Appendix 2-4: Hydrological Monitoring Network of the South Florida Water Management District

(DRAFT)

Edited by Chandra S. Pathak

Hydrologic Monitoring Network of the South Florida Water Management District

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Operations and Hydro Data Management Division

SCADA and Hydro Data Management Department
South Florida Water Management District

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EXECUTIVE SUMMARY

Acquisition of hydrologic and hydraulic data is a critical and key component of the South Florida Water Management District's (SFWMD or the District) mission. The District is responsible for the collection, validation, and archival of hydrologic data for real-time water management as well as for data analysis that results in historical hydrologic records that are used to evaluate and assess the status of the water resources systems. Data collection is accomplished via the District's hydrologic monitoring network, which has evolved over the years but were not specifically designed or optimized. This report provides status and inventory of the network as of December 31, 2005, and includes progress on the District's network optimization or design studies that began in 2002.

The hydrologic monitoring network is divided into five parts: rainfall, meteorological, surface water stage, surface water flow, and groundwater. The network is spatially distributed over the geographic areas of the District with sensors that record data specifically based on a time variant, i.e., rainfall, meteorological, stage, flow, and groundwater data. Description of each network presents the history and evolution of the network; information on sensors/instrument(s) used; number and location of instruments; frequency of data collection; time interval of the available data; and optimization or design.

The District actively operates and maintains an extensive network of 279 rain gauges to obtain rainfall data. Since 2002, the District has been acquiring radar rainfall NEXRAD data coverage. The District has a meteorological monitoring network that includes 41 active weather stations. The meteorological data such as air temperature, barometric pressure, humidity, solar radiation, wind speed, and water temperature are collected and are available on breakpoint and daily time intervals. In addition, daily potential evapotranspiration (PET) data are available for 18 weather stations. The PET data were estimated using the Simple Method.

A network of 1,195 active surface water stage gauges provides the surface water stage data for various water bodies. Additionally, the District owns a network of 425 active surface water flow monitoring sites that provide instantaneous and mean daily flow data in 15-minute intervals. The groundwater monitoring network contains a total of 975 active groundwater wells that were monitored on 15-minute continuous, monthly, or greater than 1-month interval basis. The District is responsible for monitoring, maintenance, quality assurance/quality control (QA/QC), data archival, and funding for 613 of these wells. The U.S. Geological Survey is responsible for the remaining 362 wells.

Hydrologic data management includes processing the data collected, summarizing, deriving and analyzing, storing, and publishing. Processed data are archived into two different databases, namely, Data Collection/Validation Pre-Processing (DCVP) and DBHYDRO. Instantaneous (breakpoint) data are stored into the DCVP database, while daily summary and 15-minute interval data are published in the DBHYDRO database. End users can retrieve data from either of these two databases.

I. INTRODUCTION

By Chandra Pathak

A. Background

The South Florida Water Management District (SFWMD or the District) is responsible for managing and protecting water resources in a 46,439-square kilometer (17,930-square mile) region of South Florida. This area extends from Orlando in the north to Key West in the south and from the Gulf Coast in the west to the Atlantic Ocean in the east and includes Lake Okeechobee, the country's second largest freshwater lake. This region is also the focus of an $8 billion environmental restoration program, known as the Comprehensive Everglades Restoration Plan (CERP). The District operates approximately 3,000 kilometers (1,800 miles) of canals and more than 500 water control structures across 16 counties to serve a population of over six million people.

Water flows from the northern part of the District south from the Upper Chain of Lakes near Orlando, along the Kissimmee River, through Lake Okeechobee, and finally to canals that release surface water to estuaries along the east and west coasts. Lake Okeechobee is at the center of this system and is the primary source of supplemental water supply for the Everglades Agricultural Area (EAA) to the south, the Caloosahatchee Basin to the west, the St. Lucie Basin to the east, and several other basins around the lake (**Figure 1**).

Lake Okeechobee receives the majority of its inflow from large tributary basins to the north, including the Kissimmee River and Fisheating Creek. The tributary basin area is more than five times the surface area of the lake. During normal climatic conditions, inflow volumes offset the large water needs to the south of the lake. However, when the climate remains abnormally dry for an extended period (for one or two seasons), inflows may diminish to very low levels, during the same period such that demands on the lake will peak. Consequently, lake stages may fall very quickly to extremely low levels. Conversely, when climatic conditions are wetter than normal, large volumes of water enter the lake, coinciding with periods when water use to the south will be minimal. These events cause lake stages to rise very quickly and require large volumes of water to be discharged to the Water Conservation Areas (WCAs) or to tide through the St. Lucie and Caloosahatchee estuaries. Abrupt changes in flow or very large releases through the estuaries are harmful to these ecosystems.

The WCAs are the primary source of supplemental water for the highly developed urban areas along the southeast coast of Florida, with the lake being the alternate source. The WCAs were built as large water storage impoundments in the Everglades to provide both water supply and flood protection for the urban areas. In addition to the agricultural and municipal water consumptive needs, water releases from the lake are required to meet the needs of the Everglades and the numerous coastal ecosystems. The WCAs and the Everglades National Park (ENP) are known today as the remnant Everglades. Water held in and released from the WCAs effectively recharges the Biscayne aquifer in some areas.

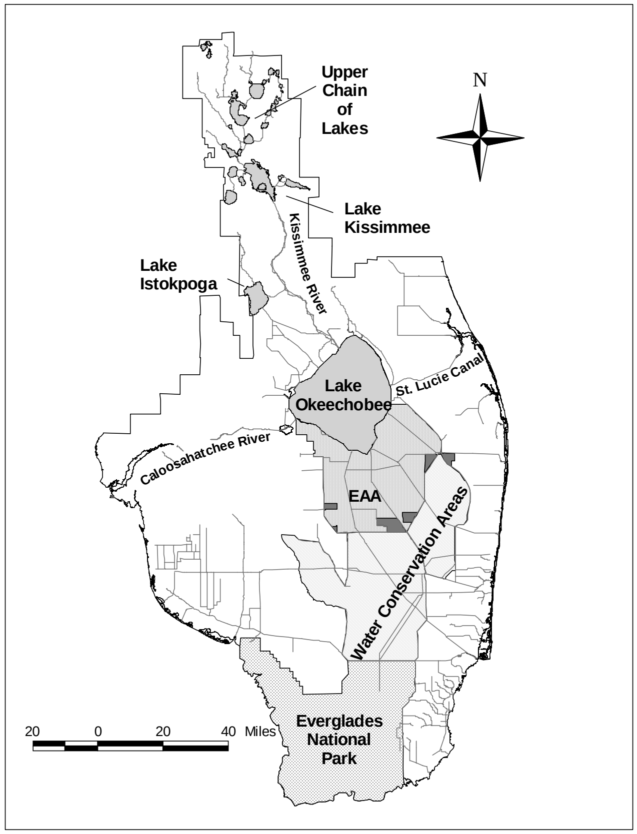

Figure 1. Map of the water resources area the District is responsible for managing and protecting.

The Florida Everglades – one of the world's largest freshwater wetlands – has changed dramatically over the past century. Historically, hundreds of lakes once flowed into the Kissimmee River, which runs south through 16,187 hectares (40,000 acres) of marsh to Lake Okeechobee. The lake in turn flowed into the Everglades, which extended over 1.2 million hectares (3 million acres) from the south shore of Lake Okeechobee to the Florida Bay and the Gulf of Mexico. The Everglades consisted of a continuous, shallow river flowing through grass-like plants, bordering expanses of cypress swamp, mangrove forest, and tropical hardwood hammocks on aquatic deep-water sloughs that extended nearly 80 kilometers (50 miles) wide and more than 160 kilometers (100 miles) long. These marshes and swamps acted as natural filters that recharged underground aquifers in the South Florida region.

B. Hydrologic Monitoring Network

In order to effectively and efficiently manage the water resources system, acquisition of hydrologic and hydraulic data is a critical and key component. The District is responsible for the collection, validation, and archival of the hydrologic data from the water resources area. Data are collected via the hydrologic monitoring network of the District. The types of data include rainfall, evaporation, evapotranspiration, water levels (stage), water control structure (gate and pump) operations, flow, etc. The District requires accurate data collection, processing and archival of these data for many purposes. There is a constant need for adding new stations/sites with instrumentation for hydrologic data collection within the District, and this need will be growing at a faster pace as the Acceler8 and CERP projects are implemented.

All of the monitoring networks at the District have evolved over the last several decades. Until 2002, these networks were not designed and/or optimized. During the last three to four years, the District began studies on the optimization and design of these networks. The optimization and/or design of the network involve consideration of the following elements:

- Purpose or objective of monitoring
- Total optimal number of monitoring stations (or points) needed
- Locations of the monitoring stations (spatial distribution)
- Sensor(s) needed for the monitoring station
- Frequency of data sampling needed at the monitoring station (temporal distribution)

C. Objective and Scope

This report provides a status of the hydrologic monitoring network as of December 31, 2005, at the District. The information presented herein is a prerequisite to expanding and refining the District's hydrologic network to meet the needs of CERP and non-CERP projects. The objective of this report is to describe the hydrologic monitoring network of the District. The hydrologic monitoring network is divided into five parts:

1. Rainfall Monitoring Network
2. Meteorological Monitoring Network
3. Surface Water Stage Monitoring Network
4. Surface Water Flow Monitoring Network
5. Groundwater Monitoring Network

In this report, the network is considered the collection of the sensors that are spatially distributed and record time variant specific types of data, i.e., rainfall, meteorological, stage, flow, and groundwater data. The report includes for each network the history and evolution of the network; information on sensor(s)/instrument(s) used; number and location of instruments; frequency of data collection; time interval of the available data; optimization or design studies of the network completed and in progress; and relevant references used.

In addition, the report briefly describes data-related processes that are common to all the networks. These include data collection; data acquisition system; data processing, storage and retrieval; and data quality assurance and quality control.

D. Approach Used in the Report

The hydrologic monitoring network at the District is dynamic in nature and is constantly being expanded due to the needs of the District initiatives such as Acceler8 and CERP projects. Rainfall, meteorological monitoring networks are not expanding that often and relatively stable because of adequacy of these data. However, stage and flow networks are expanding at a faster pace as new Acceler8 and CERP projects that changes stage and flow data are implemented in the District. The groundwater monitoring network is also growing.

The approach used for this report includes compilation of a group of the stations and their respective "x" and "y" coordinates (based on Florida state plane coordinate system). These datasets were retrieved from DBHYDRO database using pl/sql scripts. This report uses active monitoring stations that are only archived in DBHYDRO. The stations were considered "active" if time series data were available before and after December 31, 2005. The station names and their respective locations were plotted on maps using ArcGIS software. The Microsoft Excel spreadsheets and ArcGIS data files are available in electronic format as the appendices of this report on a CD-ROM.

This report provides comprehensive information on the hydrologic monitoring network. The majority of information presented is available at a higher level of detail in various District documents that are referenced in this report. For additional level of details, readers are requested to review referenced documents.

II. HYDROLOGIC DATA MANAGEMENT

By John Raymond and Chandra Pathak

The District has an extensive data collection and monitoring network. The SCADA and Hydro Data Management (SHDM) Department is responsible for data collection and management (**Figure 2**). The Department is made up of two divisions: SCADA and Instrumentation Management (SIM), which is responsible for designing, installing, maintaining and repairing environmental data recording instrumentation; and Operations and Hydro Data Management (OHDM), which is responsible for producing, managing and maintaining the highest quality operational and hydro-meteorological data.

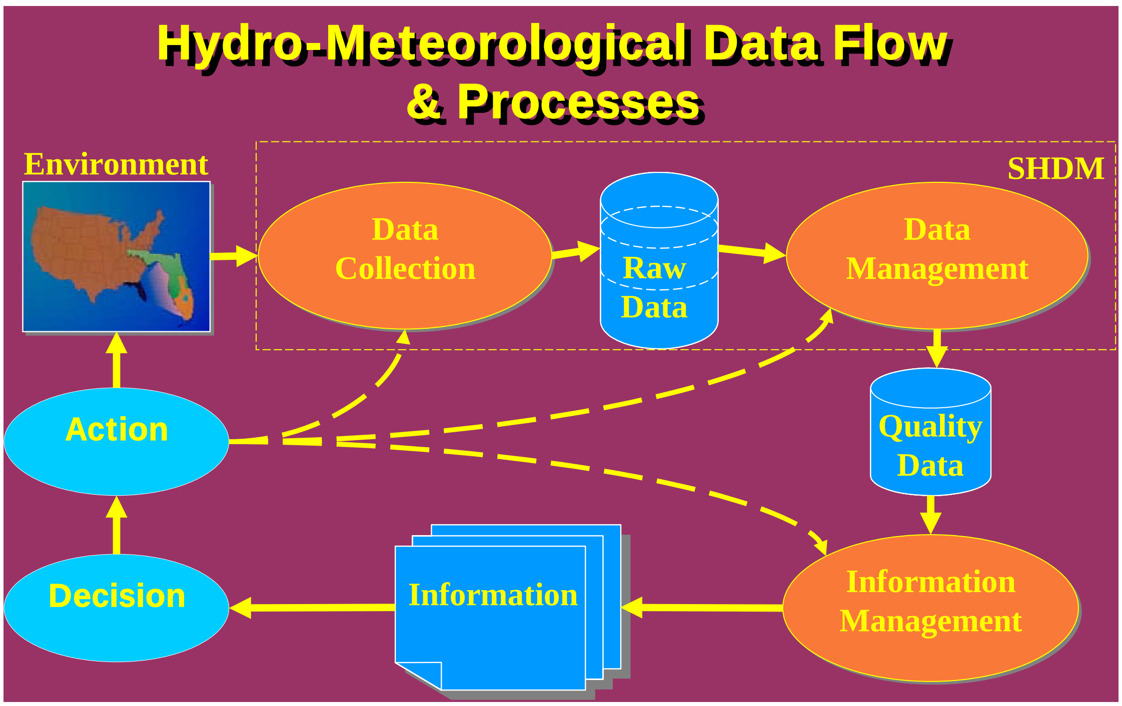

Figure 2. The hydro-meteorological data flow and process.

A. Data Collection

The data collection network supports the District's mission and goals by using acquired information on the state of water resources for multipurpose objectives. The District's critical mission includes: flood control, water supply, environmental deliveries and ecosystem restoration. The data collection network addresses (1) legal mandates, such as hydrologic documentation of the Central and South Florida (C&SF) Control Project Operations; (2) key resource issues, such as well field protection; and (3) general purpose and restoration needs, such as the Kissimmee River and the Everglades restoration efforts.

