1 2	178 137	16 16	NSD
NH_3 (µg/l)	99.9	1 2	703 146	16 16	A B
NO_x (µg/l)	61.0	2 1	14 6	16 16	NSD
Diss. Organic N (µg/l)	91.3	1 2	596 301	16 16	NSD
Total N (µg/l)	99.5	1 2	1,964 846	16 16	A B
Ortho-P (µg/l)	99.9	1 2	170 29	16 16	A B
Diss. Organic P (µg/l)	79.1	1 2	80 35	16 16	NSD

1. Well Area: 1 = Injection Well 1 and 2 = Injection Well 2
2. NSD: No significant difference at the 0.05 level

TABLE 3-27 -- CONTINUED

ANOVA COMPARISON OF INJECTION WELL CHARACTERISTICS COLLECTED AT THE "MIDDLE" MONITORING DEPTH

PARAMETER	PROB. OF UNEQUAL MEANS	WELL SITE[1]	MEAN CONCENTRATION	NUMBER OF OBSERVATIONS	TUKEY'S MULTIPLE COMPARISON
Total P (µg/l)	99.9	1 2	329 114	16 16	A B
BOD (mg/l)	99.9	1 2	5.8 1.4	16 16	A B
Chloride (mg/l)	5.8	2 1	15,409 15,174	16 16	NSD
Fecal Coliform (# organisms/100 ml)	99.0	2 1	51 1	16 16	A B
Total Cd (µg/l)	0.0	1 2	< 1 < 1	16 16	NSD
Total Cr (µg/l)	0.0	1 2	< 5 < 5	16 16	NSD
Total Cu (µg/l)	6.7	1 2	40 39	16 16	NSD
Total Fe (µg/l)	98.3	1 2	1,543 664	16 16	A B
Total Pb (µg/l)	67.5	2 1	10 1	16 16	NSD
Total Zn (µg/l)	82.1	1 2	13 8	16 16	NSD

1. Well Area: 1 = Injection Well 1 and 2 = Injection Well 2
2. NSD: No significant difference at the 0.05 level

TABLE 3-28

ANOVA COMPARISON OF INJECTION WELL CHARACTERISTICS COLLECTED AT THE "DEEP" MONITORING DEPTH

PARAMETER	PROB. OF UNEQUAL MEANS	WELL SITE[1]	MEAN CONCENTRATION	NUMBER OF OBSERVATIONS	TUKEY'S MULTIPLE COMPARISON
pH (s.u.)	84.5	1 2	7.61 7.47	16 16	NSD[2]
Temperature (°C)	97.8	1 2	26.53 25.76	16 16	A B
Salinity (ppt)	72.3	2 1	33.7 31.9	16 16	NSD
Diss. O_2 (mg/l)	38.1	1 2	0.61 0.57	16 16	NSD
ORP (mV)	99.9	2 1	180 142	16 16	A B
Conductivity (µmho/cm)	72.9	2 1	51,186 48,482	16 16	NSD
Alkalinity (mg/l)	69.0	2 1	149 119	16 16	NSD
NH_3 (µg/l)	10.8	2 1	149 144	16 16	NSD
NO_x (µg/l)	24.5	2 1	8 6	16 16	NSD
Diss. Organic N (µg/l)	20.8	1 2	450 390	16 16	NSD
Total N (µg/l)	35.9	1 2	1,169 972	16 16	NSD
Ortho-P (µg/l)	89.8	1 2	59 10	16 16	NSD
Diss. Organic P (µg/l)	48.3	1 2	34 23	16 16	NSD

1. Well Area: 1 = Injection Well 1 and 2 = Injection Well 2
2. NSD: No significant difference at the 0.05 level

TABLE 3-28 -- CONTINUED

ANOVA COMPARISON OF INJECTION WELL CHARACTERISTICS COLLECTED AT THE "DEEP" MONITORING DEPTH

PARAMETER	PROB. OF UNEQUAL MEANS	WELL SITE[1]	MEAN CONCENTRATION	NUMBER OF OBSERVATIONS	TUKEY'S MULTIPLE COMPARISON
Total P (µg/l)	96.2	1 2	158 63	16 16	A B
BOD (mg/l)	96.6	1 2	3.1 1.3	16 16	A B
Chloride (mg/l)	73.5	1 2	21,198 19,680	16 16	NSD
Fecal Coliform (# organisms/100 ml)	93.4	2 1	9 1	16 16	NSD
Total Cd (µg/l)	0.0	1 2	< 1 < 1	16 16	NSD
Total Cr (µg/l)	0.0	1 2	< 5 < 5	16 16	NSD
Total Cu (µg/l)	67.1	1 2	55 42	16 16	NSD
Total Fe (µg/l)	82.2	1 2	258 142	16 16	NSD
Total Pb (µg/l)	26.6	1 2	12 8	16 16	NSD
Total Zn (µg/l)	85.6	1 2	10 6	16 16	NSD

1. Well Area: 1 = Injection Well 1 and 2 = Injection Well 2
2. NSD: No significant difference at the 0.05 level

3.8 Characteristics of Soils at the Key Colony Site

As discussed in Section 2.2.6, soil sampling was conducted in both pond and control areas to evaluate the potential of the pond soils for retaining stormwater pollutants. A total of 10 separate core samples was collected in the pond, with additional core samples collected from areas outside of the pond which are unaffected by runoff inputs or other potential pollutant sources. Each of the collected samples was divided into four layers: 0-1 cm, 1-5 cm, 5-10 cm, and 10-25 cm, and analyzed for physical characteristics, nutrients, and heavy metals. A complete listing of the results of laboratory and analyses on sediment sites at the Key Colony site is given in Appendix L.1. A statistical summary of the characteristics of sediment samples in pond and control areas is given in Appendix L.2.

A comparison of mean characteristics of control and pond soil samples collected at the Key Colony site is given in Table 3-29. In general, soil samples collected in the pond have a higher moisture content in each of the four layers than similar samples collected within the control area. Soil samples from the pond also have a substantially higher organic content in the 0-1 cm layer, with relatively similar characteristics between the two sites at depths below 1 cm. The elevated organic content observed in the 0-1 cm layer within the pond is probably related to soil associated with the sod used for cover within the pond.

Measured nitrogen concentrations in soils within the pond are higher in value in each of the four layers than soils collected from the control area. However, this trend is not apparent for total phosphorus which exhibits higher values in the control area in the top 5 cm. Below a depth of 5 cm, total phosphorus concentrations are higher within the pond area.

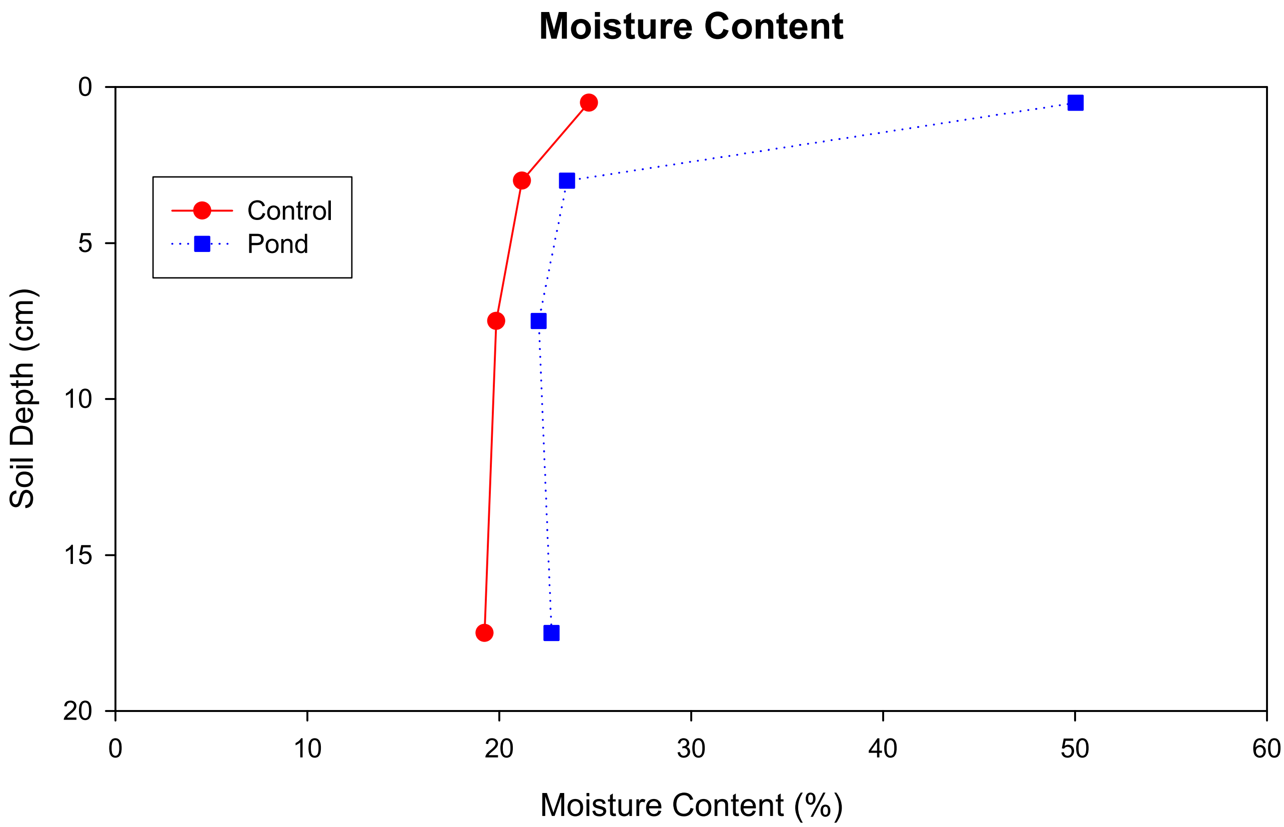
Concentrations of cadmium, chromium, and copper are extremely low in value in soils collected in both the pond and control areas, with measured values for these parameters below detectable limits for the methodology used for analysis. However, measurable levels were observed for aluminum, iron, lead, and zinc. Measured concentrations of iron and lead are greater in the pond samples in each of the four layers compared with samples collected from the control area. Sediment concentrations of aluminum are found to be greater in surface samples collected from the control site with higher concentrations in the pond site at depths greater than 1 cm. Soil concentrations of zinc are found to be greater in control areas than pond areas for three of the four evaluated layers.

A graphical comparison of soil moisture content and organic content with depth in pond and control areas is given Figure 3-7. Moisture content within the pond soils is greater than moisture content in the control areas in each of the four evaluated layers. This difference is particularly apparent in the surface layer where pond moisture contents are substantially greater than observed in the control area. Surface soil organic contents are substantially higher in the pond areas compared with the surface values at the control sites. However, at depths deeper than 1 cm, organic content appears to be relatively similar in pond and control areas.

TABLE 3-29

COMPARISON OF MEAN CHARACTERISTICS OF CONTROL AND POND SOIL SAMPLES COLLECTED AT THE KEY COLONY DETENTION POND SITE

PARAMETER	UNITS	SAMPLE DEPTH (cm)	SAMPLE LOCATION	
			CONTROL	POND
Moisture Content	Percent	0-1 1-5 5-10 10-25	24.7 21.2 19.8 19.2	50.0 23.5 22.0 22.7
Organic Content	Percent	0-1 1-5 5-10 10-25	16.4 9.9 6.1 4.2	53.0 7.1 5.9 4.8
Density	g/cm^3	0-1 1-5 5-10 10-25	1.95 2.07 2.13 2.16	1.39 2.07 2.10 2.10
Total N	µg/g wet weight	0-1 1-5 5-10 10-25	8,523 4,276 1,620 1,230	11,106 5,043 2,529 1,522
Total P	µg/g wet weight	0-1 1-5 5-10 10-25	704 1,106 128 98	414 336 213 216
Al	µg/g wet weight	0-1 1-5 5-10 10-25	682 573 526 833	426 637 707 907
Cd	µg/g wet weight	0-1 1-5 5-10 10-25	< 2 < 2 < 2 < 2	< 2 < 2 < 2 < 2
Cr	µg/g wet weight	0-1 1-5 5-10 10-25	< 10 < 10 < 10 < 10	< 10 < 10 < 10 < 10
Cu	µg/g wet weight	0-1 1-5 5-10 10-25	< 6 < 6 < 6 < 6	< 6 < 6 < 6 < 6
Fe	µg/g wet weight	0-1 1-5 5-10 10-25	668 585 515 827	870 1,083 964 1,133
Pb	µg/g wet weight	0-1 1-5 5-10 10-25	3.7 5.8 4.9 6.4	7.2 8.7 7.5 8.3
Zn	µg/g wet weight	0-1 1-5 5-10 10-25	20.2 11.2 7.4 6.2	11.0 10.7 9.3 5.2



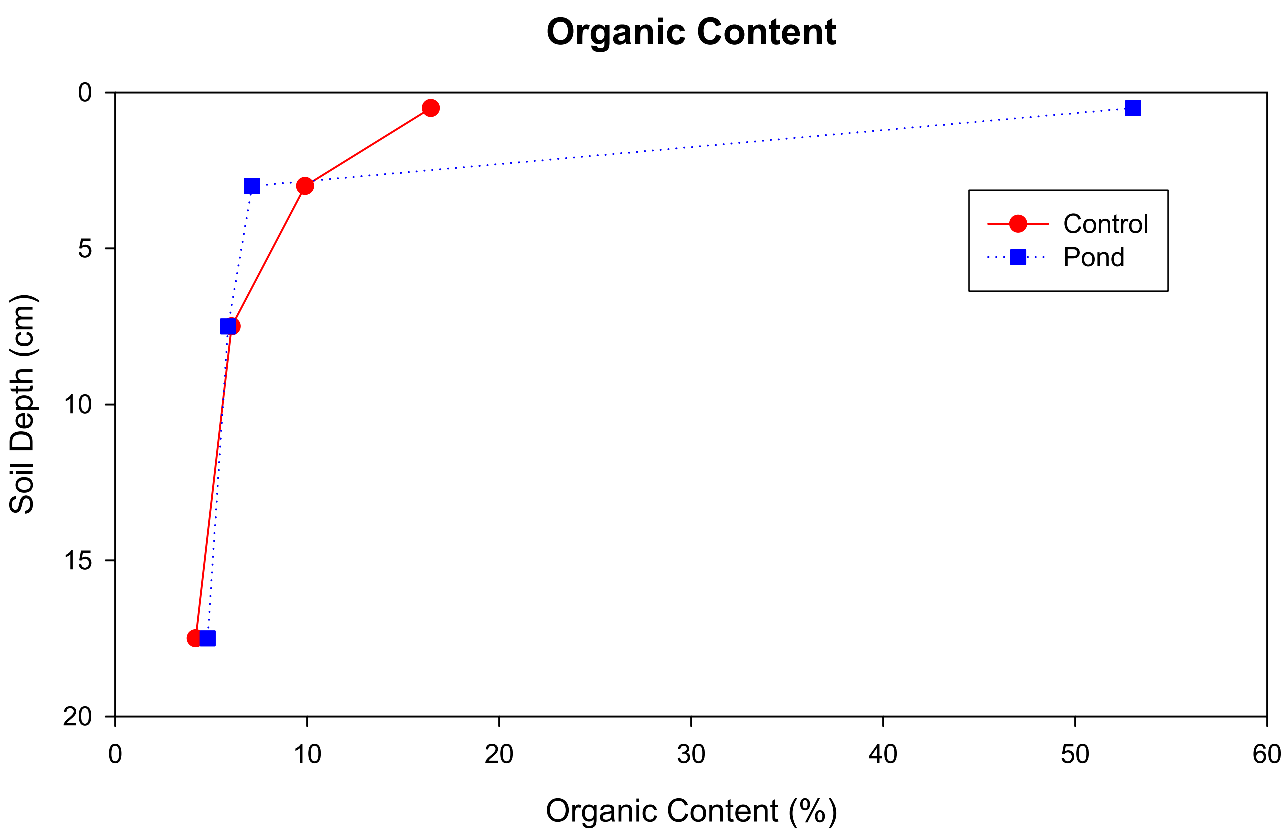


Figure 3-7. Soil Concentrations of Moisture Content and Organic Content vs. Depth in Pond and Control Areas.

