SOUTH FLORIDA WATER MANAGEMENT DISTRICT

Groundwater - Surface Water Interaction Along the C-2 Canal, Miami-Dade County, Florida

Technical Publication WS-22

Prepared for:
Hydrologic & Environmental Systems Modeling

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Abstract

The South Florida Water Management District (SFWMD or District) Water Supply Department participated in this project to support the SFWMD Hydrologic & Environmental Systems Modeling (HESM) Department, and to help quantify the interaction between surface water and groundwater near the C-2 Canal in Miami-Dade County, Florida.

The HESM Department requested field measurements along the C-2 Canal near the Southwest, Alexander Orr, and Snapper Creek wellfields to improve the calibration of the SFWMM and the NSM in Miami-Dade County.

The investigation focused on trying to quantify the freshwater flow to Biscayne Bay that is being intercepted in the C-2 Canal by pumping from the Snapper Creek, Alexander Orr, and Southwest wellfields. The investigation combined data from different sources to help meet its goals: groundwater levels, surface water levels, wellfield withdrawal data, and stream gauging data.

The District installed two pairs of monitor wells on either side of the C-2 Canal adjacent to the Snapper Creek wellfield. Each well cluster had a 30-foot and a 60-foot deep well below land surface. Stilling wells installed at the northern and southern boundaries of the study area and adjacent to the Snapper Creek wellfield collect surface water data. Electronic data loggers collected water level data every 15 minutes from the stilling and monitor wells. Under the permitting process, the Miami-Dade Water and Sewer Department (Miami-Dade WASD) provided the District with current and historical withdrawal data for the Alexander Orr, Snapper Creek, and Southwest wellfields. The District used the historical data to determine the appropriate times to conduct stream gauging. The current data helped determine how current wellfield operations affected both surface and groundwater levels. The District used stream gauging to quantify how much water was being lost along six cross-sections of the canal.

The data showed that groundwater levels were affected by surface water changes, but not vice versa (i.e., while groundwater levels were affected by wellfield withdrawals, surface water levels were not). Between November 16, 2002 and December 31, 2004, the surface water elevation in the C-2 Canal was above the groundwater water levels in the four monitor wells so the canal was always recharging the aquifer near the Snapper Creek wellfield during this investigation. The District performed stream gauging on April 20, 2004, at a time when water use was above average in the three surrounding wellfields. The data showed that 20 cubic feet per second (cfs) of water was leaving the canal just north of the Snapper Creek wellfield. According to Miami-Dade WASD's wellfield data, the two northern wells at the Snapper Creek wellfield were operational that day, but the southern wells were not.

1: Introduction

The Hydrogeology Section of the South Florida Water Management District (SFWMD or District) Water Supply Department participated in this project to support the District's Hydrologic & Environmental Systems Modeling (HESM) Department and helped quantify the interaction between surface water and groundwater along the C-2 Canal in Miami-Dade County, Florida. The HESM Department requested field measurements along the C-2 Canal near the Southwest, Alexander Orr, and Snapper Creek wellfields to improve the calibration of the South Florida Water Management Model (SFWMM) and the Natural System Model (NSM) in Miami-Dade County. The investigation focused on quantifying the freshwater flow to Biscayne Bay that is being intercepted in the C-2 Canal by pumping from the three wellfields. The study involved tasks as follows: surveying cross-sections of the canal, installing four groundwater monitor wells, installing five electronic groundwater and surface water recorders, surveying all transect cross-sections, evaluating current and historical wellfield withdrawals (1997–2001), and stream gauging along selected cross-sections of the C-2 Canal. This report presents the data collection methods and results of this investigation. **Figure 1** shows a map of the study area.

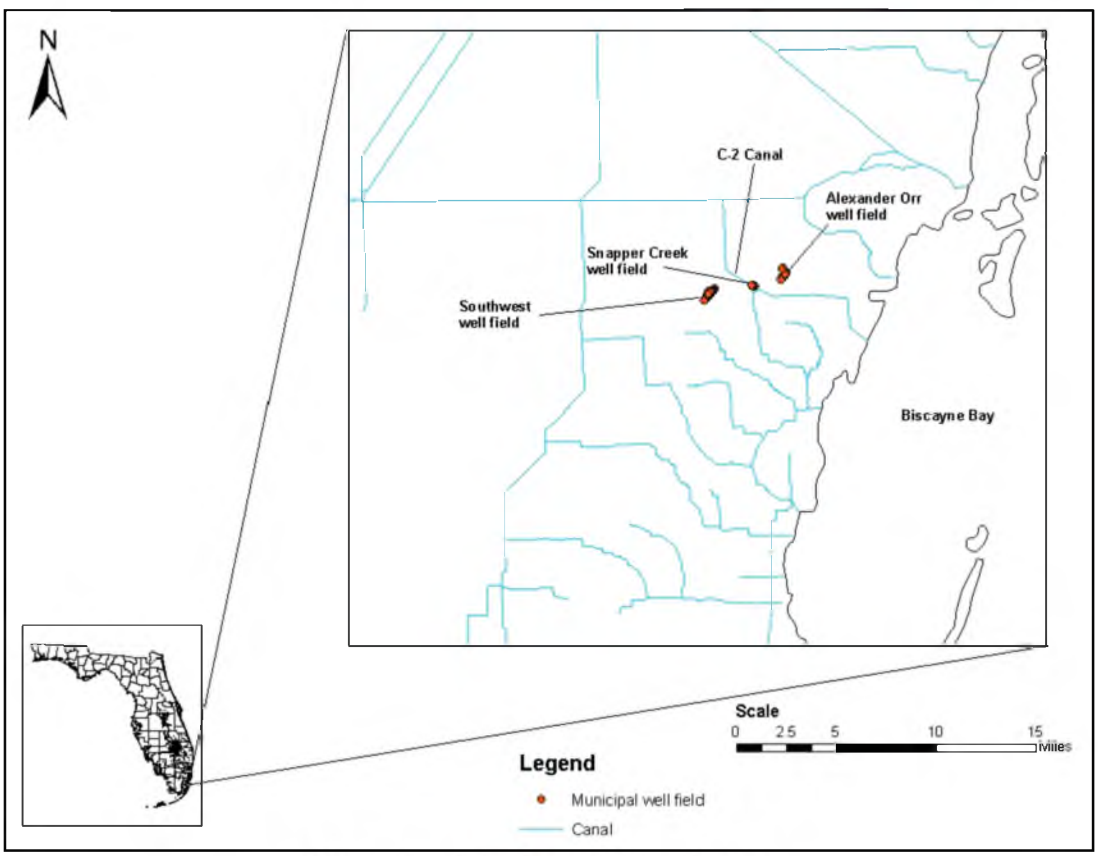

Figure 1. Location of the study area.

1.1 Geomorphology and Physiography of South Florida

Miami-Dade County, located at the southeastern tip of peninsular Florida, encompasses an area of about 2,000 square miles. The county is bounded by the Atlantic Ocean to the east, Broward County to the north, Collier and Monroe counties to the west, and the Florida Keys (Monroe County) to the south. The area is characterized as a subtropical, marine environment with long, hot, wet summers and mild, dry winters. Seasonal variation in rainfall is pronounced; about 75 percent of the annual rainfall occurs during the 5-month wet season from June through October. Long-term records (1966–1995) indicate that average annual rainfall in Miami is about 59 inches, ranging from as low as 39 inches in 1975 to as high as 83 inches in 1968.

Physiographic features have significantly controlled the environment, drainage, and ultimately the land use in Miami-Dade County (Fish and Stewart 1991). The Atlantic Coastal Ridge, 2 miles to 10 miles in width, forms the highest ground in the county. Elevations along the ridge range from about 8 feet to 15 feet above sea level, but are 20 feet above sea level or greater in some places. The Atlantic Coastal Ridge is a natural barrier to drainage of the interior, except where it is breached by shallow sloughs or rivers. The Sandy Flatlands in northeastern Miami-Dade County is lower in elevation (6 feet to 18 feet above sea level) than the Atlantic Coastal Ridge, and prior to development was poorly drained. The Everglades, by far the largest feature, is slightly lower than the Sandy Flatlands, and before development, was wet in most years and subject to seasonal flooding. Drainage was slow and generally to the south and southwest, channeled behind the higher Atlantic Coastal Ridge. The Everglades forms a natural trough in north-central, central, and southwestern Miami-Dade County. Elevations range from about 9 feet above sea level in the northwestern corner to about 3 feet above sea level in southwestern Miami-Dade County, except for tree islands or hammocks, which may be a few feet higher than the surrounding land. Coastward from the Everglades and the Atlantic Coastal Ridge lie coastal marshes and mangrove swamps at elevations that generally range from 0 feet to 3 feet above sea level.

1.2 Hydrologic Setting

The District's system of canals, levees, pump stations, and gated water control structures was constructed over the last century to guard communities against flood, drought, hurricanes, and fires. The water management system provides flood protection during the wet season (June–October) by storing excess water in the water conservation areas and by discharging water through the east coast canals when flood events occur. During the dry season (November–May), replenishment of groundwater supplies along the east coast is accomplished by conveying water through the primary canals from the water conservation areas. All of the major tributary canals along the east coast contain gated control structures, which are opened during flood events to discharge excess water, and are closed during dry periods to maintain high freshwater heads to help recharge groundwater and retard saltwater intrusion.

The close hydraulic connection that exists between ground and surface water in south Florida is due to the highly transmissive nature of the Biscayne aquifer, the sole source of drinking water for residents of Miami-Dade County. Depending on the relation of the canal stages to the surrounding water table, water is exchanged from surface water to groundwater or vice versa, and canals can be classified as either "gaining" or "losing" (**Figure 2**). In Miami-Dade County, canal gates are opened during the wet season to discharge excess water to the Atlantic Ocean and are closed during the dry season to prevent saltwater intrusion. When the gates are opened during the wet season, canal stages generally become lower than the surrounding water table, causing groundwater flow to the canals (gaining) with eventual discharge to tide. During the dry season when canal gates are closed, the groundwater hydraulic gradient is generally seaward, and the inland reaches of the coastal canals continue to collect groundwater and transport it downstream to the coastal controls. The stages at the gated control structures are generally higher than the surrounding groundwater levels, and the canals (losing) recharge the aquifer and retard saltwater intrusion.

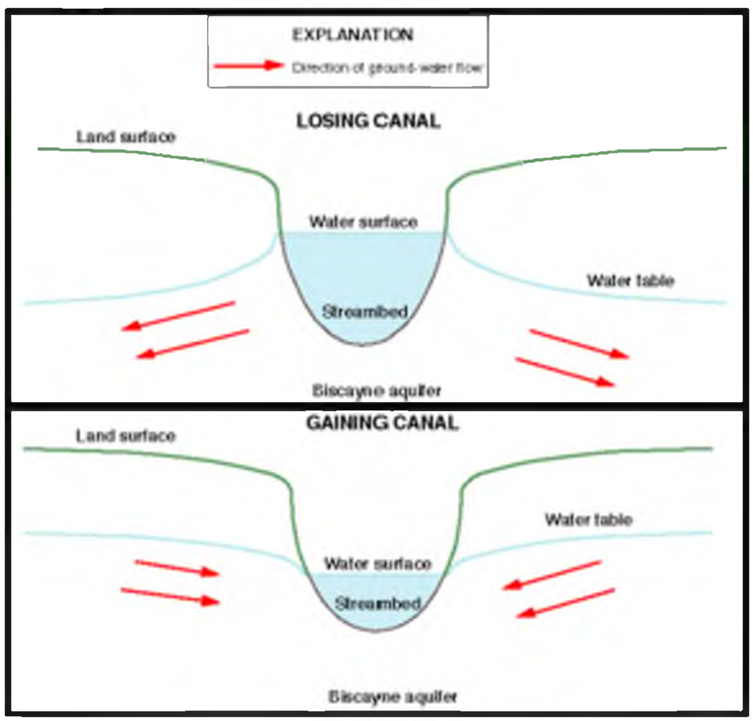

Figure 2. Hydraulic connection between gaining and losing canals. Adapted from Winter et al., 1988.

In Miami-Dade County, the surficial aquifer system includes all rock and sediment from land surface downward to the top of the intermediate confining unit. The rock and sediment are mostly composed of limestone, sandstone, sand, shell, and clayey sand and ranges in age from Holocene to Pliocene (Causaras 1987). The top of the system is land surface, and the base is defined by a substantial decrease in permeability. The permeability of the rock and sediment of the surficial aquifer system is variable, allowing the system to be divided locally into one or more aquifers separated by less-permeable or semi-confining units. The uppermost part of these water-bearing units is the Biscayne aquifer and the lowermost water-bearing unit is the gray limestone aquifer (Fish and Stewart 1991). The groundwater and surface water interaction discussed in this report take place between the C-2 Canal surface water body and the Biscayne aquifer.

The Biscayne aquifer underlies an area of about 4,000 square miles and is the principal source of water for all of Dade and Broward counties and the southeastern part of Palm Beach County in south Florida. The aquifer has been designated as a sole source aquifer (Federal Register Notice 1979) because it is the only source of drinking water for about three million people in the area. Water in the Biscayne aquifer is unconfined (conditions in which the upper surface forms a water table), and the water table fluctuates in direct and rapid response to variations in precipitation or as a result of canal operations.

The aquifer consists of highly permeable limestone and less-permeable sandstone and sand. Most of the geologic formations comprising the aquifer are of Pleistocene age, but locally, Pliocene rocks also are included in the aquifer. Most of the formations are thin and lens-like, and are not present in some places. Some of the units interfinger and some are lateral equivalents of each other. For example, the Anastasia Formation and Key Largo Limestone interfinger with the Fort Thompson Formation; in places, the Miami Limestone is equivalent to the Key Largo Limestone and in other places comparable to the upper part of the Fort Thompson Formation. The thickest and most extensive geologic unit in the Biscayne aquifer is the Fort Thompson Formation, which is the major water-producing unit of the aquifer. The Anastasia Formation comprises much of the Biscayne at Fort Lauderdale and northward into Palm Beach County. However, the Pamlico Sand is the surficial unit in this area. The Miami Limestone, although thin, is a very porous, oolitic limestone that is present at the land surface throughout much of Miami-Dade County and parts of Broward and Monroe counties (**Figure 3**). In general, the entire aquifer is more sandy in its northern and eastern parts, and contains more limestone and calcareous sandstone to the south and west.

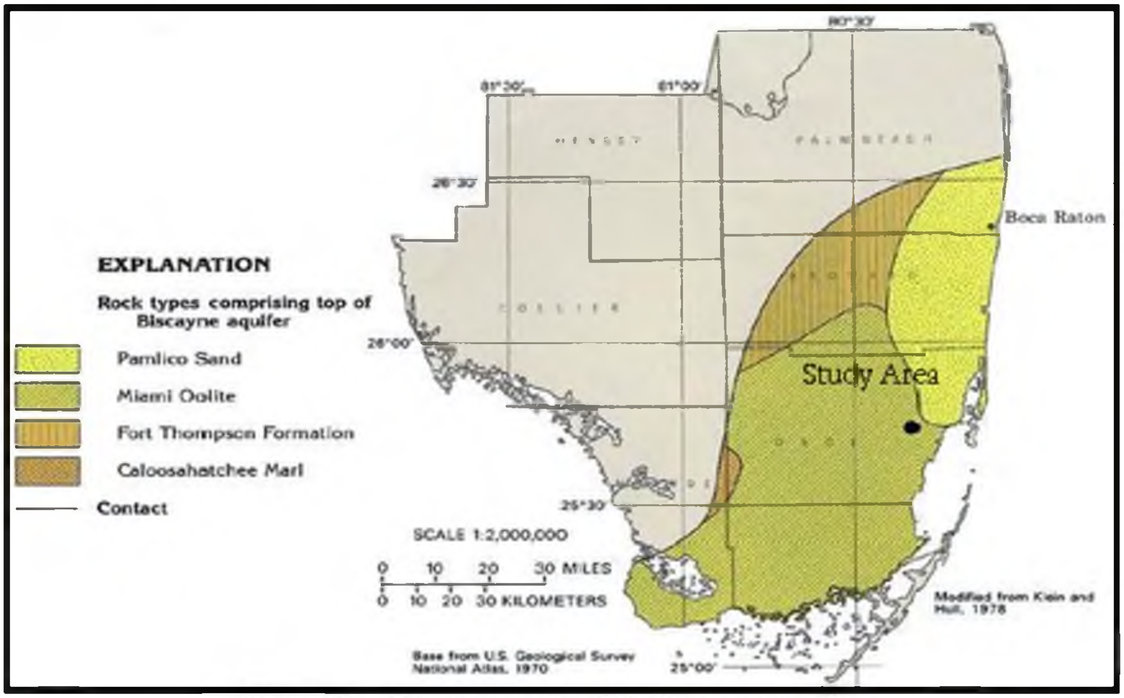

Figure 3. The upper units of the Biscayne aquifer.

The Biscayne aquifer grades northward and westward into sandy deposits, which are part of the surficial aquifer system. Well yields from these sandy deposits are small compared to well yields from the Biscayne. A sequence of low-permeability, largely clayey deposits about 1,000 feet thick separates the Biscayne aquifer from the underlying Floridan aquifer system. The Floridan contains salt water in southeastern Florida, and is not hydraulically connected to the Biscayne aquifer. The base of the Biscayne aquifer in Miami-Dade County and southern Broward County is low-permeability sandy silt that is part of the Tamiami Formation. Farther north, the base is not as distinct; it consists of a transition zone, which changes from a mixture of moderately permeable calcareous sand, shell, and silt. This zone is probably part of the Anastasia Formation, to low-permeability silty clay, which is part of either the Anastasia or Tamiami Formation.

Groundwater and surface water form an integrated hydrologic system in south Florida. Before development of these water resources, a large portion of the abundant precipitation that fell on the flat, low-lying area drained southward to the Gulf of Mexico and Florida Bay. Most of this drainage was in the form of wide, shallow sheets of water that moved sluggishly southward during the wet season, when as much as 90 percent of areas, such as the Everglades, were inundated. This drainage was the major source of recharge to the underlying aquifers. During the dry season, water moved only through the deeper sloughs and covered probably less than 10 percent of the Everglades. Lake Okeechobee was a major water storage component in the system, functioning as a retarding basin for streams, such as the Kissimmee River, which drained southward into the lake. Today, the shallow, southward-moving sheet of surface water is still a major source of recharge to the Biscayne aquifer in addition to the precipitation that falls directly on the aquifer. Where the Biscayne is either exposed at the land surface or covered only by a veneer of soil, the slowly moving surface water passing over the recharge area of the aquifer is able to readily percolate downward into the aquifer.

The general movement of water in the Biscayne aquifer is seaward from the water conservation areas. Some of the local variations in the water table are due to other causes, such as local topographic highs, large-scale withdrawals from major wellfields, and canal operations.

Major fluctuations in the water table result from variations in recharge and natural or artificial discharge, or both. Fluctuations may range from 2 feet to 8 feet per year, depending primarily on variations in precipitation and groundwater withdrawals. A thin layer of porous soil covers the highly permeable rocks of the Biscayne aquifer in most places. Accordingly, water levels in the aquifer rise rapidly in response to rainfall. The hydraulic connection between the Biscayne aquifer and the canals that cross it is direct. Water passes freely from the canals into the aquifer and vice versa. When canal water levels decline, they lower the adjacent water table of the aquifer almost immediately. Similarly, when canal water levels rise, they are rapidly followed by a rise in the water table of the aquifer adjacent to the canal. The degree of connection decreases as fine sediment settles out of the canal water and lines the canal bottom. Accordingly, the degree of connection may change from time to time because of either accumulation or removal of these sediments.

2: Canal Cross-section Selection

During the first phase of this investigation, the Hydrogeology Section, along with staff from the Operations & Hydro Data Management (OHM) Division, went to site stream gauging locations along the C-2 Canal. The OHM staff selected six locations along the C-2 Canal where they could conduct stream gauging readings to assess the impact of the Snapper Creek, Alexander Orr, and Southwest wellfields. Two locations were sited at the northern and southern extents of the study area, and the four remaining locations were placed near the Snapper Creek wellfield. Field crews placed a metal rod in the ground on both sides of the canal bank at each cross-section area. The SFWMD Engineering Department's Surveying Division measured the canal bottom and bank elevations and constructed cross-sections showing these areas at each cross-section. The cross-sectional area calculations combined with the stream gauging values at each location allow the end user of the data to calculate the volume of water flowing through that area. **Figure 4** shows the cross-section locations along the C-2 Canal. **Appendix A** contains the calculated areas for each cross-section.

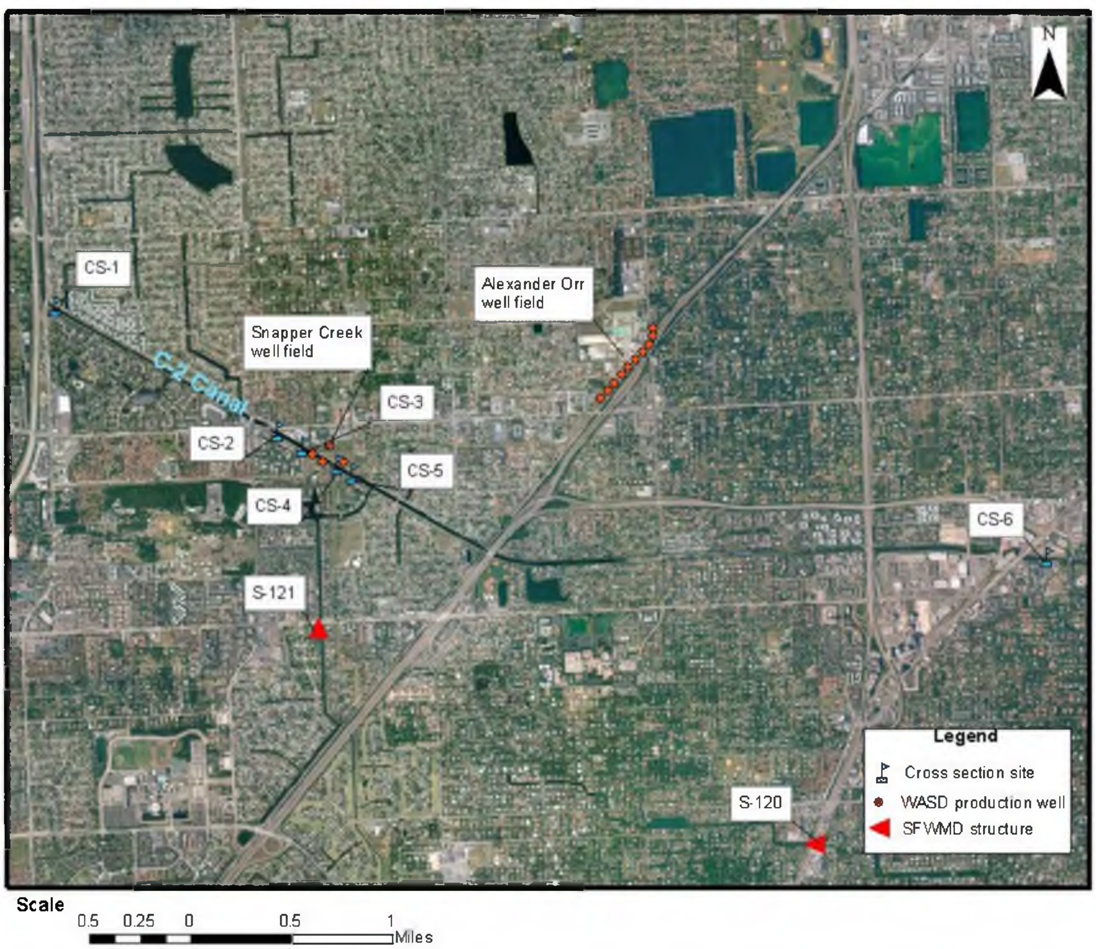

Figure 4. Location of the six cross-sections along the C-2 Canal.

3: Drilling and Well Construction

The second phase of this investigation involved the drilling and construction of monitor wells to measure groundwater fluctuations adjacent to the C-2 Canal. The District hired a drilling contractor, Hydrologic and Associates U.S.A., Inc. (Hydrologic), to install two pairs of monitor wells on either side of the canal near the Snapper Creek wellfield (**Figure 5**). **Table 1** presents the well names and construction details. Hydrologic installed the wells on the District's right-of-way approximately 30 feet from the canal bank. Each pair consists of a two-well cluster, with one well installed to a depth of 25 feet below land surface (bls) and another to 60 feet bls. The purpose of these monitor wells was to measure water levels in the surrounding Biscayne aquifer in response to wellfield withdrawals and surface water level fluctuations.

Figure 5. Locations of the paired monitor wells.

Table 1. Monitor well construction details.

Well Name	Description	X	Y	Depth (feet bls)	Screened Interval (feet bls)
C2GSW1_GW1	Shallow well on north side of C-2 Canal	866693.3	496879.8	25	22.5-25
C2GSW1_GW2	Deep well on north side of C-2 Canal	866693.3	496879.8	60	57.5-60
C2GW1_GW1	Shallow well on south side of C-2 Canal	866475.3	496774.2	25	22.5-25
C2GW1_GW2	Deep well on south side of C-2 Canal	866475.3	496774.2	60	57.5-60

bls - below land surface

3.1 Well Drilling

From October 16, 2001 through October 18, 2001, Hydrologic performed drilling activities near the Snapper Creek wellfield at the north and south sides of the canal, and constructed well pads and manholes at both sites.

Hydrologic used the dual-tube drilling method to complete the boreholes for these wells. The dual-tube drilling method uses flush-jointed double-wall pipe in which the drilling fluid (air in this case) moves by reverse circulation (Driscoll 1986). Unlike conventional reverse circulation drilling, the air does not run down the outside of the pipe. Instead, the air is contained between the two walls of the dual-wall pipe and only contacts the walls of the borehole near the drill bit. This drilling method allows the field geologist to obtain accurate geologic samples from known depths.

3.2 Formation Samples

A District geologist continuously collected formation samples from each well during drilling. The geologist collected the samples from the dual-tube drilling discharge and stored them in core trays provided by Hydrologic. The formation samples showed that semi-permeable to permeable limestone was present through the entire interval of each borehole. These samples were representative of the Miami Limestone and the Fort Thompson Formation. **Appendix B** contains the lithologic logs for each well.

3.3 Well Casing, Well Screen, and Filter Pack Installation

Hydrologic constructed each well with 2-inch diameter Schedule 40 polyvinyl chloride (PVC) Tri-Loc riser pipe and screens. The well screens consisted of 2½-foot sections of 0.050-inch machine slotted PVC screen. The wells were completed above the screens with solid Schedule 40 PVC riser pipe. All well casings and screen joints were connected with threaded connections and manufacturer-supplied "O" rings, cleaned and sealed in plastic at the factory.

Hydrologic placed an 8/20 silica sand filter pack, using the Tremie method, in the annular space around the screened interval of each well. The filter pack extended 3 feet above the top of the screened interval after well development. In the deep (60-foot) wells, the filter pack extended from 60 feet bls to 54 feet bls. Similarly, in the shallow (25-foot) wells the filter pack extended from 25 feet bls to 19 feet bls. Hydrologic placed bentonite pellets 2 feet thick above the filter pack in each well. They hydrated the bentonite to provide a seal between the filter pack and the cement grout. The remaining annular space in each well was filled with neat cement to land surface. The drilling contractor developed each well with a centrifugal pump before adding the bentonite and neat cement. Developing the wells before sealing the remaining annular space with cement allows the drilling contractor to add sand to the filter pack to account for any subsidence that occurred during well development. According to standard well design practices a suitable filter pack will pass 10 percent of its material through a well screen during development (USEPA 1990). After Hydrologic developed the well, they measured where the top of the filter pack was and added additional sand to each borehole to raise the level of the filter pack up to the appropriate level, where needed. **Figure 6** is a well completion diagram showing 25-foot and 60-foot deep monitor wells.