Construction, installation and maintenance of these data collection sites follow strict quality control practices and procedures to ensure that the best quality data will be collected. The accuracy of the entire data collection network depends upon the site selection; equipment selection and proper installation; data collection methodology; recorder and sensor maintenance; data processing and verification; data storage and database management; and quality control.

The District's hydrologic data collection and management program is focused on a controlled expansion of its data collection networks through modernization, consolidation, and enhancement of current monitoring practices. As a result of controlled expansion, the data acquisition networks are evaluated for redundancy and increased coverage areas to meet current needs.

Data collection involves three major processes: observation, recording and transfering, and loading of the raw data (**Figure 3**). The District collects data through telemetry or remote access technology, remote terminal units (RTUs), manual measurements, analog graphic recorders, and mechanical punch-tape recorders. The main data acquisition systems are SCADA (Supervisory Control And Data Acquisition), ARDAMS (Automatic Remote Data Acquisition and Monitoring System), and LoggerNet. The RTU devices include Motorola SCADA (MOSCAD), Remote Acquisition Control Unit (RACU), and Campbell Scientific, Inc. data logger (CR10).

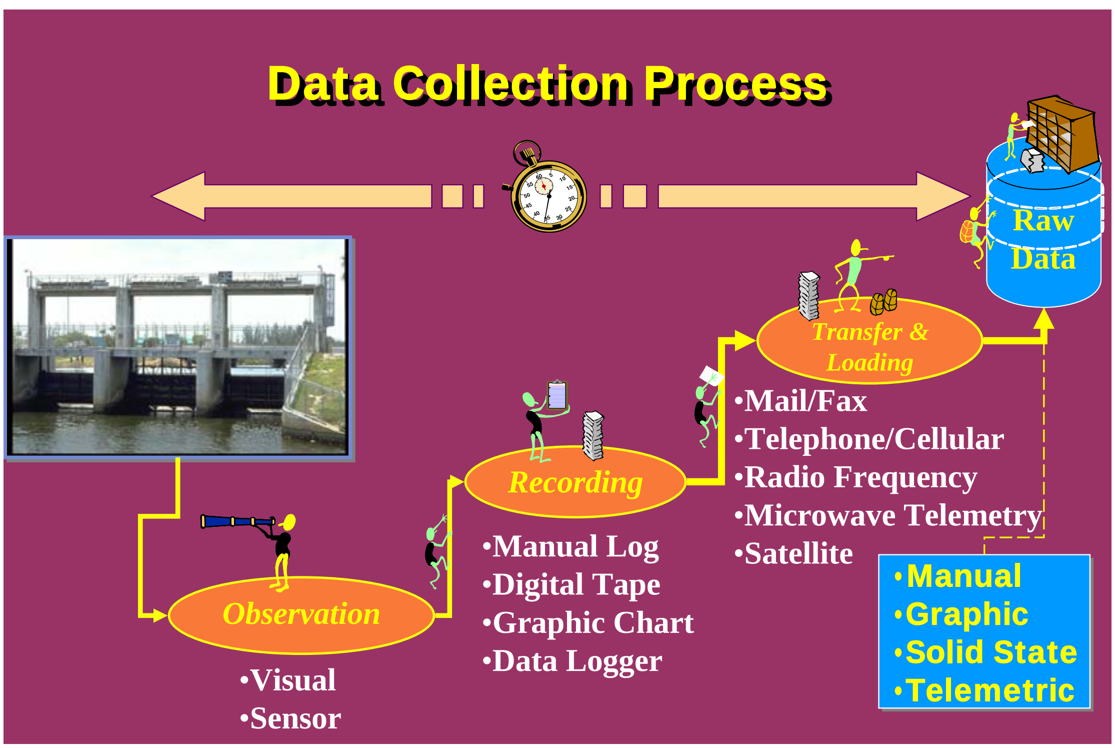

Figure 3. Data collection process.

The District's SCADA system transmits and receives information on water stages or levels, wind velocities, rainfall, water temperature, salinity levels, and other data. The system operates on a 24-hour basis and uses wireless communications to monitor and control water level, water control gate positions, and pumping activities. The SCADA system provides an early warning mechanism to anticipate flood problems by observing water level and rainfall trends. This computerized data collection system comprises the cornerstone of the District's data collection through a District-wide network of real-time and near-time data collection stations.

The District obtains manually observed readings of water level (stage), pump operations, gate openings, flashboard changes, rainfall, and evaporation data at various cooperative sites. The field observer records the daily observations onto a log sheet. The log sheets are collected from the sites at timed intervals and delivered to the District for data processing.

B. Data Management

Data management includes processing the data collected, summarizing, deriving, storing and publishing into the DBHYDRO database (**Figure 4**). During the processes of deriving and publishing, two major groups are required to support data processing: the engineering and hydraulics support, and the post-processing QA/QC support. The engineering and hydraulics group provides support in deriving, computing flow at water control structures or open channels, and evapotranspiration at weather stations; the post-processing QA/QC evaluates the processed data and assembles single time series for a subset of the database as baseline in modeling and as required by legal mandates.

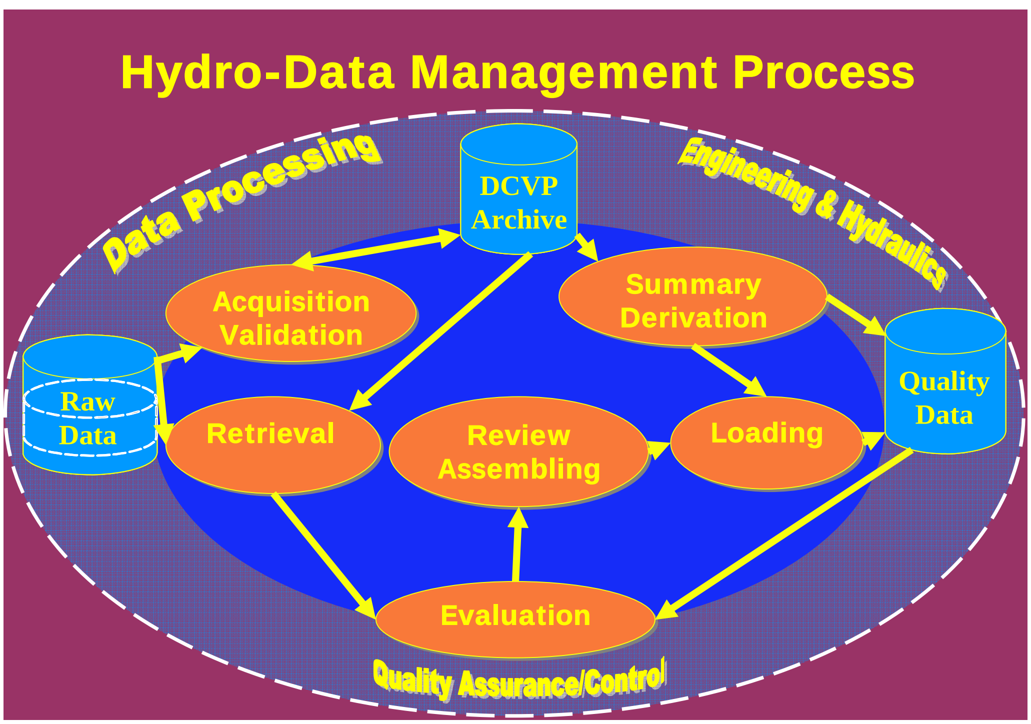

Figure 4. Hydro-data management process.

1. Data Processing

Data processing involves the review, interpretation, processing, analysis, and validation of hydrologic data in support of the environmental monitoring and assessment activities. Data processing includes a set of activities performed on raw time series data collected within the District's monitoring networks. The raw data are reviewed through various validation procedures and processes to assure the quality of the data values.

Several standard operating procedures were developed for data processing by the District (Bachand et al., 2002; Bachand et al., 2003; Bachand et al., 2003a; Bachand and Dawkins, 2004; Bazell et al., 2004; Burkhardt and Dawkins, 2003; Carltron and Dawkins, 2002; Carlton and Dawkins, 2003; Danz and Dawkins, 2002; Danz et al., 2004; Hanson and Dawkins, 2003; Smelt and Dawkins, 2002; and Smelt and Dawkins, 2002a). Many of these procedures and processes are automated. The Data Collection/Validation Preprocessing System (DCVP) database provides for the storage and extraction of preliminary time series data for further inspection. Once data is extracted from DCVP, it is subjected to an initial QA/QC check in order to ascertain or improve data quality. This is accomplished through the use of the Graphical Verification Analysis (GVA) Program, a software tool which provides analysts with a graphical user interface in which to plot, edit, and apply quality tags and comments to data. The GVA application is used for the validation of the data. Once data has undergone analysis in GVA, it is uploaded into the DBHYDRO database, finalizing the preprocessing stage (Bachand et al., 2002; Bachand et al., 2003; Bachand et al., 2003a; Bachand and Dawkins, 2004; Bazell et al., 2004; Burkhardt and Dawkins, 2003; Carltron and Dawkins, 2002; Carlton and Dawkins, 2003; Danz and Dawkins, 2002; Danz et al., 2004; Hanson and Dawkins, 2003; Smelt and Dawkins, 2002; Smelt and Dawkins, 2002a; Damisse et al., 2005; Sangoyomi et al., 2005a; Sangoyomi and Dawkins, 2005; Sangoyomi et al., 2005b; and Sangoyomi et al., 2006).

2. Data Storage

Processed data are archived into two different databases (**Figure 5**). Breakpoint data are stored in the DCVP Archive database, while daily summary and 15-minute data are published into the WREP or DBHYDRO database.

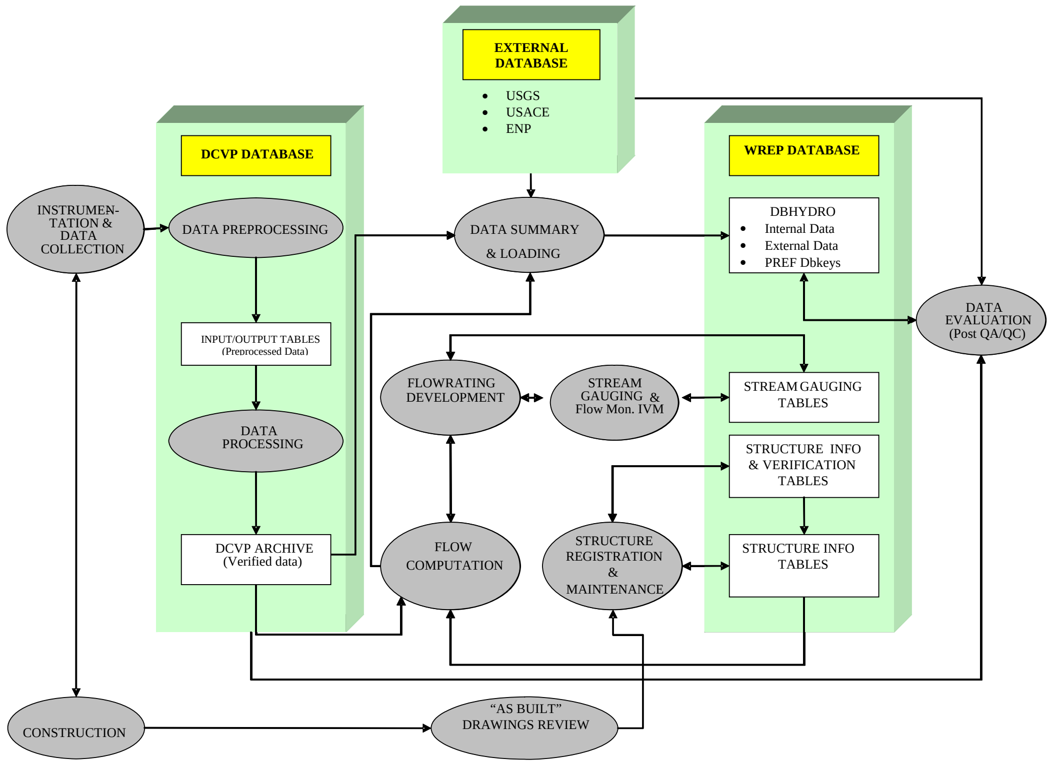

Figure 5. Hydro Data Management System

District stores data received from its gauge stations in the DBHYDRO database. The DBHYDRO database contains meteorological, hydrologic and water quality data collected from District monitoring stations, available as public domain and accessible in a variety of different time series formats. Some external data from U.S. Geological Survey (USGS), U.S. Army Corps of Engineers (USACE), National Oceanic and Atmospheric Administration (NOAA) and ENP are also available in DBHYDRO. Current and historic data are stored in DBHYDRO, allowing for the generation of specialized analyses relating to water control issues, as well as providing data necessary for use in operations, hydrologic models, and in generating statistics.

3. Data Retrieval

DBHYDRO data are accessible to users through the web browser. Internal users can also retrieve information from DCVP archive using the web browser. **Figure 6** shows the DBHYDRO web browser. DBHYDRO can be accessed via the Internet at http://glades.sfwmd.gov/pls/dbhydro_pro_plsql/show_dbkey_info.main_page. However, some functionality of the DBHYDRO is not publicly available.

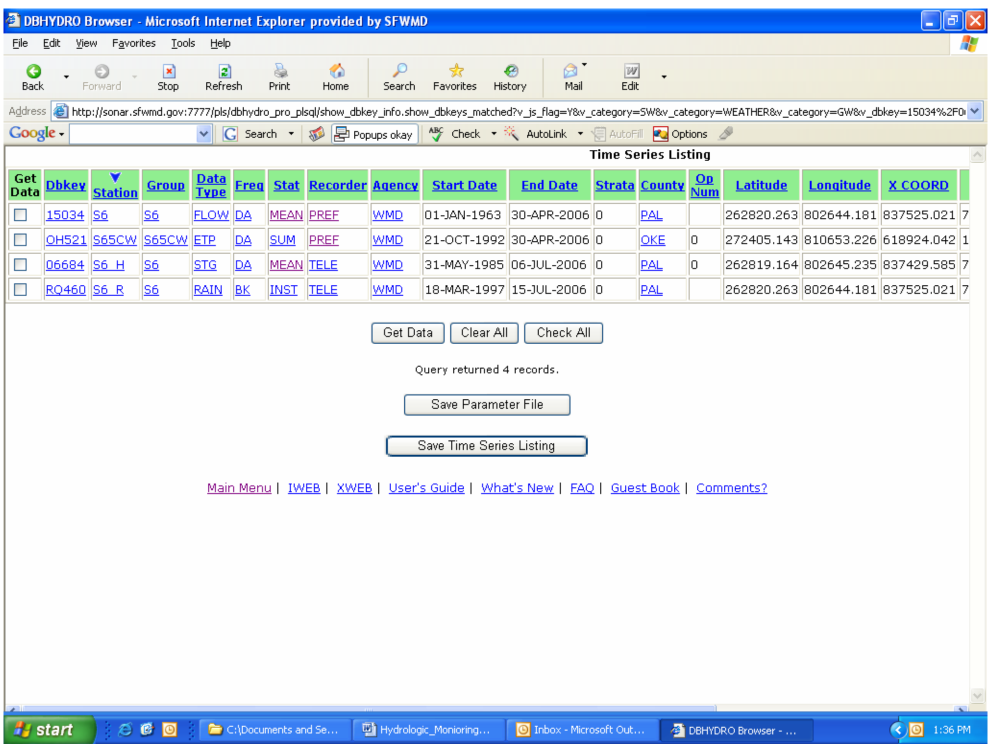

Figure 6. Screenshots of the DBHYDRO—main page and output.