A graphical comparison of nutrient concentrations in soil samples collected in pond and control areas is given in Figure 3-8. Nitrogen concentrations appear to decrease rapidly with increasing depth in both pond and control areas. In general, nitrogen concentrations in soils beneath the pond appear to be greater than values measured within the control area. However, no distinct trend is apparent for soil concentrations of total phosphorus. Total phosphorus concentrations appear to be greater in the control area for the surface layers while greater in pond areas for the deeper sediment samples. However, in both areas, total phosphorus concentrations decrease rapidly with increasing soil depth.

Soil concentrations of aluminum and iron as a function of depth in pond and control areas are illustrated in Figure 3-9. In contrast to the trends observed for moisture content, organic content, and nutrients, soil concentrations of aluminum and iron appear to increase with increasing depth in both pond and control areas. Surface concentrations of aluminum in the control area are somewhat greater than values measured within the pond. However, below a depth of 1 cm, pond concentrations of aluminum are greater than values measured within the control area. Soil concentrations of iron are greater than concentrations in the control area at each of the monitored depths.

Soil concentrations of lead and zinc as a function of depth in pond and control areas are illustrated in Figure 3-10. Soils concentrations of lead exhibit a trend similar to that previously observed for aluminum and iron, with slightly increasing concentrations with increasing soil depth. In contrast, soil concentrations of zinc appear to decrease with increasing soil depth, with higher zinc concentrations observed in the control area in the surface layer and relatively similar values in pond and control areas at depths in excess of 1 cm.

The results of sieve analyses collected on composite soil samples collected from pond and control areas at the Key Colony site are given in Appendix L.3. In general, soils in both pond and control areas consist of relatively large-grained particles with grain sizes ranging from approximately 0.1-0.5 mm. In general, soil particles in the control area appear to be somewhat larger than in the pond area in each of the evaluated layers. The soils in each area appear to be poorly graded, with a majority of the soil particles exhibiting diameters in excess of 0.25 mm. The large diameter of the soils at the site is a key factor in regulating the rapid infiltration characteristics of surficial soils at the Key Colony site.

In general, soils within the pond area appear to be accumulating concentrations of nitrogen, lead, iron, and to a lesser extent aluminum, in excess of values observed in the control area. It appears that these increased soil concentrations may be a result of runoff related pollutants which were trapped within layers of the soil during migration within the pond. However, no significant differences appear to exist in accumulation patterns for total phosphorus or zinc in pond and control areas. In fact, surface soil concentrations of these parameters appear to be greater in the control area than observed in the pond samples.

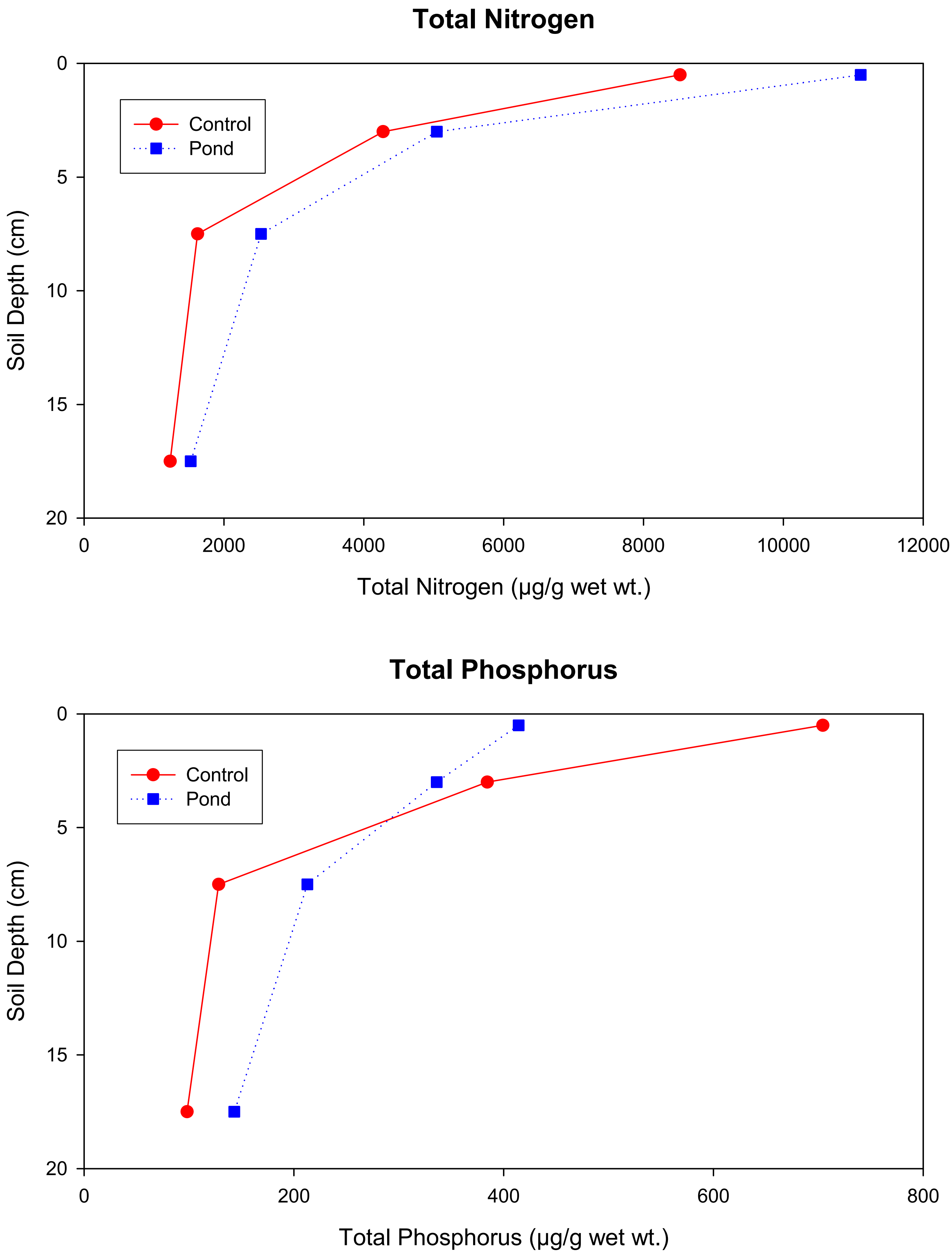
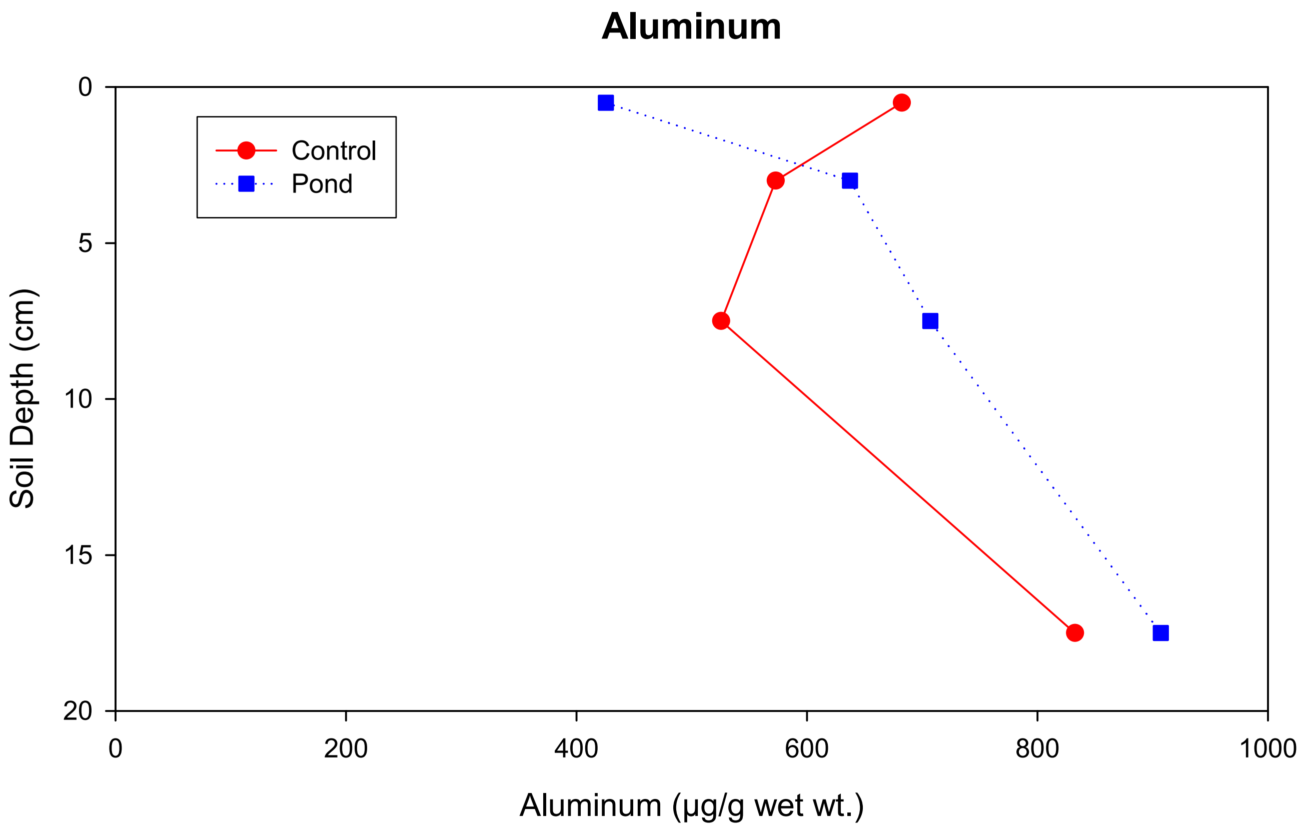


Figure 3-8. Soil Concentrations of Nitrogen and Phosphorus vs. Depth in Pond and Control Areas.



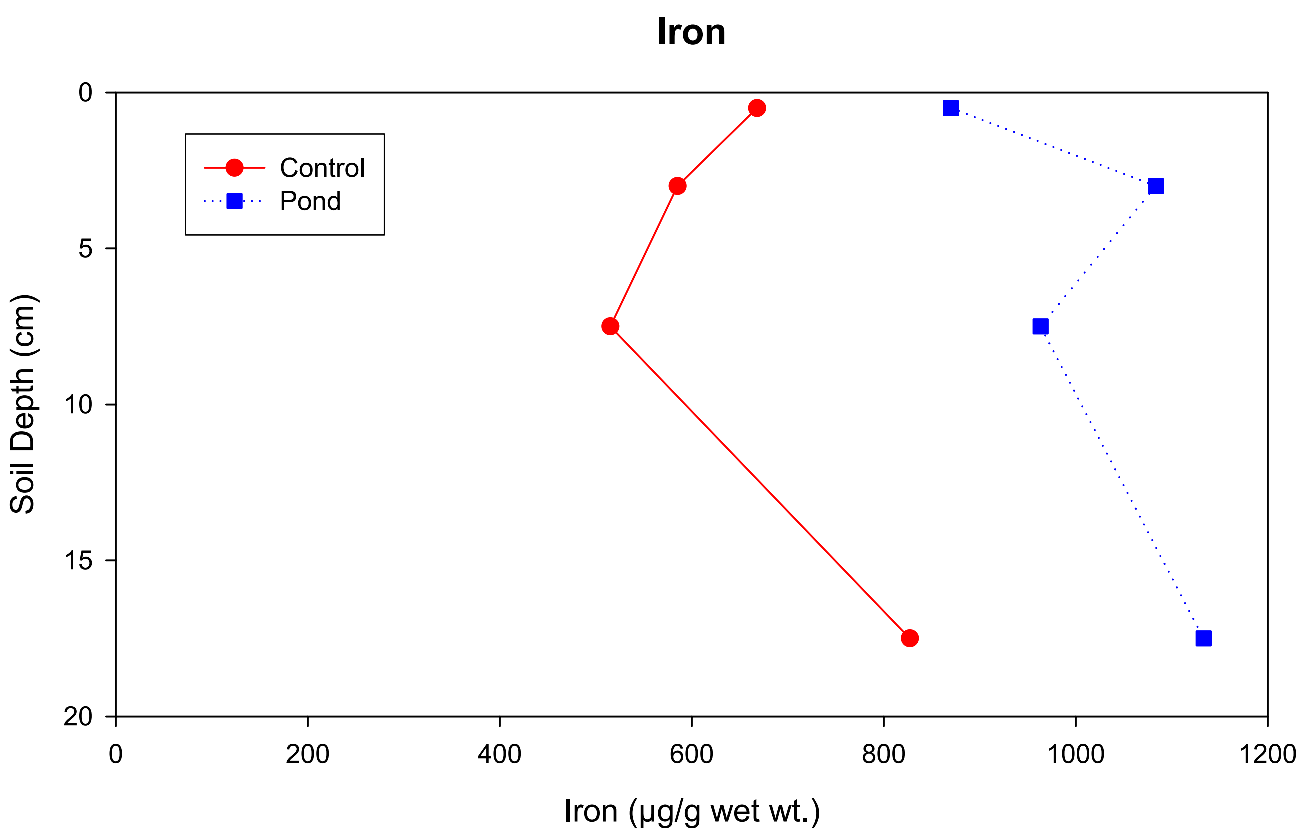
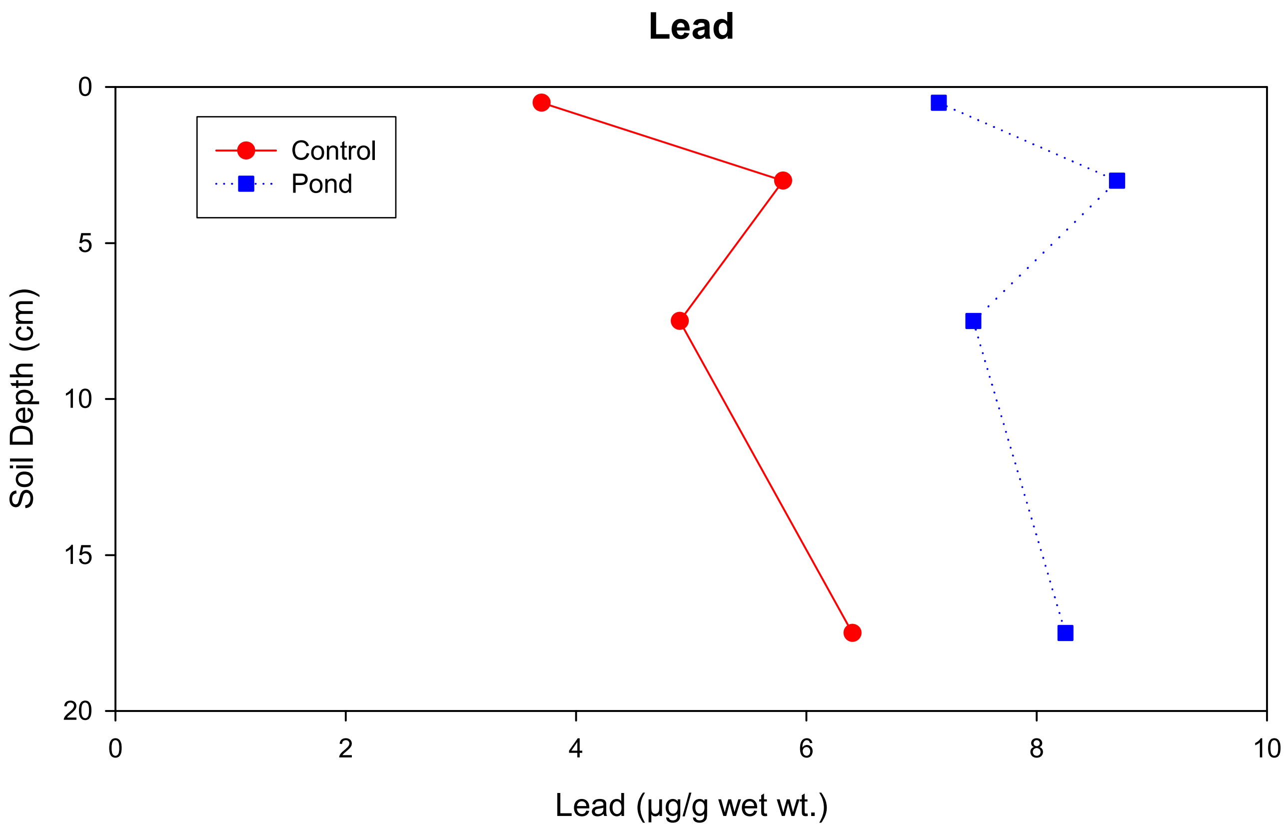


Figure 3-9. Soil Concentrations of Aluminum and Iron vs. Depth in Pond and Control Areas.