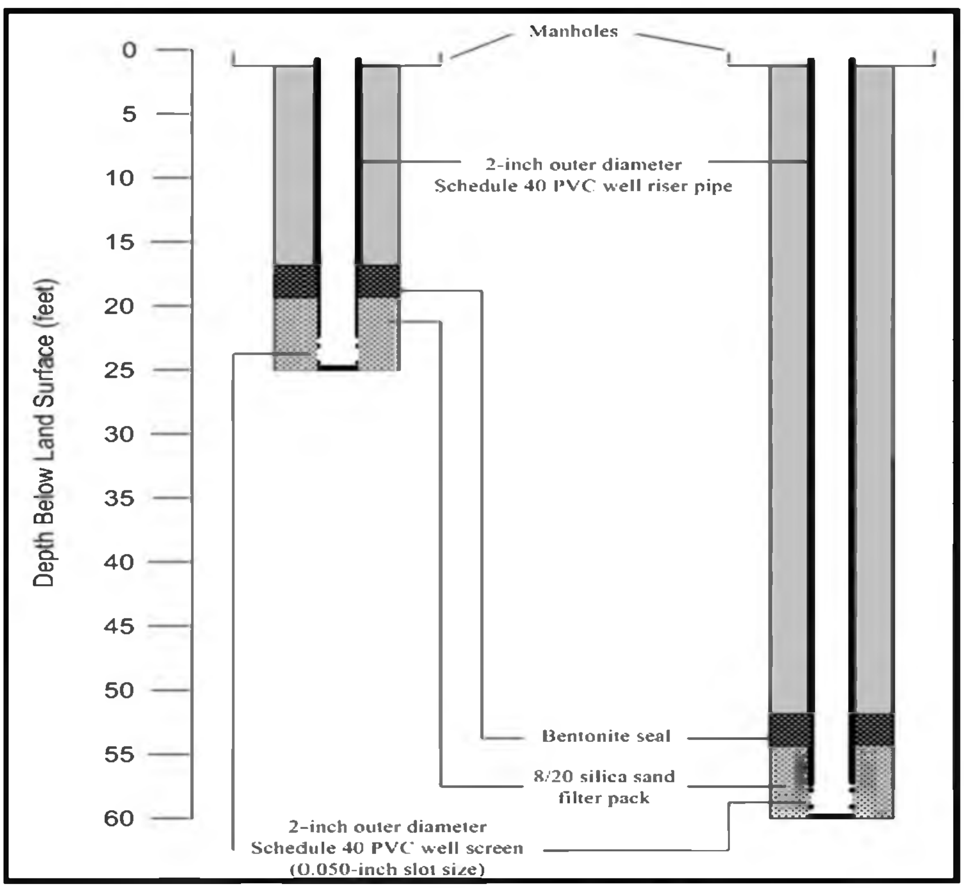

Figure 6. Monitor well completion diagram.

3.4 Wellhead Completion

All wells were recessed below the grade of the surrounding land and enclosed in a "meter" type protective box with bolting lids. These boxes were made of cast iron and dipped in primer and Rustoleum® brand red paint before installation to prevent corrosion. The well recesses have two ½-inch diameter drain holes, placed 180 degrees apart, to remove excess water that may collect in the manhole after a rainfall event (**Figure 7**). Additionally, each well has a 1-inch diameter 90° elbow made of gray electrical conduit that extends 1 inch above the concrete and extends several inches below and beyond the side of the concrete pad. This conduit provides access for the transducer cable connected to a Campbell Scientific CR10X data logger and a Rittmeyer submersible 15 pounds per square inch (psi) pressure transducer. Each well was completed and sealed at the surface with a 30-by-30-by-6-inch rebar-reinforced cement pad that slopes slightly away from the well to prevent water from collecting inside the manhole.

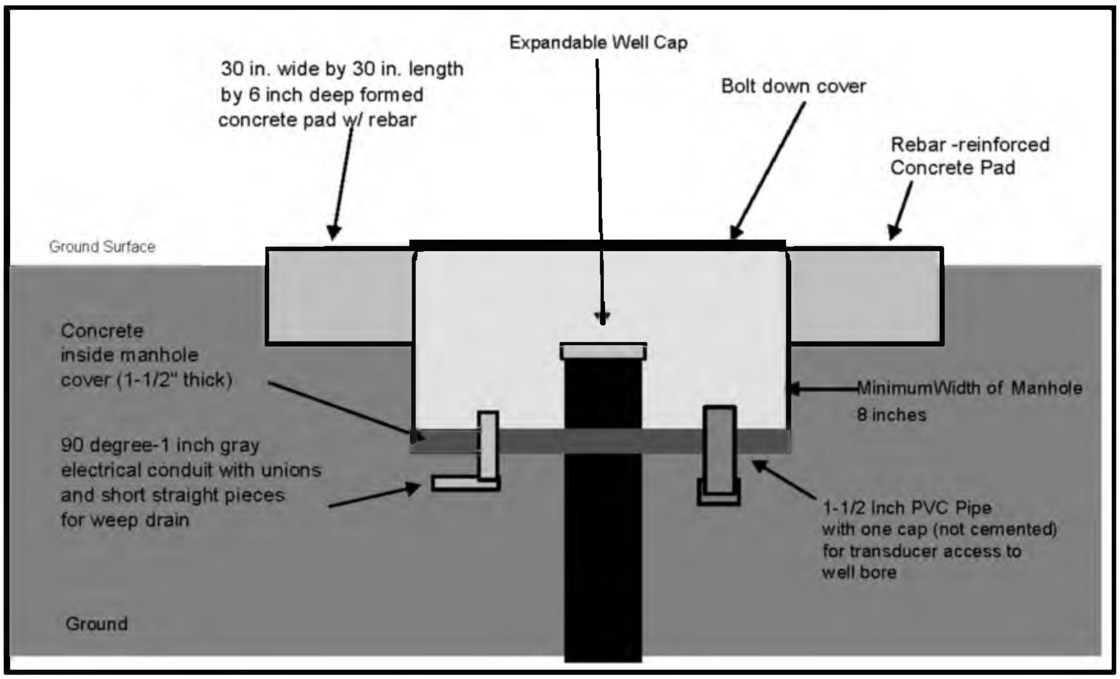

Figure 7. Wellhead completion diagram.

3.5 Well Development

Developing the four monitor wells involved overpumping them with a centrifugal pump until all visible particulate matter was removed from the formation waters and the water quality field parameters (pH, temperature, and specific conductivity) were stable (<5% change between three successive readings). A District geologist used a Hydrolab water quality sensor to monitor field parameters during development. The water quality parameters collected during well development are presented in **Table 2**. Hydrologic developed each well for 30 minutes because the water quality parameters stabilized quickly due to the high production capacity of each well. Development water from each well was discharged onto the ground near the wells.

Table 2. Water quality parameters collected during well development.

Well	Date & Time	Temperature (°C)	pH	Spec. Cond. (umhos)	ORP (MilliVolts)
C2GSW1_GW2	10/16/01 12:15	26.99	6.94	517	410
	10/16/01 12:25	26.99	7.51	521	383
C2GSW1_GW1	10/16/01 15:33	29.14	7.50	509	346
	10/16/01 14:00	27.64	7.46	516	346
C2GW1_GW2	10/17/01 11:10	26.27	7.48	523	258
	10/17/01 11:15	26.41	7.44	523	258
	10/17/01 11:25	27.32	7.47	518	262
C2GW1_GW1	10/17/01 14:03	26.83	7.54	500	263
	10/17/01 14:12	26.42	7.51	509	242
	10/17/01 14:33	26.88	7.54	513	241

°C - degrees Celsius
Spec. Cond. - specific conductance
ORP- oxidation reduction potential

4: Water Level Data Collection

Throughout mid-2002, the District worked with a contractor to install electronic data loggers at two groundwater monitoring sites and three surface water sites along the C-2 Canal. **Figure 8** shows the locations of the data recorder sites. The groundwater sites are located where the monitor wells described in the previous section were installed, adjacent to the Snapper Creek wellfield. One of the surface water sites (C2GSW1) is located adjacent to a groundwater monitor well on the north side of the canal. The other two surface water sites are located at the northern (C2SW1) and southern (C2SW2) boundaries of the project area.

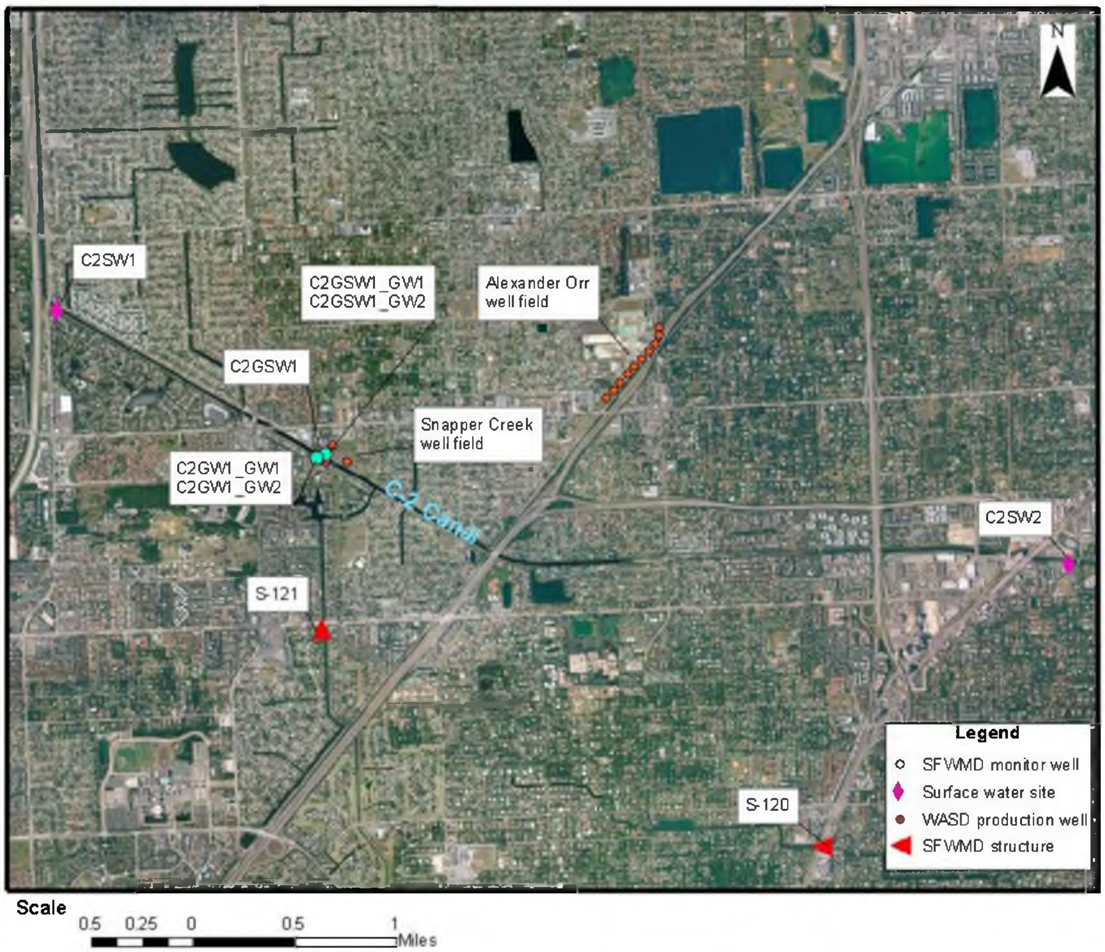

Figure 8. Locations of groundwater and surface water monitor stations.

Groundwater and surface water data collection began on November 16, 2002. All data used in this report have undergone a quality assurance/quality control (QA/QC) check following District procedures. After passing the QA/QC check, the data were stored in the District's environmental database, DBHYDRO available from:

https://my.sfwmd.gov/portal/page?_pageid=2894,19708232&_dad=portal&_schema=PORTAL. DBHYDRO stores hydrometerologic, water quality, and hydrogeologic data collected from over 6,000 monitor stations across the District. The database also stores additional information about each monitor station, such as well or structure details, location of the station, data collection method, etc. Users can retrieve data from DBHYDRO several ways, such as by station name, DBKey (database key), or all stations within a giver coordinate block. DBHYDRO assigns each data time series a DBKey, which is a unique identifier to the individual time series.

Table 3 lists the DBKeys and corresponding Station and Site names for the data used in this report.

Table 3. DBHYDRO DBKeys for the C-2 Canal study data.

Station	DBKey	Data Type	Frequency	Start Date
C2GSW1	OU844	STG	DA	16-NOV-2002
C2GSW1	OU845	STG	BK	16-NOV-2002
C2GSW1_GW1	OU846	WELL	DA	16-NOV-2002
C2GSW1_GW1	OU847	WELL	BK	16-NOV-2002
C2GSW1_GW2	OU848	WELL	DA	16-NOV-2002
C2GSW1_GW2	OU849	WELL	BK	16-NOV-2002
C2GW1_GW1	OU427	WELL	DA	16-NOV-2002
C2GW1_GW1	OU428	WELL	BK	16-NOV-2002
C2GW1_GW2	OU836	WELL	DA	16-NOV-2002
C2GW1_GW2	OU837	WELL	BK	16-NOV-2002
C2SW1	OU840	STG	DA	16-NOV-2002
C2SW1	OU841	STG	BK	16-NOV-2002
C2SW2	OU842	STG	DA	16-NOV-2002
C2SW2	OU843	STG	BK	16-NOV-2002

STG - stage or surface water level
Well - groundwater level
DA - daily average
BK - break point (15-minute data)

4.1 Groundwater Monitoring Sites

The two groundwater monitoring sites consist of the two well clusters described in Section 2.0. A pressure transducer (Rittmeyer SDI-12 MPxSTRN) was set approximately 24 feet below the top of each well casing in the shallow wells, and approximately 40 feet below the top of the deep well casings. The transducers are connected to a Campbell Scientific CR10X data recorder and storage module (Model SM4M). The CR10X and storage module are powered by a 12-volt battery. A solar panel installed at each site recharges the battery and each site is equipped with radio telemetry, which sends data back to the District at the end of each day.

The District programmed the CR-10x to collect water level data from each well every 15-minute intervals. Past experience at the District shows that this frequency best shows the influences of water level changes in the canal and the effects of the adjacent wellfields on the groundwater level adjacent to the site. Section 6.1 discusses the hydrographs for the groundwater sites and what they show. **Appendix C** includes copies of the hydrographs.

Every two months District technicians visit each groundwater site to perform routine maintenance on the equipment and verify the accuracy of the data. Maintenance involves checking the voltage of the battery, checking the condition of the equipment, and changing desiccant packs. The technicians also verify the accuracy of the water level data collected by the instrument. During these visits, the technicians measure the water level in each well using a hand-held electronic water level sensor. The elevation of the hand-collected water level is compared to the recorder measurement. If there is a discrepancy between the two readings, the CR10X reading is adjusted and the correction factor is noted in the site inspection worksheet. **Figure 9** is a photograph showing one of the groundwater/surface water monitoring sites outfitted with a CR10X and its ancillary equipment. The surface water stilling well is offset from the canal bank to facilitate maintenance.

Figure 9. Instrumented groundwater monitor station.

4.2 Surface Water Monitoring Sites

The District outfitted three surface water monitoring sites with electronic water level recorders for this study. One site is located at the north side of the C-2 Canal adjacent to the Snapper Creek wellfield. The other two sites are located at the northern and southern limits of the study area. The northern site (C2SW1) is located at the south side of the C-2 Canal near the Florida Turnpike, just before the canal changes direction from northwest/southeast to north/south. The southern site (C2SW2) is located at the south side of the C-2 Canal just west of Ludlam Road. **Figure 8** shows the locations of the surface water monitoring sites. **Table 4** presents the locations of the surface water sites.

Table 4. Locations of each surface water monitoring site.

Surface Water Site	Location	X	Y
C2SW1	Located near SW 117 Avenue	859726.443	500628.591
C2GSW1	Located adjacent to Snapper Creek wellfield	866693.267	496879.81
C2SW2	Located near Ludlam Road	886061.141	494047.617

A stilling well is installed at each site to measure the surface water fluctuations in the canal. Traditional stilling wells were not installed in the C-2 Canal as they would have been a hazard to navigation. These stilling wells consist of a 12-inch diameter section of corrugated drainage connected to a section of 2-inch diameter PVC pipe that runs perpendicular to the corrugated pipe into the C-2 Canal. The 2-inch diameter PVC pipe was set in a trench dug with a backhoe approximately 10 feet below land grade. The trench was backfilled to cover the PVC pipe and an Enviro System SDI Shaft Encoder (SE105S) was installed on top of the 12-inch corrugated pipe. The shaft encoder was connected to a Campbell Scientific CR10X data recorder and storage module (Model SM4M). As with the groundwater sites, District technicians visit each surface water site every two months to perform routing maintenance on the equipment and verify the accuracy of the data.

Water level data at each surface water site are collected in 15-minute intervals. The District selected this data collection frequency to show the influences changes in canal water levels so this data could be compared to groundwater levels in the adjacent aquifer. Hydrographs for the surface water sites are discussed in Section 6.1. Copies of the hydrographs are included in **Appendix D**. **Figure 10** is a photograph showing one of the surface water monitoring sites outfitted with a CR10X and its ancillary equipment.

Figure 10. Instrumented surface water monitor station.

5: Evaluation and Summary of Wellfield Data

As required under the limiting conditions of their water use permit, Miami-Dade WASD provided the District with daily wellfield withdrawal data for the Alexander Orr, Snapper Creek, and Southwest wellfields from January 1, 1997 to August 31, 2001. The District requested the data to determine the optimal times to conduct stream gauging in the C-2 Canal. The goal of evaluating the wellfield withdrawal data was to determine appropriate rates at which to hold wellfield withdrawals, while the District conducted stream gauging. In addition to the historical data, Miami-Dade WASD sent the District wellfield withdrawal data for 2004, and hourly data for the Snapper Creek wellfield covering the stream gauging event conducted in April 2004. These data helped determine how wellfield operations affect both surface water and groundwater levels.

The Miami-Dade WASD calculates withdrawal rates for each well from pump curves. Each wellfield has a large pump that transfers water from the wellfield to a water treatment plant. The withdrawal rate for each well is determined from the pump curve for each pump and is divided by the number of wells that operate during a given day. There is inaccuracy in calculating the flow rate using this method. The Miami-Dade WASD indicated that there is a +/- 30 percent error in the calculated withdrawal rates, partly due to the pumps being old, and partly because the pump curves are for older pumps installed when the wellfield was first constructed. The error associated with calculating the wellfield withdrawal rates should be noted so it can be factored into any computer models. For example, when the District performed the stream gauging measurements on the C-2 Canal in April 2004, the reported pumping rate from the two operating wells at the Snapper Creek wellfield was 10.7 million gallons per well (21.4 million gallons for the wellfield). With the +/- 30 percent error factor, the flow rate from each well ranged between 7.5 and 13.9 million gallons, or between 15.0 and 27.8 million gallons for the wellfield.

5.1 Wellfield Data Evaluation

The data and discussion presented in this section document work completed by District staff. It serves as a reference for similar procedures that may be needed in the future.

The first stage of the data evaluation involved summarizing the historical daily withdrawal from each well in each wellfield into one monthly value. Next, the monthly value was plotted on a graph to show how the withdrawal rate at each wellfield varied between January 1997 and August 2001. An additional line shows the total withdrawal from all three wellfields for the period of record (January 1, 1997 to August 31, 2001). **Figure 11** presents the monthly average wellfield withdrawal graph from January 1997 to August 2001.

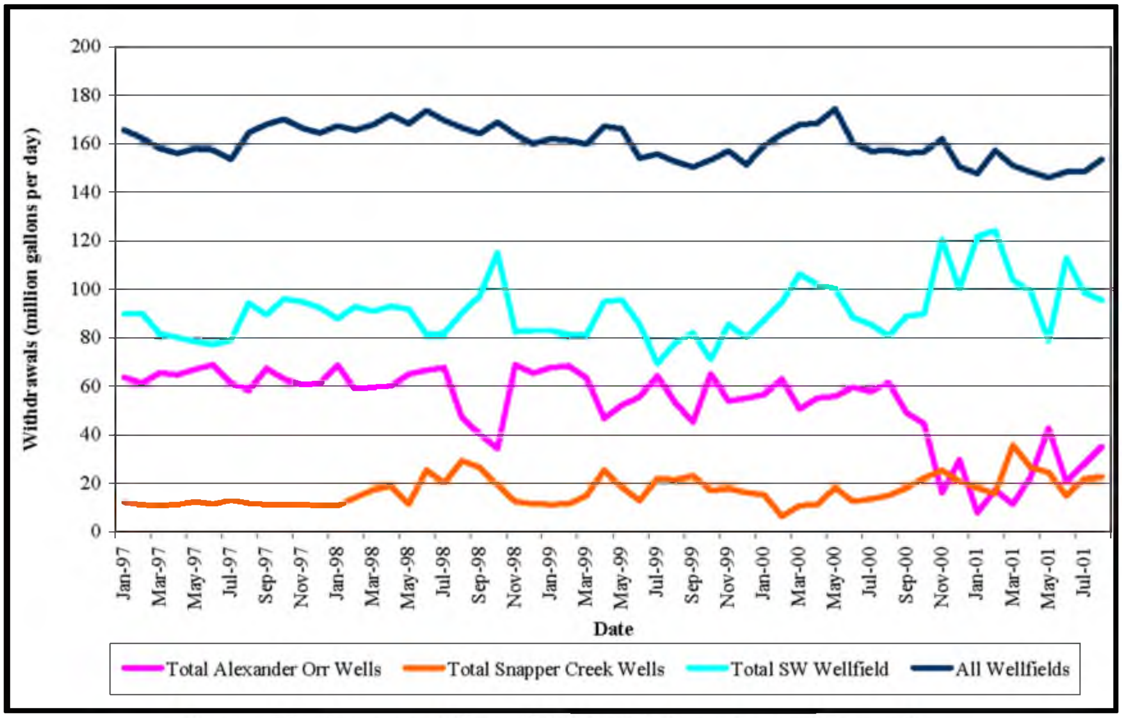

Figure 11. Average daily wellfield withdrawal rates by month.

Figure 11 shows that despite the different withdrawal rate for each wellfield, the total amount of water withdrawn from all three wellfields remained constant. In addition, **Figure 11** shows there is an inverse relationship between the withdrawal rates of the Alexander Orr and Southwest wellfields. It also shows there is a slight inverse relationship between the withdrawal rates of the Alexander Orr and Snapper Creek wellfields. Interestingly, the combined withdrawal rate of the Alexander Orr and Snapper Creek wellfields equals the withdrawal rate of the Southwest wellfield.

After plotting the average monthly withdrawal rates for each wellfield, the median (50^{th}), 25^{th}, and 75^{th} percentiles for each wellfield's data were calculated and plotted. **Figure 12** is an example of a graph showing the monthly withdrawal data for the Snapper Creek wellfield with lines denoting the median, 25^{th}, and 75^{th} percentiles.

Having the quartiles plotted on each graph allowed the District to determine the most appropriate times to conduct stream gauging in the C-2 Canal. The April 2004 stream gauging event corresponded to a time of higher than normal water use, especially as it took place near the end of the dry season. When the District performed the stream gauging measurements on the C-2 Canal, the reported pumping rate from the two operating wells at the Snapper Creek wellfield was 10.7 million gallons per well (21.4 million gallons for the wellfield).

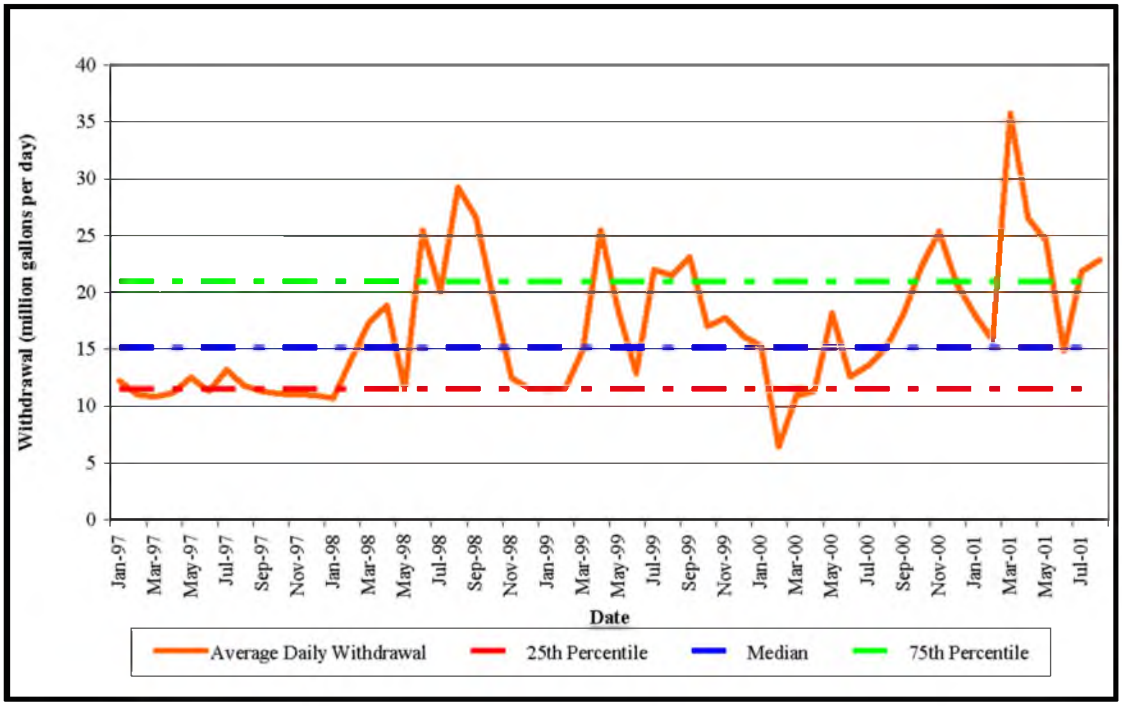

Figure 12. Snapper Creek wellfield average daily withdrawal data by month with quartiles.

5.2 Wellfield Data for 2004

The Miami-Dade WASD submitted wellfield withdrawal data for the 2004 calendar, which were plotted to show how water use changed throughout the year, and to determine how much water the three wellfields were withdrawing during the stream gauging. **Figure 13** shows the 2004 wellfield withdrawal data for the Snapper Creek, Alexander Orr, and Southwest wellfields.

Based on the data presented in **Figure 13**, April 2004 was the month of highest withdrawals from the three wellfields. As seen in **Figure 11**, April is one of the months of greatest withdrawals from the Snapper Creek wellfield. **Figures 14**, **15**, and **16** show that the 2004 wellfield withdrawals fall within the percentiles created from the historical data of the Snapper Creek (**Figure 14**), Alexander Orr (**Figure 15**), and Southwest (**Figure 16**) wellfields.