DBHYDRO contains identification information for all District monitoring stations and associated instrumentation, as well as geographic location information. For every time series data, the records include the station name, a database unique identifier (Dbkey), latitude, longitude, basin, county, state plane coordinates, section, township, range, data type (flow, rain, water level), and sampling frequency. Dbkeys change when sensors have been upgraded, or when gauges are moved at District sites, and become obsolete when gauges are removed from the gauge network altogether or a different combination of sensors are used in flow computation.

Data are stored within DBHYDRO for the period of record for each station and includes breakpoint and non-breakpoint data. Breakpoint data are accessible in 15-minute, 30-minute, hourly, and daily time intervals, while non-breakpoint data are available only as daily accumulation totals (rainfall) or daily mean (water level and flow). Daily data are used most often at the District and represent the preferred time interval for the support of many operations, such as hydrologic modeling. This is because the daily time interval makes use of the full extent of data available through the network, and also because daily data take up less storage volume in computer applications than data of smaller time increments.

Data codes, or tags, accompany daily data within DBHYDRO in order to provide data users and analysts with an indication of data quality and processing status. A “null value” in the data code field corresponds to data that are missing. The “M” tag designates that data are missing, a code indicative of gauge equipment malfunction. The “X” data code for rain designates that data are unknown. Data demonstrating the “X” tag are eventually followed with an “A” code, meaning that an accumulative amount of data (rainfall) was measured over the time period indicated by an “X” tag. The complete record of DBHYDRO data codes used for rainfall and associated definitions are presented in **Table 1**.

Table 1. DBHYDRO data tags and associated definitions.

Data Tag	Meaning	Description
A	Accumulated	Reserved for rainfall data accumulated over a period exceeding 24 hours
E	Estimated	Designate estimated data. “E” tags are converted to “M” codes when data cannot be reasonably estimated.
M	Missing	Reserved for missing data
X	Included in Next Amount Marked “A”	Indicate days where manually observed rainfall has accumulated. “X” tags precede “A” tags, where the accumulation total is given.
!	Normal Limits Exceeded	Indicate instances when normal data values have been exceeded
?	Questionable (Do Not Use)	Indicate questionable data, not to be used
<	Less Than	Less Than
>	Greater Than	Greater Than
N	Not Processed	Not Yet Available
P	Partial	Computed from Partial Record

4. Data Quality Assurance and Quality Control

The District maintains a structured QA/QC procedure to ensure that data collected is of the best possible quality before it is further published. Preprocessing is the first stage of operations applied to “raw” time series data collected within the District’s monitoring network. The initial step of preprocessing involves the import of data collected manually and electronically from the field and data formatting for subsequent entry into the DCVP database. These tasks are accomplished through a series of software applications, which also perform validation checks on the data (Damisse et al., 2005; Sangoyomi et al., 2005a; Sangoyomi and Dawkins, 2005; Sangoyomi et al., 2005b; Sangoyomi et al., 2006).

Millions of data records are collected and posted to the District’s database DBHYDRO after data processing. Data quality assurance is normally performed during data processing. However, for some select legally mandated sites and for baseline data used in regional modeling and CERP, some post-processing QA/QC are also performed. Some of these mandates include Everglades Agricultural Area (EAA) Rulemaking, Chapter 40E-63 of Florida Forever Act; Stormwater Treatment Areas (STA); and Everglades Construction Project (ECP).

The QA/QC post-processing analysis is a second set of operations, which extract preprocessed data from DBHYDRO for select stations to undergo further examination. Post-processing QA/QC provides the opportunity to visualize and analyze current data with historical time series data. Presently, data from approximately 277 District gauge stations receive additional processing due to legal mandates under the Florida Forever Act. Data that have received the additional scrutiny of the QA/QC post-processing analysis are known in DBHYDRO as “preferred data” (PREF) or “modeling data” (MOD) and represent the “best available single time series data” at the District.

The initial step of QA/QC post-processing entails graphical plotting to show general data trends, gaps and overlapping portions (some of these are handled at the data processing level). Statistical analyses are then performed in order to compare historical trends and identify suspect data (Damisse et al., 2005; Sangoyomi et al., 2005a; Sangoyomi and Dawkins, 2005; Sangoyomi et al., 2005b; Sangoyomi et al., 2006). In post processing, missing data may be estimated with data estimation techniques and processes such as spatial and temporal interpolation, and statistical or simulation model applications. Erroneous data can be replaced with higher quality data, be deleted, or qualified and tagged. The level of scrutiny and data selection will correspond to the data usage or application. The post-processing QA/QC is conducted monthly, quarterly, or yearly according to pre-established and published schedules.

III. METEOROLOGIC MONITORING NETWORK

By Gary Wu and Chandra Pathak

According to the *Guide to Meteorological Instruments and Methods of Observation* published by the World Meteorological Organization (1996), "meteorological (and related environmental and geophysical) observations are made for a variety of reasons. They are used for the real-time preparations of weather analyses and forecasts, for the study of climate, for local weather-dependent operations (such as operation of the water control structures), for hydrology and agro-meteorology, and for research in meteorology and climatology."

The climate in South Florida is subtropical, humid, and prone to severe conditions. The variability in rainfall is often characterized by multiple wet and dry cycles with severe droughts from time to time. Evapotranspiration in South Florida has been estimated to be from 70 to 90 percent of the rainfall in undisturbed wetlands. Tropical cyclones (hurricanes and tropical storms) produce the most severe weather conditions in South Florida. The high tides and heavy rains – often in excess of 5 inches – associated with these storms can produce coastal and inland flooding, and strong winds can cause extensive damage. Tropical cyclones have repeatedly passed through the region, most frequently in late summer or early fall (USGS, Circular 1134).

Several meteorologic parameters (such as barometric pressure, solar radiation, air temperature, relative humidity, and wind speed) are measured at the weather stations that form the District meteorologic monitoring network. Typically, these parameters also include rainfall measurements—one of the most important meteorologic parameters that is used at the District for water management, hydrologic analyses, and other purposes. Because of this reason, the District has a large number of rain gauge stations (seven to eight times more than the total number of weather stations). Because of its shear size the rainfall monitoring network, it is excluded from this chapter and it is presented in Section IV of this report.

Considering these natural conditions in South Florida, the District's weather stations are valuable in providing monitoring and prediction in the following three areas: evapotranspiration; hurricanes and tropical storms; and soil dryness and associated wildfire conditions.

Evapotranspiration (ET)

Evapotranspiration is a major component of the hydrologic cycle. This hydrometeorological parameter is needed for various water budgeting purposes, which accounts for surface and groundwater. Potential evapotranspiration (PET), or reference evapotranspiration, is the hydrologic parameter needed to estimate evapotranspiration from the given soil and vegetation surfaces in an area. Potential evapotranspiration is the rate at which water loss to the atmosphere occurs from well-watered soil and plant surfaces. Reference evapotranspiration is the PET specific to either short grass or alfalfa crop. Actual or crop evapotranspiration can either be measured or derived by applying crop coefficients to the PET. There are many methods that have been used to estimate PET, provided that adequate input data is available. These methods are generally classified into three groups: energy balance methods, mass balance methods, and combination methods (such as Penman, Corrected Penman, and Penman-Monteith) which include both energy and mass balance approaches. The District developed historical and current daily PET data sets for wetlands using Simple Method (Abtew et al., 2002).

Hurricanes and tropical storms

The hurricane seasons in 2004 and 2005 inflicted severe damage and economical loss to South Florida. To better understand the strong winds created by hurricanes, the National Hurricane Center has identified the weather stations operated by the District as a good source for information. The debate over Hurricane Wilma's strength of either Category 2 or 3 [based on the Saffir-Simpson Hurricane Scale of National Oceanic and Atmospheric Administration (NOAA) National Hurricane Center] has called for the needs of better monitoring schemes and measurement methods.

Soil dryness and associated wildfire conditions

The Keetch-Byram Drought Index was designed specifically for fire potential assessment. The index number represents the net effect of evapotranspiration and precipitation in producing cumulative moisture deficiency in deep duff and upper soil layers. It is a continuous index, relating to the flammability of organic material in the ground. The rainfall measured and PET calculated from a weather station determines the Keetch-Byram Drought Index for a site.

A. Development of the Meteorological Monitoring Network

1. History

The meteorological monitoring of Central and South Florida can be traced back to the early twentieth century. In 1912, the then named Everglades District conducted pan evaporation observation. Before the Central and Southern Florida Flood Control District was established in 1949, meteorological monitoring was conducted by NOAA, the U.S. Army Corp of Engineers (USACE), and local drainage districts. In 1972, the Central and Southern Florida Flood Control District was renamed as South Florida Water Management District (SFWMD), which took over most of these responsibilities for the South Florida region. However, in addition to the agencies mentioned above, there are meteorological data obtained from other organizations including the U.S. Department of Agriculture (USDA), USGS, and the University of Florida. The historical meteorological data are stored in DBHYDRO; the lists of pan evaporation and weather station sites are shown in Appendix.

2. Evolution of the Network

The meteorological monitoring network at the District measures various weather parameters. The weather parameters that are measured include the following:

- Air Temperature (AIRT)
- Barometric Pressure (BARO)
- Relative Humidity (HUMI)
- Solar Radiation (Net) (RADN)
- Solar Radiation (Photoactive) (RADP)
- Solar Radiation (Total) (RADT)
- Wind Scalar Direction @ 10 meters (WNDD)
- Wind Scalar Speed @ 10 meters (WNDS)
- Wind Vector Direction @ 10 meters (WNVD)
- Wind Vector Speed @ 10 meters (WNVS)
- Water Temperature (at different depths) (H2OT)

Table 2 summarizes the number of meteorological monitoring sites from 1950 to the present (in calendar years). Pan evaporation observation reached its peak in the 1980s with 38 sites. It is also seen that most of meteorological monitoring of atmospheric quantities such as air temperature, barometric pressure, humidity, solar radiation, wind speed, and water temperature were conducted after the 1990s.

Table 2. Number of meteorological monitoring stations at the District from 1950 to the present.

	Before 1/1/1950	**1950–1959**	**1960–1969**	**1970–1979**	**1980–1989**	**1990–1999**	**2000–Present**
Pan Evap	12	21	24	32	38	24	20
AIRT	0	0	0	2	6	26	28
BARO	0	0	0	0	2	23	39
HUMI	0	0	0	1	5	26	28
RADN	0	0	0	0	1	13	18
RADP	0	0	0	0	4	27	30
RADT	0	0	0	0	4	25	28
WNDD	0	0	0	1	6	11	15
WNDS	0	0	0	0	7	30	30
WNVD	0	0	0	0	3	26	29
WNVS	0	0	0	1	4	26	29
H2OT	0	0	0	0	3	11	9

B. Existing Meteorological Network

1. Field Instrumentation at the Station

To measure the different weather parameters, the District uses several types of sensors at the weather stations. The most commonly used sensors are as follows:

- National Weather Service (NWS) Class A evaporation pan
- Vaisala WS425 ultrasonic wind sensor
- HMP45C temperature and relative humidity probe
- PTA-427 barometric pressure transducer
- LI-COR LI200S pyranometer
- Q-7.1 net radiometer
- LI-COR LI190SB Quantum
- CS 107-108 temperature probe

a. Class A Evaporation Pan

The standard NWS Class A evaporation pan is the most widely used sensor at District weather stations. It is made of unpainted galvanized steel or stainless steel 4 feet in diameter by 10 inches deep, and sits on a wood frame exposed beneath to let air circulate (**Figure 7**). The pan is filled to a depth of 8 inches, and is refilled when the depth falls to 7 inches. Water surface level is measured daily with a hook gauge in a stilling well. Evaporation is computed as the difference between observed levels, adjusted for any precipitation measured in a standard rain gauge. Alternatively, water is added each day to bring the level up to a fixed point in the stilling well. This method assures proper water level at all times (Kinsman et al., 1994).

Depending on the water level measurement method and how water is supplied to the pan, the measurement accuracy can be varied. The following are technical specifications for the Automatic Evaporation Monitoring System Model 6529 (http://www.geneq.com/catalog/en/auto_evap_mon_sys.html, July 2006).

Figure 7. FTPIER pan evaporation station.

Range	30 (empty) to 250 millimeter (mm) (full)
Resolution	0.2 mm of evaporation or rainfall
Accuracy	± 0.4 mm
Level Reset	Programmable default reset to 200 mm (± 1 mm) at a preset time each day
Water Level	6541 Water Level Instrument with 128k Micrologger
Power Supply	0.3 Ah/day
Battery	Model 6907B 12V 7Ah sealed lead acid
Charger	Model 6904B 12V 2W solar panel mounted on aluminum enclosure
Pan Type	ID 1208 mm OD 1290 mm Depth 250 mm US Class A compatible
Pan Mounting	Timber frame; treated plantation softwood 1300 mm × 1300 mm
Pan Bird Guard	12 mm square steel mesh Hot dip galvanized
Control Enclosure	Aluminum 320 mm × 300 mm × 750 mm (W × D × H)
System Weight	Approximately 52 kilograms (kg)

b. Vaisala WS425 Ultrasonic Wind Sensor

According to the User's Guide, the WS425 has an on-board microcontroller that captures and processes data and performs serial communications. The wind sensor has three, equally spaced ultrasonic transducers on a horizontal plane. The sensor measures transit time (the time that it takes the ultrasound to travel from one transducer to another) in both directions (**Figure 8**).