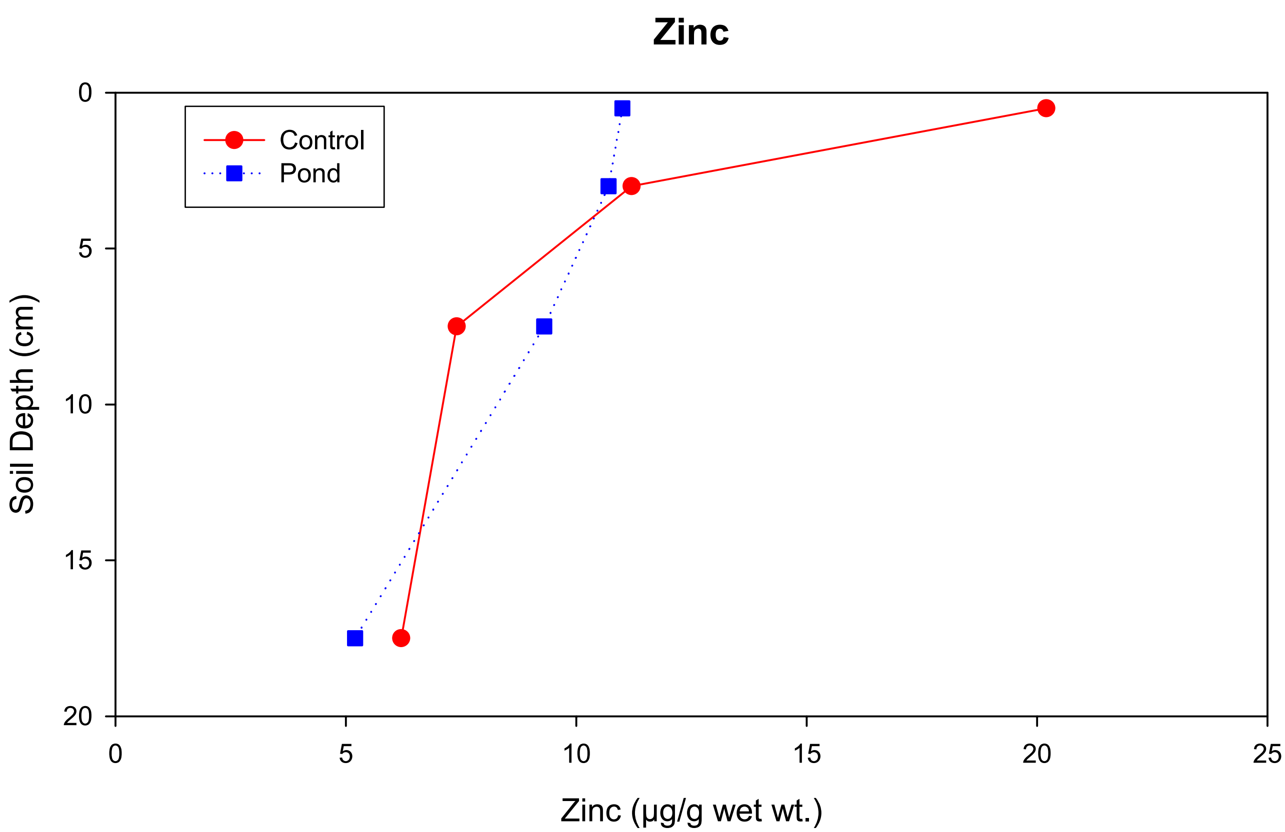


Figure 3-10. Soil Concentrations of Lead and Zinc vs. Depth in Pond and Control Areas.

3.9 <u>Estimated Mass Removal Efficiencies for System Components</u>

Estimates of total mass inputs and losses are calculated for each of the system components evaluated during the 16-month monitoring period from July 2001-October 2002. Estimates of mass inputs are calculated for direct precipitation, as well as runoff inputs measured at Inflow Monitoring Sites 1, 2, and 3. For each of these sources, mass inputs are calculated by multiplying the overall mean chemical characteristics of direct precipitation, Inflow 1, Inflow 2, and Inflow 3 times the total measured volumetric inputs at each of these sites summarized in Table 3-8. This procedure results in an estimate of the total mass loading resulting from each input over the 16-month monitoring program.

Estimates of mass losses are also calculated for discharges into Injection Wells 1 and 2 as well as seepage into shallow groundwater. Estimates of mass losses into Injection Wells 1 and 2 are calculated by multiplying the mean measured chemical characteristics times the total measured volume discharging to each injection well, as summarized in Table 3-8. Estimates of mass losses into groundwater were calculated by multiplying the mean flow-weighted concentration of discharges at Outflow 1 and Outflow 2, weighted by the relative discharge volumes summarized in Table 3-8, for each constituent times the volumetric groundwater losses, summarized in Table 3-8.

A summary of calculated mass inputs and losses for each of the measured components at the Key Colony site is given in Table 3-30. Estimated mass inputs and losses are provided for measured nutrient species, alkalinity, chloride, TSS, BOD, and total heavy metals. Dissolved heavy metals are not included in the summary loading presented in Table 3-30 since only total metals were measured for direct precipitation. The estimates provided in Table 3-30 reflect the calculated mass inputs and losses for each evaluated system component over the 16-month monitoring program.

3.9.1 <u>Mass Removal Efficiencies for the Pond System</u>

Mass retention or export within the dry retention/detention pond is defined as the difference between the estimated total mass inputs into the pond and the estimated mass losses. Inputs into the pond are assumed to occur as a result of direct precipitation, as well as stormwater runoff entering the pond at Inflow 1 and Inflow 2. Mass losses from the system are assumed to occur as a result of discharges from the pond into Injection Well 1 and Injection Well 2 as well as losses due to groundwater seepage. Mass loss from the system as a result of groundwater seepage is considered to be a significant system removal mechanism and is included in calculation of the overall pond removal efficiency. Mass retention within the dry detention pond is calculated as follows:

$$\left[\frac{Total\ \ Mass\ \ Inputs\ \ -\ \ Total\ \ Mass\ \ Losses}{Total\ \ Mass\ \ Inputs}\right] x\ 100$$

TABLE 3-30

SUMMARY OF CALCULATED MASS INPUTS AND LOSSES AT THE KEY COLONY DETENTION POND SITE

Parameter	Mass Inputs (kg)[1]				Mass Losses (kg)[1]		
	Direct Precipitation	Inflow 1	Inflow 2	Inflow 3	Outflow 1	Outflow 2	Ground-water
Alkalinity	73	284	2,826	1,057	1,152	97	1,330
NH_3-N	0.53	0.14	3.6	2.1	2.3	0.35	2.8
$NO_2 + NO_3$-N	1.6	0.73	5.6	1.8	12.0	0.16	13.0
Diss. Organic N	2.1	1.3	8.3	9.7	15.4	1.1	17.6
Particulate N	3.4	1.0	7.8	4.9	12.5	0.87	14.2
Total N	7.7	3.2	25.2	18.4	42.3	2.5	47.6
Diss. Ortho-P	0.02	0.33	1.7	3.2	5.6	0.36	6.3
Diss. Organic P	0.11	0.09	1.7	1.8	0.51	0.04	0.58
Particulate P	0.29	0.34	0.67	1.2	1.1	0.05	1.2
Total P	0.43	0.8	4.1	6.2	7.2	0.45	8.2
TSS	54.3	139	215	358	332	14.6	369
BOD_5	19.1	6.1	25.2	27.7	83.8	7.0	96.5
Chloride	90	15	17,235	2,924	3,391	296	3,924
Total Cadmium	0.00	0.00	0.01	0.01	0.01	0.00	0.01
Total Chromium	0.02	0.01	0.04	0.04	0.03	0.00	0.04
Total Copper	0.03	0.03	0.22	0.13	0.16	0.01	0.18
Total Iron	0.23	0.21	1.8	0.42	0.34	0.10	0.47
Total Lead	0.01	0.00	0.01	0.02	0.01	0.00	0.01
Total Zinc	0.61	0.07	0.35	0.24	0.53	0.03	0.60
Volume (m^3)	9,019	3,699	14,996	15,559	12,503	924	14,287

1. Mass loadings for metals given in units of grams; volume given in units of m^3

An overall mass balance for the Key Colony detention pond is summarized in Table 3-31. Total mass inputs into the pond are summarized based upon calculated inputs from direct precipitation and stormwater runoff entering the pond at Inflow 1 and Inflow 2. Total losses from the pond are assumed to occur as a result of discharges from the pond into Injection Wells 1 and 2 as well as seepage of water from the pond into shallow groundwater, based upon the information provided in Table 3-30.

TABLE 3-31

OVERALL MASS BALANCE FOR THE KEY COLONY DETENTION POND

PARAMETER	TOTAL INPUTS (kg)[1]	TOTAL LOSSES (kg)[1]	PERCENT CHANGE (%)
Alkalinity	3,183	2,580	-19
NH_3-N	4.2	5.4	29
$NO_2 + NO_3$-N	7.9	25.2	219
Diss. Organic N	11.8	34.1	189
Particulate N	12.2	27.6	126
Total N	36.1	92.4	156
Diss. Ortho-P	2.0	12.3	515
Diss. Organic P	2.0	1.1	-45
Particulate P	1.3	2.4	85
Total P	5.3	15.8	198
TSS	409	716	75
BOD_5	50.3	188	274
Chloride	17,341	7,611	-56
Total Cd	0.01	0.01	0
Total Cr	0.07	0.07	0
Total Cu	0.28	0.35	25
Total Fe	2.2	0.91	-59
Total Pb	0.03	0.03	0
Total Zn	1.0	1.2	20
Volume	27,735	27,735	0

1. Mass loadings for metals given in units of grams; volume given in units of m^3

Of the parameters listed in Table 3-31, a net mass retention within the pond is observed for only a few measured constituents, including alkalinity, dissolved organic phosphorus, chloride, and total iron. The remaining measured parameters either exhibit no change or an increase in mass during movement through the pond. Mass increases of more than 100% are observed for particulate nitrogenand total nitrogen. Mass increases of approximately 200% or more are observed for NO_X, dissolved organic nitrogen, total phosphorus, and BOD, with dissolved orthophosphorus exhibiting an increase of more than 500%.

The apparent poor performance of the Key Colony pond for attenuating pollutants is related to both hydrologic and chemical characteristics of shallow groundwater in the vicinity of the pond. As indicated in Figure 3-1, the groundwater piezometric elevation responds rapidly to rain events as the porous shallow soil layers become saturated during rain events. During rain events with sufficient rainfall depth to generate measurable runoff, the rainfall depth is also usually sufficient to saturate the porous spaces within the ground, resulting in groundwater piezometric elevations which exceed the pond bottom elevation. In other words, the shallow groundwater rises up into the pond at the same time that runoff inflow is entering the pond through the two inflow locations. The resulting water within the pond, therefore, is a mixture of shallow groundwater and runoff inflow.

As indicated in Tables 3-19 through 3-21, shallow groundwater in the vicinity of the pond, as well as in the control area, contains elevated levels of ammonia, dissolved organic nitrogen, total nitrogen, BOD, and chloride compared with concentrations measured at the two inflow monitoring locations. When the shallow groundwater mixes with the more dilute inflow, a combined pond mixture is created with characteristics which are substantially more elevated than observed in the inflows into the system. This combined mixture is the water source which discharges into the two injection wells, as well as infiltrates back into the shallow groundwater as piezometric elevations recede. Therefore, as a result of the unusual hydrologic and chemical characteristics of shallow groundwater in the vicinity of the pond, mass losses from the pond actually exceed the measured inputs for the majority of measured parameters.

A statistical comparison of characteristics of nitrogen species of inflow and outflow at the Key Colony site is given in Figure 3-11. A graphical summary of data at each site is presented in the form of Tukey box plots, also often called "box and whisker plots". The bottom of the box portion of each plot represents the lower quartile, with 25% of the data points lying below this value. The upper line of the box represents the 75% upper quartile, with 25% of the data lying above this value. The horizontal line within the box represents the median value, with 50% of the data lying both above and below this value. The vertical lines, also known as "whiskers", represent the 5 and 95 percentiles for the data sets. Individual values which lie outside of the 5-95 percentile range are indicated as **red dots**.

Several trends are apparent in the comparison of nitrogen species presented in Figure 3-11. First, for many nitrogen species, particularly organic nitrogen and total nitrogen, the variability in measured concentrations at the outflow monitoring locations is substantially greater than the variability observed at the three inflow sites. Second, among the inflow monitoring sites, Inflow 2 appears to exhibit substantially more variability for most nitrogen species than observed at the other two inflow sites. The high degree of variability observed at the outflow monitoring sites is thought to be related to the impact of shallow groundwater on inputs into the pond system.

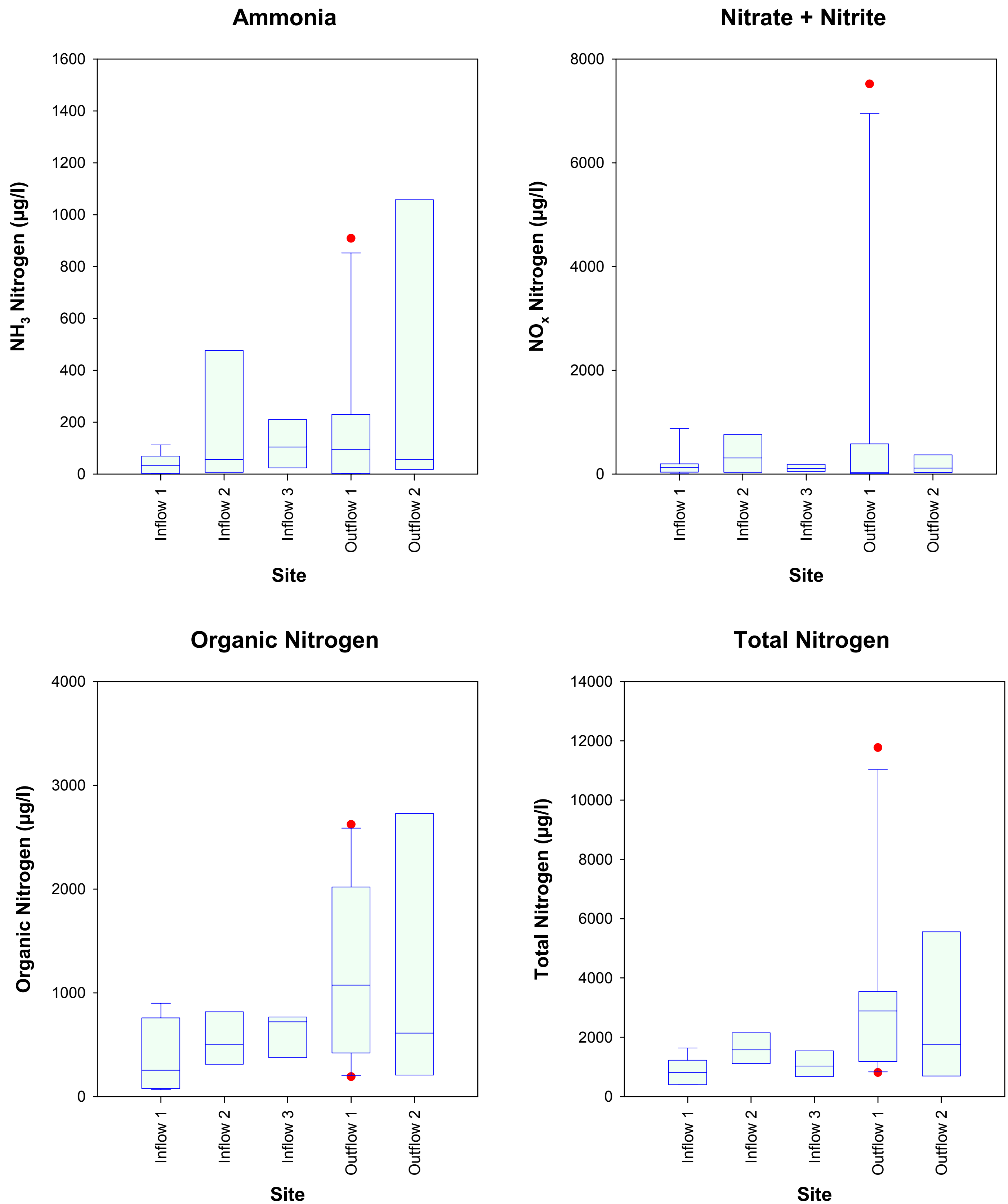


Figure 3-11. Statistical Comparison of Characteristics of Nitrogen Species at the Key Colony Site

A statistical comparison of the characteristics of phosphorus species, BOD, and TSS in inflow and outflow at the Key Colony site is given in Figure 3-12. Similar to the trends observed for nitrogen species, measured concentrations of orthophosphorus, total phosphorus, and BOD appear to be substantially more variable at the outflow monitoring locations than observed at the inflow monitoring sites. This higher degree of variability in the outflow samples is thought to be directly related to the impacts of shallow groundwater. In contrast, variability in TSS concentrations at the outflow monitoring sites appears to be similar to or less than variability observed at the inflow monitoring sites. This trend is also consistent with the theory of shallow groundwater impacts, since TSS is not a significant component in shallow groundwater.