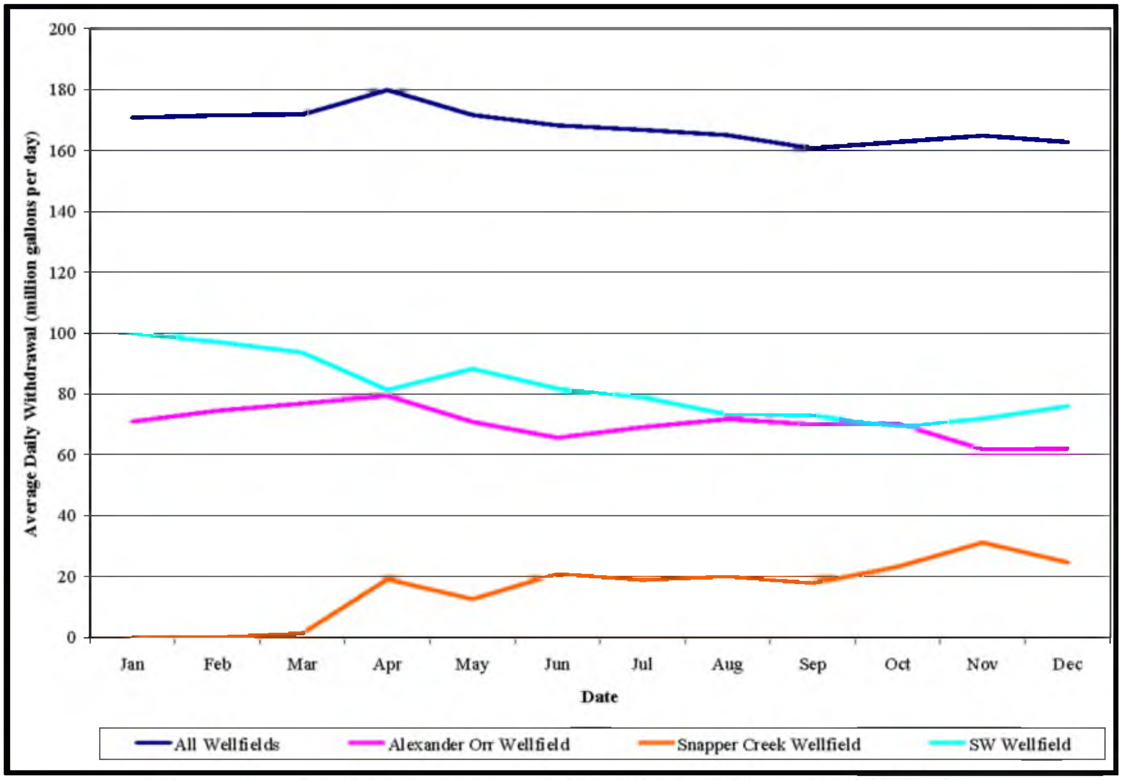

Figure 13. Average daily wellfield withdrawals by month for 2004.

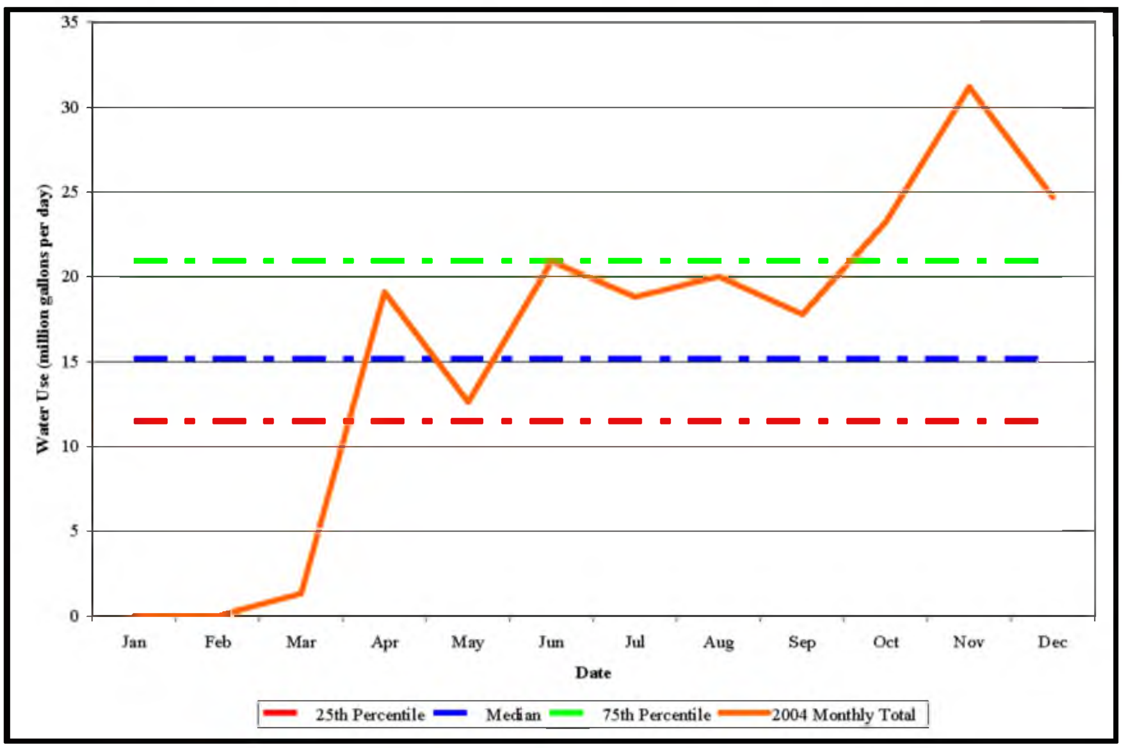

Figure 14. 2004 monthly wellfield withdrawal data with quartiles, Snapper Creek wellfield.

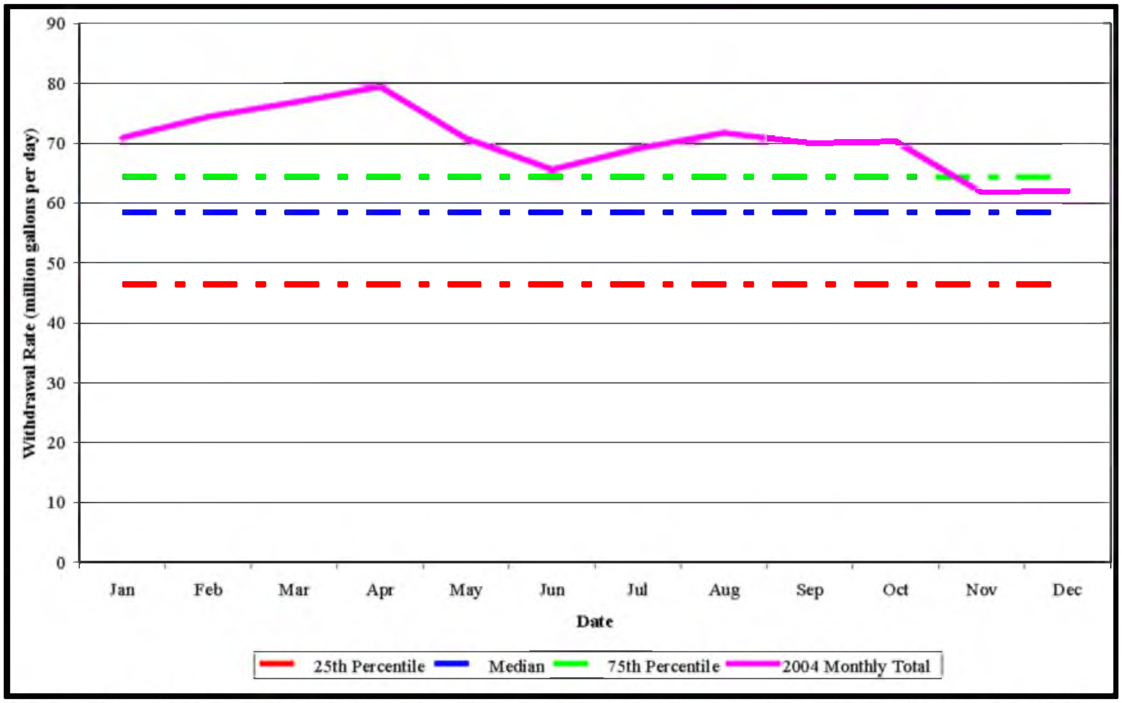

Figure 15. 2004 monthly wellfield withdrawal data with quartiles, Alexander Orr wellfield.

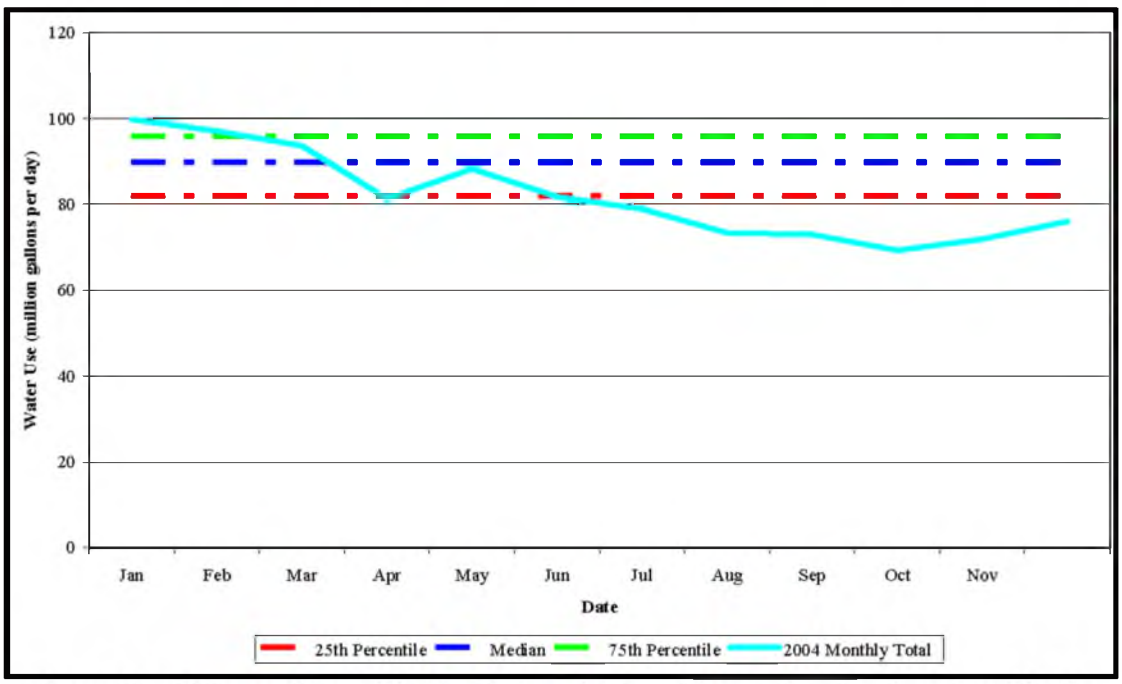

Figure 16. 2004 monthly wellfield withdrawal data with quartiles, Southwest wellfield.

Calculated by the District from the historical data given by Miami-Dade WASD (1997–2001), **Figures 14** and **15** show that the Snapper Creek and Alexander Orr wellfields operated at higher than average withdrawal rates in April 2004. **Figure 16** shows that the Southwest wellfield was withdrawing water at a lower than average rate from 1997 to 2001.

6: Stream Gauging

The District selected six locations along the C-2 Canal for stream gauging as shown in **Figure 17**. This figure also shows the locations of the groundwater and surface water monitoring sites and the control structure (S-22) at the headwaters of the canal and surrounding wellfields.

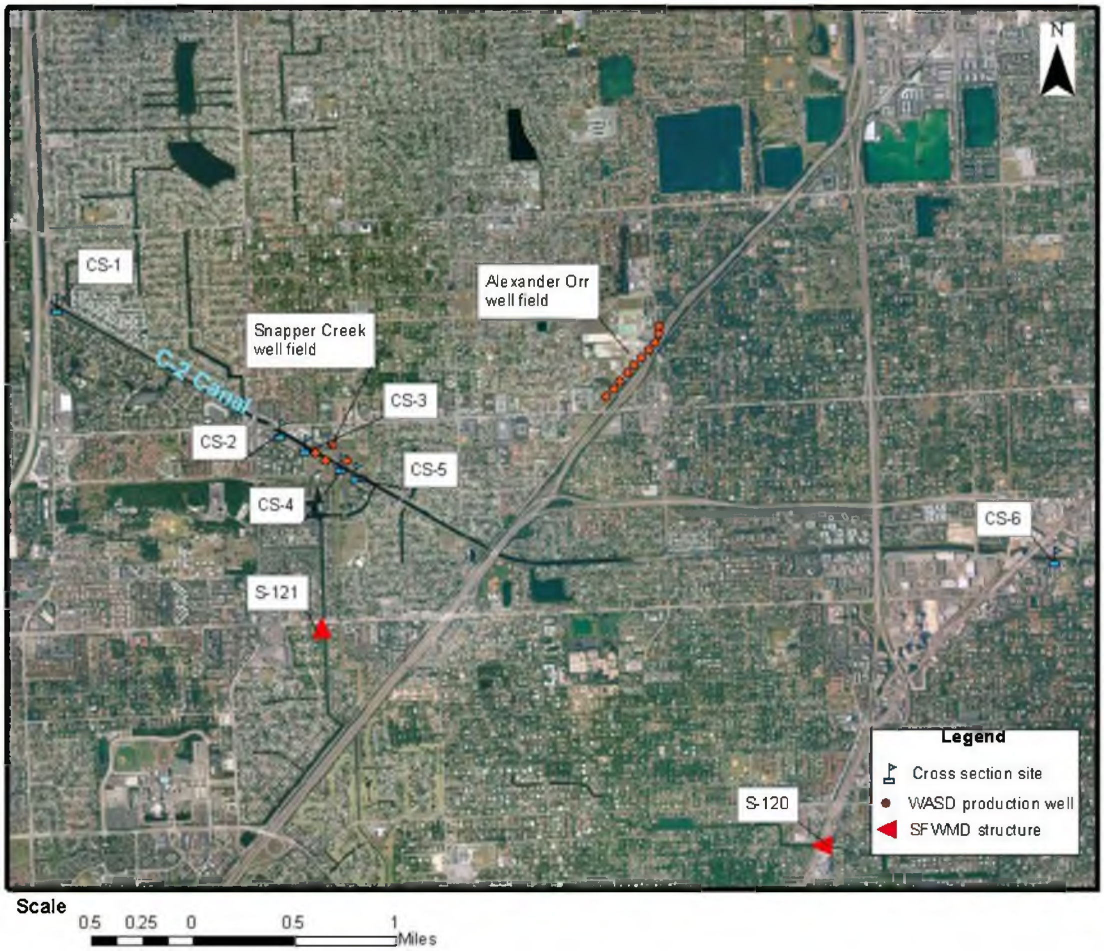

Figure 17. Locations of the stream gauging sites.

Initially the District had hoped to work with Miami-Dade WASD to have the withdrawals from the Snapper Creek, Alexander Orr, and Southwest wellfields maintained at a constant rate for three days prior to the stream gauging event. The objective was to allow time for water levels in the C-2 Canal and the surrounding aquifer to stabilize before stream gauging measurements were collected. However, this objective could not be met due to the constant change in demand for water supplied from the wellfields, as well as other logistical reasons.

Instead, the District modified its stream gauging plan to conduct flow measurements during periods when wellfields withdrawals were below average, above average, and approximately average. By comparing the stream gauging and hydrograph data from these three scenarios, the District expected to evaluate the effects of different wellfield withdrawal rates on the groundwater/surface water interaction along the C-2 Canal. Ultimately, the SFWMD was only able to conduct one stream gauging event. An active hurricane season prevented additional stream gauging events in the latter part of 2004.

Due to an active hurricane season, which prevented stream gauging events in the latter part of 2004, the SFWMD was only able to conduct one stream gauging event. The stream gauging took place on April 20, 2004, toward the end of the dry season, during a time of higher than average wellfield withdrawals.

6.1 Stream Gauging Equipment and Procedure

District staff conducted stream gauging on the C-2 Canal at six locations. The staff performing the stream gauging coordinated with the District's Operations Control Department (Operations) because the measurements required the canal to be flowing. Operations opened the S-22 Structure to meet this criterion. In general, the District maintains the water level in the C-2 Canal between 2.5 and 3.5 feet above the national geodetic vertical datum (NGVD).

The District used a Teledyne 600 kilohertz (kHz) RDI Rio Grande acoustic Doppler current profiler (ADCP) to measure flow in the C-2 Canal. The RDI Rio Grande ADCP measures flow in open channels by the "velocity-area" method (SFWMD 2003). This method is considered the most practical way of measuring discharge in open channels. The velocity area method involves measuring the water velocities and channel area at a cross-section perpendicular to the main direction of water flow. The channel is divided into a number of vertical subsections during the measuring process. The area and mean velocity in each subsection is measured, and the total discharge across the measured channel cross-section is calculated by multiplying the channel area by the mean water velocity in the channel (SFWMD 2003).

An ADCP uses acoustic energy (in the range of 300 to 3,000 kilohertz) to measure the velocity of water in the channel (Simpson 2001). It works by estimating the velocity of water using the Doppler shift principle. The Doppler instrument sends out a fixed frequency and measures the change in frequency and wavelength of acoustic waves that return to the instrument. A receiver then calculates the water velocity from the respective echoes of the returning sound scattered in the water. The Doppler shift is directly proportional to the velocity of the particles that are moving with the flow. The RDI Rio Grande ADCP is capable of measuring the velocity of the flow across a stream from a moving boat and of keeping track of the velocity of the boat through a technique known as bottom tracking. The ADCPs compute the net discharge of an open channel body by combining the velocity and cross-sectional area data.

$$F_{doppler} = -2F_{source} (V/C) \qquad \textbf{(Equation 1)}$$

In **Equation 1**, **V** is the relative velocity between source and receiver (i.e., motion that changes the distance between the two), **C** is the speed of sound, $\mathbf{F_{doppler}}$ is the change in the received frequency at the receiver (i.e., the Doppler shift), and $\mathbf{F_{source}}$ is the frequency of the transmitted sound. Doppler shift devices, such as an ADCP measure water velocities in a two-dimensional plane. The ADCPs used in this study were monostatic meaning that the unit had transducers that send and receive acoustic energy used to measure the water velocity.

For the stream gauging event, the District needed four boats to complete the work. The plan required one boat stationed for the entire day at the stream gauging sites located near the northern and southern ends of the study area (CS-1 and CS-6). The remaining two boats took measurements at two sites, each on either side of the Snapper Creek wellfield (CS-2/CS-3 and CS-4/CS-5, respectively). Each boat was equipped with a RDI Rio Grande ADCP hanging off the bow to measure the amount of water flowing in the C-2 Canal. At each site, the field crews strung a line across the canal and tethered the boat to it. A mechanical winch passed the boat slowly across the width of the canal, while the ADCP measured the flow of water in the canal. After five passes across the canal, the crews moved the boat to the center of the canal to run a vertical profile. The Operations & Hydro Data Management Division compiled the stream gauging data into a summary report, which was presented to the Water Supply Department (Goodson 2005). **Appendix E** provides a copy of the summary report.

7: Results of the Field Investigation

This section provides an interpretation and discussion of the data and implications of the interaction between surface water and groundwater in the study area.

7.1 Rainfall and Hydrographs

To account for fluctuations in both groundwater and surface water in the study area, this investigation focused on times when the S-22 Structure was opened and days when it rained. The purpose of seeking these data was to try to determine how quickly groundwater responded to changes in surface water related to recharge and/or discharge events. **Figure 18** is a hydrograph showing surface water fluctuations for April 2004. The two peaks (April 13 and 28) in this figure correspond to water level increases due to rainfall. According to rainfall records for April 2004, 0.75 inches of rain fell on April 13 and 1 inch fell on April 28, 2004. After the rainfall event on April 13, the water level in the C-2 Canal rose 0.4 feet and took approximately 5 days to return to its pre-rainfall level.

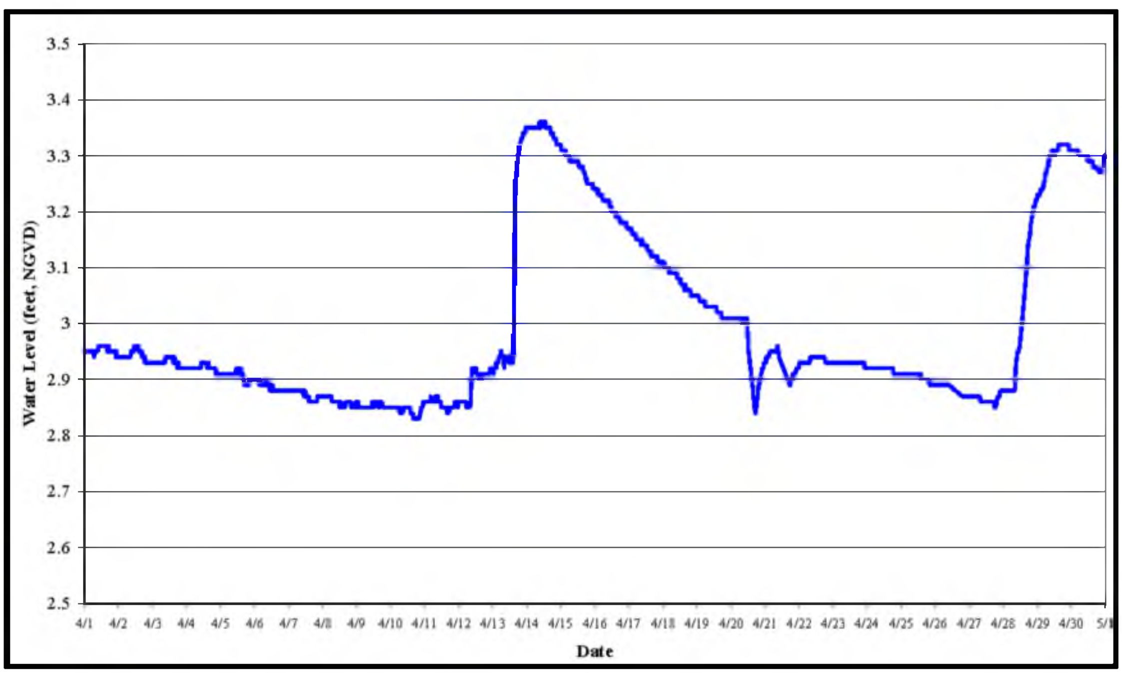

Figure 18. Surface water level in the C-2 Canal during April 2004.

Additionally, the two sharp declines in water level on April 20 and 21, 2004 correspond to days when the District opened the S-22 Structure to discharge water from the C-2 Canal. The April 20th decrease corresponds to the request by District staff to open the S-22 Structure for the stream gauging event.

Figure 19 is a hydrograph showing both surface water and groundwater levels for April 2004 near the Snapper Creek wellfield. Below the hydrograph, a separate chart shows the daily wellfield withdrawals from the Snapper Creek wellfield for April 2004. The focus of this figure is to show how changes in pumping influence groundwater around the Snapper Creek wellfield.

It appears that surface water level is minimally affected by groundwater withdrawals. During times of high water use, there is only a minimal (<0.1 feet) decline in the water level in the canal. **Figure 14** shows that withdrawals from the Snapper Creek wellfield have a greater influence on groundwater levels than surface water discharges. Days of high water use correspond to lower water levels in the aquifer. Of the groundwater wells, C2GSW1G1 seems to be the one most influenced by surface water because it shows a drop in water level corresponding to the drop in water level seen in the C-2 Canal on April 20 and 21, 2004. This could be an indication that there are preferential flow pathways in the aquifer. The monitor wells were installed in the porous limestone of the Biscayne aquifer, which exhibits conduit flow (Cunningham, *et al.* 2004).

During April 2004, **Figure 19** shows that surface water elevations are approximately 2 feet to 3 feet higher than the groundwater elevation in the shallow monitor wells. The surface water elevation is also 3 feet to 5 feet higher than the groundwater elevation in the deep monitor wells. These differences in water level elevations show that surface water is recharging groundwater in the adjacent aquifer, and that groundwater is moving from the shallow monitor zone to the deeper monitor zone. In fact, over the period of record available for the monitoring sites (November 16, 2002 to December 31, 2004), groundwater levels were consistently below surface water levels.

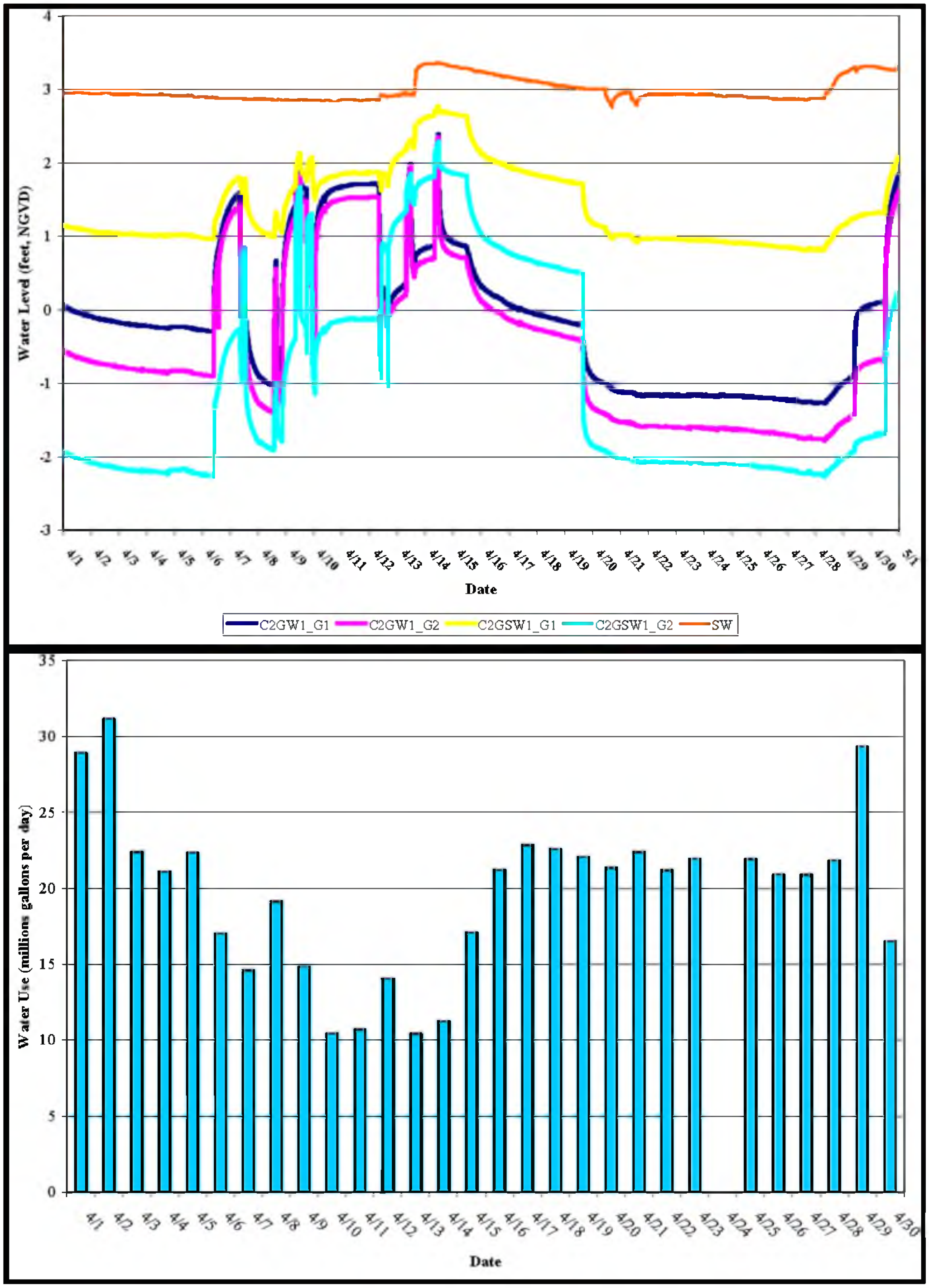

Figure 19. Surface water and groundwater hydrograph, and Snapper Creek wellfield withdrawals - April 2004.