The transit time depends on the wind velocity along the ultrasonic path. For zero wind velocity, both the forward and reverse transit times are the same. With wind along the sound path, the up-wind transit time increases and the down-wind transit time decreases. The microprocessor of the microcontroller calculates the wind speed from the transit times using the following formula:

$V_W = 0.5\ L\ (1/t_f - 1/t_r)$

where

V_W	= Wind velocity
L	= Distance between two transducers
t_f	= Transit time in the forward direction
t_r	= Transit time in the reverse direction

Measuring the six transmit times allows wind velocity to be calculated for each of the three ultrasonic paths, which are offset to each other by 120 degrees. The calculated wind speeds are independent of altitude, temperature, and humidity because they cancel out with the six measurements even though the velocity of sound affects individual transit times.

Incorrect readings may occur when a large raindrop or ice pellet strike a transducer. These incorrect readings are eliminated by a proprietary signal processing technique. For example, a wind velocity figure most affected by turbulence error is eliminated to calculate the wind speed and wind direction from the best two values. The following are some of the specifications of the WS425:

Wind Speed: Resolution of reported values of average speed and vector speed are accurate to sensor accuracy.

Range	0–144 mph
Accuracy	± 3 percent < 110 mph
	± 8 percent > 110 mph

Wind Direction: Reported values of vector direction are accurate to sensor accuracy.

Range	0–360 degrees
Accuracy	± 2 degrees
Resolution	1 degree

Figure 8. A Vaisala WS425 ultrasonic wind sensor at weather station L006.

c. HMP45C Temperature and Relative Humidity Probe

The HMP45C Temperature and Relative Humidity probe contains a Platinum Resistance Temperature (PRT) detector and a Vaisala HUMICAP 180 capacitive relative humidity sensor (**Figure 9**).

Temperature:

Range	-33 degrees Celsius (°C) to 48 °C
Accuracy	± 0.4 °C over full range

Relative Humidity:

Range	0–100 percent
Accuracy	at 20 °C, including nonlinearity and hysteresis
	± 2 percent relative humidity at 0–90 percent
	± 3 percent relative humidity at 90–100 percent

Figure 9. An air temperature and relative humidity probe at weather station L006.

d. PTA-427 Barometric Pressure Transducer

The PTA-427 uses a silicon capacitive pressure sensors patented by Vaisala (**Figure 10**). It is temperature compensated and produces a linear voltage output over the full operating range.

Range	600.35–795.47 millimeters mercury (mm Hg)
Accuracy	± 0.375 mm Hg

Figure 10. A typical Vaisala barometric pressure sensor.

e. LI-COR LI200S Pyranometer

A pyranometer is an instrument for measuring solar radiation received from an entire hemisphere. It is suitable for measuring the amount of global sun plus sky radiation (**Figure 11**). The LI-COR LI200S pyranometer utilizes a silicon photodiode which has a spectral response in the wavelength band from 0.4 micrometer (µm) to 1.2 µm.

Linearity	Maximum deviation of 1 percent up to 3,000 watts per meters squared (Wm^{-2})
Typical Sensitivity	0.2 kilowatts per meters squared per millivolt ($kWm^{-2}mV^{-1}$)
Accuracy	± 5 percent maximum (absolute error in natural daylight) ± 3 percent typical
Stability	< ± 2 percent change over a one year period

Figure 11. An LI-COR LI200S pyranometer.

f. Q-7.1 Net Radiometer

The Q-7.1 is a high-output thermopile sensor that measures the algebraic sum of incoming and outgoing all-wave radiation (i.e., short- and long-wave components). Incoming radiation consists of direct (beam) and diffuse solar radiation plus long-wave irradiance from the sky (**Figure 12**). Outgoing radiation consists of reflected solar radiation plus the terrestrial long-wave component.

Range	Approximately -0.5 (during darkness) to approximately 1.500 (during sunny conditions, full sky)
Spectral response	0.25–60 µm
Uncorrected wind effect	Up to 6 percent reduction at 7 meters per second (ms^{-1}) for positive fluxes Up to 1 percent reduction at 7 ms^{-1} for negative fluxes
Reported values	Kilowatts per meter squared (kWm^{-2})
Accuracy	± 0.075 kWm^{-2}

Figure 12. An Q-7.1 net radiometer at weather station Belle Glade.

g. LI-COR LI190SB Quantum

The LI190SB accurately measures Photosynthetic Photon Flux Density (PPFD) in both natural and artificial light (**Figure 13**). PPFD is the number of photons in the 400–700 nanometer (nm) waveband incident per unit time on a unit surface, which plants can use for photosynthesis.

Linearity	Maximum deviation of 1 percent up to 10,000 micromoles per second per meters squared ($\mu ms^{-1}m^{-2}$)
Sensitivity	Typically 5 microamps (µA) per 1,000 $\mu ms^{-1}m^{-2}$
Stability	< ± 2 percent change over a 1 year period
Calibration	± 5 percent traceable to the U.S. National Institute of Standards Technology (NIST)

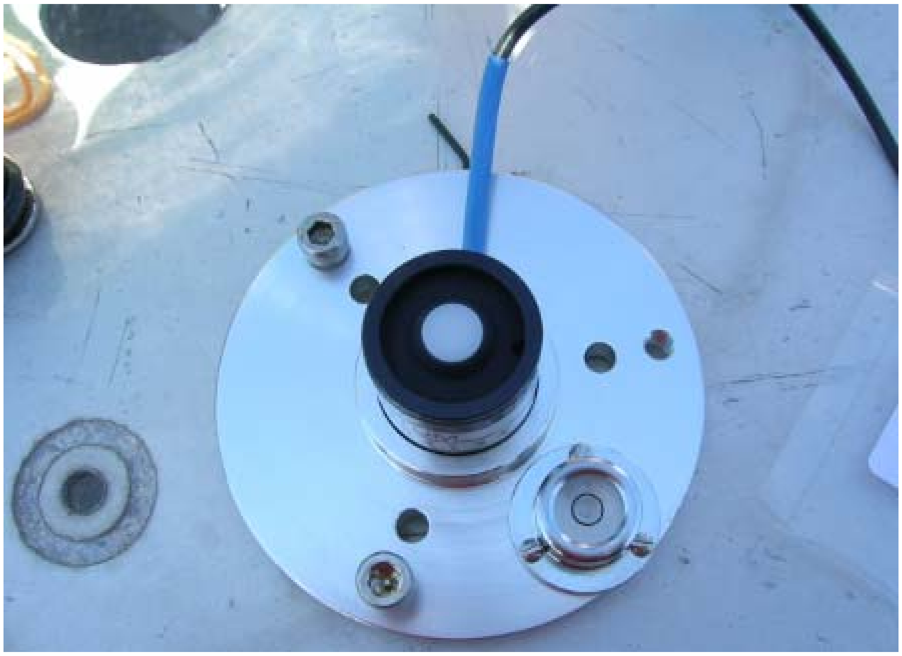

Figure 13. An LI-COR LI190SB Quantum.

h. CS 107/108 Temperature Probe

Campbell Scientific Models 107 and 108 are rugged, accurate temperature probes that measure air, soil, and water temperature in a variety of applications. These probes consist of a thermistor encapsulated in an epoxy-filled housing (**Figure 14**). The housing protects the thermistor allowing the probes to be buried or submerged.

Campbell Scientific Model 107 Specifications

Temperature measurement range	-35 °C to 50 °C
Polynomial linearization accuracy	Typically less than ± 0.5 °C over -38 to 50 °C range less than ± 0.1 °C over -24° to +48°C range
Interchangeability error	Typically less than ± 0.2 °C over 0 to 50 °C range increasing to ± 0.4 °C at -40 °C

Campbell Scientific Model 108 Specifications

Temperature measurement range	-5 °C to 95 °C
Polynomial linearization accuracy	Typically less than ± 0.5 °C at the -5 to 90 °C range
Interchangeability error	Typically less than ± 0.2 °C over 0 to 70 °C range increasing to ± 0.3 °C at 95 °C

Figure 14. A Campbell Scientific Thermistor temperature probe at weather station L006.

2. *Active Meteorological Stations*

Tables 3 and **4** show 20 active pan evaporation stations and 41 weather stations at the District as of December 31, 2005. **Table 4** also shows 18 stations where PET data are estimated from meteorological data using the Simple Method. **Table 5** shows the major climatic indices measured at active meteorological stations.

Table 3. Active pan evaporation monitoring stations.

No.	Station	Freq	Stat	Recorder	Agency	Start Date	Latitude	Longitude
1	WRWX	DA	SUM	CR10	WMD	29-Aug-03	280254.057	812358.224
2	S65_E	DA	SUM	APAN	WMD	1-Oct-83	274814.088	811153.228
3	FT. PI 2_E	DA	SUM	APAN	WMD	1-Nov-69	272616.135	802059.167
4	S65CW	DA	SUM	CR10	WMD	25-Feb-04	272405.143	810653.226
5	FT. PIER_E	DA	SUM	APAN	WMD	1-Mar-82	272202.353	803052.906
6	S65DWX	DA	SUM	CR10	WMD	25-Feb-04	271851.303	810119.74
7	EVP376NE	DA	SUM	DWR	WMD	1-May-05	271512.4	804708.6
8	OKEE FIE_E	DA	SUM	APAN	WMD	1-Oct-83	271505.16	804720.202
9	S75WX	DA	SUM	CR10	WMD	2-Sep-02	271130.763	810740.829
10	WPB.EEDD_E	DA	SUM	APAN	EDD	1-May-83	264254.229	800344.141
11	WWTP_E	DA	SUM	COMP	WMD	1-Jan-99	264254	800345
12	S5A	DA	SUM	CPAN	WMD	1-Mar-90	264104.231	802203.172
13	BELLE GL	DA	SUM	CR10	WMD	14-Nov-96	263925.237	803747.196
14	STA5WX	DA	SUM	CR10	WMD	18-Sep-02	262651.075	805324.698
15	FPWX	DA	SUM	CR10	WMD	10-Sep-05	262557.289	814324.268
16	S7_E	DA	SUM	APAN	WMD	8-Mar-60	262009.283	803212.191
17	BCBNAPLE_E	DA	SUM	APAN	WMD	31-Dec-90	261331.318	814829.304
18	S140 SPW_E	DA	SUM	APAN	WMD	18-Jun-85	261019.308	804938.221
19	SGGEWX	DA	SUM	CR10	WMD	22-Sep-03	260843.335	813432.316
20	S331W	DA	SUM	CR10	WMD	4-Aug-05	253639.383	803035.205

Table 4. Active atmospheric monitoring stations.

No.	Station	Recorder	Agency	Latitude	Longitude	Start Date	County	Profile*	ETP DBKEY
1	S61W	CR10	WMD	280824	812105	20-Oct-92	OSC	Full	
2	WRWX	CR10	WMD	280254	812358	16-Apr-97	POL	Full	OU852
3	S65CW	CR10	WMD	272405	810653	20-Oct-92	OKE	Full	OH521
4	S65DWX	CR10	WMD	271851	810120	23-Feb-00	OKE	Full	OH511
5	S75WX	CR10	WMD	271131	810741	1-Sep-02	GLA	Full	
6	L001	CR10	WMD	270822.623	804720.522	4-Aug-94	OKE	Full	
7	JDWX	CR10	WMD	270143	800955	12-Sep-97	MAR	Full	OH512
8	L005	CR10	WMD	265724.229	805820.586	5-Aug-88	GLA	Full	
9	LZ40	CR10	WMD	265406	804720	25-Apr-90	PAL	Full	
10	L006	CR10	WMD	264918.307	804700.314	27-Jan-89	PAL	Full	OH519
11	S78W	CR10	WMD	264723	811810	21-Oct-92	GLA	Full	RW483
12	CFSW	CR10	WMD	264406	805343	21-Oct-92	HEN	Full	OU851
13	BELLE GL	CR10	WMD/UF	263925	803747	16-Apr-96	PAL	Full	OH518
14	ENR308	CR10	WMD	263721	802620	7-Apr-94	PAL	Full	
15	WCA1ME	CR10	WMD	263038.256	801837.167	12-Feb-96	PAL	Partial	
16	LOXWS	CR10	WMD	262956	801320	29-Jun-93	PAL	Full	RW485
17	STA5WX	CR10	WMD	262651	805325	17-Sep-02	HEN	Full	
18	FPWX	CR10	WMD	262557	814324	3-Sep-97	LEE	Full	OH520
19	S7WX	CR10	WMD	262009	803212	12-Jan-98	PAL	Full	RW484
20	ROTNWX	CR10	WMD	261955	805248	23-Dec-97	BRO	Full	RW486
21	BCSI	CR10	WMD	261917	810404	25-Jun-93	HEN	Full	OU850
22	WCA2F4	CR10	WMD	261901.283	802306.178	1-May-97	BRO	Partial	
23	SILVER	CR10	WMD	261749.301	812618.269	5-Dec-00	COL	Full	RW482
24	BBCW5	CR10	WMD	261558.042	802231.095	17-May-05	BRO	Partial	
25	S140W	CR10	WMD	261016.654	804933.561	21-Oct-92	BRO	Full	OH516
26	SGGEWX	CR10	WMD	260843	813432	18-Sep-02	COL	Full	
27	3AS3WX	CR10	WMD	255106	804559	3-Apr-00	DAD	Full	OH515
28	BBCW1	CR10	WMD	254035.067	801923.678	18-May-05	DAD	Partial	
29	S331W	CR10	WMD	253639	803035	21-Jul-94	DAD	Full	OH514
30	BBCW7GW1	CR10	WMD	253605.41	801834.239	18-May-05	DAD	Partial	
31	BBCW7GW2	CR10	WMD	253605.41	801834.239	18-May-05	DAD	Partial	
32	BBCW8GW1	CR10	WMD	253604.406	801820.788	18-May-05	DAD	Partial	
33	BBCW8GW2	CR10	WMD	253604.406	801820.788	18-May-05	DAD	Partial	
34	BBCW2	CR10	WMD	253015.012	802051.36	17-May-05	DAD	Partial	
35	BBCW9GW1	CR10	WMD	252821.229	802048.744	17-May-05	DAD	Partial	
36	BBCW9GW2	CR10	WMD	252821.229	802048.744	17-May-05	DAD	Partial	
37	BBCW4	CR10	WMD	252720.467	802202.673	17-May-05	DAD	Partial	
38	MDTS	CR10	WMD	251643.4	802342.21	1-Jan-91	DAD	Partial	
39	MBTS	CR10	WMD	251526.429	802520.208	31-May-96	DAD	Partial	
40	JBTS	CR10	WMD	251328	803224	23-May-91	DAD	Full	OH513
41	TPTS	CR10	WMD	251223.4	802229.2	1-Jan-91	DAD	Partial	

* The "Full" designation under the Profile column means that wind, radiation, humidity, and air temperature measurements are collected at those sites. The "Partial" designation does not contain a full spectrum of the above parameters.