A statistical comparison of characteristics of heavy metals in inflow and outflow at the Key Colony site is given in Figure 3-13. In contrast to the trends observed with the previous parameters, a relatively high degree of variability is apparent in measured heavy metal concentrations for both inflow and outflow monitoring sites. However, variability in outflow samples appears to be somewhat greater for total copper and total zinc than variability observed for these same parameters at the inflow monitoring sites.

Although the overall mass balance for the Key Colony detention pond, presented in Table 3-31, suggests that losses from the pond exceed measured inputs over the 16-month monitoring period, all inputs into the pond were either infiltrated into shallow groundwater or injected into a deep aquifer. No direct surface discharges of stormwater runoff occurred from the Key Colony detention pond at any time during the 16-month monitoring program. Therefore, the overall treatment efficiency of the pond, with respect to direct discharges to adjacent marine surface waters, is 100% for all measured parameters.

3.9.2 Estimated Mass Removal Efficiency for the Swale Treatment System

As discussed in Section 2.2.1, one of the objectives of this project is to evaluate the performance proficiency of the vegetated swale which enters along the southeastern side of the pond. The swale system in this area is densely grassed, approximately 0.3-0.6 m (1-2 ft) deep, and conveys untreated runoff from portions of the watershed into the pond. Since the swale is a component of the overall treatment train constructed at the site, the performance efficiency of this swale component was also evaluated. As indicated in Figure 2-4, field instrumentation was installed at two separate locations along the swale, approximately 180 m (600 ft) apart. These monitoring locations are designated as Inflow 2 and Inflow 3, and are used to evaluate the overall treatment efficiency of the swale system by comparing the quantity and quality of runoff inputs measured at Inflow 3 (upstream location) with the quantity and quality of runoff inputs measured at Inflow 2 (downstream location).

Mass loadings measured at Inflow Monitoring Sites 2 and 3 are calculated by multiplying the mean chemical characteristics of storm water runoff measured at each of the two sites, as reflected in Table 3-13, times estimated total volumetric inflow measured at each of the two sites, as summarized in Table 3-5. As indicated in Table 3-5, a total runoff inflow of 15,547 m^3 (549,029 ft^3) was measured at Inflow 3 compared with a total of 14,997 m^3 (529,591 ft^3) measured at Inflow 2. On a volumetric basis, a water loss of approximately 4% occurred during migration from Inflow 3 to Inflow 2.

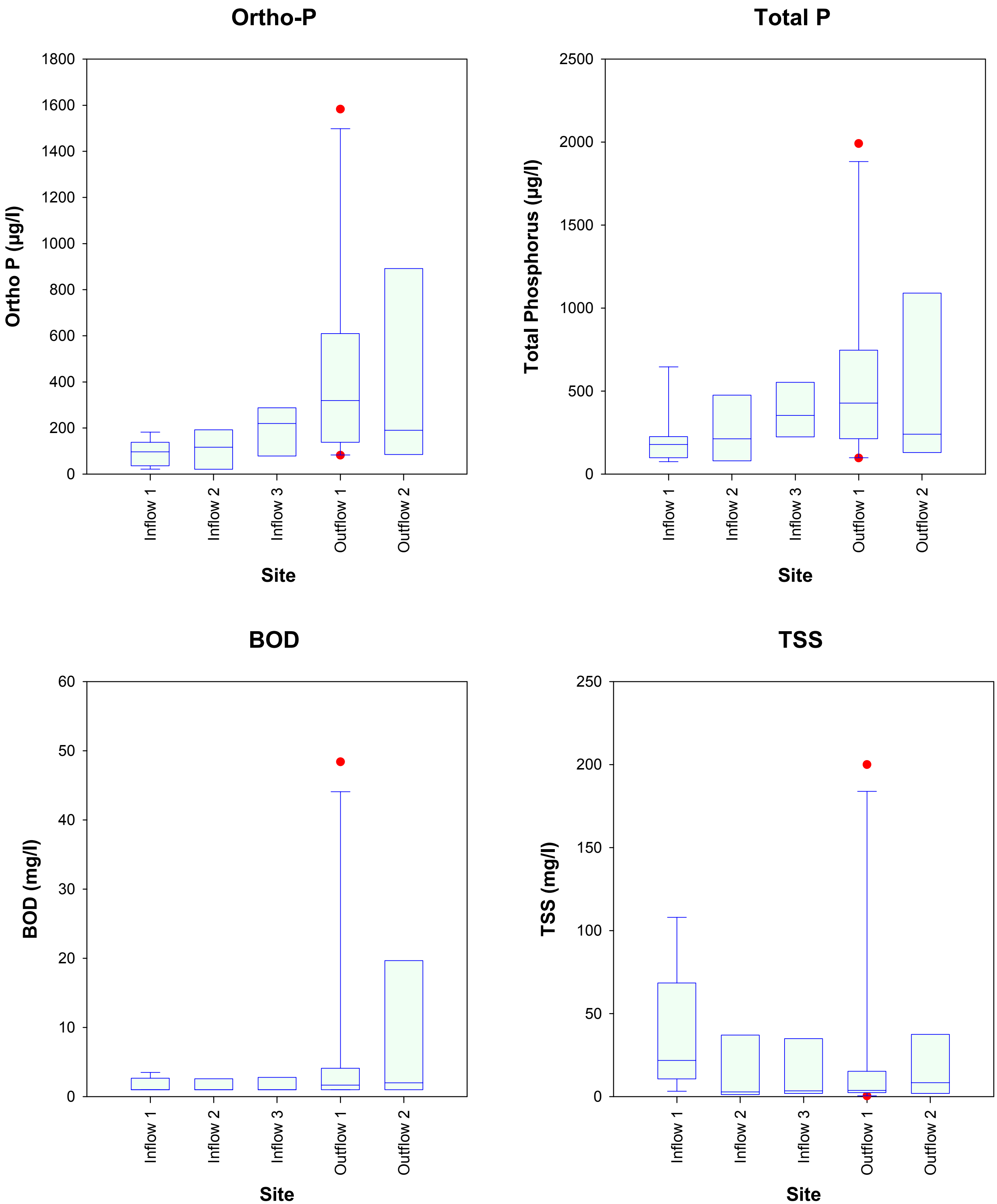


Figure 3-12. Statistical Comparison of Characteristics of Phosphorus, BOD and TSS at the Key Colony Site

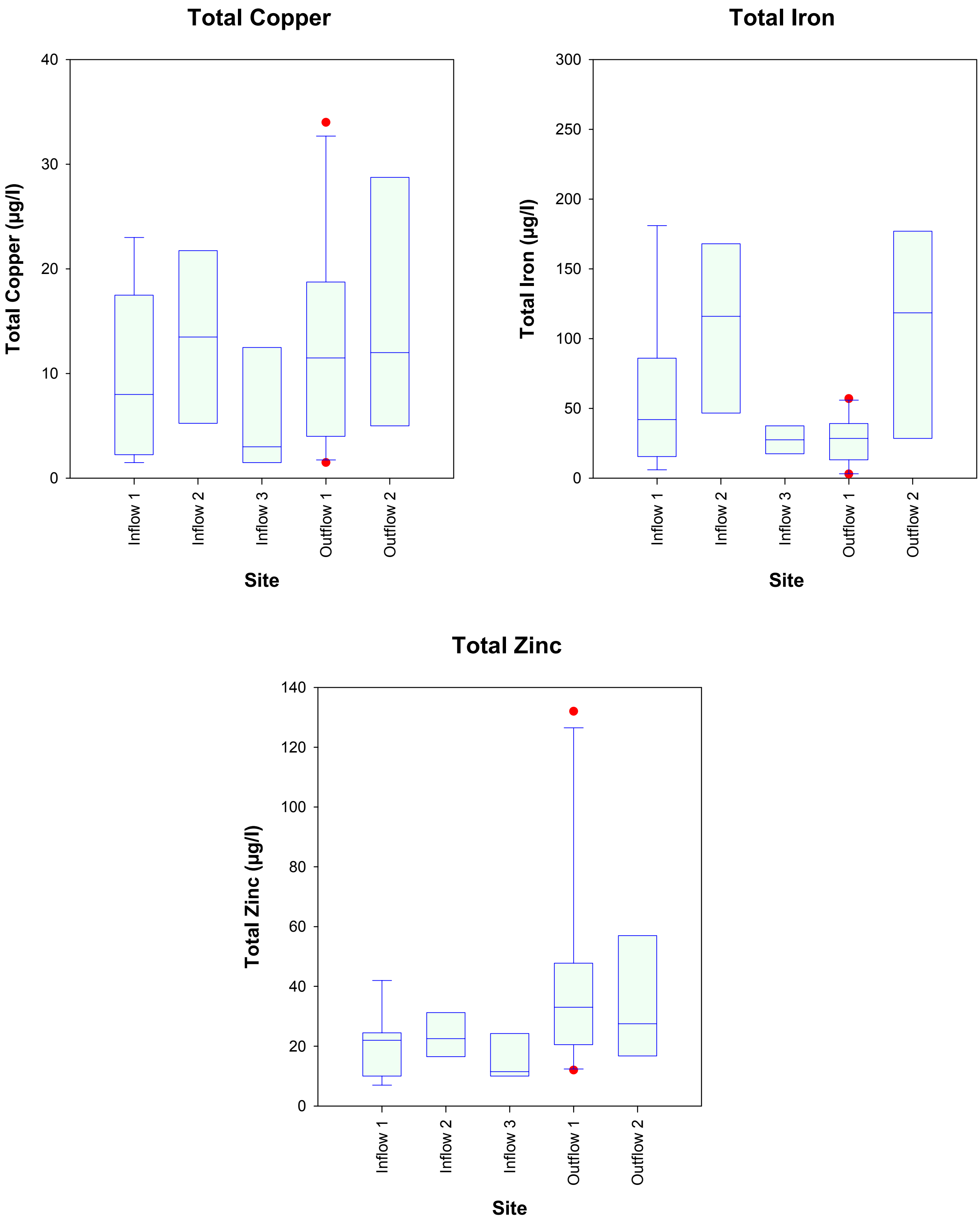


Figure 3-13. Statistical Comparison of Characteristics of Copper, Iron and Zinc at the Key Colony Site

A summary of calculated mass loadings measured at Inflow Sites 2 and 3 is give in Table 3-32. These values are obtained by multiplying the mean chemical characteristics of samples collected at each site times the total volumetric runoff inputs measured during the 16-month monitoring period. Approximately half of the evaluated parameters exhibit a decrease in mass loading during migration from Inflow 2 to Inflow 3, while the remaining parameters exhibit an increase in mass loading between the two sites. Decreases in mass loadings between the two sites occur for dissolved organic nitrogen, dissolved orthophosphorus, dissolved organic phosphorus, particulate phosphorus, total phosphorus, TSS, BOD, dissolved and total cadmium, dissolved and total chromium, and dissolved and total lead.

Since the volumetric flows at each of the two sites are approximately equal, the differences in mass loadings are due primarily to differences in mean chemical characteristics at the two monitoring locations. As seen in Table 3-13, inflow 2, which is located downstream of Inflow 3, was observed to have substantially higher measured concentrations for conductivity, alkalinity, ammonia, NO_x, particulate nitrogen, total nitrogen, turbidity, chloride, dissolved and total iron, and dissolved and total zinc compared with values measured at Inflow 3. It appears that the phenomenon previously described for the detention pond is also occurring within the swale system between Inflow 2 and Inflow 3. As piezometric elevations increase during heavy rain events, the elevation of the groundwater begins to intercept portions of the swale system upstream of Inflow 2. As the poor quality surficial groundwater begins to enter the swale system, it causes increases in measured concentrations for many constituents. As a result, the chemical characteristics of Inflow 2 are actually higher in value for many parameters than observed at Inflow 3 in spite of the fact that removal of constituents has probably occurred during migration through the swale system.

The removal efficiencies presented in Table 3-32 should not be viewed as an indication that the swale system is not efficient in reducing pollutant loadings during migration from Inflow 3 to Inflow 2. Vegetated swale have been repeatedly demonstrated to be effective in reducing both the quantity and quality of runoff inputs when used as conveyance channels (Harper 1988; Yousef, et al. 1985; Harper, et al. 1984). It is virtually certain that a substantial pollutant mass is being attenuated within the swale system, although the effectiveness is masked due to the influx of poor quality groundwater into the system.

TABLE 3-32

CALCULATED MASS REMOVAL EFFICIENCY OF THE INFLOW SWALE BETWEEN INFLOW 3 AND INFLOW 2

PARAMETER		MASS LOADING (kg)[1]		PERCENT CHANGE (%)
		INFLOW 3	INFLOW 2	
Alkalinity		1,057	2,826	167
NH_3-N		2.12	3.55	67
$NO_2 + NO_3$-N		1.77	5.58	215
Diss. Organic N		9.66	8.34	-14
Particulate N		4.90	7.76	58
Total N		18.5	25.2	36
Diss. Ortho-P		3.19	1.66	-48
Diss. Organic P		1.81	1.75	-3
Particulate P		1.22	0.67	-45
Total P		6.22	4.08	-34
TSS		358	215	-40
BOD_5		27.7	25.2	-9
Chloride		2,924	17,235	489
Cadmium	Diss.	7.76	7.49	-3
	Total	7.76	7.49	-3
Chromium	Diss.	38.8	37.4	-4
	Total	38.8	37.4	-4
Copper	Diss.	32.3	101	213
	Total	127	217	71
Iron	Diss.	210	724	245
	Total	417	1,774	325
Lead	Diss.	15.5	15.0	-3
	Total	15.5	15.0	-3
Zinc	Diss.	103	195	89
	Total	243	354	46

1. Mass loadings for metals given in grams

3.10 Concentration-Based Removal Efficiencies for System Components

3.10.1 Pond

Concentration-based removal efficiencies were calculated for nutrient species, turbidity, TSS, BOD, chloride, and heavy metals for pollutant attenuation which occurred during migration through the retention/detention pond. An overall flow-weighted inflow concentration was calculated based on total inputs into the pond from Inflow 1, Inflow 2, and bulk precipitation. Mean concentrations for each of these inputs were weighted by the measured inflow volume for each source summarized in Table 3-8. An overall weighted outflow concentration for the pond was calculated based upon the mean chemical characteristics of discharges to Injection Well 2, Injection Well 1, and shallow groundwater. Each of these mean concentrations were weighted based upon the total measured volume for these outputs, as summarized in Table 3-8. Concentration-based removal efficiencies were estimated by comparing the weighted inflow and outflow concentrations according to the following equation:

$$\left[\frac{\textit{Weighted Inflow Concentration} - \textit{Weighted Outflow Concentration}}{\textit{Weighted Inflow Concentration}}\right] x \ 100$$

The concentration-based removal efficiencies obtained using this procedure evaluate processes which occur within the pond after introduction of inputs from the respective sources. Concentration-based removal efficiencies allow an evaluation of pond processes which are independent of changes in water volume.