C2GW1_G1 - shallow monitor well on south side of C-2 Canal
C2GW1_G2 - deep monitor well on south side of C-2 Canal
C2GSW1_G1 - shallow monitor well on north side of C-2 Canal
C2GSW1_G2 - deep monitor well on north side of C-2 Canal
SW - surface water
withdrawal rate from the Snapper Creek wellfield in millions of gallons per day

7.2 Stream Gauging Results

During stream gauging, District staff collected measurements at the northern (CS1) and the southern (CS6) locations. Two additional stream gauging crews rotated between four other sites throughout the day (CS2/CS3 and CS4/CS5, respectively). **Figure 20** presents the results from the stream gauging.

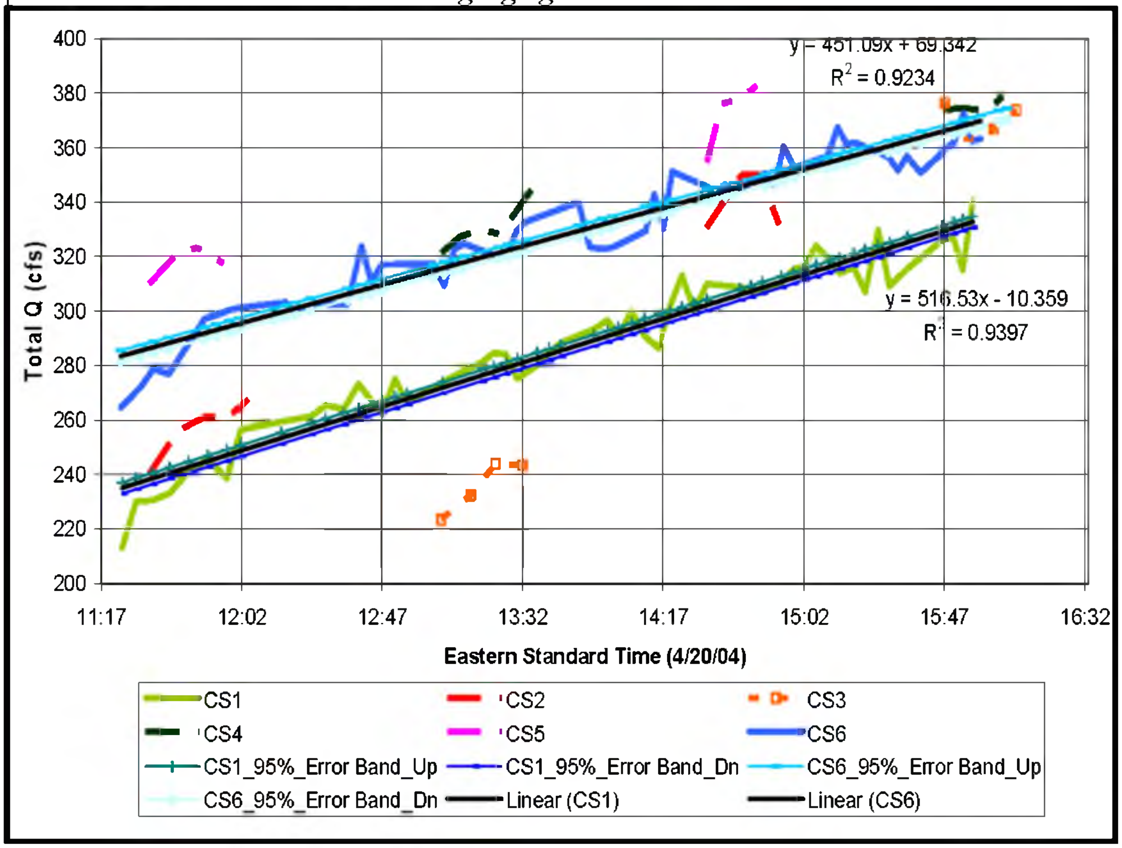

Figure 20. Results from stream gauging in the C-2 Canal, April 20, 2004.

Figure 20 shows that total flow in the C-2 Canal increased during the day based on the measurements collected from CS1 and CS6. The solid lines sloping from left to right show the increasing flow in the canal. Flow at CS1 increased from approximately 230 cubic feet per second (cfs) at 11:30 to approximately 330 cfs at 16:00 on April 20, 2004. Flow at CS6 increased from approximately 270 cfs at 11:30 to approximately 360 cfs at 16:00. Even though the measured flow was increasing, the difference in flow between the two sites remained relatively constant (approximately 90 cfs). The other stream gauging locations also show the same trend – increasing flow during the day with the difference in flow rate at each site remaining the same. However, location CS3, located just to the north of the Snapper Creek wellfield, showed a much greater increase in flow at 140 cfs as compared to the other locations. This increase was due to the effects of the Snapper Creek wellfield. During the early portions of the stream gauging, the wellfield withdrew water from the aquifer, pulling water out of the C-2 Canal to recharge the aquifer. The stream gauge readings taken at CS3 in late afternoon were higher than in the morning because the wellfield had stopped operations for the day so less water was leaving the canal to recharge the aquifer. The canal still recharged the aquifer as shown in **Figure 19**; the water level in the aquifer was lower than the water level in the canal. **Table 5** shows the changes in flow rate at each stream gauging location during April 20, 2004.

Table 5. Flow data collected during the April 20, 2004 stream gauging in the C-2 Canal.

Location	Flow at Start of Day (cfs)	Flow at End of Day (cfs)	Difference in Flow (cfs)
CS1	230	330	100
CS2	240	340	100
CS3	220	370	140
CS4	320	380	60
CS5	310	380	70
CS6	270	370	100

cfs - cubic feet per second

The next stage of this data evaluation involved comparing how flow changed between each stream gauging location moving from the north (CS1) to the south (CS6) for the start of the day and the end of the day. **Table 6** presents these data.

Table 6. Change in flow between stream gauging locations during April 20, 2004.

Locations	Change in Flow - Start of the Day (cfs)	Change in Flow - End of the Day (cfs)
Between CS1 and CS2	+10	+10
Between CS2 and CS3	-20	+30
Between CS3 and CS4	+100	+10
Between CS4 and CS5	-10	0
Between CS5 and CS6	-40	-10
Between CS1 and CS6	+40	+40

cfs - cubic feet per second

The data in **Table 6** shows that flow in the canal varied between measurement locations and over the course of the day. Between CS1 and CS2, flow in the C-2 Canal increased 10 cfs at both the start and the end of the day. This increase in flow is probably due to water entering the C-2 Canal from a tributary canal located between CS1 and CS2 (see **Figure 17**). At the start of the day, flow in the canal decreased 20 cfs between CS2 and CS3. This loss is attributed to water leaving the canal to recharge the surficial aquifer as the two northern wells at the Snapper Creek wellfield were pumping. The 20 cfs decrease in flow roughly equates to a wellfield withdrawal rate of 21 million gallons per day (MGD). The Miami-Dade WASD's records show that the combined withdrawal of the Snapper Creek wellfield's north wells was 21.367 MGD. At the end of the day, flow in the canal increased 30 cfs between these two locations, indicating the wellfield was no longer withdrawing water from the aquifer. The stream gauging showed an increase in flow of 100 cfs between CS3 and CS4 at the start of the day. This increase in flow occurred because CS4 was south of the Snapper Creek wellfield, which was pulling water from the canal into the surrounding aquifer. The flow increase also indicates that CS4 was outside the wellfield's influence on the canal. Flow in the canal increased 10 cfs between CS3 and CS4 at the end of the day when the wellfield had ceased pumping. The flow measurements in the canal presented in **Table 5** show that in the morning the flow in the canal increased from approximately 240 cfs north of the Snapper Creek wellfield (at CS2) to approximately 320 cfs south of the wellfield (at CS4). The measurements taken at the end of the day show that flow in the C-2 Canal remained constant (between 330 and 380 cfs) between the six stream gauging locations. South of the Snapper Creek wellfield, flow in the canal decreased 10 cfs between CS4 and CS5 and 40 cfs between CS5 and CS6 at the start of the day. At the end of the day, these flow differences had changed to 0 cfs and a decrease of 10 cfs between CS4 and CS5 and between CS5 and CS6, respectively. The decrease in flow in the canal between CS5 and CS6 can be attributed to water being lost to aquifer recharge as the cone of influence (100-day travel time) from the Alexander Orr wellfield intersected the C-2 Canal. **Appendix F** includes a map showing the cone of influence for each Miami-Dade County wellfield outlining the study area around the C-2 Canal.

Overall, the flow between CS1 and CS6 remained the same throughout the course of the day. The flow between these two measuring locations increased 40 cfs, even as the total flow in the canal increased by 100 cfs between the morning and afternoon measurements.

7.3 Calculated Water Velocity in the C-2 Canal

This section calculates the horizontal and seepage (vertical) velocity of water in the C-2 Canal during the April 20, 2004 stream gauging. While the stream gauging took place with the S-22 Structure open and the C-2 Canal flowing, most of the District's modeling scenarios assume this canal is static with the S-22 Structure closed (i.e., no canal discharge). Both the SFWMM and the Lower East Coast (LEC) Subregional Groundwater Flow Model use an average discharge rate in the C-2 Canal of 50 cfs. This report uses Darcy's Law to calculate the horizontal velocity of the water flowing in the C-2 Canal. Two methods were used to calculate the vertical water velocity adjacent to the Snapper Creek wellfield: the U.S. Geological Survey (USGS) three-dimensional finite difference model (MODFLOW) riverbed conductance term (McDonald and Harbaugh 1988), and Darcy's Law.

The Darcian velocity is calculated using **Equation 2**.

$$V = Q/A \qquad \text{(Equation 2)}$$

Where:
V = Velocity (length/time)
Q = Discharge (length^3/time)
A = Cross-sectional area (length^2)

Table 7 presents the results of the velocity calculations. For comparison, **Table 7** also shows a velocity based on the discharge rates calculated from the SFWMM and the LEC

Subregional Groundwater Flow Model. To calculate the velocity using the modeling data, District staff used a cross-sectional area of 900 square feet ($feet^2$), which is the average area of the six surveyed sections for this investigation (**Section 2.0** and **Appendix A**).

Table 7. Darcian velocity calculations in the C-2 Canal.

Morning			
C-2 Canal Segment	**Surveyed Cross-Section Area ($feet^2$)**	**Measured Discharge ($feet^3$/sec)**	**Mean Horizontal Canal Velocity at Cross-Section (feet/sec)**
Cross-section 1	684	230	0.336
Cross-section 2	992	240	0.242
Cross-section 3	1025	220	0.215
Cross-section 4	854	320	0.375
Cross-section 5	756	310	0.410
Cross-section 6	960	270	0.281
Afternoon			
C-2 Canal Segment	**Surveyed Cross-Section Area ($feet^2$)**	**Measured Discharge ($feet^3$/sec)**	**Mean Horizontal Canal Velocity at Cross-Section (feet/sec)**
Cross-section 1	684	330	0.482
Cross-section 2	992	340	0.343
Cross-section 3	1025	370	0.361
Cross-section 4	854	380	0.445
Cross-section 5	756	380	0.503
Cross-section 6	960	370	0.385
From Water Models			
	Surveyed Cross-Section Area ($feet^2$)	**Calculated Discharge ($feet^3$/sec)**	**Mean Horizontal Canal Velocity at Cross-Section (feet/sec)**
Water Models	900	50	0.056

$feet^2$ - square feet
$feet^3$/sec - cubic feet per second
feet/sec - feet per second

The water velocities calculated from the stream gauging event are an order of magnitude higher than those determined in the models. This discrepancy is because the discharge value for the canal in the models assumes that the S-22 Structure is closed and the canal is not discharging. Both the SFWMM and the LEC Subregional Groundwater Flow Model estimate flow in the C-2 Canal at approximately 50 cubic feet per second (cfs) where actual flow measurements in the canal range from 230 cfs to 380 cfs with the S-22 Structure open and the canal discharging.

Vertical water velocities were calculated using the USGS's MODFLOW riverbed conductance term, and Darcy's Law. Since the monitoring site adjacent to the Snapper Creek wellfield is the only one that collects surface water and groundwater level data, it was used to determine the seepage (vertical) water velocity in the C-2 Canal.

Calculating the vertical water velocity using the MODFLOW river package involves three steps. The first step is to calculate the conductance of the sediments on the bottom of the canal. The second step uses this calculated conductance and multiplies it by the head difference between the river and the aquifer to determine the flow through the river bed. The seepage velocity is then calculated using the flow value determined from the previous step. Sediment conductance is determined using **Equation 3**.

$$CRIV = K * L * W / M \qquad \textbf{(Equation 3)}$$

Where:
CRIV = Riverbed conductance
K = Hydraulic conductivity of the sediments
L = Length of canal reach
W = Canal width
M = Thickness of riverbed sediments

For this calculation a value of 1 foot per day and 1 foot were used for K and M, respectively. These values were consistent with those used in the LEC Subregional Groundwater Flow Model (SFWMD, forthcoming). District survey crews measured values for L and W at each stream gauging location. Although only one location was used to calculate the vertical water velocity, District staff calculated the river bed conductance between each of the six stream gauging sites. **Table 8** presents the results of these calculations.

Table 8. Riverbed conductance along the C-2 Canal.

C-2 Canal Segment	Surveyed Wetted Surface of Canal (feet)	Distance Between Station and Down Stream Station (feet)	Hydraulic Conductivity of Canal Bed Material (feet/day)	Canal Bed Thickness (feet)	MODFLOW River Conductance ($feet^2$/day)	MODFLOW River Conductance ($feet^2$/sec)
Between Cross-section 1 and 2	75.8	6,655	1.0	1.0	504,582	5.84
Between Cross-section 2 and 3	109.2	778	1.0	1.0	84,934	0.98
Between Cross-section 3 and 4	105.8	1,047	1.0	1.0	110,794	1.28
Between Cross-section 4 and 5	104.2	437	1.0	1.0	45,531	0.53
Between Cross-section 5 and 6	95.6	18,874	1.0	1.0	1,804,166	20.88
Mean	98.1	5,558	1.0	1.0	510,001	5.9

The second step involves calculating the flow from the canal into the aquifer using Equation 4.

QRIV = CRIV * (HRIV - HAQ) **(Equation 4)**

Where:
QRIV = Flow from the river
CRIV = Riverbed conductance
HRIV = Water level in the river (feet, NGVD)
HAQ = Water level in the aquifer (feet, NGVD)

Water level data used in **Equation 4** included various times during the day of April 20, 2004, and noon from the day before and after the stream gauging. Data from the day before and the day after were used to understand flow and seepage velocities when the canal was under static conditions. The water level elevations are provided in **Table 9**.

Table 9. Water level elevation data used to calculate riverbed flow rates.

Date	Surface Water Elevation (feet, NGVD)	C2GSW1_GW1 Groundwater Elevation (feet, NGVD)	C2GSW1_GW2 Groundwater Elevation (feet, NGVD)	C2GW1_GW1 Groundwater Elevation (feet, NGVD)	C2GW1_GW2 Groundwater Elevation (feet, NGVD)
4/19/2004 12:00	3.02	1.72	0.51	-0.20	-0.40
4/20/2004 08:00	3.01	1.14	-1.90	-0.99	-1.40
4/20/2004 10:00	3.01	1.13	-1.91	-1.00	-1.41
4/20/2004 12:00	2.90	1.07	-1.93	-1.01	-1.43
4/20/2004 16:00	2.85	0.99	-1.97	-1.06	-1.47
4/20/2004 22:00	2.92	1.02	-2.02	-1.11	-1.52
4/21/2004 12:00	2.84	0.95	-2.05	-1.14	-1.56

The flow from the river adjacent to the Snapper Creek wellfield was then calculated using the conductance value in **Table 8** between cross-sections 3 and 4 and the water level date presented in **Table 9**. The conductance value for the stream reach between cross-sections 3 and 4 represented the area where the groundwater monitor wells are located. The previously mentioned information was then input into **Equation 4**; results are presented in **Table 10**.

Table 10. Seepage velocities between the C-2 Canal and the adjacent monitor wells.

Date	Seepage Velocity at C2GSW1_GW1 (feet/sec)	Seepage Velocity at C2GSW1_GW2 (feet/sec)	Seepage Velocity at C2GW1_GW1 (feet/sec)	Seepage Velocity at C2GW1_GW2 (feet/sec)
4/19/2004 12:00	1.67	3.22	4.13	4.39
4/20/2004 08:00	2.40	6.30	5.13	5.66
4/20/2004 10:00	2.41	6.31	5.14	5.67
4/20/2004 12:00	2.35	6.19	5.01	5.55
4/20/2004 16:00	2.39	6.18	5.01	5.54
4/20/2004 22:00	2.44	6.33	5.17	5.69
4/21/2004 12:00	2.42	6.27	5.10	5.64
Average	2.30	5.83	4.96	5.45

Table 10 shows that the seepage velocity increased based on the gradients between the surface water and groundwater in each monitor well when the S-22 Structure was opened for the stream gauging. Nearly 24 hours later, when the S-22 Structure was closed, the seepage velocity remained as high as it was when the structure was open.

For comparison, staff calculated the Darcian velocity based on the elevation differences between the surface water and groundwater in each of the monitor wells using **Equation 5**. Again, the water level data used in **Table 9** was input into Equation 5.

$$V = (-K * {}^{dh}/_{dl})/\alpha \qquad \textbf{(Equation 5)}$$

Where:
V = Water velocity
K = Hydraulic conductivity (feet/sec)
$^{dh}/_{dl}$ = Hydraulic gradient between surface water and groundwater (feet/foot)
α = Effective porosity

For this calculation a hydraulic conductivity of 2,000 feet per day (1.39 feet per second) and an effective porosity of 0.15 were used. The hydraulic conductivity value was an average for several wells around the Snapper Creek wellfield. These data are stored in DBHYDRO. An effective porosity of 0.15 was selected to represent the fractured limestone present beneath the study area. **Table 11** presents the seepage velocity values calculated using **Equation 5**.

Table 11. Darcian seepage velocities between the C-2 Canal and the adjacent monitor wells.

Date	Seepage Velocity at C2GSW1_GW1 (feet/sec)	Seepage Velocity at C2GSW1_GW2 (feet/sec)	Seepage Velocity at C2GW1_GW1 (feet/sec)	Seepage Velocity at C2GW1_GW2 (feet/sec)
4/19/2004 12:00	12.04	23.24	29.81	31.67
4/20/2004 08:00	17.31	45.46	37.04	40.83
4/20/2004 10:00	17.41	45.56	37.13	40.93
4/20/2004 12:00	16.94	44.72	36.20	40.09
4/20/2004 16:00	17.22	44.63	36.20	40.00
4/20/2004 22:00	17.59	45.74	37.31	41.11
4/21/2004 12:00	17.50	45.28	36.85	40.74
Average	16.57	42.09	35.79	39.34

Seepage velocities calculated using **Equation 5** are approximately 12 times higher than those calculated based on the MODFLOW river package. This discrepancy could be due to the hydraulic conductivity values used in Equation 5. Perhaps, obtaining hydraulic conductivity values from slug tests conducted in each well would yield different seepage velocity values.

Figure 21 is a representative cross-section through the C-2 Canal at the Snapper Creek wellfield. The cross-section shows equipotential lines and how water flows out of the C-2 Canal into the Biscayne aquifer. **Appendix G** includes a larger copy of this figure.

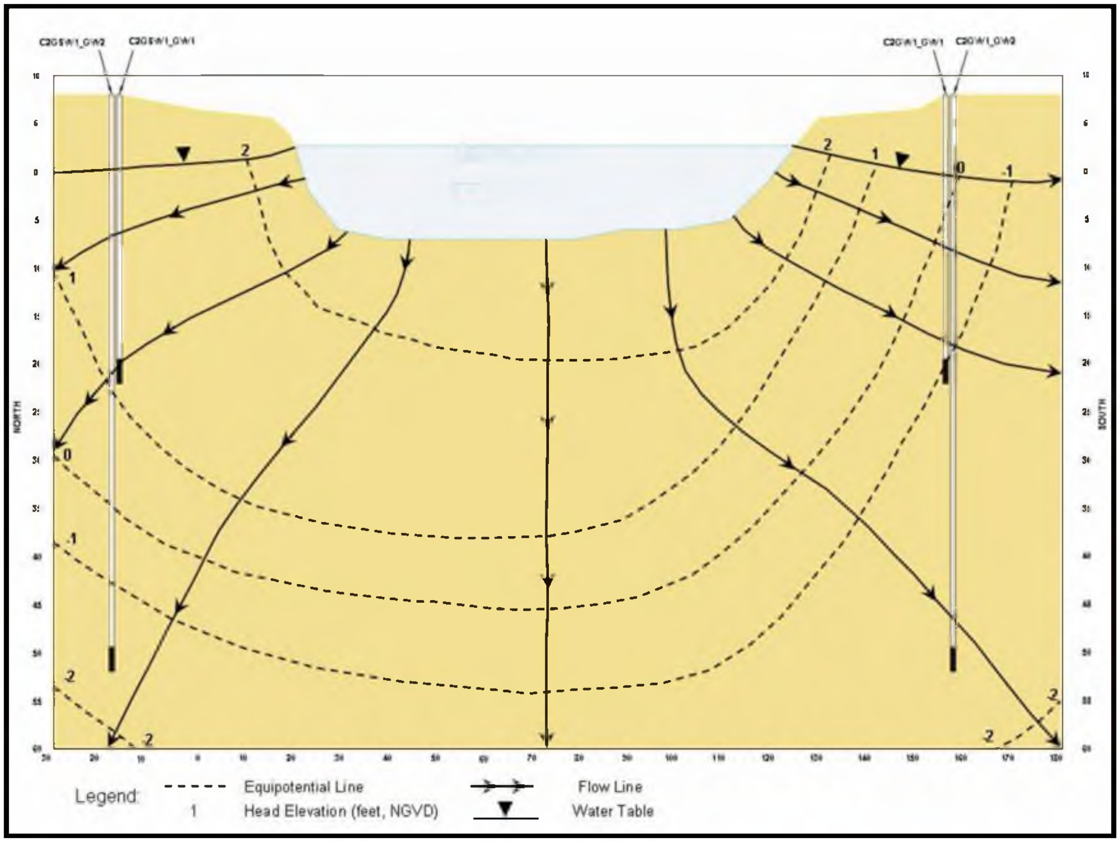

Figure 21. Cross-section showing equipotential lines and water flow from the C-2 Canal.

8: Conclusions and Recommendations

Based on the results of this investigation, it appears that the C-2 Canal was losing approximately 20 cfs of water around the Snapper Creek wellfield on April 20, 2004. The data shows that the groundwater elevation is influenced by surface water elevation changes along the canal. This conclusion can be drawn because increases in the C-2 Canal water level from rainfall correspond to increases in groundwater levels in the monitor wells (**Figures 14**, **15**, and **16**). However, groundwater does not appear to influence surface water. Although the stream gauging shows that 20 cfs is leaving the canal near the wellfield, the water loss does not have an impact on the groundwater (i.e., water levels in the monitor wells did not increase, indicating that the aquifer has a very high permeability).

At times when the surrounding wellfields are withdrawing water, the groundwater level in the four monitor wells declines, but a decline in surface water levels is not seen. Over the course of this investigation (November 16, 2002 to December 31, 2004), the water level in the canal was always higher than the water level in the aquifer, meaning that the C-2 Canal was constantly recharging the aquifer in the vicinity of the Snapper Creek wellfield. Based on the findings of this investigation, the following recommendations would substantially increase the understanding of the interaction between groundwater and surface water along the C-2 Canal.

- Perform additional stream gauging event with the C-2 Canal under flowing conditions with four boats continuously gauging at sites CS1, CS3, CS4, and CS6 (one boat per site).
- Perform additional stream gauging by holding the canal under static conditions (not flowing) and have four boats perform stream gauging continuously at sites CS1, CS3, CS4, and CS6 (one boat per site).

  The two previously mentioned scenarios will allow investigators to compare flow conditions within the canal under flowing and static conditions. The objective would be to see different conditions (flowing or static) in the canal affect the quantity of water lost around the Snapper Creek wellfield. It may be necessary to use small standing flow meters due to the difficult wind conditions and low velocity in the canal when it is discharging.
- Install additional monitor wells at the northern and southern surface water monitoring sites constructed for this investigation. These additional sites would allow for comparison of groundwater and surface water elevations and determine if the canal is gaining or losing water away from the wellfield.
- Install seepage meters in the canal to measure seepage through the canal bed.
- Conduct slug tests in each monitor well to determine a hydraulic conductivity of the aquifer to help improve the accuracy of calculating seepage velocities.