Table 5. Major climatic indices measured at the active existing meteorological stations.

No.	Station	Start Date	AIRT	BARO	HUMI	RADN	RADP	RADT	WNDD	WNDS	WNVD	WNVS	TWAT
1	S61W	20-Oct-92	X	X	X		X	X		X	X	X	
2	WRWX	16-Apr-97	X	X	X	X	X	X		X	X	X	
3	S65CW	20-Oct-92	X	X	X		X	X		X	X	X	
4	S65DWX	23-Feb-00	X	X	X	X	X	X	X	X	X	X	
5	S75WX	1-Sep-02	X	X	X	X	X	X	X	X	X	X	
6	L001	4-Aug-94	X	X	X		X	X		X	X	X	X
7	JDWX	12-Sep-97	X	X	X	X	X	X		X	X	X	
8	L005	5-Aug-88	X	X	X		X	X	X	X	X	X	X
9	LZ40	25-Apr-90	X	X	X		X	X	X	X	X	X	X
10	L006	27-Jan-89	X	X	X		X	X	X	X	X	X	X
11	S78W	21-Oct-92	X	X	X		X	X		X	X	X	
12	CFSW	21-Oct-92	X	X	X		X	X		X	X	X	
13	BELLE GL	16-Apr-96	X	X	X	X	X	X	X	X	X	X	
14	ENR308	7-Apr-94	X	X	X	X	X	X		X	X	X	X
15	WCA1ME	12-Feb-96					X						
16	LOXWS	29-Jun-93	X	X	X	X	X	X		X	X	X	
17	STA5WX	17-Sep-02	X	X	X	X	X	X	X	X	X	X	
18	FPWX	3-Sep-97	X	X	X	X	X	X	X	X	X	X	
19	S7WX	12-Jan-98	X	X	X	X	X	X		X	X	X	
20	ROTNWX	23-Dec-97	X	X	X	X	X	X		X	X	X	
21	BCSI	25-Jun-93	X	X	X		X	X		X	X	X	
22	WCA2F4	1-May-97		X									
23	SILVER	5-Dec-00	X	X	X	X	X	X	X	X	X	X	
24	BBCW5	17-May-05		X									
25	S140W	21-Oct-92	X	X	X	X	X	X	X	X	X	X	
26	SGGEWX	18-Sep-02	X	X	X	X	X	X	X	X	X	X	
27	3AS3WX	3-Apr-00	X	X	X	X	X	X	X	X	X	X	
28	BBCW1	18-May-05		X									
29	S331W	21-Jul-94	X	X	X	X	X	X		X	X	X	
30	BBCW7GW1	18-May-05		X									
31	BBCW7GW2	18-May-05		X									
32	BBCW8GW1	18-May-05		X									
33	BBCW8GW2	18-May-05		X									
34	BBCW2	17-May-05		X									
35	BBCW9GW1	17-May-05		X									
36	BBCW9GW2	17-May-05		X									
37	BBCW4	17-May-05		X									
38	MDTS	1-Jan-91											X
39	MBTS	31-May-96					X		X	X	X	X	X
40	JBTS	23-May-91	X	X	X		X	X		X	X	X	X
41	TPTS	1-Jan-91											X

KEY:

AIRT	Air Temperature
BARO	Barometric Pressure
HUMI	Relative Humidity
RADN	Solar Radiation (Net)
RADP	Solar Radiation (Photoactive)
RADT	Solar Radiation (Total)
WNDD	Wind Scalar Direction @ 10 meters
WNDS	Wind Scalar Speed @ 10 meters
WNVD	Wind Vector Direction @ 10 meters
WNVS	Wind Vector Speed @ 10 meters
TWAT	Water Temperature (measurements at different depths of a site may exist)

Figures 15 and **16** are the location maps of active pan evaporation monitoring and atmospheric monitoring stations. **Figure 17** is the location map of 18 active PET stations. **Figure 18** shows a photograph of a typical weather station.

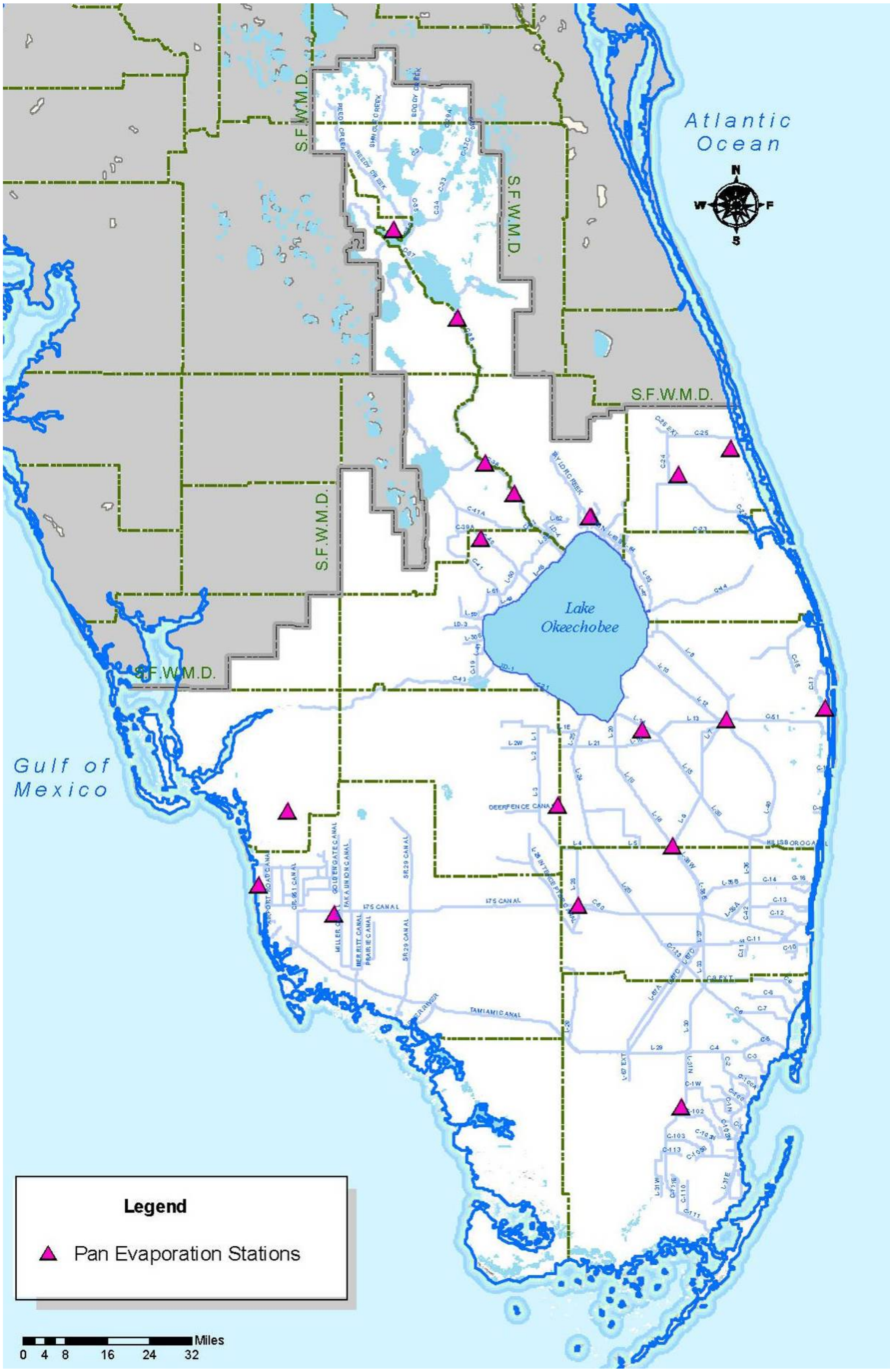

Figure 15. Location of active pan evaporation monitoring stations.

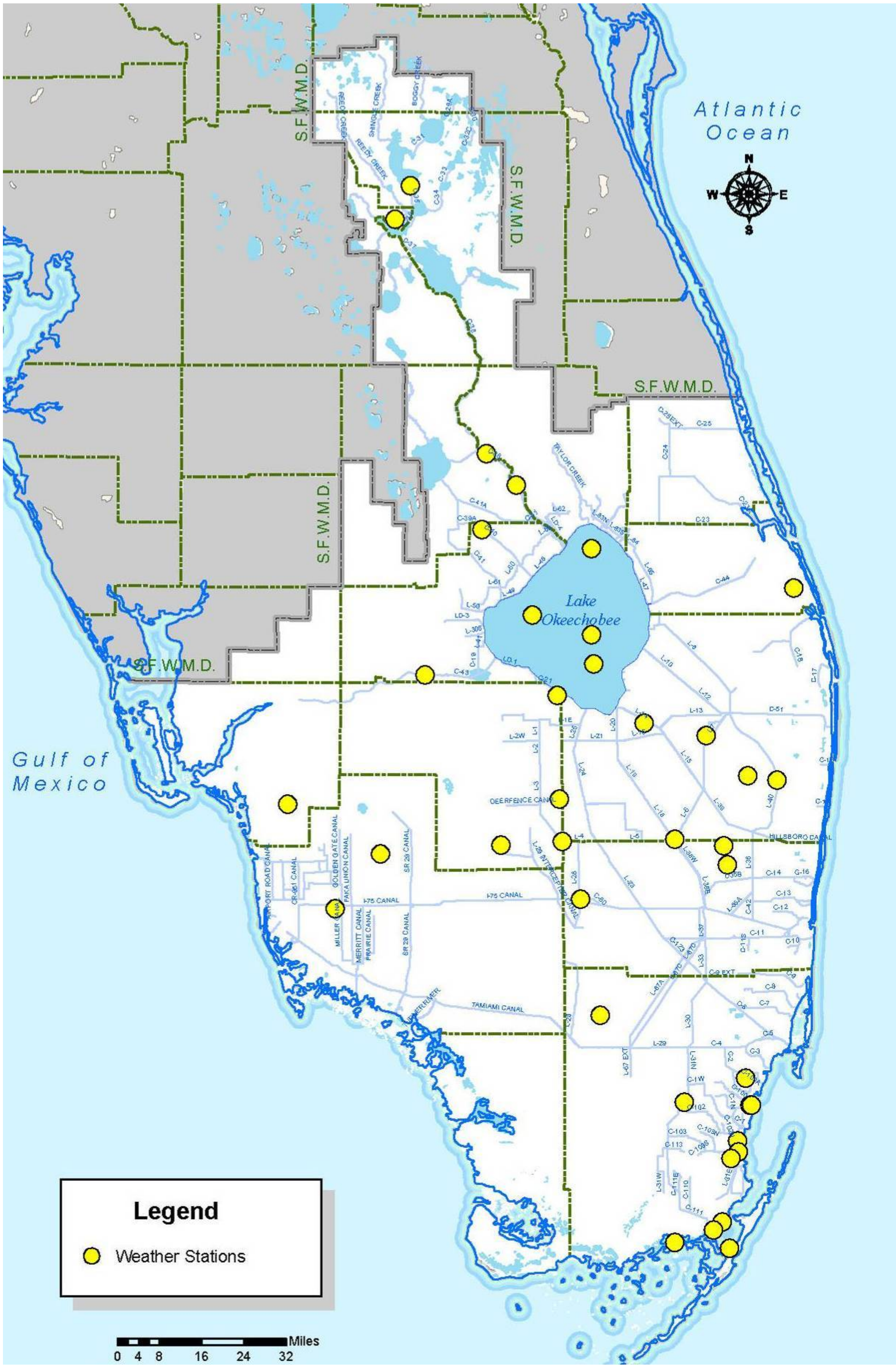

Figure 16. Location of active atmospheric monitoring stations.

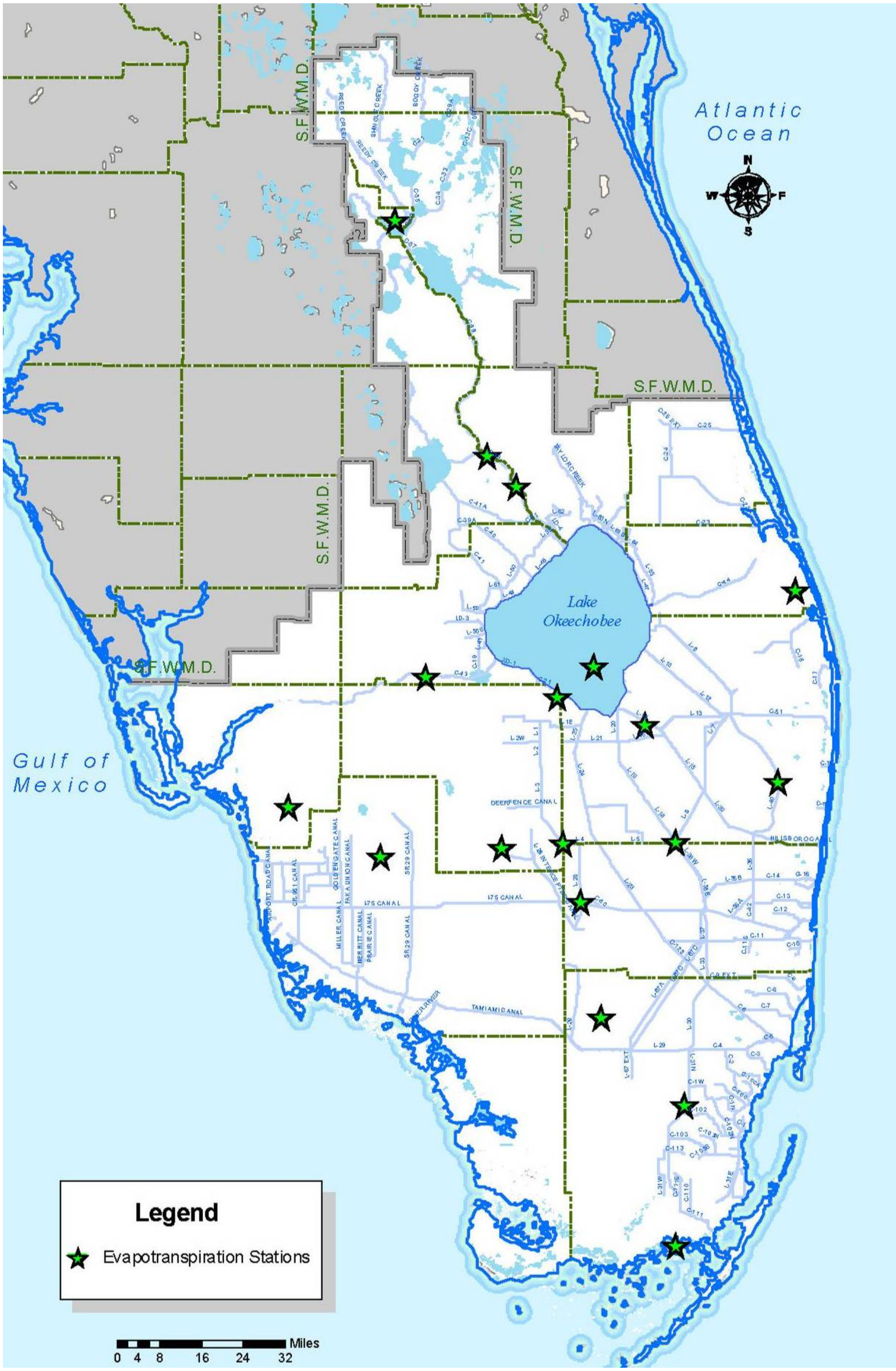

Figure 17. Location of active potential evapotranspiration computation stations.