A comparison of flow-weighted inflow and outflow concentrations for the Key Colony detention pond is given in Table 3-33. The majority of measured parameters, including ammonia, NO_X, dissolved organic nitrogen, particulate nitrogen, total nitrogen, orthophosphorus, particulate phosphorus, total phosphorus, TSS, BOD, total copper, and total zinc, exhibit increases in concentration during migration through the pond. Only four parameters, including alkalinity, dissolved organic phosphorus, chloride, and total iron, exhibit decreases in concentration within the pond.

As discussed in previous sections, the observed increases in concentrations within the pond are related to the hydrologic and water quality characteristics of shallow groundwater at the site. The extremely porous soils at the site allow shallow groundwater to migrate upward into the pond at the same time that runoff inflow is entering the pond through Inflow 1 and Inflow 2. As indicated in Tables 3-19 through 3-21, shallow groundwater at the site contains extremely elevated levels of specific conductivity, ammonia, dissolved organic nitrogen, total nitrogen, dissolved orthophosphorus, total phosphorus, BOD, and chloride. As this water migrates upward into the pond, it mixes with the more dilute inflow water, resulting in the estimated chemical characteristics summarized in Table 3-33 as the mean outflow concentration. Therefore, it appears that concentrations for most parameters actually increase during migration through the pond rather than

TABLE 3-33

COMPARISON OF FLOW-WEIGHTED INFLOW AND OUTFLOW CONCENTRATIONS FOR THE KEY COLONY DETENTION POND

Parameter	Units	Mean Inflow Conc.[1]	Mean Outflow Conc.[2]	Percent Change (%)
Alkalinity	mg/l	115	93	-19
NH_3-N	µg/l	153	197	29
NO_2 + NO_3-N	µg/l	286	911	219
Diss. Organic N	µg/l	427	1234	189
Particulate N	µg/l	440	996	127
Total N	µg/l	1305	3338	156
Diss. Ortho-P	µg/l	73	444	508
Diss. Organic P	µg/l	71	41	-42
Particulate P	µg/l	47	87	85
Total P	µg/l	190	572	201
TSS	mg/l	14.8	25.9	75
BOD_5	mg/l	1.8	6.8	278
Chloride	mg/l	627	275	-56
Total Cadmium	mg/l	< 1	< 1	0
Total Chromium	µg/l	< 5	< 5	0
Total Copper	µg/l	10	13	30
Total Iron	µg/l	80	33	-59
Total Lead	µg/l	< 2	< 2	0
Total Zinc	µg/l	38	42	11

1. Reflects weighted inputs from Inflow 1, Inflow 2, and bulk precipitation

2. Reflects weighted outputs to Injection Well 1, Injection Well 2, and groundwater seepage

exhibit significant decreases, as is commonly observed. The observed increases in concentration within the pond could be reduced if the pond were constructed so that the pond bottom did not intercept the shallow groundwater during significant rain events. However, given the high water table elevations at the site, combined with the extremely porous nature of the surficial soils, it appears unlikely that any pond could be constructed which would not intercept the groundwater table during at least some portions of the year.

3.10.2 Swale System

Concentration-based removal efficiencies were calculated for general parameters, nutrient species, TSS, BOD, fecal coliform bacteria, and heavy metals for pollutant attenuation which occurred during migration through the inflow swale from Inflow 3 to Inflow 2. The estimated mean chemical characteristics at each of the two sites are assumed to be equivalent to the overall mean chemical characteristics measured at each of the two sites for samples collected over the 16-month monitoring period. This comparison allows an evaluation of attenuation processes which occurred during migration through the swale which are independent of changes in measured water volumes. As indicated previously, Inflow 2 is located approximately 180 m (600 ft) downstream from Inflow 3 along a densely grassed shallow swale system.

A summary of changes in chemical characteristics during migration through the inflow swale from Inflow 3 to Inflow 2 is given in Table 3-34. Similar to the trends observed in the pond, the majority of measured parameters appear to increase in concentration during migration through the swale system from Inflow 3 to Inflow 2. Significant increases in concentration were observed for conductivity, alkalinity, ammonia, NO_X, particulate nitrogen, total nitrogen, turbidity, chloride, dissolved and total copper, dissolved and total iron, and dissolved and total zinc. Reductions in measured concentrations were observed for dissolved organic nitrogen, orthophosphorus, particulate phosphorus, total phosphorus, and TSS. No change in concentration was observed for BOD, dissolved and total cadmium, dissolved and total chromium, and dissolved and total lead.

Water movement through the grassed swale appears to be impacted by the same processes which impact concentration characteristics within the pond. During rain events of sufficient depth to generate measurable runoff at the two monitoring sites, the piezometric elevation of the shallow groundwater increases and intercepts the bottom of the swale system, particularly in the vicinity of Inflow 2 which is slightly lower in elevation than Inflow 3. As indicated previously, the shallow groundwater contains elevated levels of specific conductivity, alkalinity, ammonia, total nitrogen, chloride, copper, and iron. The input of shallow groundwater results in increases in measured concentrations for these parameters since concentrations in the shallow groundwater are higher in value than the water discharging through the swale system from Inflow 3. This process results in an increase in measured concentrations at Inflow 2 which results in an overall apparent increase in concentration during migration through the swale system. Since previous research has indicated that vegetated swales are very effective in attenuating stormwater related pollutants, the increases in concentrations observed between Inflow 3 and Inflow 2 reflect net inputs of chemical constituents which remain following the attenuation processes within the swale system.

TABLE 3-34

SUMMARY OF CHANGES IN CHEMICAL CHARACTERISTICS DURING MIGRATION THROUGH THE INFLOW SWALE FROM INFLOW 3 TO INFLOW 2

PARAMETER		UNITS	INFLOW 3	INFLOW 2	PERCENT CHANGE (%)
pH		s.u.	7.70	7.89	2
Spec. Cond.		µmho/cm	603	2,843	371
Alkalinity		mg/l	68	189	178
NH_3-N		µg/l	137	237	73
NO_2 + NO_3-N		µg/l	114	372	226
Diss. Organic N		µg/l	623	557	-11
Particulate N		µg/l	316	518	64
Total N		µg/l	1,189	1,685	42
Diss. Ortho-P		µg/l	206	111	-46
Diss. Organic P		µg/l	116	117	1
Particulate P		µg/l	79	45	-43
Total P		µg/l	401	272	-32
Turbidity		NTU	2.9	14.5	400
TSS		mg/l	23.1	14.4	-38
BOD_5		mg/l	< 2	< 2	0
Chloride		mg/l	188	1,151	512
Fecal Coliform		No./100 ml	1,044	1,063	2
Cadmium	Diss.	µg/l	< 1	< 1	0
	Total	µg/l	< 1	< 1	0
Chromium	Diss.	µg/l	< 5	< 5	0
	Total	µg/l	< 5	< 5	0
Copper	Diss.	µg/l	< 3	7	367
	Total	µg/l	8	15	88
Iron	Diss.	µg/l	14	48	243
	Total	µg/l	27	119	371
Lead	Diss.	µg/l	< 2	< 2	0
	Total	µg/l	< 2	< 2	0
Zinc	Diss.	µg/l	7	13	86
	Total	µg/l	16	24	50

Similar to the conclusions reached for the pond, the effectiveness of the swale system could be enhanced if the bottom of the swale were constructed at an elevation which did not intercept the shallow groundwater table during heavy rain events. However, it appears unlikely that this could be accomplished, since the shallow groundwater table rises almost to the soil surface at virtually all parts of the site during extreme rain events.

3.11 Groundwater Impacts of the Key Colony Treatment System

3.11.1 Shallow Groundwater Impacts

Impacts of the Key Colony retention/detention pond on shallow groundwater characteristics are evaluated using two separate mechanisms. First, a comparison is provided of mean inflow concentrations into the detention pond with shallow groundwater characteristics measured beneath the pond. Mean inflow concentrations into the pond are obtained from the values presented in Table 3-33 which reflect mean flow-weighted inputs from Inflow 1, Inflow 2, and bulk precipitation. Characteristics of shallow groundwater are obtained from information provided in Table 3-22 for areas beneath the pond. A comparison of flow-weighted inflow concentrations and shallow groundwater characteristics is given in Table 3-35.

As seen in Table 3-35, measured concentrations in shallow groundwater are greater, for the majority of measured parameters, than the calculated mean inflow concentrations. Shallow groundwater has substantially higher concentrations of alkalinity, ammonia, organic nitrogen, total nitrogen, orthophosphorus, dissolved organic phosphorus, total phosphorus, BOD, chloride, and total copper. Since the characteristics of shallow groundwater are substantially higher in value than the mean inflow characteristics into the pond, it appears unlikely that infiltration of water from the pond could increase concentrations of chemical constituents in the shallow groundwater. In fact, infiltration of water from the pond into the shallow groundwater should dilute the concentrations of constituents within the groundwater and result in lowered concentrations for the measured parameters compared with values which would exist in the absence of the pond infiltration.

A second method of evaluating impacts of the stormwater treatment system on shallow groundwater is to compare the groundwater characteristics in pond, adjacent, and control areas. An ANOVA comparison of shallow groundwater characteristics in pond, adjacent, and control areas was given in Table 3-23. Of the evaluated parameters, virtually all measured nutrient species were found to have significantly higher concentrations in pond and adjacent areas compared with concentrations measured in control areas. This comparison appears to suggest that some factor, presumably operation of the stormwater management system, is resulting in significantly higher nutrient concentrations in shallow groundwater in the pond and adjacent areas compared with values measured in the control area. However, since the mean concentration of water infiltrating into the shallow groundwater is substantially lower in value for virtually all measured parameters, there appears to be no reasonable mechanism by which infiltration through the pond bottom could be increasing measured concentrations of constituents in shallow groundwater when compared with characteristics in control areas. As a result, an additional unknown factor, such as differences in the chemical characteristics of deeper soil layers beneath pond and control areas, is likely responsible for the observed differences in chemical characteristics. In addition, it should be noted that the Key Colony Sewage Treatment Plant, which is located immediately adjacent to the pond, utilizes deep well injection for disposal of treated effluent which could possibly impact shallow groundwater characteristics in the vicinity of the pond.

TABLE 3-35

COMPARISON OF FLOW-WEIGHTED INFLOW AND SHALLOW GROUNDWATER CONCENTRATIONS FOR THE KEY COLONY DETENTION POND

Parameter	Units	Mean Inflow Conc.	Mean Shallow Groundwater Conc.	Percent Change (%)
Alkalinity	mg/l	115	614	434
NH_3-N	µg/l	153	16,217	10,499
$NO_2 + NO_3$-N	µg/l	286	6	-98
Diss. Organic N	µg/l	427	7,243	1,596
Total N	µg/l	1305	23,468	1,698
Diss. Ortho-P	µg/l	73	122	67
Diss. Organic P	µg/l	71	116	63
Total P	µg/l	190	238	25
BOD_5	mg/l	1.8	103	5,622
Chloride	mg/l	627	8,338	1,230
Total Cadmium	mg/l	< 1	< 1	0
Total Chromium	µg/l	< 5	< 5	0
Total Copper	µg/l	10	24	140
Total Iron	µg/l	80	75	-6
Total Lead	µg/l	< 2	< 2	0
Total Zinc	µg/l	38	11	-71

In summary, there appears to be no significant evidence to suggest that operation of the stormwater management system is creating any negative impacts on shallow groundwater characteristics in the vicinity of the detention pond. Mean characteristics of inflow to the pond are substantially lower in value than the chemical characteristics of shallow groundwater, suggesting that pond inputs can only result in dilution of existing groundwater characteristics.

3.11.2 Injection Well Impacts

The impacts of injecting treated stormwater runoff into the two deep injection wells were also evaluated using two separate methodologies. First, the chemical characteristics of inflow into each of the two injection wells is compared with the mean chemical characteristics of samples collected from the deep depths at Injection well 1 and Injection Well 2. The chemical characteristics of the deep well samples are utilized for this comparison since this represents the characteristics of the zone into which the inflow is directly injected.

A comparison of mean chemical characteristics of inflow and deep well samples collected at Injection Well 1 is given in Table 3-36. As indicated in Table 3-7, approximately 93% of the total injection well discharges originating enter Injection Well 1 due to a raised area in the swale leading to Injection Well 2. Overflow into Injection Well 2 can only occur during relatively extreme events at the site; therefore, Injection Well 2 serves at a quasi-control for comparison of injection well impacts.

A comparison of mean chemical characteristics of inflow and deep well samples collected at Injection Well 1 is given in Table 3-36. In general, the deep layer into which the injection well discharges is a saline environment, with conductivity and chloride concentrations similar to those commonly observed in seawater. For many of the measured parameters, concentrations measured in the inflow are greater than concentrations measured in the deep portions of the injection well. This trend is particularly apparent for NO_x, dissolved organic nitrogen, particulate nitrogen, total nitrogen, orthophosphorus, total phosphorus, turbidity, BOD, TSS, fecal coliform, and total zinc. In contrast, inputs into the injection well have substantially lower concentrations of total copper, total iron, and total lead than observed in deep portions of the well. The volume of water discharging through Outflow 1 into the injection well, approximately 12,503 m^3, is sufficient to cover a 100 m x 100 m area with a water depth of 1.25 m. However, since the physical characteristics of the deep aquifer are not known, the relative significance of inputs into Injection Well 1 cannot be evaluated.