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A: Canal Cross-section Profiles

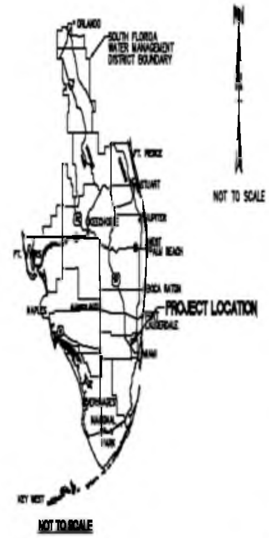
SOUTH FLORIDA WATER MANAGEMENT DISTRICT

ENGINEERING AND PROJECT IMPLEMENTATION

CANAL C-2

STUDY WELLS

MIAMI-DADE COUNTY, FLORIDA



SURVEYOR'S NOTES

1. THE ELEVATIONS SHOWN HEREON REFER TO THE NATIONAL GEODETIC VERTICAL DATUM OF 1929, (NGVD29) AND ARE BASED ON THE FOLLOWING BENCHMARK.

   a. BENCHMARK "P578" STATION IS A PK NAIL AND BRASS WASHER, STATION IS LOCATED AT THE PIPE CROSSING OF C-2 CANAL AT THE INTERSECTION OF S.W. 56TH STREET (MILLER ROAD) AND S.W. 117TH AVE. STATION IS 95 FEET NORTH OF THE CENTERLINE PROJECTED FROM THE EAST OF S.W. 56TH STREET, 142 FEET WEST OF THE CENTERLINE PROJECTED FROM THE NORTH OF S.W. 117TH AVE. AND 30' FEET WEST OF THE CENTERLINE OF THE BIKE PATH ELEVATION = 10.38'

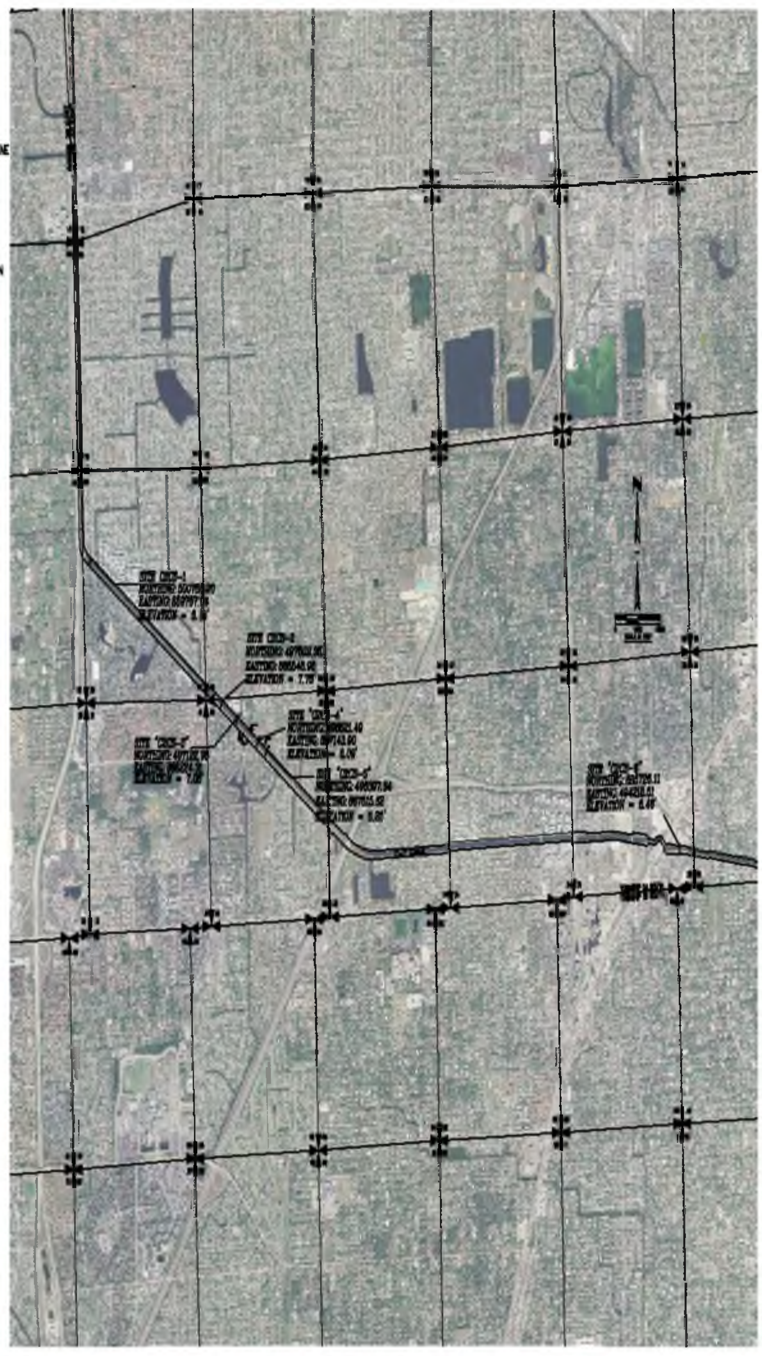
   b. BENCHMARK "J489-2" STATION IS A DADE COUNTY BRASS DISK SET IN CONCRETE STAMPED "J489-2 DADE" STATION IS LOCATED AT THE SOUTHEAST CORNER AT THE BRIDGE OVER C-2 CANAL AND SUNSET ROAD ELEVATION = 12.40'

   c. BENCHMARK :FCE 1471 RESET" STATION IS A STANDARD U.S. ARMY CORPS OF ENGINEERS BRASS CAP SET IN CONCRETE STAMPED "FCE 1471 1956". STATION IS 1.65 MILES MILES SOUTHWESTERLY ALONG U.S. HIGHWAY 1 FROM THE JUNCTION OF STATE HIGHWAY 959 (S.W. 57TH AVE.) IN SOUTH MIAMI, IN TOP OF AND 0.7 FEET SOUTHEAST OF THE IN TOP OF AND 0.7 FEET SOUTHEAST OF THE NORTHWEST END OF THE SOUTHWEST CONCRETE ABUTMENT OF THE SOUTHBOUND HIGHWAY BRIDGE SPANNING SNAPPER CREEK CANAL NUMBER C-2, STATION IS LOCATED 24.6 FEET NORTHWEST OF THE CENTERLINE OF THE SOUTHBOUND LANES OF THE HIGHWAY, AND 3.3 FEET ABOVE THE LEVEL OF THE HIGHWAY, ELEVATION = 16.19'

   d. BENCHMARK "BM C25W 1", STATION IS 1 1/2" GALVANIZED PIPE SET IN CONCRETE WITH S.F.W.M.D. ALUMINUM DISK, TO REACH STATION FROM THE INTERSECTION OF S.W. 116TH AVE. AND NORTH SNAPPER CREEK ROAD, STATION IS 22.7 FEET SOUTH OF THE SOUTH OF THE EDGE OF PAVEMENT OF NORTH SNAPPER CREEK ROAD AND 16.2' FEET WEST OF THE CENTERLINE OF S.W. 116TH AVE EXTENDED, STAMPED "C25W 1", ELEVATION = 6.31'

   e. BENCHMARK "BM C25W 2", STATION IS 1 1/2" GALVANIZED PIPE SET IN CONCRETE WITH S.F.W.M.D. ALUMINUM DISK, TO REACH STATION FROM THE INTERSECTION OF S.W. 67TH AVE. (LUDLUM ROAD) AND U.S. HIGHWAY 1, CONTINUE SOUTHERLY ALONG S.W. 67TH AVE 0.2 MILE MORE OR LESS TO A BRIDGE OVER C-2 CANAL, TURN RIGHT (WESTERLY) AT NORTHERLY SIDE OF BRIDGE, GO THROUGH GATE AND CONTINUE CANAL, TURN RIGHT (WESTERLY) AT NORTHERLY SIDE OF BRIDGE, GO THROUGH GATE AND CONTINUE WESTERLY 573 FEET MORE OR LESS TO STATION, STAMPED "BM C25W2-2002" ELEVATION = 6.66'

2. THE BEARINGS AND DISTANCES SHOWN IN THE DIGITAL FILES REFER TO THE FLORIDA STATE PLANE COORDINATE SYSTEM TRANSVERSE MERCATOR PROJECTION, EAST ZONE, NORTH AMERICAN DATUM 1983 (NAD83), AND ARE BASED ON SOUTH FLORIDA WATER MANAGEMENT DISTRICT GPS CONTROL POINTS ESTABLISEHD AT EACH INDIVIDUAL SITE USING THE TRIMBLE PATHFINDER PRO-XR REAL TIME GPS UNIT, THE EXPECTED HORIZONTAL ACCURACY IS (±) 5.0 FEET. CAUTION SHOULD BE TAKEN IF COORDINATES ARE USED FOR ANYTHING OTHER THAN THESE SPECIFIC SITES.
3. THE PICTORIAL REPRESENTATION SHOWN HEREON IS A DIGITAL ORTHO QUARTER QUAD, 1 METER PIXEL RESOLUTION. OBTAINED FROM THE UNITED STATES GEOLOGICAL SURVEY, MAP NAMED SOUTH MIAMI, NUMBER 281 AND SOUTH MIAMI NORTHWEST NUMBER 280 AND IS NOT PART OF THIS SURVEY
4. THE SECTION CORNERS AND LINES SHOWN HEREON ARE APPROXIMATE, THEY WERE TAKEN FROM THE S.F.W.M.D. GEOGRAPHIC INFORMATION SYSTEM (GIS) SECTIONAL COVERAGE OF DADE COUNTY WHICH WERE DIGITIZED FROM THE UNITED STATES GEOLOGICAL SURVEY QUADRANGLE MAPS AND IS NOT PART OF THIS SURVEY
5. NO RIGHT OF WAY OR BOUNDARY SURVEY WAS PERFORMED AS A PART OF THIS SURVEY
6. CROSS SECTIONS SHOWN HEREON WERE TAKEN PERPENDICULAR, AT 90° TO THE EXISTING CANAL UNLESS OTHERWISE STATED.
7. THERE WAS NO CLOSED TRAVERSE ESTABLISHED AS A PART OF THIS SURVEY.
8. THE GROUND ELEVATIONS AND LOCATIONS FOR THIS SURVEY WERE ESTABLISHED BY TRIGONOMETRIC MEANS, USINGTHE TOPCON GTS-710 TOTAL STATION AND MC5 DATA COLLECTOR WITH C & G FIELD AND OFFICE SOFTWARE.
9. THE BENCHMARKS SHOWN HEREON WERE ESTABLISHED USING CONVENTIONAL THIRD ORDER SURVEYING PROCEDURES, AND ARE BASED ON A CLOSED LEVEL LOOP.
10. ALL COORDINATES SHOWN HEREON ARE APPROXIMATE AND WERE ESTABLISHED USING THE TRIMPLE PRO-XL REAL TIME GPS UNIT.
11. UNLESS IT BEARS THE SIGNATURE AND ORIGINAL RAISED SEAL OF A FLORIDA LICENSED SURVEYOR AND MAPPER, THIS DRAWING, SKETCH, PLAT, OR MAP IS FOR INFORMATIONAL PURPOSES ONLY AND IS NOT VALID.



LEGEND

DIA. = DIAMETER
BM = BENCHMARK
CMP = CORRUGATED METAL PIPE
ELEV. = ELEVATION
FCE = FLOOD CONTROL EVERGLADES
GPS = GLOBAL POSITIONING SYSTEM
INV. = INVERT
NGS = NATIONAL GEODETIC SURVEY
NGVD = NATIONAL GEODETIC VERTICAL DATUM
P.O.L. = POINT ON LINE
R/W = RIGHT OF WAY
SFWMD = SOUTH FLORIDA WATER MANAGEMENT DISTRICT
USGS = UNITED STATES GEOLOGICAL SURVEY
⊕ = BENCHMARK
× 20.3 = SPOT ELEVATION
= APPROXIMATE SECTION CORNER LOCATION
= APPROXIMATE CANAL RIGHT OF WAY

INDEX OF SHEETS

THIS IS NOT A SURVEY
FOR EXHIBIT ONLY

SOUTH FLORIDA WATER MANAGEMENT DISTRICT
3301 GUN CLUB ROAD
WEST PALM BEACH, FL 33416-4680

C-2 CANAL
SPECIFIC PURPOSE SURVEY
STUDY WELLS AND CROSS SECTIONS
COVER SHEET

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SHEET 1 of 7

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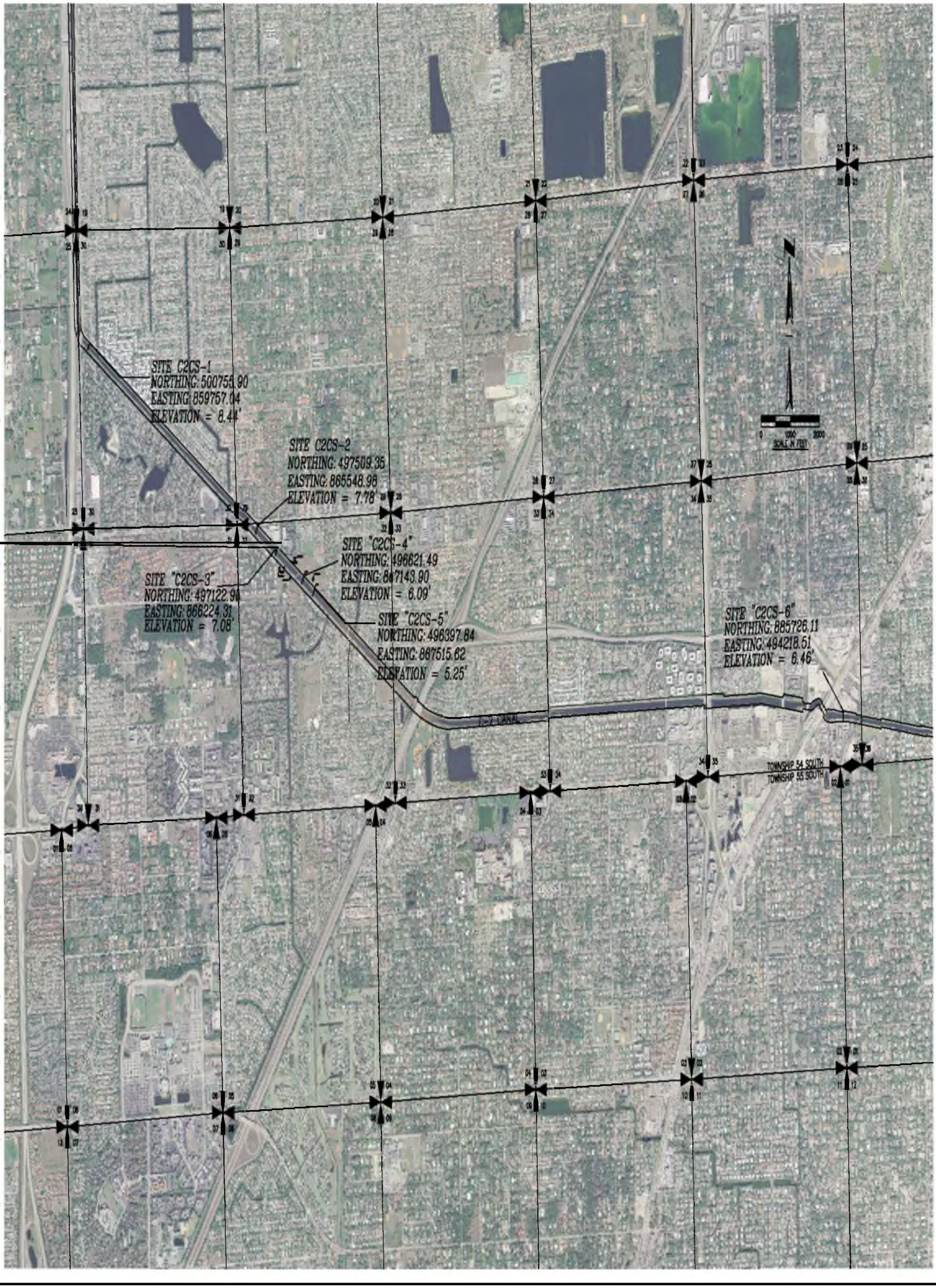
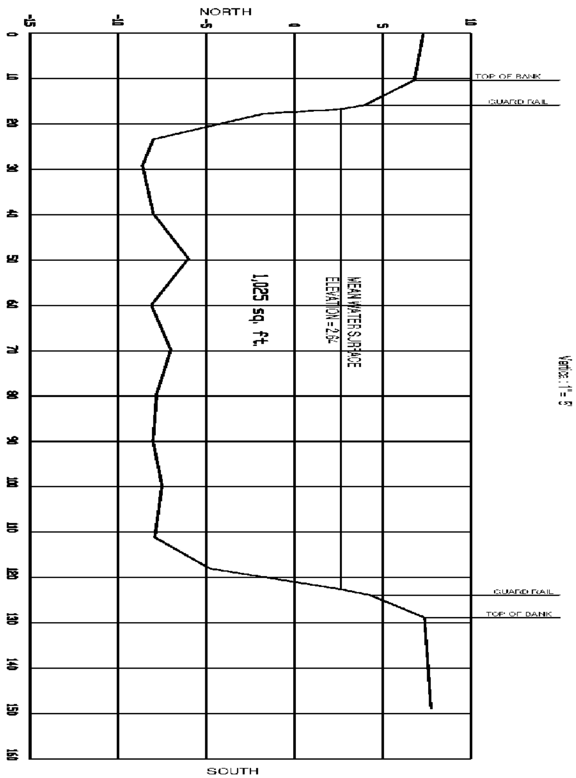


SOUTH FLORIDA WATER MANAGEMENT DISTRICT
3301 GUN CLUB ROAD
WEST PALM BEACH, FL 33416-4680

C-2 CANAL
SPECIFIC PURPOSE SURVEY
STUDY WELLS AND CROSS SECTIONS
PLAN VIEW

SHEET 2 of 7



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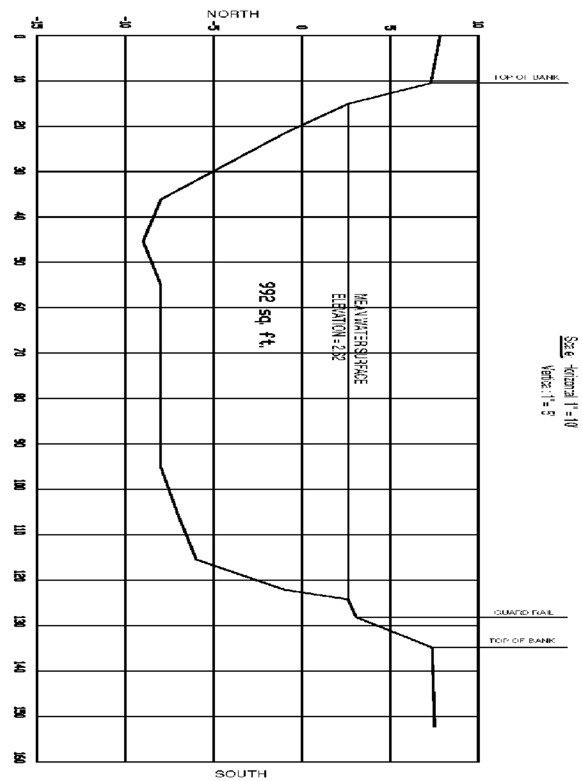

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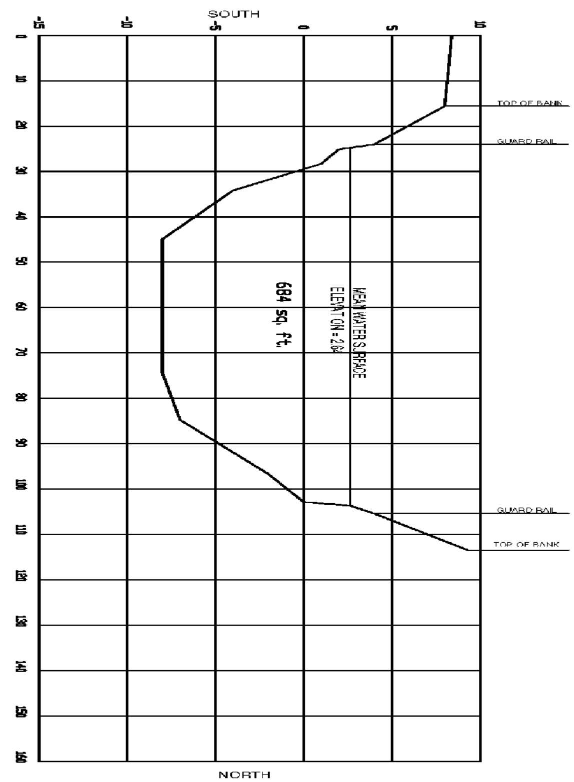

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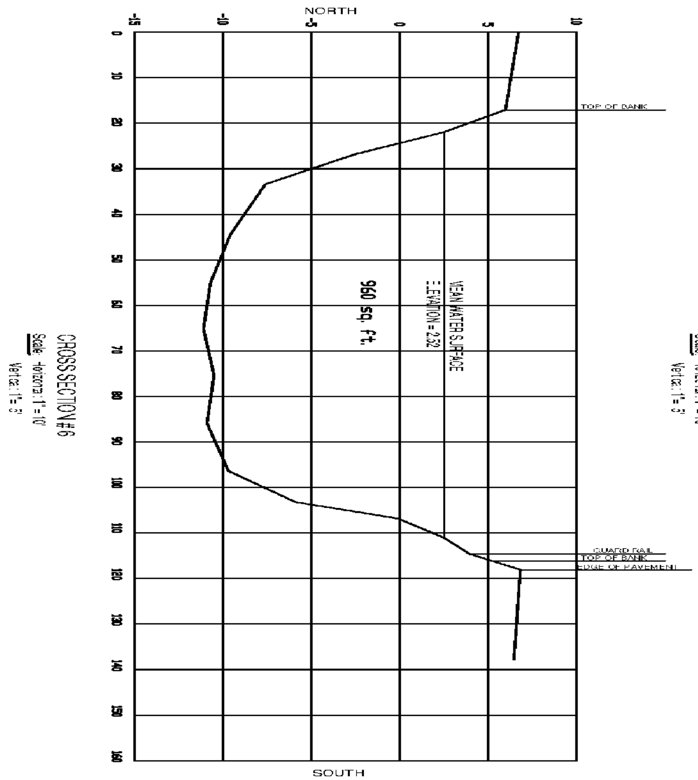

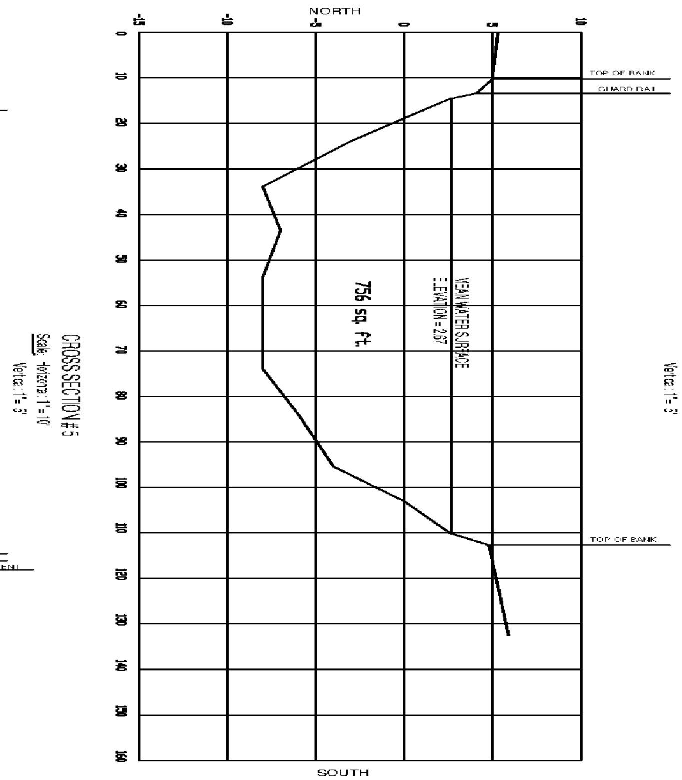

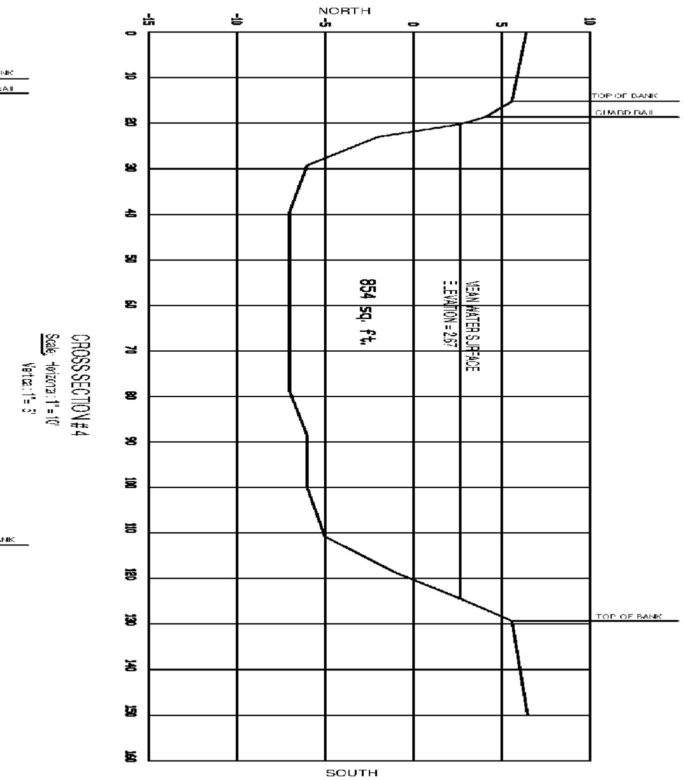

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C- 2 CANAL
SPECIFIC PURPOSE SURVEY
STUDY WELLS AND CROSS SECTIONS

SOUTH FLORIDA
WATER MANAGEMENT DISTRICT
3301 GUN CLUB ROAD
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DATACOLL C- 2 WELLS

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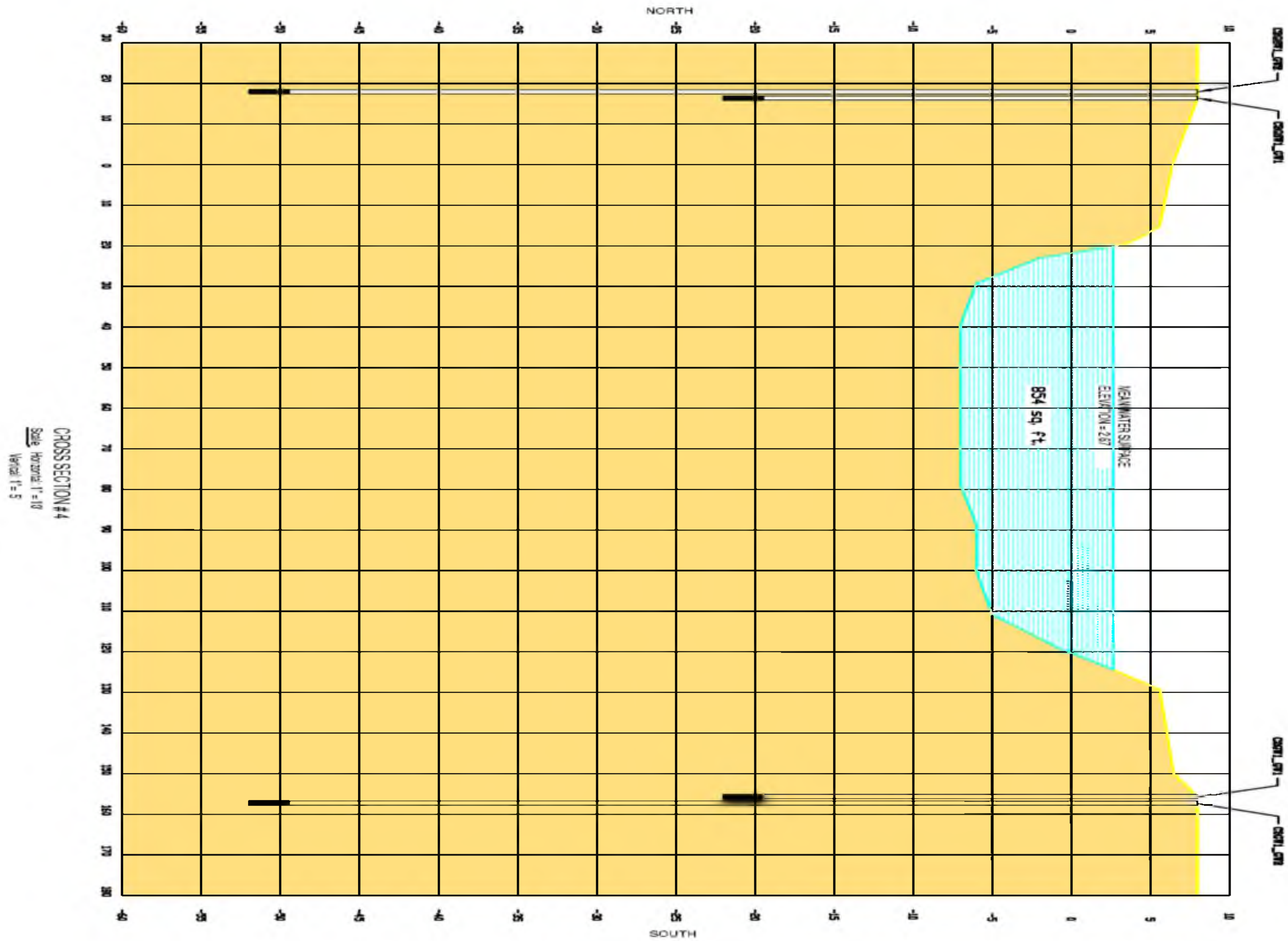