Figure 18. Weather station L006 in Lake Okeechobee.

C. Meteorological Data

The District operates an extensive network of 41 active weather stations. The meteorological data such as air temperature, barometric pressure, humidity, solar radiation, wind speed, and water temperature are available on breakpoint basis. The breakpoint data can be obtained in 15-minute, hourly, and daily interval formats from the DBHYDRO database. However, pan evaporation data from 20 stations are available as daily data in the DBHYDRO database. In addition, daily PET data are available for 18 weather stations. The PET data were estimated using the Simple Method (Abtew et al., 2002). Additionally, historical time series data from the District are also available in DBHYDRO.

Data codes, or tags, accompany daily data within DBHYDRO in order to provide data users and analysts with an indication of data quality. A "null value" in the data code field corresponds to data that are missing. The "M" tag designates that data are missing, a code indicative of equipment and/or network malfunction. The complete record of DBHYDRO data codes used for rainfall and associated definitions are presented in **Table 1**.

The QA/QC post-processing analysis is a second set of operations, which extract preprocessed data from DBHYDRO for select stations to undergo further examination. Presently, data from only 18 PET stations undergo this post processing. Data that has received the additional scrutiny of the QA/QC post-processing analysis is known as “preferred data” (PREF) and represents “best available data” at the District (Sangoyomi et al. 2006).

Since 2004, the District has worked jointly with USGS and the other four water management districts on a satellite-based ET estimation project (SFWMD, 2004). The project uses the Geostationary Operational Environmental Satellite (GOES) satellite data for hourly estimates of solar radiation with a spatial resolution that is significantly better than that available from the ground-based network of radiation sensors. This project will develop estimates of solar radiation, net radiation, PET, and reference evapotranspiration (RET) at a cell scale of 2 km x 2 km (same as the NEXRAD rainfall data grid), and a daily time scale from 1995 to 2004 for the entire state of Florida. The satellite-based PET and RET data are expected to be available in 2007.

D. Meteorological Network Design

The existing meteorological network has evolved more than two decades whereas the current pan evaporation network has evolved over many decades. An assessment of the evaporation pan network of the District was conducted in 1995 (Chin, 1995). In this study, ordinary kriging (OK) and universal kriging (UK) methods were used in the network evaluation and assessment.

Initially, the main purpose of weather stations was to obtain weather conditions for operations of water control facilities. Later, these weather parameters were used for evapotranspiration estimation purposes. However, the actual designs of the meteorological network for ET estimation were not performed. An evapotranspiration network design is now planned and is expected to be performed in the next few years depending upon availability of funds at the District.

IV. RAINFALL MONITORING NETWORK

By Chandra Pathak and Madhav Pandey

One of the most important processes in the hydrologic cycle is precipitation. The main source of precipitation, even over land masses, is water vapor derived by evaporation at the ocean's surface. The air is cooled by being lifted up the slope of a mountain range, or up and over colder (and heavier) polar air, or straight up by heated air rising in the process of thermal convection. In all cases, the end result is the same: the air cools below the dew point, moisture condenses on the ever-present condensation nuclei, and a cloud forms.

Rainfall is by far the most important source of precipitation in most areas and the main contributor to runoff, stream flow, and aquifer recharge. In the United States, rainfall is measured by a combination of radar and rainfall readings taken at more than 13,000 standard and automatically recording gauges. These data are input to much-used regional maps and information printouts.

Despite advances in remote-sensing technologies, such as radar and satellite, rain gauges remain the most common method for the measure of rainfall. Rain gauges are fixed instruments that sample precipitation in a cylindrical collector, which is typically 8 inches in diameter.

Although rainfall is a meteorologic parameter, it has a more significant role in water resources management and hydrology. Therefore, a separate section on rainfall monitoring network is included herein.

A. Development of the Rainfall Monitoring Network

A set of rain gauges were installed in various locations in Florida in the early 1900s by the NOAA. The District began operating its own set of rain gauges after its formation in 1949. Since that time, the locations of the rain gauges were determined based on the District projects that needed the rainfall data. The number of rain gauges increased significantly after 1965 at the District. A total of 780 unique stations have collected rainfall data between 1950 and 2005 at the District. **Table 6** shows the total number of stations where daily rainfall time series data are available on decade basis.

Table 6. Total number of rain gauge stations in the District from 1950 to 2005.

Years	Total Number of Rain Gauge Stations
1950-1959	61
1960-1969	132
1970-1979	213
1980-1989	311
1990-1999	539
2000-2005	491

The number of existing rain gauges has increased over several decades based on the project needs of the District. The rain gauge network is geographically and spatially uneven; it is relatively dense in some areas and sparse in other areas. For example, the network contains several clusters of rain gauges that are located within 2 to 6 miles of each other. However, there are several tens of square miles within the District without rain gauges. In order to address this deficiency, the District has completed a rain gauge network optimization study (SFWMD, 2006) and a summary of that study is presented later in this report.

B. Existing Active Rain Gauge Network

The District operates a network of rain gauging stations to provide precipitation data for use in water management operations, modeling, and planning (Huebner et al., 2003). Several limitations have been shown to exist, however, in the sole reliance of point rain gauge measurements, including the introduction of error through the spatial extrapolation of such data. Accounting for spatial rainfall distributions is of particular concern in South Florida, where intense, highly variable convective rain events predominate in the wet season that starts in June and ends in October. Because of the tropical nature of the summer rainfall in South Florida, the gauges only give representative rainfall measurements for long averaging periods, and can often miss, or erroneously assess the magnitude of significant rainfall events.

1. Field Instrumentation at the Station

Rain gauges are classified as recording or non-recording. Recording rain gauges supply breakpoint data, or precipitation measurements, collected at "fine time resolution." Consequently, recording-type gauges offer information regarding temporal rainfall distribution and intensity. The District currently maintains 233 recording gauges, which produce breakpoint rainfall data in 1-, 3-, or 5-minute intervals.

Non-recording rain gauges, also referred to as accumulation gauges, lack the mechanical capabilities of recording-type devices and, as a result, cannot produce breakpoint rainfall data. These instruments collect and store rainfall over a specified time period (usually 24 hours) until a manual reading is taken. The District uses a total of 46 standard-type, non-recording rain gauges to provide daily rainfall accumulation data. The recording and non-recording rain gauges used by the District can be found in **Table 7**.

Table 7. Types of rain gauge instruments used by the District.

Type	Instrument	Description
Recording	Tipping Bucket 	The tipping bucket precipitation gauge operates by measuring water volume in a lightweight, dual compartment, tipping device. The apparatus, which has two equally sized buckets on either end that balance on a horizontal axis. As one bucket is in the upright fill position, the other one is draining the rain water. Rain collected in the first bucket fills the compartment until the weight of the water causes the container to tip due to instability. This causes the second bucket to move into the upright fill position, while the first bucket empties below. Each tip of the container is recorded as an electronic signal over time, and corresponds to a volume of 1/100th (0.01) of an inch of rainfall. This allows for the capture of a discrete series of precipitation measurements over time.
Recording	Weighing Bucket 	The weighing bucket rain gauge consists of a rainfall collection reservoir that rests on a scale. Rainfall collected inside the reservoir exerts a weight proportional to the volume of rainfall, which is then recorded on a clock-driven chart. Thus, a continuous account of precipitation over time is achieved, usually in the form of a 7-day graph. The weighing bucket rain gauge allows the analyst to discern rainfall depth to the nearest 1/100th (0.01) of an inch.
Recording	Float-Type Stilling Well 	The float-type stilling well rain gauge provides continuous precipitation data by using a float mechanism inside the rainfall collection reservoir. Rainfall enters the collection chamber through a funnel to minimize disturbance of the water surface. A stilling device is located inside the reservoir to lessen erroneous oscillations caused by incoming water. The position of the float is recorded by a pen-trace system on a clock-driven chart to generate a plot of rainfall over time, usually in the form of a 30-day graph.
Non-recording	Standard 	The standard rain gauge is a simple device that contains no mechanical components and is non-recording. The gauge itself consists of a collection area, funnel, and collection reservoir. Manual readings are typically made on a daily basis with a measuring stick calibrated to express rainfall volume in inches. Measurements are recorded in a field log to the nearest 1/100th (0.01) of an inch.

Rainfall is traditionally measured at a "point" using various types of rain gauges such as the non-recording cylindrical container or the recording weighing, float and tipping bucket. Three types of recording rain gauges are used by the District, and include tipping bucket, weighing, and float-type gauges.

The tipping bucket rain gauge is the preferred instrument for measuring rainfall due to its relative ability to minimize systematic sampling errors and transmit data via telemetry (SFWMD, 2004b). A tipping bucket rain gauge measures the amount of rainfall by the tips of the bucket (**Figure 19**). Each time the bucket tips, one event is recorded. Each event represents 1/100th (0.01) of an inch of rainfall. A magnetic sensor in the gauge sends a signal to the event recorders, data loggers, or other data acquisition devices. Utilizing real-time radio frequency telemetry through a series of repeater networks, the data collected can be sent to the District.

Figure 19. View inside of a tipping bucket.

a. Rain Gauge Limitations

Point Measurements

Precipitation gauges are capable of providing accurate point measurements of rainfall. However, rain gauges alone cannot feasibly provide spatial rainfall distributions necessary for use in hydrologic modeling applications (Huebner et. al., 2003). As a result, several approximation techniques have been developed for the aerial extrapolation of point gauge measurements to estimate mean precipitation. These techniques include the arithmetic mean method, the Thiessen polygon method, the isohyetal method, and the inverse distance squared method. The isohyetal method is not commonly used at the District due to the minimal variability in elevation of the South Florida region.

These rainfall-averaging techniques assume mathematical representations of rainfall distributions, which may not be indicative of actual precipitation characteristics. In addition, approximation techniques may not account for rainfall values which may be higher or lower than those observed at gauge locations, specifically during convective and tropical events (Sangoyomi and Dawkins, 2005). As a result, adopting approximation techniques may introduce a significant amount of error.

Rain gauges may not accurately capture rainfall events that demonstrate high spatial variability. Such events include convective and tropical disturbances that predominate in South Florida during the wet season. Huff (1970) demonstrated the pronounced spatial variability of rainfall rates in Illinois “within and between convective storms” by using a dense network of recording rain gauges, concluding that accurate sampling of convective precipitation may not be feasible for areas greater than 100 square miles. The District realizes that highly variable storm events “may not be captured by the current District rain gauge network” and that this represents a major limitation in the continued use of rain gauge technology.

Equipment Maintenance

Precipitation gauges require a considerable amount of general maintenance in the form of periodic calibration and cleaning, which are time consuming and expensive. Individual gauges must also be attended to when they are not working properly or are in need of relocation or upgrade. Equipment malfunction can also result in the loss of data. Data gaps resulting from mechanical or electrical failure hinder subsequent hydrologic analysis and decision making.

Random and Systematic Errors

Errors produced in rain gauge sampling are generally classified as random or systematic. Random errors are caused by irregular fluctuations in the measurement of rainfall but tend to naturally decrease in magnitude as more samples are taken. Such errors are deemed unavoidable. Conversely, systematic errors produce consistent measurement inaccuracies, thus, introducing bias. Some common systematic errors in precipitation sampling include errors due to wind, obstructions, evaporation loss, wetting loss, and instrument errors. Systematic errors must be reduced as much as possible to obtain the most accurate rainfall data available from a given rain gauge network (World Meteorological Organization, 1996).

One of the greatest sources of error to consider is undercatch of precipitation due to wind effects (World Meteorological Organization, 1996). Linsley et al. (1975) described gauge catch deficiency as a function of wind speed at the height of the gauge orifice, and further concluded that wind speeds exceeding 20 miles per hour may result in an overall error of 20 percent or more. Similarly, Pathak (2001) reported that “rainfall amounts are under estimated due to wind, and are under estimated as much as 1 percent (of rainfall) per mile per hour (mph) of wind speed.” Guo et al. (2001) developed a model to estimate undercatch as a function of wind speed and gauge height. Findings from this study conclude that “rain undercatch ranges from 10 percent to 15 percent under 15 mph wind and can increase to 56 percent under 50 mph wind.” Therefore, error produced by wind may be considerable in South Florida, as thunderstorms can produce winds of up to 50 mph and tropical events demonstrate wind speeds of 38 mph to over 156 mph (National Hurricane Center, 2006).

Other systematic errors in rain gauge measurements are caused by evaporation and wetting loss. Evaporation is primarily a problem in non-recording gauges when the collection reservoir is not protected. Error associated with wetting loss, or the loss of rainfall that adheres to the collection system itself without being collected, is also more prevalent in non-recording gauges (World Meteorological Organization, 1996). The presence of insects, leaves, and other debris can clog gauges or otherwise offset actual readings and lead to error. In addition, the placement of sampling instruments in the proximity of obstructions such as buildings and trees can affect rain gauge accuracy.

Instrument errors result from inaccuracies caused by sampling equipment, and vary according to rain gauge type. Sampling errors specific to the tipping bucket (TB) rain gauge have been studied extensively as the TB gauge is the choice gauge for many hydrologic applications. Nystuen (1999) conducted a study in Miami over a 17-month period to analyze the relative performance of several rain gauge types in different rainfall conditions, including convective, frontal, and tropical event (one occurrence). The investigation concluded that the TB rain gauge consistently underestimated measurements during extremely high rainfall rates. Nystuen (1999) attributed this occurrence to "water loss between tips," meaning that a fraction of rainfall may bypass sampling in heavy rainfall events when rainfall accumulates faster than the bucket mechanism can tip. TB gauges are also known to exhibit error due to splashing of rainfall from the collector during intense rainfall events. These findings suggest that the TB gauge may not be best suited for determining rainfall amounts during periods of heavy rainfall. To adjust for these inaccuracies, the District performs regular monthly calibration of TB gauges. The gauges are also calibrated between servicing when QA/QC pre- or post-processing reveals that measurements are consistently low.