A comparison of mean chemical characteristics of inflow and deep well samples collected at Injection Well 2 is given Table 3-37. In general, chemical characteristics of the inflow to Injection Well 2 appear to be slightly more dilute than the characteristics of inflow entering Injection Well 1. The characteristics of the deep aquifer portion of the well also appear to lower in value for many parameters that observed in the deep well portion of Injection Well 1. Therefore, both the inflow and aquifer portions of Injection Well 2 are lower in concentrations for most parameters than observed at Injection Well 1. However, concentrations measured in the inflow to Injection Well 2 are still greater than the characteristics of water within the deep aquifer portions of the well. This difference in concentrations is particularly apparent for ammonia, NO_X, dissolved

TABLE 3-36

COMPARISON OF MEAN CHEMICAL CHARACTERISTICS OF INFLOW AND DEEP WELL SAMPLES COLLECTED AT INJECTION WELL 1

PARAMETER	UNITS	WELL 1 INFLOW	DEEP WELL CHARACTERISTICS	PERCENT CHANGE (%)
pH	s.u.	7.31	7.61	4
Spec. Conductivity	µmho/cm	1,011	48,682	4,715
Alkalinity	mg/l	92	119	29
NH_3-N	µg/l	184	144	-22
$NO_2 + NO_3$-N	µg/l	965	6	-99
Diss. Organic N	µg/l	1,238	450	-64
Particulate N	µg/l	1,001	569	-43
Total N	µg/l	3,387	1,169	-65
Diss. Ortho-P	µg/l	448	59	-87
Diss. Organic P	µg/l	41	34	-17
Particulate P	µg/l	89	65	-17
Total P	µg/l	578	158	-73
Turbidity	NTU	6.2	1.6	-74
TSS	mg/l	26.6	3.4	-87
BOD_5	mg/l	6.7	3.1	-54
Chloride	mg/l	272	21,198	7,693
Fecal Coliform	No./100 ml	308	1	-99
Total Cadmium	µg/l	< 1	< 1	0
Total Chromium	µg/l	< 5	< 5	0
Total Copper	µg/l	13	55	323
Total Iron	µg/l	27	258	856
Total Lead	µg/l	< 2	12	1,100
Total Zinc	µg/l	43	10	-77

TABLE 3-37

COMPARISON OF MEAN CHEMICAL CHARACTERISTICS OF INFLOW AND DEEP WELL SAMPLES COLLECTED AT INJECTION WELL 2

PARAMETER	UNITS	WELL 2 INFLOW	DEEP WELL CHARACTERISTICS	PERCENT CHANGE (%)
pH	s.u.	7.42	7.47	1
Spec. Conductivity	µmho/cm	528	51,186	9,594
Alkalinity	mg/l	106	149	41
NH_3-N	µg/l	377	149	-60
NO_2 + NO_3-N	µg/l	174	8	-95
Diss. Organic N	µg/l	1,183	390	-67
Particulate N	µg/l	938	425	-55
Total N	µg/l	2,672	972	-64
Diss. Ortho-P	µg/l	389	10	-97
Diss. Organic P	µg/l	45	23	-49
Particulate P	µg/l	53	30	-43
Total P	µg/l	487	63	-87
Turbidity	NTU	7.9	2.2	-72
TSS	mg/l	15.9	3.5	-78
BOD_5	mg/l	7.6	< 2	-87
Chloride	mg/l	321	19,680	6,031
Fecal Coliform	No./100 ml	1,123	9	-99
Total Cadmium	µg/l	< 1	< 1	0
Total Chromium	µg/l	< 5	< 5	0
Total Copper	µg/l	15	42	180
Total Iron	µg/l	108	142	31
Total Lead	µg/l	< 2	8	700
Total Zinc	µg/l	34	6	-82

organic nitrogen, particulate nitrogen, total nitrogen, orthophosphorus, total phosphorus, TSS, BOD, chloride, and fecal coliform bacteria. Measured concentrations of total copper, total iron, and total lead in the inflow to Injection Well 2 are lower than values measured in the deep aquifer. However, the volumetric inflow to Injection Well 2 is only a small fraction of the volumetric inflow to Injection Well 1. The total volumetric inflow to Injection Well 2 of 924 m^3 is sufficient to cover a 100 m x 100 m area to a depth of approximately 9 cm. Although this volume appears to be exceptionally low in value, the relative significance of this input into the aquifer cannot be determined.

An ANOVA comparison of injection well characteristics collected at the deep monitoring depths in Injection Well 1 and Injection Well 2 was given in Table 3-28. Statistically significant differences were observed between the two injection wells only for total phosphorus and BOD. No significant differences were observed for any of the remaining evaluated parameters. Therefore, even though inputs into the injection wells appear to have concentrations which are somewhat greater than ambient characteristics within the deep aquifer, virtually no statistically significant differences were observed between Injection Well 1, which received 93% of the total injection well inputs, and Injection Well 2, which received only 7% of the total inputs. In spite of this disparity of inputs, the only two parameters which appear to be significantly different between the two sites are total phosphorus and BOD.

In summary, it appears that inputs into the two injection wells contain somewhat greater concentrations for the majority of measured constituents than observed in deep aquifer portions of the wells themselves. However, few statically significant differences were detected in chemical characteristics between the injection well which received the majority of the volumetric inputs and the well which received 7% of the volumetric inputs. The only parameters exhibiting statistically significant differences appear to be total phosphorus and BOD. Therefore, with the possible exception of these parameters, inputs of inflow into the injection wells do not appear to be significantly impacting chemical characteristics of the deep aquifer at this time.

3.12 Potential System Modifications

Based on the analyses and discussions presented in the previous sections, it appears that the dry detention pond may be a questionable component in the overall treatment train present at the site. Although approximately 52% of the overall hydrologic inputs into the pond infiltrated into shallow groundwater, the water which remained within the pond experienced significant increases in measured concentrations for many constituents as a result of the shallow piezometric surface rising into the pond. As inflow into the pond mixed with the shallow groundwater, the resulting mixture was characterized by concentrations substantially in excess of inflow concentrations for many parameters.

An analysis was conducted to provide a comparison of total mass discharges to the two injection wells which would have occurred if the detention pond had been absent, or modified such that the bottom elevation did not intercept the shallow groundwater, and water discharging through Inflow 1 and Inflow 2 had been input into the injection wells without concentration increases from mixing with shallow groundwater . In this case, the mass discharges into the injection well would equal the total mass inputs measured at Inflow 1 and Inflow 2. This mass can then be compared with the mass discharges into the two injection wells under current conditions with the pond in place.

A comparison of estimated mass inputs to the injection wells without impacts from the detention pond is given Table 3-38. Mass input with the pond is summarized based upon the estimated mass discharges to each of the two injection wells as summarized in Table 3-30. A calculation is also provided of the estimated mass inputs which would occur to the injection wells without the existing detention pond. This is estimated as the sum of mass inputs from Inflow 1 and Inflow 2, as summarized in Table 3-30.

TABLE 3-38

ESTIMATED IMPACTS TO THE INJECTION WELLS WITH THE DETENTION POND REMOVED

PARAMETER	UNITS	MEAN CONCENTRATIONS			MASS INPUTS (kg)[1]	
		WITH POND	WITHOUT POND INCREASES	DEEP WELL CHARACTERISTICS AT SITES 1 & 2	CURRENT CONDITIONS	WITHOUT POND
Alkalinity	mg/l	93.0	166	134	1,250	3,110
NH_3-N	µg/l	198	197	146	2.6	3.7
$NO_2 + NO_3$-N	µg/l	910	337	7	12.2	6.3
Diss. Organic N	µg/l	1,234	517	410	16.5	9.7
Particulate N	µg/l	997	469	497	13.4	8.8
Total N	µg/l	3,337	1,521	1,070	44.7	28.5
Diss. Ortho-P	µg/l	444	106	34	6.0	2.0
Diss. Organic P	µg/l	41	98	29	0.55	1.8
Particulate P	µg/l	86	154	47	1.2	1.0
Total P	µg/l	572	259	110	7.7	4.8
TSS	mg/l	25.9	18.9	3.5	347	354
BOD_5	mg/l	6.8	1.7	2.2	90.7	31.3
Chloride	mg/l	275	922	20,439	3,687	17,250
Total Cadmium	µg/l	< 1	< 1	< 1	0.01	0.01
Total Chromium	µg/l	< 5	< 5	< 5	0.03	0.05
Total Copper	µg/l	13	13.5	48	0.17	0.25
Total Iron	µg/l	33	106	200	0.44	2.0
Total Lead	µg/l	< 2	< 2	10	0.01	0.01
Total Zinc	µg/l	42	23	8	0.56	0.43
Volume	m^3	--	--	--	13,437	18,710

1. All loadings given in terms of kg except metals which are given in grams

With the existing detention pond in place, approximately 13,437 m^3 of water discharged into the two injection wells during the 16-month monitoring program. If the pond had been removed, the total volume discharging to the injection wells would increase to 18,710 m^3. However, in spite of the increase in volume which would occur if the pond were removed, the mass loadings into the injection wells would actually decrease for many of the measured parameters, since the concentration increases which occur during migration through the pond would not occur. If the pond were to be removed or modified, decreases in mass loadings would be observed for NO_X, dissolved organic nitrogen, particulate nitrogen, total nitrogen, orthophosphorus, total phosphorus, BOD, and total zinc. For many of these parameters, the reductions in mass loadings would be substantial. Increases in mass loadings would occur for alkalinity, ammonia, dissolved organic phosphorus, chloride, and total iron. However, for parameters which exhibited increases, the increases appear to be relatively small.

A comparison of chemical characteristics entering the injection wells, with and without impacts from the pond, with the mean characteristics of samples collected from the deep monitoring site in Injection Wells 1 and 2 is also given in Table 3-38 for comparison purposes. The estimated mean chemical characteristics of inputs to the injection wells without impacts from the pond are calculated based upon the flow-weighted average of inputs entering the pond from Inflow 1 and Inflow 2. Chemical characteristics of the deep samples collected from Injection Wells 1 and 2 reflect the arithmetic mean of all samples collected at this depth. This comparison allows an analysis of estimated input concentrations into the injection wells without the increasing concentrations observed for runoff inputs during migration through the pond.

If the pond were to be removed or modified, input concentrations into the injection wells would be lower than current concentrations entering the injection wells, as well as lower in value for many of the measured parameters, than currently exists in deep portions of the injection wells. Input concentrations to the injection wells would be lowered for NO_x, dissolved organic nitrogen, particulate nitrogen, total nitrogen, orthophosphorus, total phosphorus, TSS, BOD, and total zinc. For many parameters, such as particulate nitrogen, BOD, chloride, copper, iron, and lead, the input concentrations would be lower than current characteristics measured at the deep well sites.

A second comparison was performed to evaluate mass loadings discharging to the injection wells under current conditions and an alternative scenario where the pond would be removed or modified along with elimination or modification of portions of the inflow swale between Inflow 3 and Inflow 2. As discussed in previous sections, concentrations of virtually all measured parameters increase substantially during migration from Inflow 3 to Inflow 2 due to interception of the shallow groundwater table by the swale system near the point of measurement for Inflow 2. This new evaluated option assumes that the portion of the swale between Inflow 3 and Inflow 2 would be removed and runoff would discharge directly from Inflow 1 and Inflow 3 directly into the two injection wells.

A comparison of estimated mass inputs to the injection wells with the detention pond and portions of the inflow swale removed or modified is given in Table 3-39. Similar to the trend observed for the previous scenario, total volumetric inputs into the injection well would increase substantially under the proposed alternative. However, mass loadings into the injection well would decrease for many of the measured constituents. Substantial decreases of mass loadings into the

TABLE 3-39

ESTIMATED MASS INPUTS TO THE INJECTION WELLS WITH THE DETENTION POND AND PORTIONS OF THE INFLOW SWALE REMOVED

PARAMETER	UNITS	MEAN CONCENTRATIONS			MASS INPUTS TO INJECTION WELLS (kg)[1]	
		WITH POND	WITHOUT POND AND PORTIONS OF INFLOW SWALE	DEEP WELL CHARACTERISTICS AT SITES 1 & 2	CURRENT CONDITIONS	WITHOUT POND AND PORTIONS OF THE INFLOW SWALE
Alkalinity	mg/l	93.0	69.6	134	1,250	1,341
NH_3-N	µg/l	198	117	146	2.6	2.3
$NO_2 + NO_3$-N	µg/l	910	130	7	12.2	2.5
Diss. Organic N	µg/l	1,234	571	420	16.5	11.0
Particulate N	µg/l	997	307	497	13.4	5.9
Total N	µg/l	3,337	1,126	1,070	44.7	21.7
Diss. Ortho-P	µg/l	444	183	34	6.0	3.5
Diss. Organic P	µg/l	41	99	29	0.55	1.9
Particulate P	µg/l	86	81	47	1.2	1.6
Total P	µg/l	572	363	110	7.7	7.0
TSS	mg/l	25.9	25.8	3.5	347	497
BOD_5	mg/l	6.8	1.8	2.2	90.7	33.8
Chloride	mg/l	275	153	20,439	3,687	2,939
Total Cadmium	µg/l	< 1	< 1	< 1	0.01	0.01
Total Chromium	µg/l	< 5	< 5	< 5	0.3	0.5
Total Copper	µg/l	13	8	48	0.17	0.16
Total Iron	µg/l	33	33	200	0.44	0.63
Total Lead	µg/l	< 2	< 2	10	0.01	0.01
Total Zinc	µg/l	42	16	8	0.56	0.31
Volume (m^3)			--	--	13,437	19,258

1. All loadings given in terms of kg except metals which are given in grams

injection wells would be observed for ammonia, NO_X, dissolved organic nitrogen, particulate nitrogen, total nitrogen, orthophosphorus, total phosphorus, BOD, chloride, total copper, and total zinc. Increases in mass loadings to the injection wells would be observed only for alkalinity, dissolved organic phosphorus, particulate phosphorus, TSS, total chromium, and total iron. However, the projected increases for these constituents are relatively small.

Similar to the trends observed in Table 3-38, input concentrations to the injection wells would also be reduced for many parameters compared with input concentrations under existing conditions. Reductions in input concentrations would be observed for alkalinity, NH_3, NO_x, dissolved organic nitrogen, particulate nitrogen, total nitrogen, orthophosphorus, particulate phosphorus, total phosphorus, TSS, BOD, chloride, copper, and zinc. For several parameters, including NH_3, particulate nitrogen, BOD, chloride, copper, iron, and lead, the input concentrations would be less than ambient characteristics in the wells.

Estimates of the chemical characteristics of inflow into the injection wells without the pond and portions of the inflow swale were generated based upon the flow-weighted concentrations of runoff inputs measured at Inflow 1 and Inflow 3. Estimates of the mean chemical characteristics of deep samples collected at Injection Wells 1 and 2 are also provided for comparison purposes. If the retention/detention pond and portions of the inflow swale were to be removed or modified, the inflow into the injection wells could be estimated as the flow-weighted average of the characteristics of Inflow 1 and Inflow 3. As seen in Table 3-39, if the pond and portions of the inflow swale were to be removed or modified, the chemical characteristics of inflow into the injection wells would have lower concentrations for many of the measured parameters, including alkalinity, ammonia, particulate nitrogen, BOD, chloride, total copper, total iron, and total lead. Other parameters would exhibit slight increases in concentration compared with the ambient characteristics of the deep well samples. However, the input concentrations would be substantially lower than currently exist under current conditions.

Although these recommendations are specific to the Key Colony Site only, and should not necessarily be extrapolated to other areas within the Florida Keys, it appears that injection wells appear to be an effective method for disposing of excess runoff at the site. The overall performance could be enhanced for many parameters by eliminating the detention pond system and constructing all of the conveyance swales above normal water table elevations. This type of system would allow for substantial pre-treatment and infiltration of runoff within the swale system, while minimizing interception of the shallow groundwater with the bottom of the swale which leads to a degradation in water quality characteristics. The swale systems could then discharge directly into injection wells, provided that the injection wells contained sufficient hydraulic capacity to accept the runoff inputs. If ponds are utilized within the region, care must be taken to be certain that the bottom of the pond is sufficiently high in elevation so that the pond bottom does not intercept the shallow groundwater except during extreme events.

SECTION 4

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

4.1 Summary

4.1.1 Introduction

During the period from 1995-2000, the City of Key Colony Beach installed an array of BMPs to minimize discharges of stormwater runoff into adjacent marine waters. Several of the primary BMP elements are evaluated in this report and include two new 61 cm (24 in) diameter Class V injection wells and a 0.59 ha (1.45 ac) shallow grassed dry retention/detention pond. Although dry retention/detention stormwater management systems have been commonly used in the Florida Keys, no previous studies have been performed to evaluate the effectiveness of these systems for retaining stormwater pollutants and preventing downward migration of pollutants into shallow groundwater in areas with highly permeable soils. In addition, drainage wells are also commonly used in the Florida Keys for disposal of both treated and untreated stormwater runoff. However, no previous research has been performed to evaluate potential groundwater impacts resulting from the use of these wells for disposal of stormwater runoff.