C- 2 CANAL
SPECIFIC PURPOSE SURVEY
STUDY WELLS AND CROSS SECTIONS

SOUTH FLORIDA
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3301 GUN CLUB ROAD
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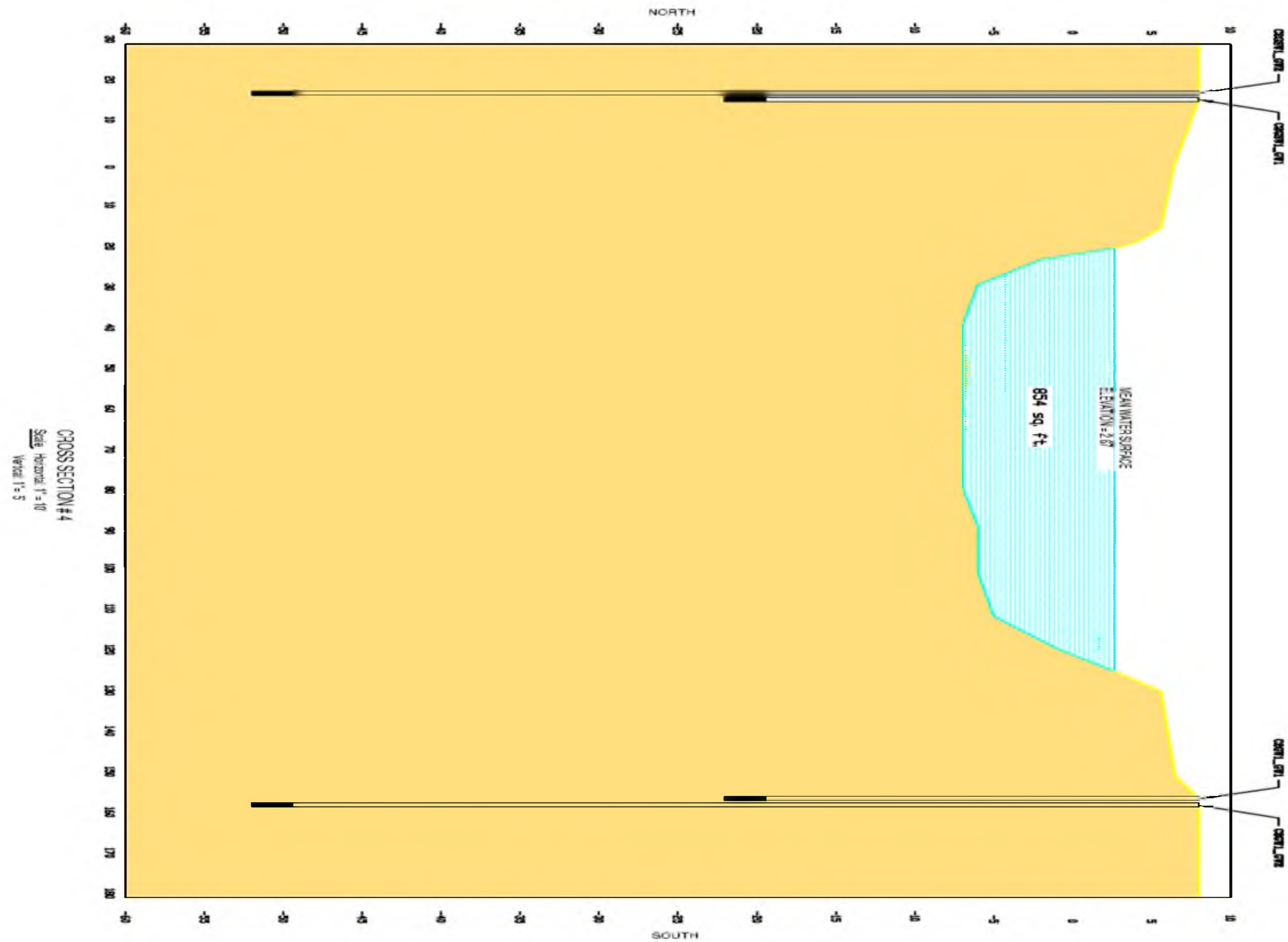

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SOUTH FLORIDA WATER MANAGEMENT DISTRICT
3301 GUN CLUB ROAD
WEST PALM BEACH, FL 33416-4680

C-2 CANAL
SPECIFIC PURPOSE SURVEY
STUDY WELLS AND CROSS SECTIONS
PLAN VIEW

DRAWING NO. 0000
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SHEET 7 OF 7

DATE	DRAWN	REV#	REVISION DESCRIPTION

PLOT SCALE: 1" = 1" (PAPER SPACE)

B: Lithologic Logs

Table B-1. Monitor Well C2GSW1_GW1 Lithologic Log

Depth (feet)	Lithology
0-5	Tan limestone (grainstone), some vugs.
5-10	Light brown limestone (grainstone), oolitic.
10-15	Light brown limestone (grainstone), oolitic.
15-20	Dark gray limestone (wackestone), dense, low permeability.
20-25	Light brown limestone (packstone), friable.
25-30	Olive brown limestone (packstone/wackestone), moldic and vuggy porosity, bivalve shells.
30-35	Olive brown limestone (grainstone), moldic and vuggy porosity, bivalve shells, some recalcification, very permeable.
35-40	White limestone (packstone), moldic and vuggy porosity, bivalve shells, some recalcification, permeable, ~10% fine to medium grain, poorly sorted quartz sand, rounded grains near bottom of interval.
40-45	White quartz sand, fine to medium rounded grains, poorly sorted, ~20% white limestone (packstone), moldic and vuggy porosity, bivalve shells, some recalcification, permeable.
45-50	White limestone (packstone), moldic and vuggy porosity, bivalve shells, some recalcification, permeable, ~10% fine to medium grain, poorly sorted quartz sand, rounded grains near bottom of interval.
50-55	White quartz sand, fine to medium rounded grains, poorly sorted, ~20% white limestone (packstone), moldic and vuggy porosity, bivalve shells, some recalcification, permeable.
55-60	White limestone (packstone), moldic and vuggy porosity, friable, bivalve shell molds, some recalcification, permeable.

Table B-2. Monitor Well C2GSW1_GW2 Lithologic Log

Depth (feet)	Lithology
0-5	Tan limestone (grainstone), some vugs.
5-10	Tan to white limestone (wackestone), moldic and vuggy porosity, permeable, some hard/recalcified layers (caliche).
10-15	Tan to white limestone (wackestone), moldic and vuggy porosity, permeable.
15-20	Light gray limestone (wackestone), dense, low permeability, some recalcification, bivalves.
20-25	White quartz sand, fine to medium rounded grains.

Table B-3. Monitor Well C2GW1_GW1 Lithologic Log

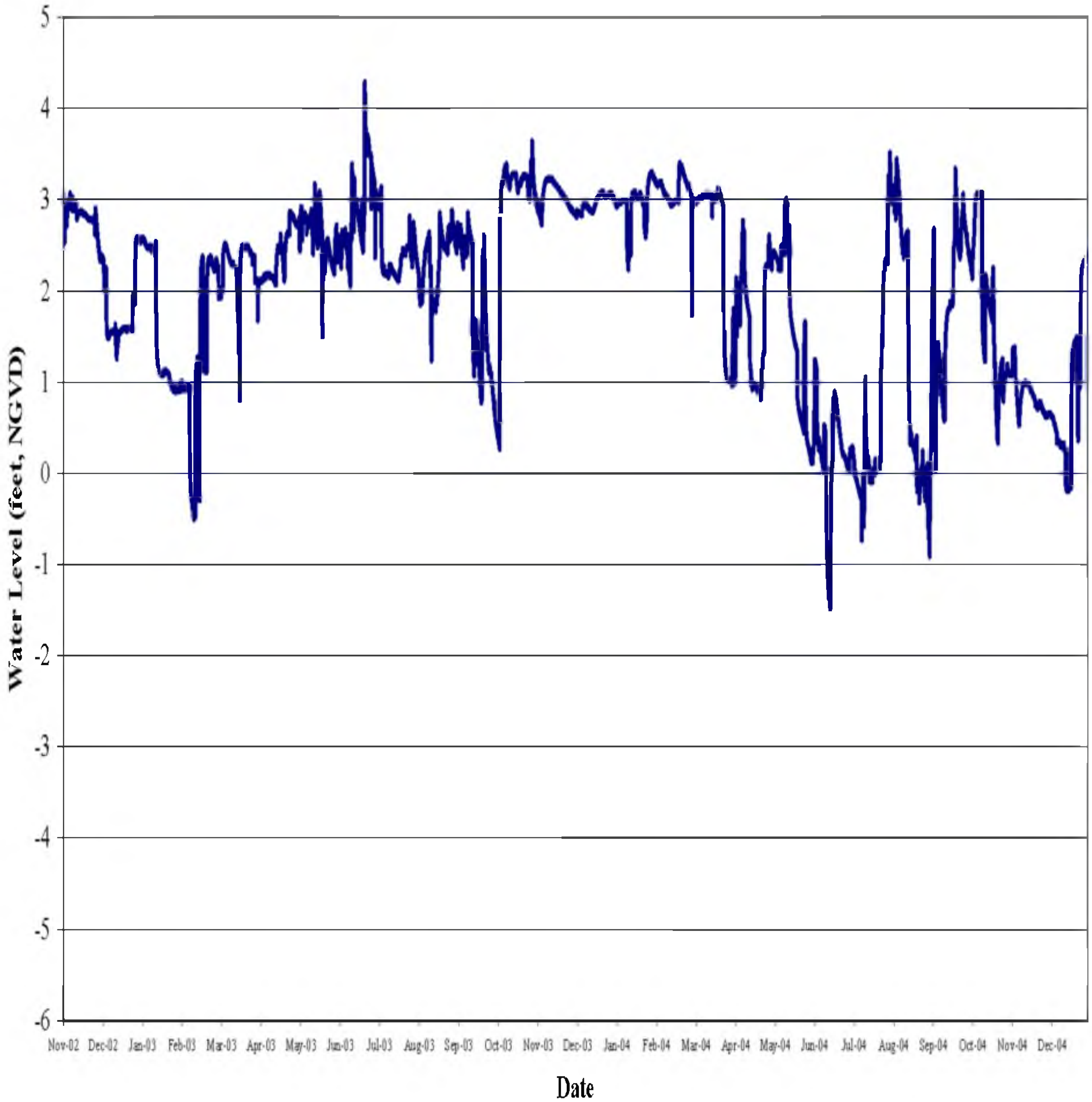
Depth (feet)	Lithology
0-5	Tan limestone (grainstone), some vugs, ~20% fine to medium grained quartz sand, rounded grains.
5-10	Light brown to tan limestone (grainstone), oolitic, vuggy porosity, very permeable.
10-15	White to tan limestone (grainstone), oolitic, vuggy and moldic, very permeable, bivalve shells.
15-20	Olive brown to white limestone (packstone), vuggy and moldic porosity, permeable, bivalve shells.
20-25	White limestone (packstone), dense, some bivalves, low permeability.
25-30	White limestone (packstone), dense, some bivalves, low permeability.
30-35	White limestone (grainstone), moldic and vuggy porosity, bivalve shells, very permeable.
35-40	White limestone (grainstone), moldic and vuggy porosity, bivalve shells, permeable.
40-45	White limestone (grainstone), moldic and vuggy porosity, bivalve shells, permeable.
45-50	White limestone (grainstone), moldic and vuggy porosity, bivalve shells, permeable.
50-55	White limestone (grainstone), moldic and vuggy porosity, bivalve shells, permeable.
55-60	White limestone (grainstone), moldic and vuggy porosity, bivalve shells, permeable.

Table B-4. Monitor Well C2GW1_GW2 Lithologic Log

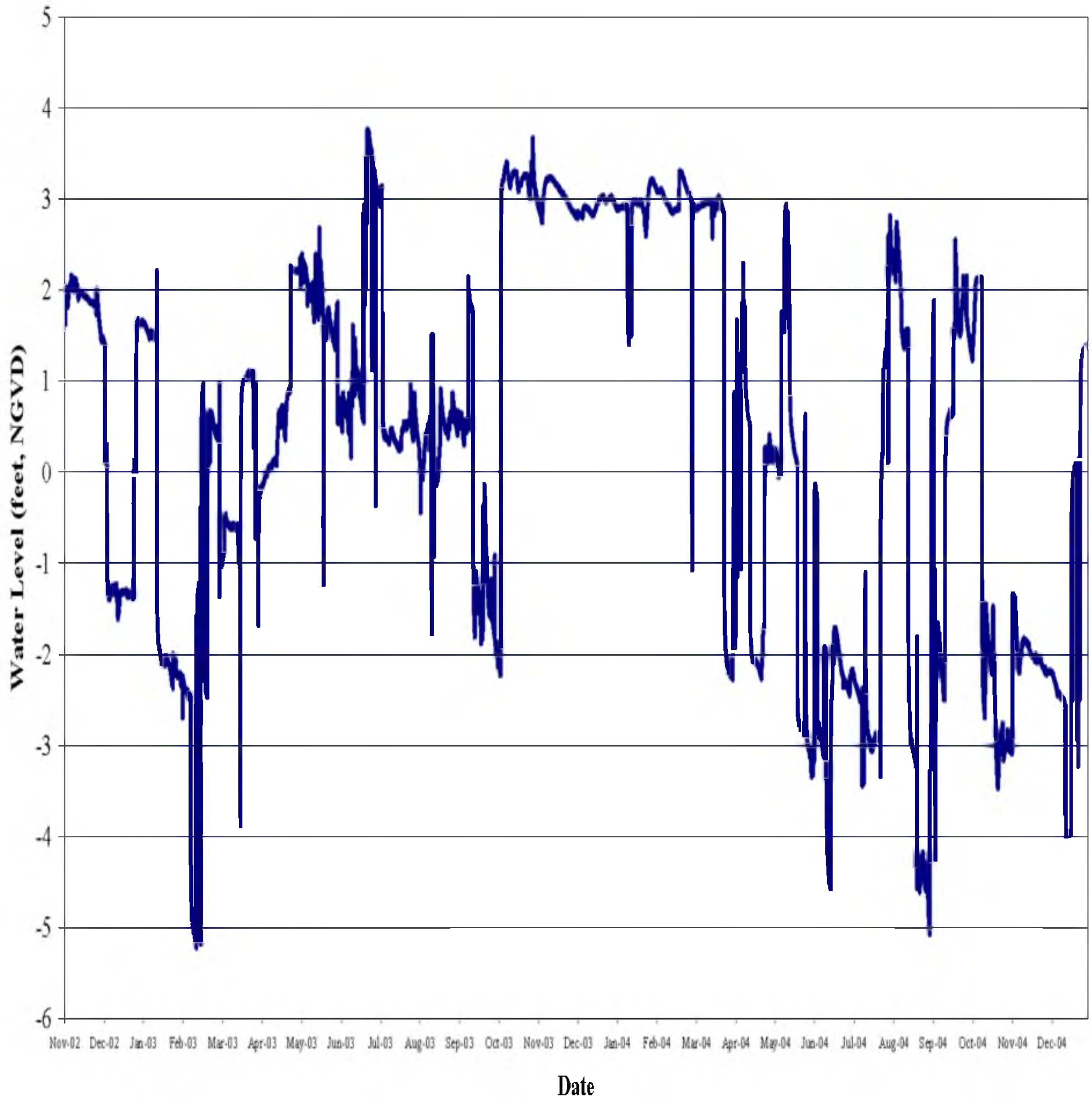
Depth (feet)	Lithology
0-5	Light gray quartz sand, fine to medium rounded grains, poorly sorted.
5-10	Light brown quartz sand, fine to medium rounded grains, poorly sorted.
10-15	White to tan limestone (packstone), dense, low permeability.
15-20	White to tan limestone (packstone), vuggy and moldic porosity, moderate permeability, bivalve shells.
20-25	White to tan limestone (packstone), dense, low permeability, ~20% white quartz and carbonate sand, fine to medium rounded grains, poorly sorted.