2. Breakpoint Rain Gauge Stations

The District uses various methods for the acquisition of precipitation data collected at its rain gauge sites. Data transfer occurs through two different processes: the District's supervisory control and data acquisition (SCADA) system and the manual transport of data. The SCADA system provides direct acquisition of real-time rainfall data wirelessly by means of microwave, radio-frequency telemetry, or telephone lines. The system is also known as Automated Acquisition and Monitoring System (ARDAMS). A major advantage in the use of telemetry, within SCADA, is the transmittal of real-time data, which is pertinent in situations requiring rapid data acquisition and response.

a. Real-Time Rain Gauge Stations

Tipping bucket rain gauges connected to the SCADA system rely on three types of remote terminal units (RTUs) to provide near real-time data: Campbell Scientific CR10X-TDs (LoggerNet), Motorola SCADA (MOSCAD), and Legacy Master Concentrator Unit/Remote Access and Control Units (RACU). Detailed information regarding these RTUs and associated reporter types is presented in **Table 8**. **Figure 20** shows the location of the real-time rain gauge stations.

Table 8. Rain gauge reporter types – real-time SCADA system.

Remote Terminal Unit (RTU)	Reporter Type	Method of Data Transfer	Data Collection Frequency
Campbell Scientific CR10	LoggerNet System	Telemetry	Real Time
Motorola SCADA	MOSCAD	Telemetry	Real Time
Legacy MCU/RACU	RACU	Telemetry	Real Time

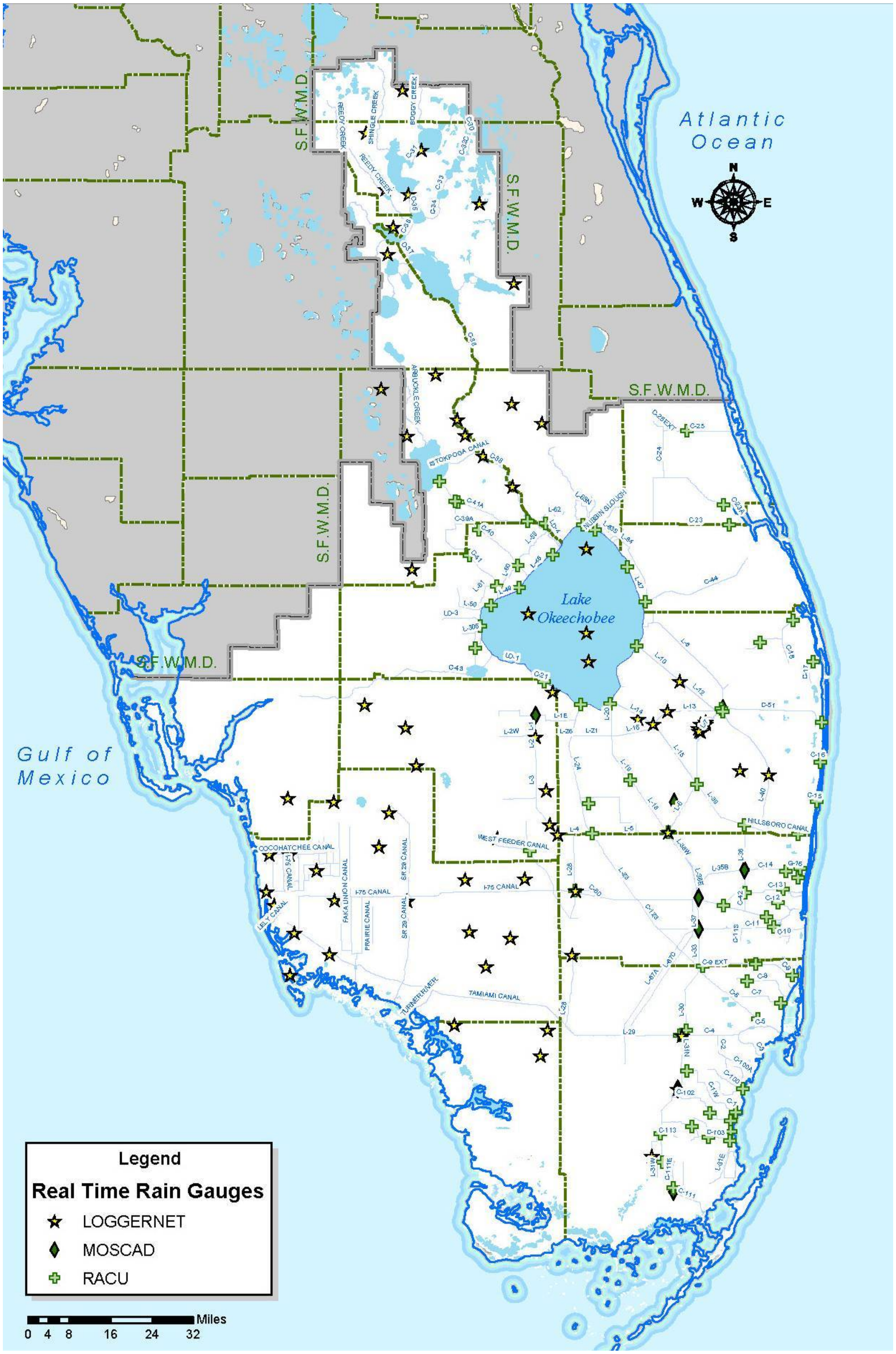

Figure 20. Location of real-time rain gauges in the District.

b. ARDAMS (Daily Rain Gauge Data Retrieval) Stations

SCADA also delivers daily accumulation data through ARDAMS, which transmits data electronically over phone lines and/or radio frequency telemetry. From several locations with Campbell Scientific CR10 data loggers, the electronic data are transferred after midnight every day via phone lines. These stations are grouped under the ARDAMS system. **Figure 21** shows the location of the CR10 rain gauge stations that provide the data via the ARDAMS system.

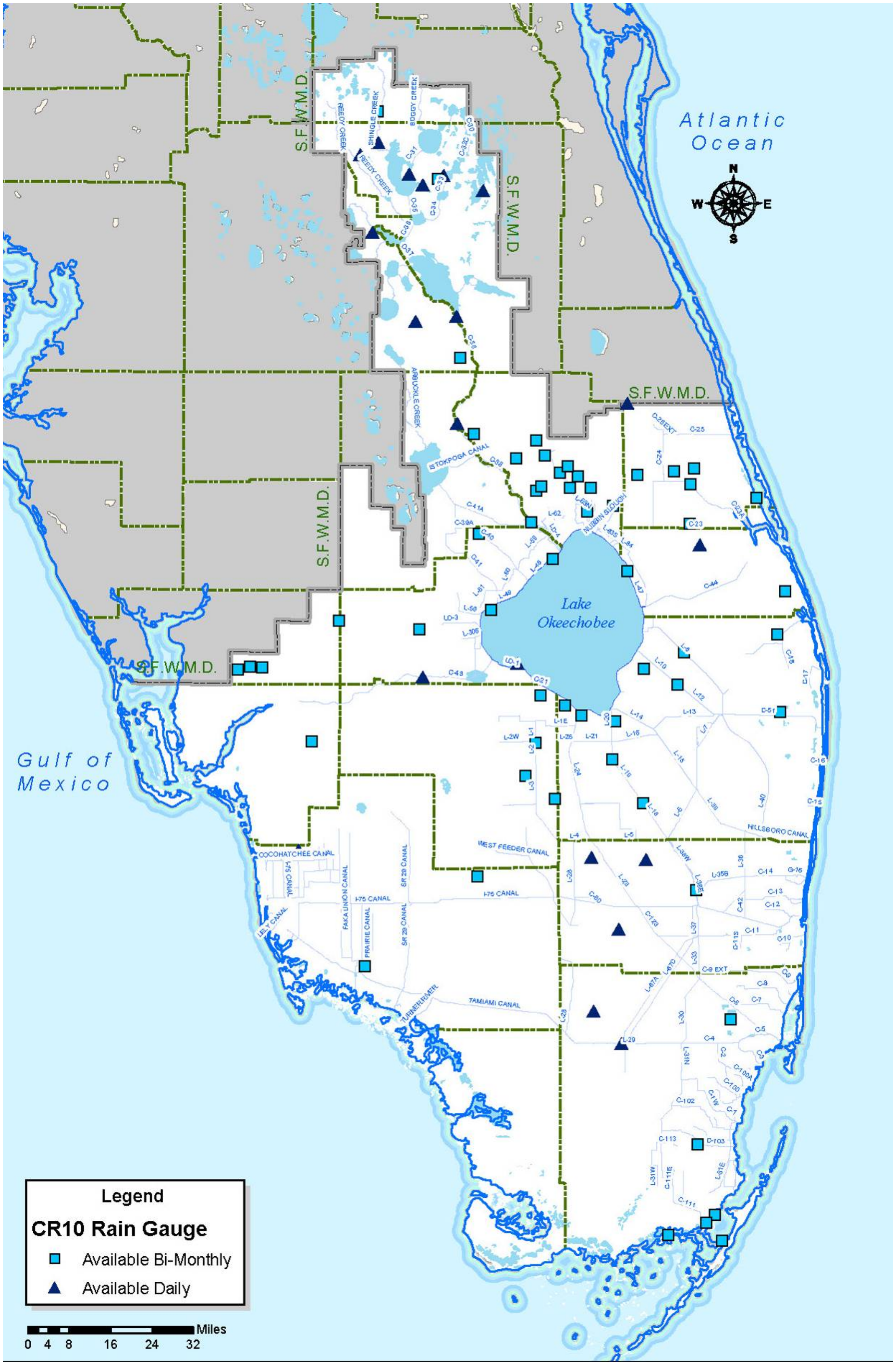

Figure 21. Location of the daily CR10 rain gauge stations.

c. CR10 (Monthly Rain Gauge Data Retrieval) Stations

In addition to RTUs required for data acquisition via SCADA, two other reporter types are used to manually transfer rainfall data. They include stand-alone Campbell Scientific CR10 data loggers (which, when not connected to the LoggerNet or ARDAMS systems, provide precipitation data that can be downloaded from the RTU each month and manually transported to the District); and graphic charts (a product of weighing and float-type rain gauges, and daily readings from standard-type rain gauges, which are recorded in field logs). **Table 9** summarizes the type of manually downloaded electronic data from this rain gauge reporter type in use. **Figure 22** shows the location of the CR10 rain gauge stations that have data downloaded on a monthly basis.

Table 9. Rain gauge reporter type – manual acquisition of electronic data.

Data Logger	Reporter Type	Method of Data Transfer	Data Collection
Campbell Scientific CR10	CR10	Manual acquisition of electronic data	Once per month

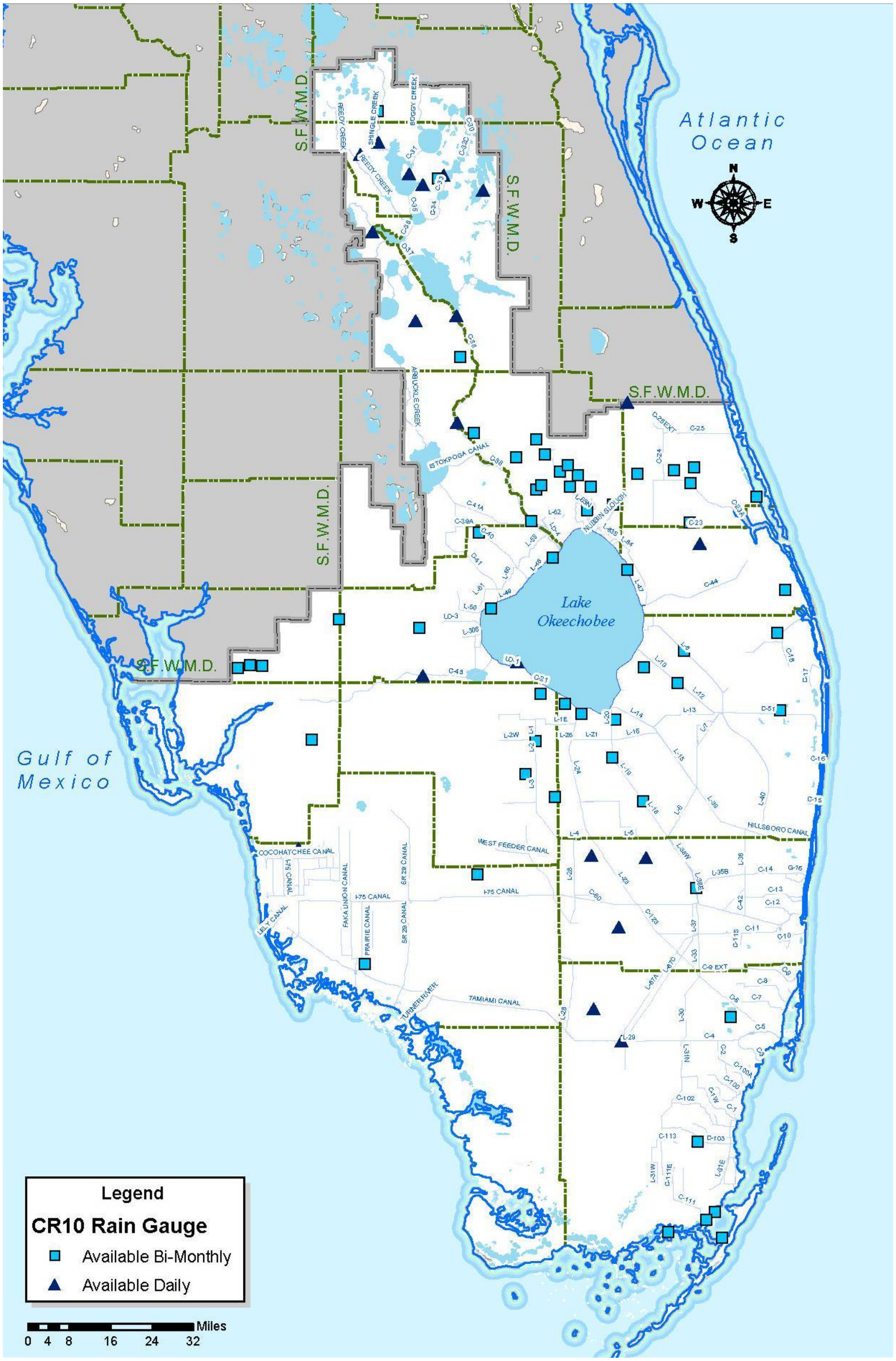

Figure 22. Location of bi-monthly CR10 rain gauges in the District.