Field and laboratory investigations were conducted from July 2001-November 2002 at the Key Colony Beach site to:

1. Evaluate the hydraulic performance and pollutant removal effectiveness of a dry detention stormwater management system operated in an area of porous soils and high groundwater table conditions

2. Evaluate the shallow groundwater impacts resulting from infiltration of runoff through the pond bottom

3. Evaluate the deep groundwater impacts of using drainage/injection wells for disposal of treated runoff

4. Provide recommendations for improvement of the current design for dry retention/ detention systems to enhance the hydraulic and pollutant removal effectiveness and to minimize impacts on shallow and deep groundwater resources

4.1.2 Description of the Project Site

The retention/detention pond site evaluated during this project is located in a single-family residential subdivision in the City of Key Colony Beach, Florida, located south of U.S. 1 and northeast of Marathon Shores in the Florida Keys. The overall drainage basin for the pond covers approximately 9.86 ha (24.34 ac) and includes portions of roadway with associated right-of-way, a 9-hole golf course, playground, sewage treatment plant, tennis court, storage yard for boats and trailers, and commercial/public businesses. The majority of the basin consists of open areas covered with grass in relatively good condition. Topography within the drainage basin is essentially flat, and no well-defined natural drainage features are present. Runoff is conveyed primarily by overland flow to a series of vegetated drainage swales located on the eastern and western boundaries of the basin. Due to the highly permeable nature of the on-site soils, the substantial retention within the drainage swales, and the small amount of impervious surfaces within the basin, rain events in excess of 2.5 cm (1.0 in) are typically required to contribute measurable runoff into the dry detention pond. The bottom of the pond is relatively flat, as well as shallow, with maximum water depths ranging from approximately 0.3-0.5 m (1-1.5 ft).

Excess runoff which reaches the dry detention pond begins to rapidly infiltrate through the pond bottom into the shallow surficial soils. When the storage capacity of the surficial soil layer has been exceeded, accumulation of water begins to occur within the pond. Drawdown of excess runoff within the pond occurs through two separate Class V injection wells. The intake inverts for each injection well are set near the bottom elevation of the pond so that excess runoff which fills the pond can rapidly be discharged into groundwater. Inputs into each drainage well discharge into a deep groundwater layer extending from approximately 12-24 m (40-80 ft) below the ground surface.

4.1.3 Field and Laboratory Procedures

Field instrumentation was installed to conduct a complete hydrologic budget for the pond, including a water level recorder, rainfall recorder, Class A pan evaporimeter, and groundwater piezometers. Automatic sequential samplers with integral flow meters were installed to provide continuous records of inflow and outflow from the pond, and to collect stormwater and outflow samples on a flow-weighted basis. Field personnel visited the project site approximately once each week to retrieve samples and flow data from the stormwater and outflow collectors and other hydrologic equipment.

A total of nine groundwater piezometers was installed in pond, adjacent, and control areas to provide information on horizontal groundwater gradients in the vicinity of the pond site. Piezometric measurements were collected from each of the nine piezometers on approximately a weekly basis. Monitoring of groundwater characteristics was performed on a monthly basis in each of the nine shallow groundwater piezometers, as well as in the two injection wells used for disposal of pond outflow. Groundwater samples from the injection wells were collected at shallow, middle, and deep sites. Characteristics of bulk precipitation were also estimated by collection and analysis of combined wet and dry fallout on a periodic basis.

Sediment sampling was conducted in pond and control areas to quantify the fate of stormwater pollutants entering the detention pond system. Each of the collected sediment core samples was analyzed for physical characteristics, nutrients, heavy metals, and particle size distribution.

Detailed laboratory analyses were conducted on collected samples of stormwater runoff, pond outflow, surface water, bulk precipitation, shallow groundwater, and injection well samples. Analyses performed included general and inorganic parameters, nutrients, demand parameters, chlorophyll-a, fecal coliform, and dissolved and total heavy metals. In excess of 280,000 separate hydrologic and laboratory measurements were generated during the course of this project.

4.1.4 Site Hydrology

A continuous record of rainfall characteristics was collected at the Key Colony project site from July 18, 2001-October 31, 2002 using a tipping-bucket rainfall collector with a digital data logging recorder. Total event rainfall ranged from 0.03-9.35 cm (0.01-3.68 in), with a mean of 0.79 cm (0.31 in) per rain event. A total of 160.2 cm (63.07 in) of rainfall was measured at the site during the 16-month monitoring period.

Piezometric surface elevations in the pond were measured on a continuous basis from September 2001-October 2002 using a water level pressure transducer with digital data logger. In general, piezometric elevations respond rapidly to rain events, with a rapid increase in piezometric surface. In general, piezometric elevations within the pond rarely exceeded the minimum ground level of 2.05 ft within the pond, with only 11 recorded occasions of standing water within the pond. Measured piezometric elevations at the Key Colony project site ranged from 0.07-3.09 ft (NGVD), with a mean piezometric elevation of 0.95 ft (NGVD), compared with a minimum pond ground level of 2.05 ft.

Piezometric elevations beneath the pond were impacted by tidal conditions in the adjacent marine waters, with piezometric elevations exhibiting sinusoidal patterns with alternating peaks and valleys at approximately 12-24 hour intervals. This type of behavior suggests an extremely porous connection between the adjacent marine waters and areas beneath the pond.

Drawdown of piezometric elevations within the pond occurred rapidly following storm events, with a mean drawdown rate of approximately 0.61 cm/hr (0.24 in/hr). In general, piezometric elevations within the pond appear to be greater than elevations measured in adjacent or control areas. This suggests that the primary direction of lateral water movement at the study site is from the pond into the adjacent groundwater areas.

Average daily evaporation losses were monitored at the Key Colony site from August 2001-October 2002 using a Class A pan evaporimeter. Mean daily evaporative losses at the site ranged from a high of 0.61 cm/day (0.24 in/day) in July to a low of 0.20 cm/day (0.08 in/day) during January, June, and December. However, since standing water is rarely present within the pond, evaporative losses are assumed to be negligible at the pond site and are not included as part of the hydrologic budget developed for the project.

Continuous inflow hydrographs were recorded for inputs of stormwater runoff into the detention pond at 10-minute intervals from July 18, 2001-October 31, 2002. No measurable baseflow was observed at any inflow monitoring site during the 16-month monitoring program. Calculated runoff coefficients at the Key Colony project site range from a low of 0.000 during the period from January-April 2002 to a high of 0.265 during November 2001. Calculated runoff coefficients at the site appear to be impacted more by rainfall depths during individual events than by the total rainfall observed during a given month, with rain events in excess of approximately 2.5 cm (1 in) required to generate measurable runoff at the site.

Continuous hydrographs of discharges from the dry retention pond to Injection Wells 1 and 2 were collected from mid-July 2001 to October 2002. Discharges to Injection Well 1 were recorded during 10 of the 16 months included in the monitoring program, with discharges to Injection Well 2 recorded during only three of the 16 months. Discharges to Injection Well 2 must first pass over a raised area in the swale leading to the injection well which limits discharge to this well.

During the 16-month monitoring program, stormwater runoff contributed approximately 67% of the hydraulic inputs into the pond, with 33% contributed by direct rainfall. The dominant mechanism for losses from the pond appears to be groundwater seepage which accounts for approximately 52% of the total pond losses. Discharges to the two injection wells accounts for the remaining 48% of the pond losses. Of the discharges to the two injection wells, approximately 93% of the total discharges entered Injection Well 1, with only 7% of the total discharges entering Injection Well 2.

4.1.5 Characteristics of Bulk Precipitation

A total of 25 separate bulk precipitation samples were collected at the Key Colony project site during the 16-month monitoring period. In general, bulk precipitation at the site was found to be slightly acidic, with a mean pH of 5.90. Bulk precipitation was also found to exhibit a moderate ionic strength, although poorly buffered.

A considerable degree of variability is apparent in measured concentrations of nitrogen species in bulk precipitation. Relatively elevated concentrations of NO_x, dissolved organic nitrogen, particulate nitrogen, and total nitrogen were observed at the site on several occasions. Elevated levels of phosphorus species were also observed in bulk precipitation at the site, with particulate phosphorus comprising the majority of the total phosphorus measured.

In contrast to the trends observed for nitrogen and phosphorus, relatively low levels of heavy metals were observed in bulk precipitation for most parameters. Evidence of elevated concentrations during specific events are apparent only for total iron and total zinc.

4.1.6 Characteristics of Stormwater Runoff

Runoff characteristics were monitored at three separate inflow monitoring sites from August 2001-October 2002 over a wide range of rain event characteristics. Total event rainfall for monitored events ranged from 4.52-9.35 cm (1.78-3.68 in), with rain event durations ranging from 1.48-14.04 hours. Two of the monitored stormwater sites represent inflows to the pond, with the third stormwater monitoring site located approximately 180 m (600 ft) upstream from Inflow 2 along a shallow vegetated swale.

Stormwater runoff measured at the Key Colony site is slightly alkaline in pH and well buffered. A high degree of variability is apparent in measured conductivity values between the three sites. Runoff inputs were found to exhibit a wide range of measured turbidity and suspended solids values, with mean BOD concentrations less than 2 mg/l at each site.

In general, mean concentrations of nitrogen species at the three monitoring sites are typical of runoff which has received pre-treatment in a vegetated swale system. However, nitrogen concentrations appear to increase during migration through the swale system, suggesting influx into the swale system from sources other than stormwater runoff.

Measured concentrations of total phosphorus at the three inflow monitoring sites are typical of values commonly observed in stormwater runoff. The dominant phosphorus species observed at the majority of the sites is dissolved orthophosphorus, followed by dissolved organic phosphorus and particulate phosphorus.

In general, measured concentrations of heavy metals at the three inflow monitoring sites are relatively low in value. Mean concentrations for dissolved and total cadmium, dissolved and total chromium, and dissolved and total lead are less than the applicable laboratory detection limits for these parameters. The majority of heavy metals measured at each of the three monitoring sites were found to exist primarily in a particulate form.

At Inflow 1, total nitrogen was found to be negatively correlated with total rainfall, suggesting that total nitrogen concentrations decrease as total rainfall amounts increase. In addition, particulate phosphorus was found to be positively correlated with rainfall intensity, suggesting that phosphorus species increase as rainfall intensity increases. Suspended solids concentrations were found to decrease with increasing event duration and increase as rainfall intensity increases. Significant correlations observed at the other two monitoring sites appear to be contrary to commonly observed relationships between runoff and rain event characteristics.

4.1.7 Characteristics of Pond Surface Water

Standing water was rarely present in the Key Colony dry retention/detention pond, and surface water samples were collected on only three separate occasions during the 16-month monitoring period. Surface water collected within the pond is slightly alkaline and well buffered, with brackish water characteristics based upon measured salinity values.

Measured nitrogen species in the detention pond are somewhat elevated, particularly for ammonia and dissolved organic nitrogen. The mean total nitrogen concentration of 3473 µg/l measured within the pond is higher than total nitrogen concentrations measured at any of the inflow monitoring sites. Elevated concentrations of phosphorus species were also observed in surface water within the pond. The mean total phosphorus concentration of 696 µg/l in the pond is substantially greater than phosphorus concentrations measured at any of the inflow monitoring sites.

Measured concentrations of fecal coliform and chlorophyll-a are highly variable between the three monitoring dates, with an exceedance of the Class III criterion for fecal coliform observed on one of the three monitoring dates.

Measured concentrations of heavy metals in the pond surface water are relatively low in value. Heavy metal concentrations in the pond appear to be less than or equal to values measured at the inflow monitoring sites.

4.1.8 Characteristics of Pond Outflow

Outflow from the dry detention pond into the two injection wells was monitored on a continuous basis from August 2001-October 2002. Due to the rapid infiltration characteristics of the on-site soils, combined with attenuation within the vegetated swales used for conveyance, discharges from the pond into the two injection wells occurred on an infrequent basis. A total of 10 separate pond outflow samples were collected entering Injection Well 1 during the 16-month monitoring program, while only four separate outflow samples were collected entering Injection Well 2.

A high degree of variability is apparent in chemical characteristics of discharges to both of the injection wells for virtually all measured parameters. Discharges to the two injection wells are slightly alkaline, with moderate to high levels of dissolved ions. Measured BOD concentrations in discharges to the two injection wells are greater than concentrations measured at either of the two inflows into the pond.

Measured nutrient concentrations in discharges to the two injection wells are elevated, particularly in comparison with concentrations measured in inflows to the pond. The dominant nitrogen species at each of the two sites is dissolved organic nitrogen, followed by particulate nitrogen.

Relatively elevated levels of phosphorus species were also observed in discharges to each of the two injection wells. Concentrations of phosphorus in discharges to the two injection wells are typically greater than concentrations measured at the inflows into the pond.

Measured concentrations of dissolved and total cadmium, dissolved and total chromium, and dissolved and total lead are extremely low in value in discharges to the two injection wells. Concentrations of dissolved and total copper, dissolved and total iron, and dissolved and total zinc are similar to characteristics measured in stormwater runoff.

4.1.9 Characteristics of Shallow Groundwater

Characteristics of shallow groundwater were evaluated using a series of nine groundwater piezometers installed in pond, adjacent, and control areas. Groundwater in each of the three areas is highly brackish, with mean salinity values ranging from 14.6-15.7 ppt. Based on field measurements conducted during the sampling processes at each monitoring well, the shallow groundwater appears to be highly reduced, with mean ORP values ranging from 34-62 mV.

Shallow groundwater in the three areas contains extremely elevated levels of ammonia and dissolved organic nitrogen. Total nitrogen concentrations range from 11.5-23.5 µg/l, reflecting values approximately 5-10 times greater than observed in inputs into the pond. In contrast, concentrations of phosphorus species in groundwater from the three monitored areas are similar to the characteristics of inflows into the pond.

Inputs of shallow groundwater in the three areas are characterized by extremely elevated levels of BOD, with mean values at two of the three sites in excess of 100 µg/l. Extremely elevated levels of chloride are also present in each of the three areas. In contrast, measured concentrations of metal species appear to be relatively low in shallow groundwater, with values equal to or less than concentrations observed in inflows into the pond.

Based on the results of an ANOVA comparison between pond, adjacent, and control areas, no statistically significant differences were observed in chemical characteristics between pond, adjacent, or control areas for the majority of measured parameters. Statistically significant differences were observed only for selected species of nitrogen and phosphorus, along with BOD. For each parameter which exhibits a statistically significant difference, the highest measured concentrations are observed in pond and adjacent areas compared with the control area.

4.1.10 Characteristics of Injection Wells

Water samples were collected from each of the two Class V drainage/injection wells on a monthly basis throughout the 16-month monitoring period, with separate samples collected from surface, middle, and bottom portions of the two drainage wells. Water within the injection wells is slightly alkaline, with increasing specific conductivity and salinity with increasing well depth. Mean salinity values range from 2.9 ppt at the shallow depth to 31.9 ppt at the deep depth.

In general, measured total nitrogen species in the injection wells are found to be relatively low in value at each of the three monitoring depths. A general trend of decreasing nitrogen concentrations with increasing depth is apparent. In general, nitrogen concentrations measured in Injection Well 2, which received only 7% of the total inflow, are somewhat lower than values measured in Injection Well 1.

Measured concentrations of phosphorus species appear to be moderate to low in value in the two injection wells, with a slight trend of decreasing phosphorus concentration with increasing water depth. In general, phosphorus concentrations measured in Injection Well 2, which received only 7% of the total inflow, are somewhat lower than values measured in Injection Well 1.

Each of the two injection wells exhibit a general trend of increasing chloride concentration with increasing depth. The reverse trend is apparent for fecal coliform counts which decrease substantially with increasing well depth. In general, measured heavy metal concentrations in the two injection wells are found to be extremely low in value for all measured parameters, with the exceptions of total iron and total copper.

ANOVA comparisons were performed to examine differences in chemical characteristics at each of the three monitored depths between Injection Well 1, which receives the majority of inflow from the detention pond, and Injection Well 2, which receives only minimal inputs from the detention pond. At the shallow monitoring depth, statistically significant differences exist between measured concentrations of dissolved oxygen, ORP, ammonia, NO_x, dissolved organic nitrogen, total nitrogen, orthophosphorus, and total phosphorus. With the exceptions of dissolved oxygen, ORP, and NO_x, statistically higher concentrations were observed in Injection Well 1 compared to values measured in Injection Well 2.

At the middle monitoring depth, statistically significant differences exist between measured concentrations of ORP, ammonia, total nitrogen, orthophosphorus, total phosphorus, BOD, fecal coliform, and total iron between the two wells. In each case where statistically significant differences exist, the highest measured concentrations for each parameter, with the exceptions of ORP and fecal coliform, occurs in Injection Well 1. At the deep monitoring depth, which is the area where inflow into the well is directly deposited, statistically significant differences between the two wells were observed only for temperature, ORP, total phosphorus, and BOD, all of which (with the exception of ORP) were higher in value at Injection Well 1 than in Injection Well 2.