C: Hydrographs for the Groundwater Monitor Wells

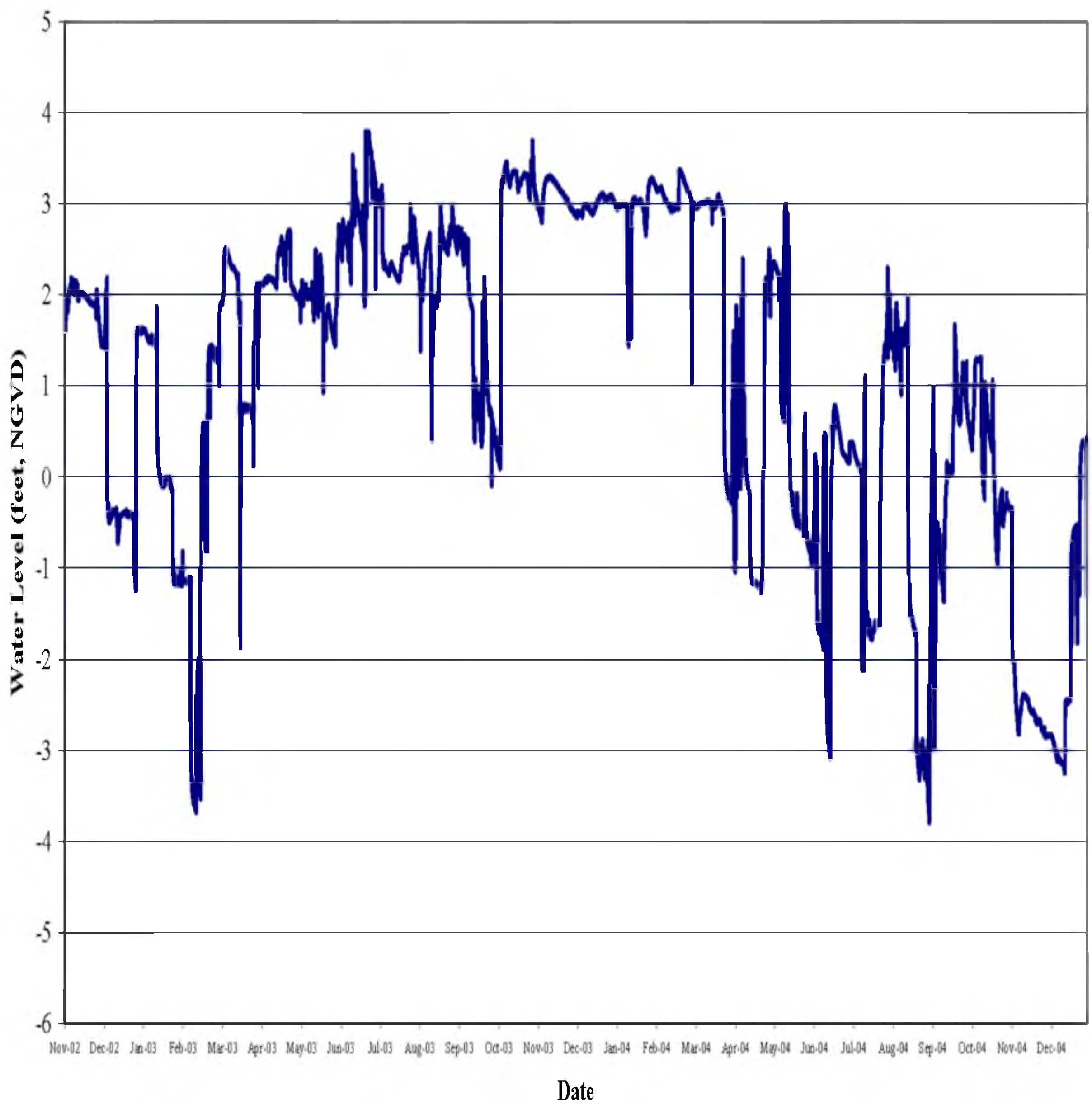
Hydrograph for C2GSW1_GW1



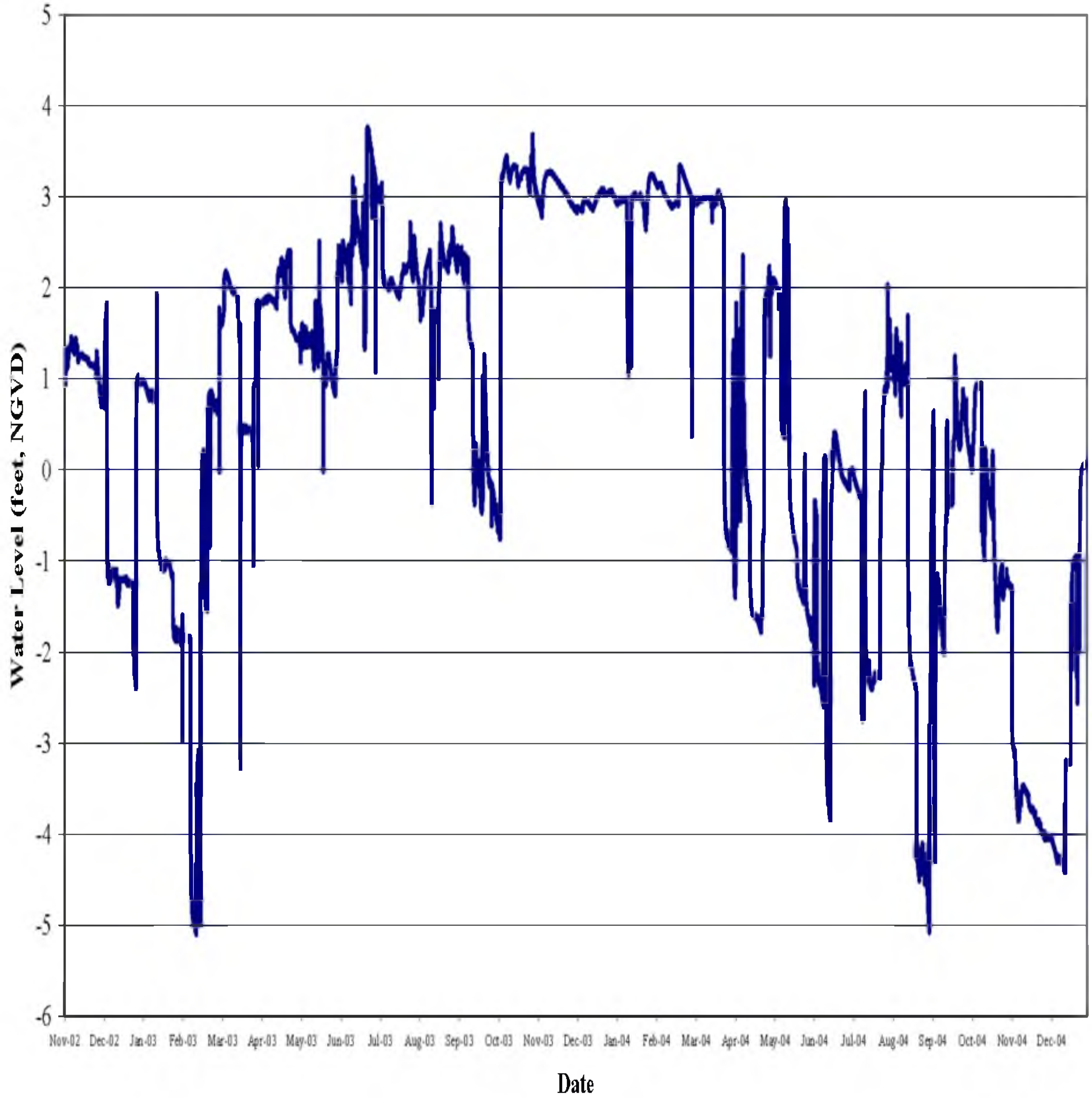
Hydrograph for C2GSW1_GW2

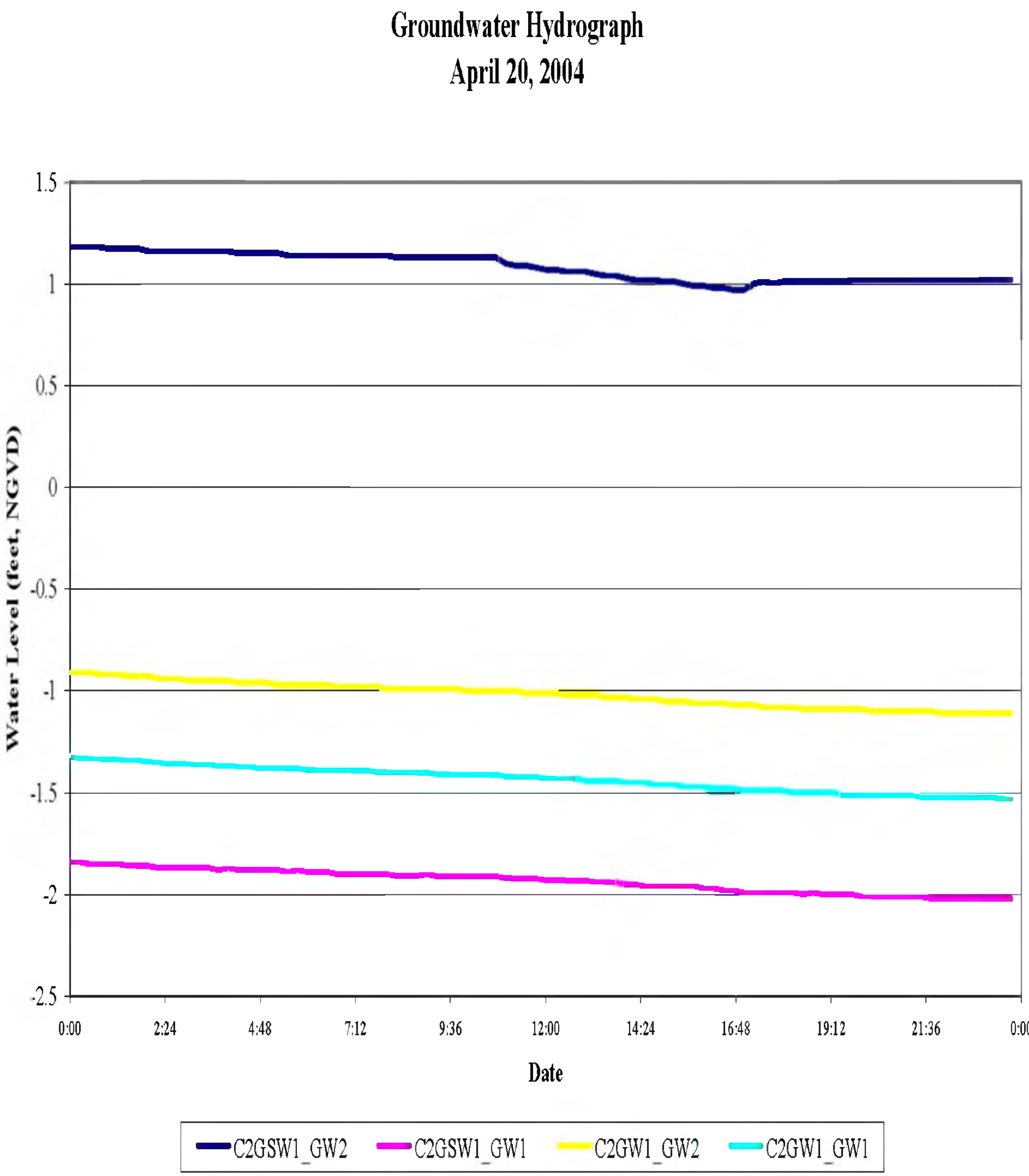


Hydrograph for C2GW1_GW1



Hydrograph for C2GW1_GW2




Groundwater Hydrograph
April 20, 2004
Water Level (feet, NGVD)
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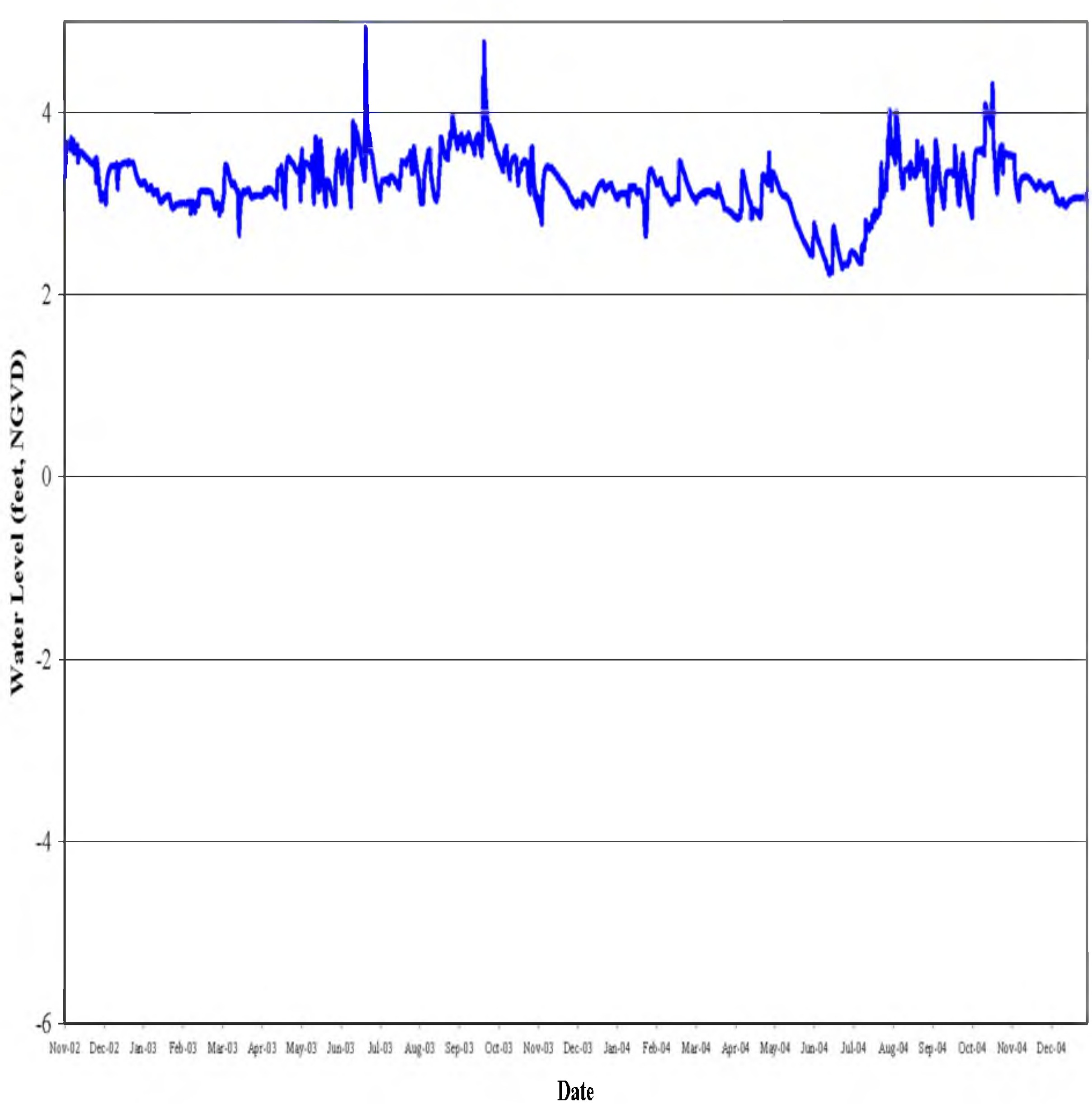
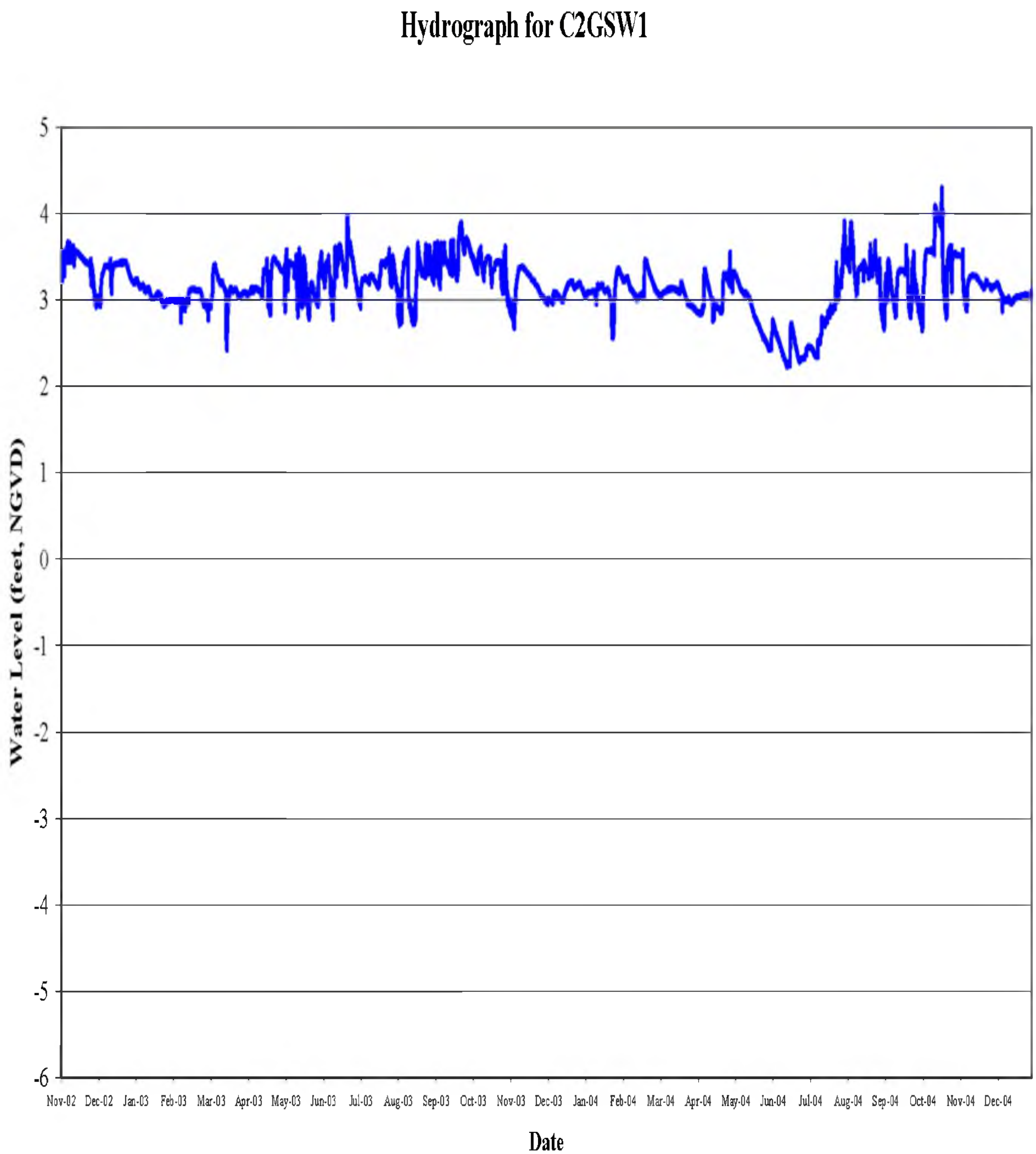
0.5
0
-0.5
-1
-1.5
-2
-2.5
0:00
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
0:00
Date
C2GSW1_GW2
C2GSW1_GW1
C2GW1_GW2
C2GW1_GW1

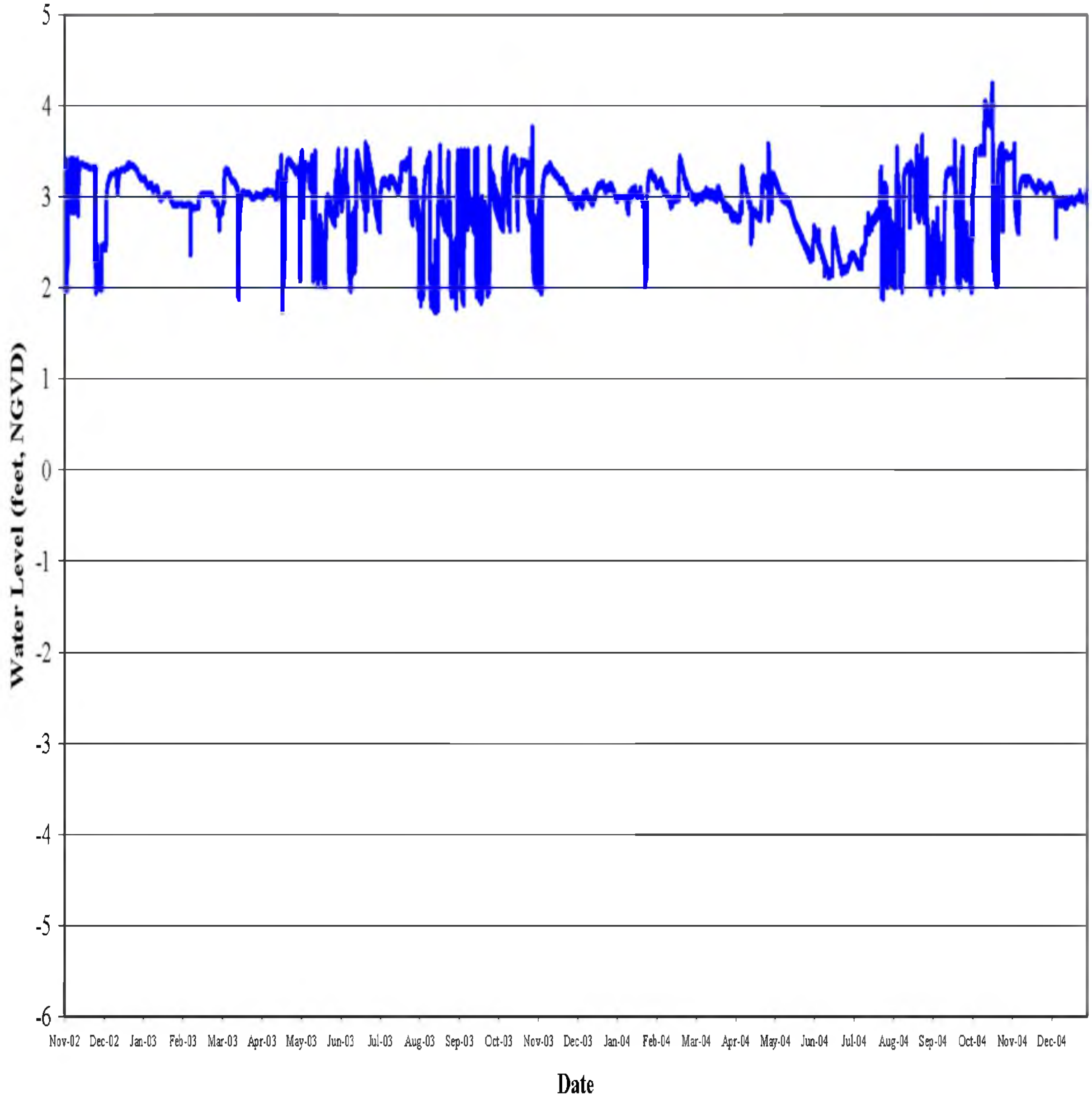
D: Hydrographs for Surface Water Monitoring Sites

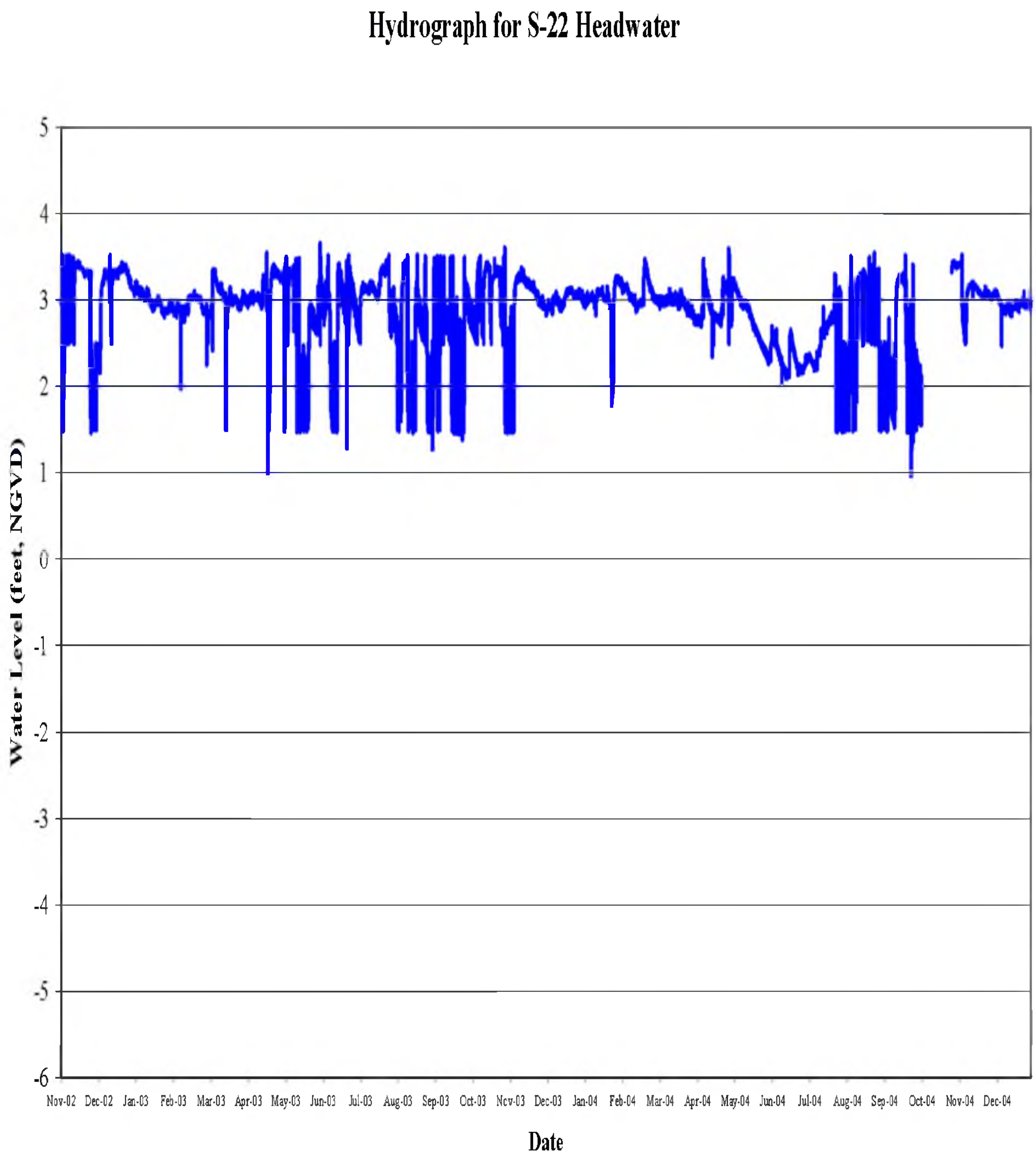
Hydrograph for C2SW1



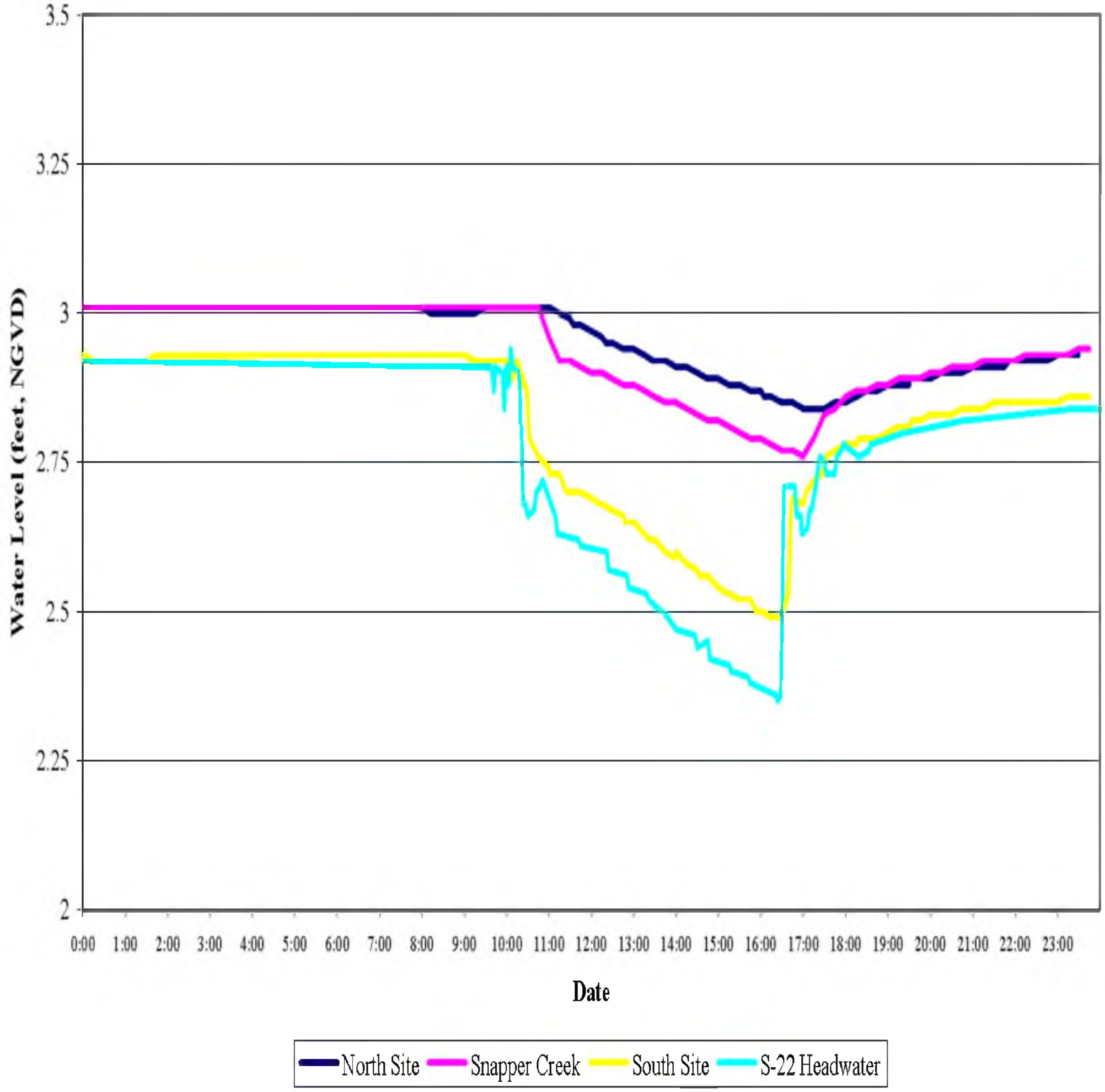

Hydrograph for C2GSW1
Water Level (feet, NGVD)
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
Nov-02 Dec-02 Jan-03 Feb-03 Mar-03 Apr-03 May-03 Jun-03 Jul-03 Aug-03 Sep-03 Oct-03 Nov-03 Dec-03 Jan-04 Feb-04 Mar-04 Apr-04 May-04 Jun-04 Jul-04 Aug-04 Sep-04 Oct-04 Nov-04 Dec-04
Date

Hydrograph for C2SW2




Hydrograph for S-22 Headwater
Water Level (feet, NGVD)
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
Nov-02
Dec-02
Jan-03
Feb-03
Mar-03
Apr-03
May-03
Jun-03
Jul-03
Aug-03
Sep-03
Oct-03
Nov-03
Dec-03
Jan-04
Feb-04
Mar-04
Apr-04
May-04
Jun-04
Jul-04
Aug-04
Sep-04
Oct-04
Nov-04
Dec-04
Date

Surface Water Hydrograph
April 20, 2004



E: Stream Gauging Summary Report

Prepared by: John Goodson Reviewed by: Juan Gonzalez, Jeff Bogin

Streamgauging at the C-2 Canal to Investigate the Influence of Groundwater Well Pumping on the SW/GW Interaction

Background

In August 2001, Hydrologic System Modeling (HSM) requested assistance from the Hydrogeology Section to quantify seepage in and out of a segment of the C-2 canal near the Snapper Creek, Alexander Orr, and Southwest Well Fields in Dade County. Hydrogeology proposed to accomplish this work, using the following field techniques: drilling and monitoring new wells, measuring canal stage with time, coordinating pumping rates at the nearby well-fields, and measuring flow. Flow measurements were to be accomplished in coordination with the streamgauging group from Operation and Hydrologic Monitoring (OHDM).

Introduction

The original concept called for Acoustic Doppler Current Profiler (ADCP) streamgauging in the C-2 Canal at 4 locations, while the surrounding well fields are pumping at sustained, stable, low, medium, and high rates. Coordination issues with the Miami-Dade Water and Sewer Authority resulted in the delay of this project for years. The streamgauging data was to be used for estimating the difference in discharge between two different cross-sections measured simultaneously under steady-state conditions. For reaches without tributaries, the discharge difference can be attributed to surface water going into the groundwater and measurement errors. ADCP measurement errors are many and difficult to quantify, but include random errors, and bias. Random errors can be reduced by averaging a number of measurements. Bias is difficult to assess and includes both instrument bias and bias introduced by the operator and caused by such things as using the incorrect transducer depth, incorrect edge estimates, Incorrect edge shape, poor cross-section choice, poor measurement techniques, and other factors. Operator induced biases are reduced as much as possible by carefully following accepted measuring techniques and guidelines.

In reality, a truly steady state condition is difficult to achieve. Canal storage, changing stages, and the limited ability to maintain a steady flow rate at the tidally influenced S-22 Spillway located downstream of the canal reach of interest, all affect the ability to maintain a steady state condition. The Miami-Dade Water and Sewer Authority have not been cooperative in promoting the required constant flow rates for this project.

ADCPs are not able to measure the entire cross-section. The flow through a top layer to a depth of approximately 12 to 14 inches from the free surface, the bottom 6% of the cross-section, and the shallow edges cannot be measured with an ADCP and must be estimated. The accuracy of that estimation depends both on measurement procedures and how well developed flow is in the cross-section. Flow lines in well developed profiles are parallel and the cross-sectional velocity distribution is approximately constant within a canal reach. The more deviation from these conditions, the less reliable the estimated portions will be. Accurate edge distance estimation and the correct estimation method for the unmeasured portions are vital to achieve an accurate final discharge.

Transect Location

After further evaluation, the original plan was modified to include 6 cross-sections where streamgauging would be performed. The State Plane Coordinates of the cross-sections are as follows:

Section	x	y
CS-1	859757.04	500755.9
CS-2	865548.98	497509.35
CS-3	866224.31	497122.9
CS-4	867143.9	496621.49
CS-5	867515.62	496397.84
CS-6	885726.11	494218.46

The cross-sections and general layout of the canal system can be seen in Figure 1 below.

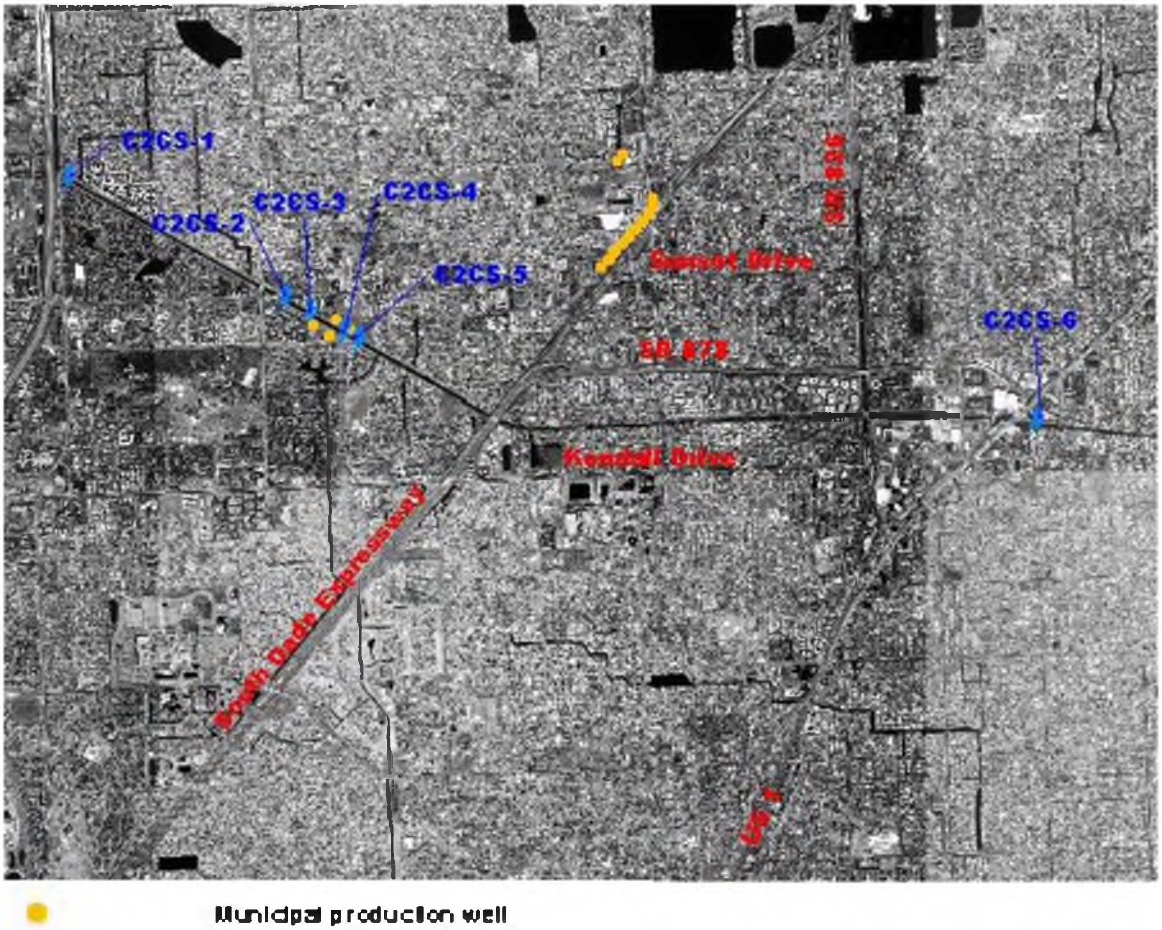


Figure 1 Aerial View of the Study Area

Measurements

Streamgauging February 11, 2004 –

The first attempt at streamgauging was done with two crews. John Goodson made the ADCP measurements at cross-section 1, 2, and 3. Orlin Kellman made the ADCP measurements at cross-sections 4, 5, and 6. Both crews used 600 kHz Rio Grand ADCP's and the best configuration possible for each site. There were many negative conditions present on this day. After 1-1/2 years of negotiation with the Miami-Dade Water and Sewer Authority to hold the pumping rate constant for the duration of this work, they shut down a key well field just before the streamgauging was done. Wind and flow conditions were not desirable as the flows were small and the wind was in general blowing 10 to 20 mph against the predominant flow direction. It was consistently difficult or impossible to keep the ADCP speed less than the water speed. Because the wind was blowing against the flow direction, negative flow (to the west) was observed in the top water layer. In some cases there was bidirectional flow on opposite sides of the canal. There was no "base flow" in the canal and the wind driven circulation in the canal made measurements difficult. Estimation methods became questionable under these conditions. Results were very questionable and we asked for a minimum base flow of 50 to 100 cfs for a future measurement. Bidirectional flow can be seen in the Velocity Direction Contour plot in Figure 2

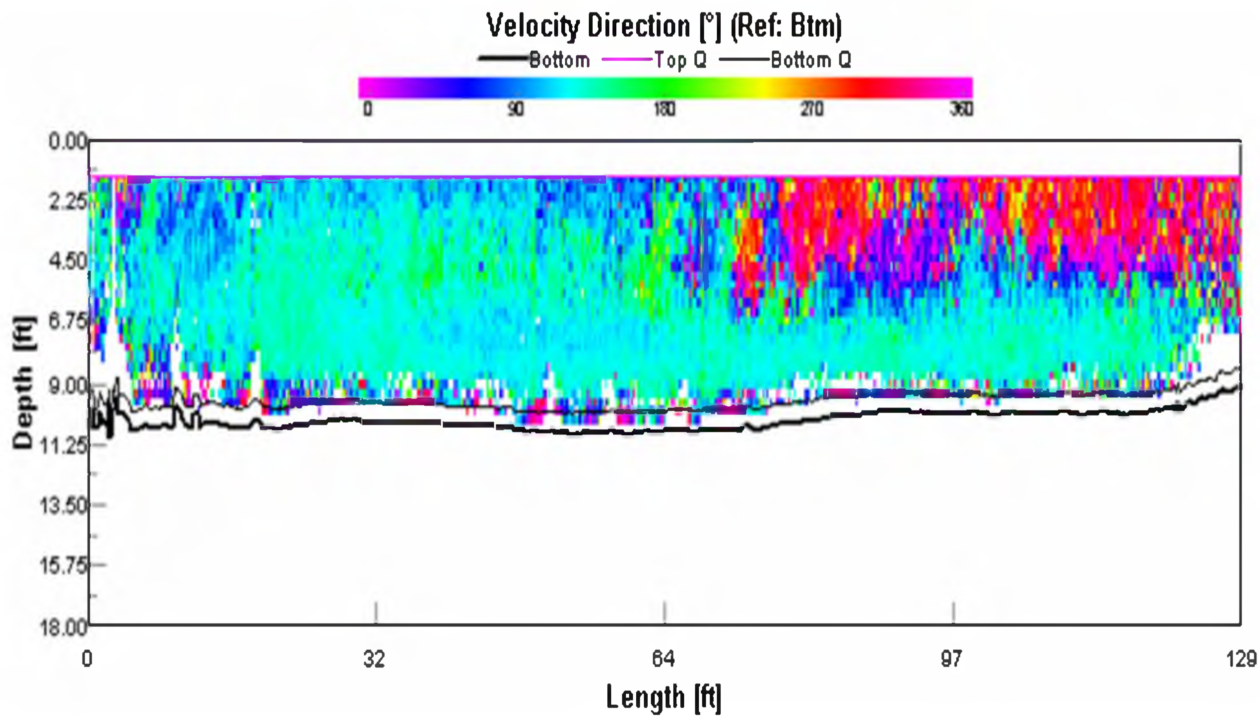


Figure 2 Velocity Direction Contour Plot

Streamgauging May 20, 2004 –

Four similarly equipped crews met at the centrally located boat ramp at about 9:30am. The six cross-sections are shown in Plate 1. Each crew used a 600 kHz Rio Grand ADCP and the best configuration possible for each site.

The teams were:

Team 1: Rodrigo Musalem and Simon Sunderland measured at CS-1. This is the narrowest and furthest west site. Simon used cotton gloves and pulled the tag-line by hand.

Team 2: John Goodson and Denise Cadmus alternated between CS-3 and CS-2. They used a tag-line puller.

Team 3: Orlin Kellman and Sashi Nair alternated between CS-4 and CS-5. They used a tag-line puller.

Team 4: Jeff Bogin and Mario Mayes measured continuously at CS-6. They used a tag-line puller.

Team 1 and Team 4 made continuous measurements throughout the day. Each set of transect measurements began with a 5-minute stationary vertical profile in the center of the canal. Team 2 alternated between CS-3 and CS-2, while Team 3 alternated between CS-4 and CS-5. Team 2 and 3 operations were closely synched in time. Team 2 and 3 communicated with each other by Walkie-talkie and cell phone and then communicated with Teams 1 and 4 by cell phone.

For these measurements, a 2.6' opening of Gate 2 at the S-22 Spillway was secured for the duration of these measurements. This opening is the minimum setting allowed because of regulations designed to protect Manatees. Gate 1 was closed. The headwater stage of the spillway was falling slowly and the tidal tailwater stage was falling quickly during these measurements. Stages, gate operation, and breakpoint flows can be seen in Figure 3. The flows were steadily increasing during this period because of the increasing head across the spillway. Structure flows varied from approximately 391 cfs to 500cfs while transects were being made.

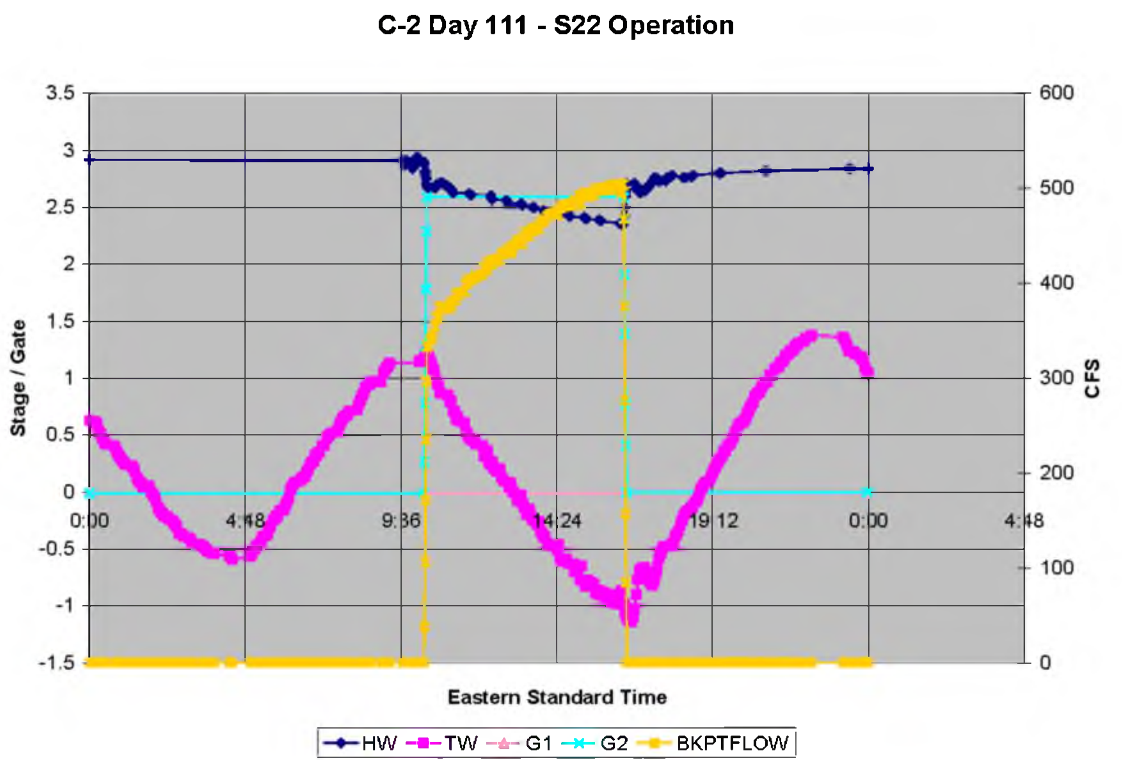


Figure 3 S22 Operation – May 20, 2004

Other less than desirable conditions were present. The canal and positive flow direction is roughly in a Southeast direction which is exactly in the opposite direction of the Southeast Tradewinds. Again, we had 15 to 20 miles per hour winds blowing from the Southeast that were of sufficient strength to cause a bendback of the velocity profile near the surface and introduced a subjective aspect to the estimation of the unmeasured surface portion. Discharge measurements were examined in post processing and it was decided that the 3-point method for estimating the top was the most desirable because of the bend back seen in the “Discharge Profile” screen available in WinRiver, the software used to process the ADCP data.

Over the length of the reach where the measurements were performed, were numerous tributaries that may possibly have contributed to or subtracted from the flow in the main canal. The stage in the C-2 canal was falling slowly but steadily throughout the streamgauging. Stages in the canal reach can be seen in Figure 4.

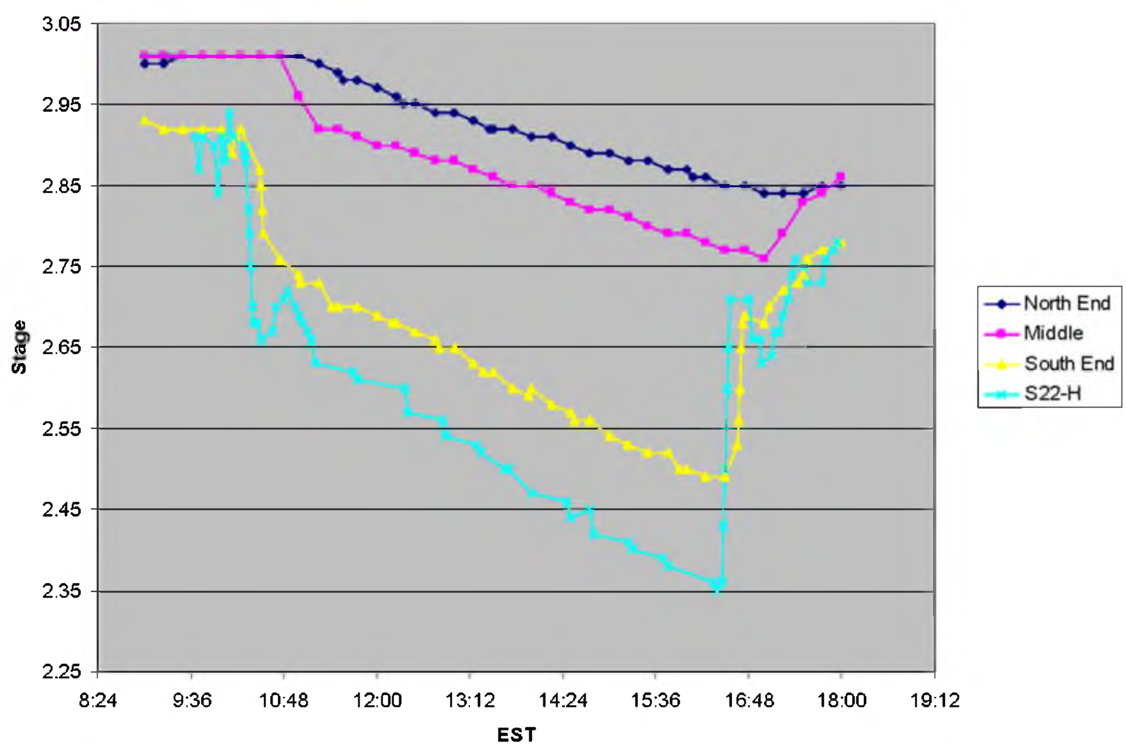


Figure 4 C-2 Stages

In general all groups of transects had a coefficient of variation of 0.05 or less. A summary of the streamgauging can be seen in Figure 5 and Table 1. Ninety-five percent error bars were placed around the best fit lines for CS-1 and CS-6 in Figure 5.

The well pumping logs are not available for this report, but it was observed that some pumping ceased in the course of the day’s streamgauging. In order to conclude that there is some groundwater / surface water interaction as a function of pumping, one needs only to note the changes between the cross-sections measured simultaneously at CS-2 and CS-5 and at the cross-sections CS-3 and CS-4, all while the differential discharge measured at the two extreme cross-sections CS-1 and CS-6.

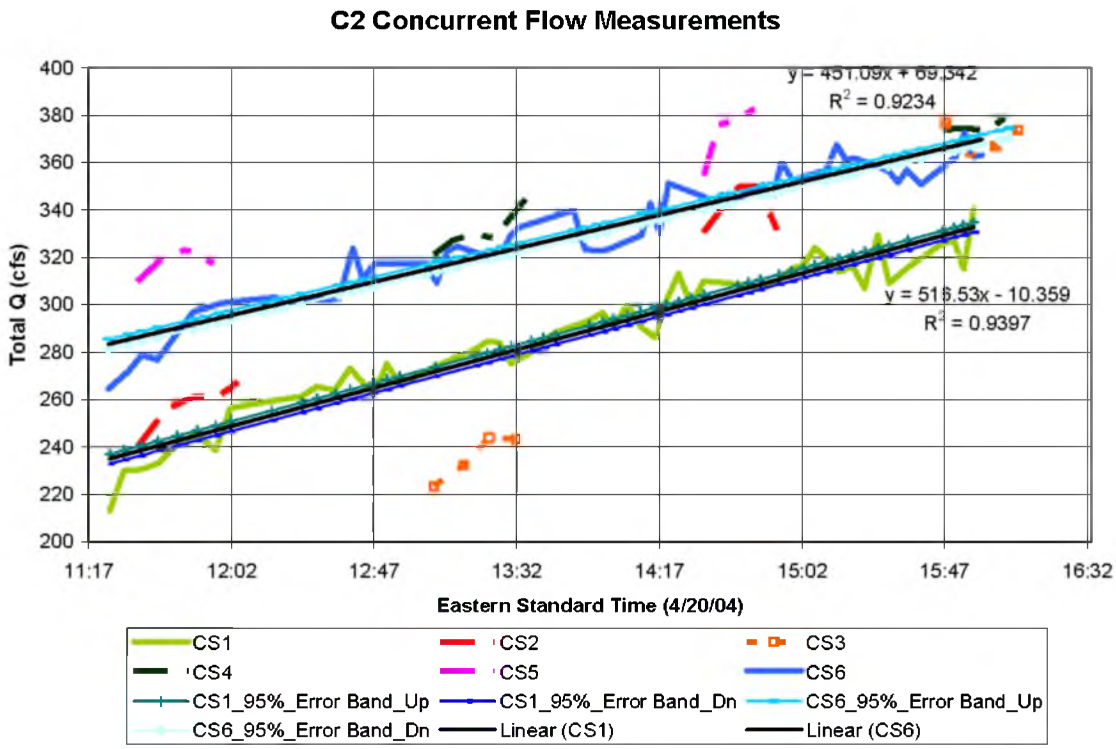
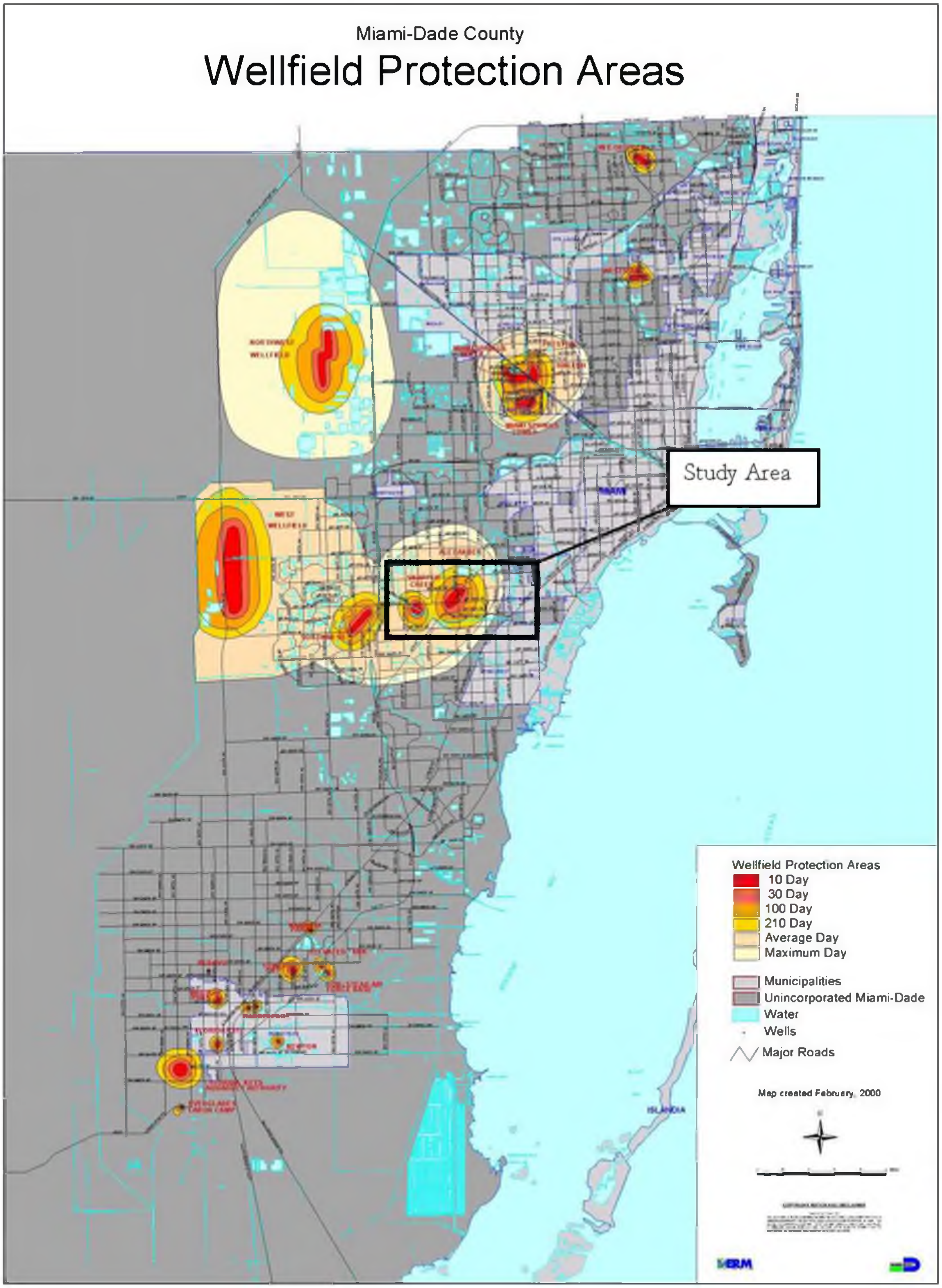


Figure 5 Concurrent Flow Measurement Plot – May 20, 2004

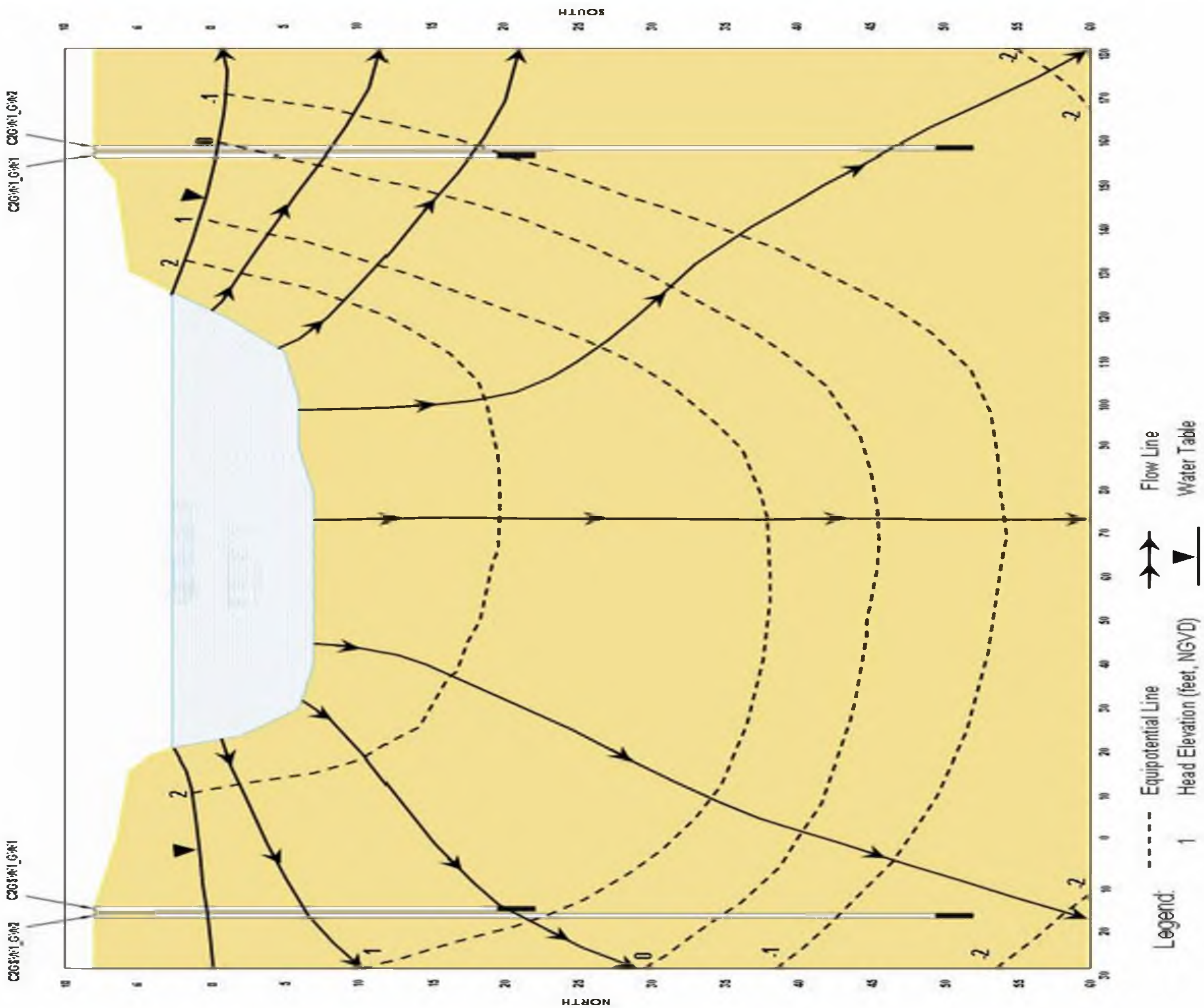
CS1		CS2		CS3		CS4		CS5		CS6	
Time	Q	Time	Q	Time	Q	Time	Q	Time	Q	Time	Q
11:24:07	213.141									11:23:39	264.617
11:28:32	230.056									11:29:59	272.14
11:33:48	230.563	11:32:44	240.043					11:32:47	310.021	11:34:06	278.659
11:39:15	233.141	11:41:58	256.035					11:41:08	320.303	11:39:03	276.941
11:45:23	240.928	11:50:59	261.4					11:48:02	323.241	11:50:28	297.07
11:51:35	245.555	11:57:46	260.943					11:56:32	317.428	11:54:10	298.494
11:57:32	238.543	12:04:29	267.394							11:58:24	300.4
12:02:07	256.488									12:01:37	301.165
12:15:03	259.373									12:12:53	302.714
12:24:36	261.352									12:16:24	303.158
12:29:19	265.444									12:19:31	299.253
12:35:05	264.043									12:24:18	302.246
12:39:52	273.222									12:36:16	302.571
12:47:18	262.102									12:40:44	323.857
12:51:29	275.093									12:43:51	310.839
12:55:25	266.287									12:47:15	317.081
13:06:40	273.892			13:06:23	223.577	13:06:26	321.345			13:03:50	317.455
13:19:25	281.27			13:15:42	232.386	13:12:25	327.396			13:07:10	309.355
13:23:04	284.592			13:23:47	244.03	13:19:25	329.738			13:10:29	322.678
13:26:57	284.177			13:32:24	243.412	13:25:13	328.212			13:13:35	324.706
13:30:41	275.233					13:35:06	344.397			13:24:39	319.907
13:37:02	280.098									13:27:35	321.28
13:40:52	284.752									13:30:24	329.378
13:44:38	288.312									13:33:23	332.891
13:55:15	293.37									13:50:21	339.925
13:59:33	296.688									13:53:55	323.516
14:02:59	290.724									13:57:44	322.857
14:07:15	300.011									14:00:54	323.233
14:11:28	290.835									14:11:49	329.449
14:15:57	286.424									14:14:31	342.972
14:19:30	301.549									14:17:29	330.374
14:23:26	313.212									14:20:15	351.224
14:27:22	300.025									14:31:27	345.686
14:31:26	309.993	14:31:26	330.742					14:31:27	354.701	14:34:10	341.562
14:42:08	308.841	14:42:34	349.993					14:36:03	375.931	14:37:15	346.515
14:45:34	307.792	14:48:23	350.177					14:42:13	378.101	14:40:08	343.5
14:49:08	306.694	14:54:26	331.79					14:47:55	383.293	14:50:03	350.609
14:55:15	310.606									14:53:13	346.036
14:59:10	315.33									14:55:56	360.373
15:02:46	316.662									14:59:27	352.583
15:06:24	324.062									15:10:05	356.892
15:10:24	319.239									15:13:20	367.458
15:14:00	313.91									15:16:11	361.435
15:18:23	316.127									15:19:08	361.843
15:22:11	307.014									15:29:33	356.609
15:26:19	329.698									15:32:38	351.71
15:29:51	309.141									15:35:29	356.874
15:35:39	315.673									15:39:54	350.808
15:46:39	325.913			15:47:44	376.384	15:47:38	374.001			15:50:43	362.237
15:50:20	327.223			15:55:24	364.422	15:53:20	374.594			15:53:37	372.625
15:53:25	315.159			16:03:25	366.78	16:01:04	373.502			15:56:25	362.605
15:56:35	340.618			16:10:30	373.734	16:10:48	383.654			15:59:07	363.276
										16:04:49	368.557
										16:07:36	375.643

Table 1 Streamgauging Data Summary – May 20, 2004

F: Miami-Dade County Wellfield Map


Miami-Dade County
Wellfield Protection Areas
Study Area
Wellfield Protection Areas
10 Day
30 Day
100 Day
210 Day
Average Day
Maximum Day
Municipalities
Unincorporated Miami-Dade
Water
Wells
Major Roads
Map created February, 2000

G: Cross-section through the C-2 Canal Showing Water Flow


SOUTH
NORTH
Legend:
Equipotential Line
Head Elevation (feet, NGVD)
Flow Line
Water Table