4.1.11 <u>Characteristics of Soils</u>

Soil samples were collected in both pond and control areas to evaluate the potential of the pond soils for retaining stormwater pollutants. In general, soils within the pond area appear to be accumulating concentrations of nitrogen, lead, iron, and to a lesser extent, aluminum, in excess of values observed in the control area. These increased soil concentrations may be a result of runoff-related pollutants which are trapped within layers of soil during migration into the pond. However, no significant differences appear to exist in accumulation patterns for total phosphorus or zinc in pond or control areas.

4.1.12 <u>Estimated Removal Efficiencies for System Components</u>

4.1.12.1 <u>Mass Removal in the Pond System</u>

Estimates of total mass inputs into the pond were calculated for direct precipitation, as well as runoff inputs. Estimates of mass losses were calculated for discharges into the two injection wells as well as seepage into shallow groundwater. Mass retention or export within the dry detention/retention is defined as the difference between the estimated total mass inputs into the pond and the estimated mass losses.

A net mass retention within the pond is observed for only a few measured constituents, including alkalinity, dissolved organic phosphorus, chloride, and total iron. The remaining measured parameters either exhibit no change or an increase in mass during migration through the pond. Mass increases of more than 100% are observed for particulate nitrogen and total nitrogen. Mass increases of approximately 200% or more are observed for NO_x, dissolved organic nitrogen, total phosphorus, and BOD, with dissolved orthophosphorus exhibiting an increase of more than 500%.

The apparent poor performance of the Key Colony pond for attenuating pollutants is related to the hydrologic and chemical characteristics of shallow groundwater in the vicinity of the pond. During rain events with sufficient rainfall depths to generate measurable runoff, the shallow groundwater rises up into the pond at the same time that runoff inflow is entering the pond through the inflow monitoring locations. The resulting water within the pond, therefore, is a mixture of shallow groundwater and runoff inflow. Shallow groundwater in the vicinity of the pond contains extremely elevated levels of ammonia, dissolved organic nitrogen, total nitrogen, BOD, and chloride which mixes with the more dilute runoff inflow, creating a combined pond mixture with characteristics which are substantially more elevated than inflows into the pond. This combined runoff mixture is the water source which discharges into the two injection wells and infiltrates into the shallow groundwater as piezometric elevations recede.

4.1.12.2 Mass Removal in the Swale System

One of the objectives of this project is to evaluate the performance efficiency of the vegetated swale which enters along the southeastern side of the pond. The swale system in this area is densely grassed and conveys runoff from portions of the watershed into the pond. Inflow monitoring locations designated as Inflow 2 and Inflow 3 are located approximately 180 m (600 ft) apart along the swale to evaluate the overall treatment efficiency of the swale system.

Approximately half of the evaluated parameters exhibit a decrease in mass loadings between the two monitoring sites, while the remaining parameters exhibit an increase in mass loading. Since the volumetric flows at each of the two sites are approximately equal, the differences in mass loadings at each site are primarily due to differences in mean chemical characteristics. The downstream monitoring site has substantially higher monitored concentrations for conductivity, alkalinity, ammonia, NO_x, particulate nitrogen, total nitrogen, turbidity, chloride, iron, and zinc compared with values measured at the upstream location. It appears that as piezometric elevations increase during heavy rain events, the shallow groundwater table begins to intercept downstream portions of the swale system, causing poor quality surficial groundwater to enter the swale. This results in increases in measured concentrations for many constituents which ultimately discharge into the pond.

The negative removal efficiencies observed for certain parameters should not be viewed as an indication that the swale system is not efficient in reducing pollutant loadings during migration between the two monitoring sites. Vegetated swales have been repeatedly demonstrated to be effective in reducing both the quantity and quality of runoff inputs. It is virtually certain that a substantial pollutant mass is being attenuated within the swale system, although the effectiveness is masked due to the influx of poor quality groundwater.

4.1.12.3 Concentration-Based Removal in the Pond

A concentration-based removal efficiencies were calculated for each measured pollutant during migration through the retention/detention pond. An overall flow-weighted inflow concentration is calculated based on inputs into the pond from stormwater runoff and bulk precipitation. An overall weighted outflow concentration is calculated based upon the chemical characteristics of outflow discharges to the injection wells and shallow groundwater.

The majority of measured parameters, including ammonia, NO_x, dissolved organic nitrogen, particulate nitrogen, total nitrogen, orthophosphorus, particulate phosphorus, total phosphorus, TSS, BOD, copper, and zinc exhibit increases in concentration during migration through the pond. Only four parameters, including alkalinity, dissolved organic phosphorus, chloride, and iron, exhibit decreases in concentration within the pond.

The observed increases in concentrations within the pond are related to the hydrologic and water quality characteristics of shallow groundwater which migrates upward into the pond during heavy rain events. Since the shallow groundwater contains elevated levels of many measured constituents, the resulting mixture exhibits chemical characteristics with values substantially in excess of the inflow concentrations.

4.1.12.4 Concentration-Based Removal in the Swale System

Concentration-based removal efficiencies were also calculated between the two monitoring locations within the vegetated swale system. Similar to the trends observed in the pond, the majority of the measured parameters appear to increase in concentration during migration through the swale system from the upstream to the downstream location. Significant increases in concentration are observed for conductivity, alkalinity, ammonia, NO_x, particulate nitrogen, total nitrogen, turbidity, chloride, copper, iron, and zinc. It appears that water movement through the grassed swale is impacted by the same processes which impact concentration characteristics within the pond.

4.1.13 Groundwater Impacts of the Key Colony Treatment System

4.1.13.1 Shallow Groundwater

As discussed in previous sections, flow-weighted inflow into the retention/detention pond contains lower measured concentrations for most constituents than present in shallow groundwater beneath the pond. Therefore, it appears unlikely that infiltration from the pond could increase concentrations of chemical constituents in the shallow groundwater. In fact, infiltration of water from the pond into the shallow groundwater should dilute the existing concentrations of constituents within the groundwater, and reduce concentrations for measured parameters compared with concentrations that would exist in the absence of the pond. There appears to be no substantial evidence to suggest that operation of the stormwater management system is creating negative impacts on shallow groundwater characteristics in the vicinity of the detention pond.

4.1.13.2 Injection Well Characteristics

In general, the deep layer into which the injection well discharges is a saline environment, with conductivity and chloride concentrations similar to those commonly observed in sea water. For many of the measured parameters, concentrations measured in the inflow are greater than concentrations measured in deep portions of the injection well. This trend is particularly apparent for NO_x, dissolved organic nitrogen, particulate nitrogen, total nitrogen, orthophosphorus, total phosphorus, turbidity, BOD, TSS, fecal coliform, and total zinc. In contrast, inputs into the injection well have substantially lower concentrations of copper, iron, and lead than observed in deep portions of the well.

Although inputs into the injection wells appear to exhibit greater concentrations for many measured constituents than observed in deep aquifer portions of the wells, few statistically significant differences were detected in chemical characteristics between Injection Well 1, which receives the majority of the volumetric inputs, and Injection Well 2, which receives only 7% of the volumetric inputs. The only parameters exhibiting statistically significant differences appear to be total phosphorus and BOD. With the possible exception of these parameters, therefore, inputs of inflow into the injection wells do not appear to be significantly impacting chemical characteristics of the deep aquifer at this time.

4.1.14 Potential System Modifications

Based on the analyses and discussions presented in the previous sections, it appears that the dry detention pond may a questionable components in the overall treatment train present at the site. If the pond had been removed, the total volume discharging to the injection wells would increase by approximately 39%. However, in spite of the increase in volume, mass loadings into the injection well would actually decrease for many of the measured parameters, since the concentration increases which occurred during migration through the pond would not occur. If the pond were to be removed, decreases in mass loadings into the injection wells would be observed for NO_x, dissolved organic nitrogen, particulate nitrogen, total nitrogen, orthophosphorus, total phosphorus, BOD, and total zinc. For many of these parameters, the reductions in mass loadings would be substantial.

If the pond were to be removed, input concentrations into the injection wells would also be lower than exists under current conditions. Input concentrations to the injection wells would be lower for NO_x, dissolved organic nitrogen, particulate nitrogen, total nitrogen, orthophosphorus, total phosphorus, TSS, BOD, and total zinc. For many of these parameters, the input concentrations would actually be lower than current concentrations measured at the deep well sites.

Estimates were also conducted to evaluate impacts on the injection wells if the grassed inflow swale had been constructed above the groundwater table and had not been impacted by inputs of shallow groundwater during extreme rain events. If the inflow swale had been constructed higher, and the retention/detention pond had been removed, the chemical characteristics of inflow into the injection wells would have substantially lower concentrations for many measured parameters. Mass loadings into the injection well would also be substantially reduced for certain parameters.

4.2 Conclusions

From the analyses and results performed during this project, the following specific conclusions are reached:

1. Piezometric elevations within the pond are less than the pond bottom elevation throughout most of the 16-month study period. On an average basis, piezometric elevations exceed the minimum pond ground level less than once each month.

2. Piezometric elevations within the pond respond rapidly to rain events, with a rapid increase in piezometric surface. Drawdown of the piezometric surface occurs at a relatively constant rate of approximately 0.61 cm/hr (0.24 in/hr).

3. Repeating sinusoidal patterns observed in piezometric elevations beneath the pond suggest a relatively free-flowing connection between the shallow groundwater and the adjacent marine water.

4. As a result of the highly permeable soils within the watershed, rain events in excess of 2.5 cm (1 in) are typically required to generate measurable runoff inputs into the pond. The volume of runoff inputs appears to be impacted more by rainfall during individual events than cumulative rainfall over an extended period of time.

5. During the 16-month monitoring program, stormwater runoff contributed 67% of the total inputs into the pond, with 33% contributed by direct precipitation.

6. The dominant source of outflow from the pond is infiltration into shallow groundwater which accounted for approximately 52% of the estimated outputs. Discharges into the two drainage well structures accounted for the remaining 48% of overall system losses. Approximately 93% of the drainage well discharges enter Injection Well 1, with only 7% entering Injection Well 2.

7. Lateral groundwater movement at the site occurs primarily from the pond into the adjacent groundwater. However, vertical movement of shallow groundwater into the pond was observed on numerous occasions.

8. Bulk precipitation at the site is highly variable in chemical characteristics, with elevated levels of nitrogen and phosphorus species and relatively low levels of heavy metals.

9. Concentrations of nitrogen species in stormwater runoff are low to moderate in value, with total phosphorus concentrations typical of values commonly observed in stormwater runoff. Measured concentrations of heavy metals at the inflow monitoring sites are relatively low in value. Runoff characteristics in at least one inflow site appear to be impacted by inputs of shallow groundwater during extreme rain events.

10. Correlations between stormwater characteristics and rain event characteristics suggest that mobilization of particulate phosphorus and suspended solids increases as rainfall intensity increases.

11. Standing water is rarely present within the retention/detention pond. However, when present, pond water contains elevated levels of nitrogen and phosphorus, with concentrations substantially in excess of inflow characteristics into the pond.

12. Outflow from the pond into the two injection wells is highly variable, with substantially higher concentrations of nitrogen and phosphorus than measured in inputs into the pond. Discharges to the injection wells are thought to be impacted by shallow groundwater which enters the pond during extreme rain events.

13. Shallow groundwater beneath the pond contains extremely elevated levels of nitrogen species, BOD, and chloride, in concentrations substantially in excess of input concentrations into the pond.

14. Inputs into the Class V drainage/injection wells discharge into an underground aquifer approximately 12-24 m (40-80 ft) below the ground surface. Chemical characteristics of this aquifer are similar to sea water, with elevated levels of salinity, chloride, and total iron. Nutrient concentrations in this deep aquifer are relatively low in value.

15. Soils in both pond and control areas are poorly graded, with a majority of the soil particles exhibiting diameters in excess of 0.25 mm. Soils within the pond appear to be accumulating concentrations of nitrogen, lead, iron, and aluminum in excess of values observed in the control area.

16. As a result of concentration increases caused by intermingling with shallow groundwater, mass losses from the pond exceed mass inputs into the pond for the majority of measured constituents.

17. The majority of measured parameters, including ammonia, NO_x, dissolved organic nitrogen, particulate nitrogen, total nitrogen, orthophosphorus, particulate phosphorus, total phosphorus, TSS, BOD, copper, and zinc exhibit increases in concentration during migration through the pond as a result of interaction with shallow groundwater which rises up into the pond during extreme events.

18. As a result of movement of shallow groundwater into the swale during extreme rain events, approximately half of the evaluated parameters exhibit an increase in mass loading between the two swale monitoring sites, with the other half exhibiting a decrease in mass loading.

19. There appears to be no significant evidence to suggest that operation of a stormwater management system is creating negative impacts on shallow groundwater characteristics in the vicinity of the detention pond. Mean characteristics of inflow to the pond are substantially lower in value than the chemical characteristics of shallow groundwater, suggesting that pond inputs can only result in dilution of existing groundwater characteristics.

20. Input concentrations for nutrients, turbidity, BOD, TSS, and fecal coliform appear to be greater than ambient characteristics measured in the deep aquifer of the well.

21. An ANOVA comparison of chemical characteristics between Injection Well 1, which receives 93% of the total injection well inputs, and Injection Well 2, which receives only 7% of the total inputs, indicates significant differences between the two aquifers only for total phosphorus and BOD. No significant differences exist between the two aquifers for any of the remaining parameters.

22. Both mass loadings and input concentrations into the injection wells could be reduced if the bottom elevation of the pond was constructed such that the shallow groundwater table did not intercept the pond during extreme events.

23. Mass loadings and input concentrations into the pond could also be reduced if the vegetated swale did not intercept the shallow groundwater during extreme events.

24. Injection wells appear to be an effective method for disposal of excess stormwater runoff in the Florida Keys. Mass loadings and input concentrations into the injection wells could be substantially reduced by modification of system components in future designs.

4.3 Recommendations

Based on the results obtained during this monitoring project, and the specific conclusions presented previously, the following recommendations are made for improving the performance of stormwater management systems in the Florida Keys:

1. The use of injection wells for disposal of stormwater runoff appears to be a viable alternative to direct discharges into the marine environment. The aquifer layer used for disposal of stormwater runoff at the Key Colony site is poor in quality and has virtually no alternative uses for either irrigation or potable water. Therefore, continued use of injection wells for disposal of stormwater runoff in the Florida Keys environment is recommended. Pre-treatment of the stormwater runoff using either grassed swales or shallow retention/detention ponds should be included in the design for each injection well outfall.

2. Shallow ponds and swales utilized as part of an overall stormwater treatment train must be constructed with bottom elevations at a sufficient height so that the shallow groundwater does not intercept the bottom of either the pond or the swale during heavy rain events. Migration of shallow groundwater into the bottom of a pond or swale substantially degrades the performance efficiency of the system. If the grade on a shallow swale requires that the bottom of the swale intercept the shallow groundwater to maintain a positive drainage gradient, it is recommended that these portions of the swale system be replaced with drainage pipe to prevent inflow of shallow groundwater. Minimization of the impacts from shallow groundwater inflow can be achieved with relatively minimal changes in grading for the stormwater management system. For example, if the retention/detention pond bottom had been raised 0.15 m (0.5 ft), approximately 75% of the events which resulted in groundwater piezometric elevations in excess of the pond bottom elevation would have been eliminated. In the event that hydraulic conditions prevent construction of a pond that does not intercept the shallow groundwater table, loading and concentration inputs into the deep aquifer would be reduced if the pond were to be replaced by a pre-treatment swale system, provided that the swale also did not intercept the shallow groundwater. Designs for stormwater management systems in the Florida Keys need to be particularly sensitive to slight changes in grades and elevations which can substantially impact the overall effectiveness of the treatment system.

SECTION 5

REFERENCES

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