3. Daily Rain Gauge Data Stations

Daily rainfall measurements are manually taken from standard rain gauge (non-recording type) installations at approximately 7:00 AM Eastern Standard Time (EST). Several limitations exist in the manual transfer of data from rain gauge sites to the District. This procedure requires that dedicated District personnel physically obtain the necessary daily, weekly, or monthly precipitation data at each rain gauge site. Obtaining the daily rainfall data can be problematic during holiday and weekend periods as District personnel are not always available to manually record the data for these days. In addition, data collected manually may incorporate more error by the analyst or from visual interpretation of the data in the field. **Table 10** summarizes the active types of manually collected data from these rain gauges. **Figure 23** shows the location of the non-recording type rain gauge stations that provide daily rainfall data.

Table 10. Rain gauge reporter types – manual data acquisition.

Manual Data	Reporter Type	Method of Data Transfer	Data Collection
Graphic Chart	Graphic Chart	Manual data transport	Once per month
Daily Data	CO-OP Log	Manual data transport	Daily

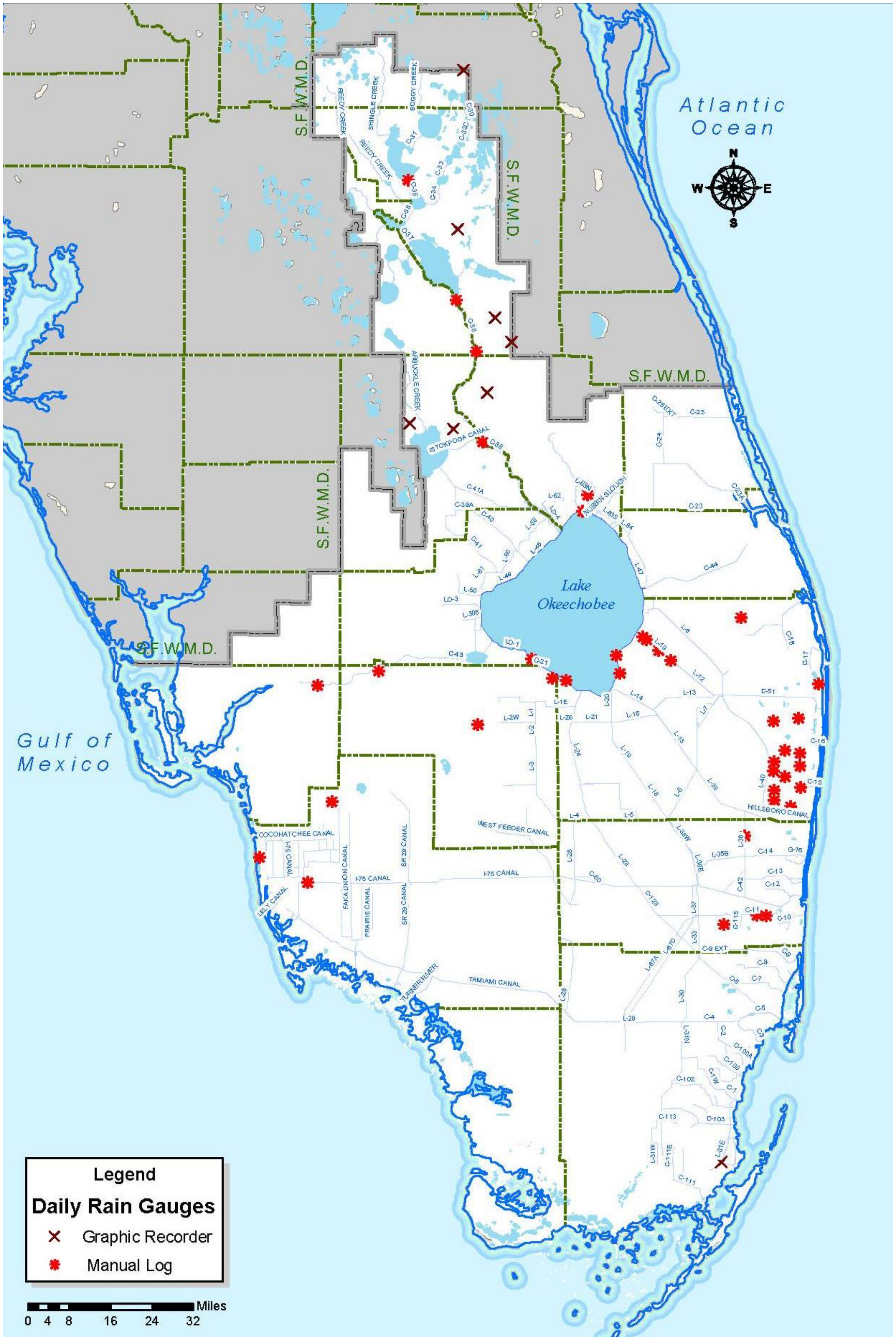

Figure 23. Location of non-recording daily rain gauges.

C. NEXRAD Rainfall Data

Radar images from the U.S. National Weather Service network cover much of the United States and provide a way of measuring the intensity of rain or snowfall. Radar can locate and follow clouds within a range of 200 to 400 kilometers. Weather radar emits microwave energy in short bursts or pulses, which are focused in a narrow conical beam that scans the atmosphere from a slowly rotating antenna. A beam passes through fog and clouds, but when it encounters rain, snow or ice particles (hail), some of the energy is scattered back to the radar's antenna as an echo. The amount of energy the antenna receives, is proportional to the intensity of the precipitation; the heavier the rain or snow, the more energy is scattered back to the antenna.

There is a statistical tradeoff between rainfall measurement data collected by rain gauges and weather radar. Rain gauges can provide precise point values of rainfall depth and intensity but cannot economically provide the spatial distribution of rainfall. While rain gauges suffice for frontal-related rainfall events, the timing and orientation of the front is often not well represented and can miss convective rainfall events altogether. South and Central Florida receive most rainfall during the wet season, which is dominated by tropical and convective processes.

Next Generation Radar (NEXRAD) or Weather Surveillance Radar 88 Doppler (WSR-88D) data provides complete spatial coverage of rainfall amounts unobtrusively using a predetermined grid resolution (usually 2 km by 2 km or 4 km by 4 km) (**Figure 24**). The NEXRAD rainfall data is limited by relying on the measurement of raindrop reflectivity, which can be affected by factors such as raindrop size and signal reflection by other objects. Because the reflected signal measured by the radar is proportional to the sum of the sixth power of the diameter of the raindrops in a given volume of atmosphere, small changes in the size of raindrops can have a dramatic effect on the radar's estimate of the rainfall. For this reason, the radar is generally scaled to match volume measured at the rain gauges (Hoblit and Curtis, 2000). The best of both measurement techniques is realized by using rain gauge data to adjust NEXRAD values. The readers can obtain additional information on this subject from several references (Huebner et al., 2003 and Skinner, 2006) that are shown in this report.

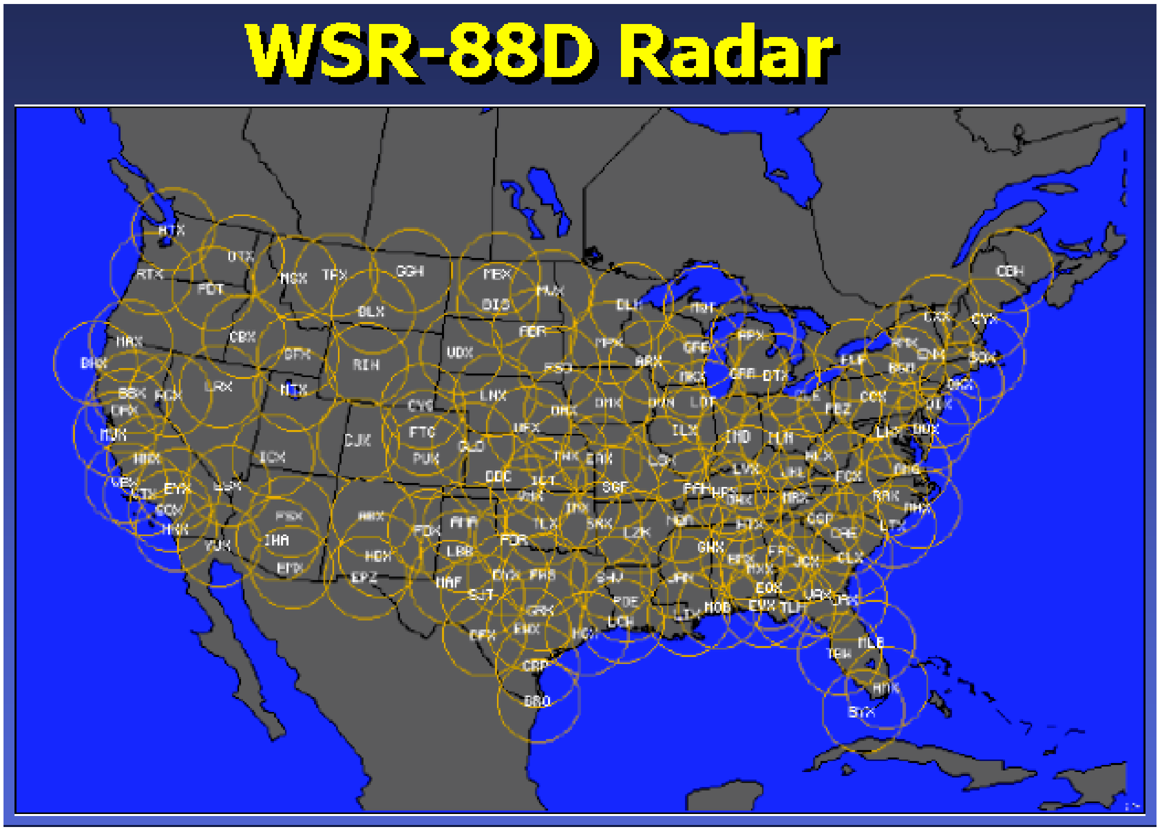

Figure 24. NEXRAD ground-based radar network – Doppler WSR-88D radar covering the U.S.

Four NEXRAD sites operated by the National Weather Service (NWS) cover the District: KBYX in Key West, KAMX in Miami, KMLB in Melbourne, and KBTW in Tampa. Although data is also available from several private radar installations, the District exclusively uses NWS sites for its NEXRAD rainfall database due to longevity and reliability issues. NEXRAD technology offers the distinct advantage of providing water management officials with a spatial and temporal account of rainfall variability. In July of 2002, the District started acquiring NEXRAD rainfall data. Skinner (2006) provides additional details on the NEXRAD rainfall data and gauge-adjustment methodology used in derivation of the data.

1. NEXRAD rainfall data acquisition

Weather data acquired from NEXRAD is used by the District in making decisions for operational purposes. However, the use has been largely limited to visual interpretation of data as opposed to quantitative analysis. Since 2002, the District has been acquiring NEXRAD data coverage from OneRain, Inc. (Huebner et al., 2003). In July 2002, the District in conjunction with three of the other four Florida water management districts began to acquire NEXRAD data coverage through a competitive contract awarded by the St. Johns River Water Management District to develop a corporate database and methods for data access. The use of a single vendor for processing NEXRAD data for the four water management districts provides an opportunity to eliminate data discontinuities at district boundaries. The use of 15-minute data (i.e., taken at 15-minute interval), rain gauge-adjusted NEXRAD data by the District's Operations Control Center (OCC) is a major objective of the acquisition.

a. Near real-time data

OneRain, Inc. provides near real-time, 15-minute rainfall amounts by using the following process:

1. Acquires 15-minute radar rainfall accumulations from the NWS via WSI Corporation, which uses an empirical look-up table to convert reflectivity values to rainfall intensities. Concurrently, 15-minute rainfall accumulation data from approximately 144 telemetry rain gauge sites are sent to OneRain, Inc. via File Transfer Protocol (FTP)
2. Adjusts radar rainfall amounts using gauge data algorithms
3. Adjusted radar rainfall depths are placed in a flat file and sent via FTP to the District
4. Checks the flat file for completeness and loads them into the Oracle® database

The process outlined above takes between 10 to 20 minutes; thus, the data is referred to as "near real-time." Each file contains 33,773 values, one value for each of the 2 km x 2 km cells in the grid covering the District. Each 15-minute interval file is 366 kilobytes (kb) in size and is loaded into the Oracle® database in less than 1 minute. The coverage includes a 35-mile area beyond the boundaries of the District. This provides rainfall information for such areas as the Biscayne and Florida bays. Data for other water management districts is processed concurrently to insure that there are no discontinuities at district boundaries.

b. End-of-month data

Near real-time data are verified each month and an end-of-month (EOM) verified set of 15-minute files is produced. The EOM files use additional 81 rain gauge data that are not available in real-time and a proprietary algorithm based on the Brandes method (Brandes, 1975) to adjust radar rainfall values. An expert from OneRain reviews the results to identify and correct any anomalies or apparent errors. When the EOM files are received by the District, the near real-time data are archived, primarily to preserve the information upon which operational decisions may have been made, and are replaced with the EOM verified data set.

2. NEXRAD Rainfall Data Availability

The NEXRAD coverage for the District (Huebner et al., 2003) includes rainfall amounts for 33,773, 2 km by 2 km cells, provided at 15-minute intervals. The current online database contains values from January 1, 2002, to the present. Each cell has a specific time series of rainfall data.

The table structure in the Oracle database complies with the Arc Hydro (Maidment, 2002) architecture. The current online database contains values starting on January 1, 2002, through present. Tables using an ArcHydro schema were produced in Oracle 8i to facilitate corporate implementation of ArcHydro and provide a common framework for accessing NEXRAD data. Several techniques were used to optimize the database and provide timely access to the database. These include storing only non-zero data values in the database and database partitioning based on the calendar year. The Arc Hydro structure was used to facilitate GIS access to the data and to support a uniform corporate database model that was consistent with a published standard, for hydrologic data.

Near real-time data is loaded directly to the Oracle database and can be accessed directly using SQL or ODBC drivers. An ArcIMS-based application (Pathak et al., 2005) is used for gauge-adjusted NEXRAD rainfall data retrieval. This web-based user interface (**Figure 25**) allows for users to access and aggregate 15-minute data for a specified period and produces a data file in ASCII format. The application provides varied spatially (such as rain areas, drainage basins, watersheds) and temporally (such as hourly, daily, event, monthly, and annual) aggregated datasets in tabular and image formats.

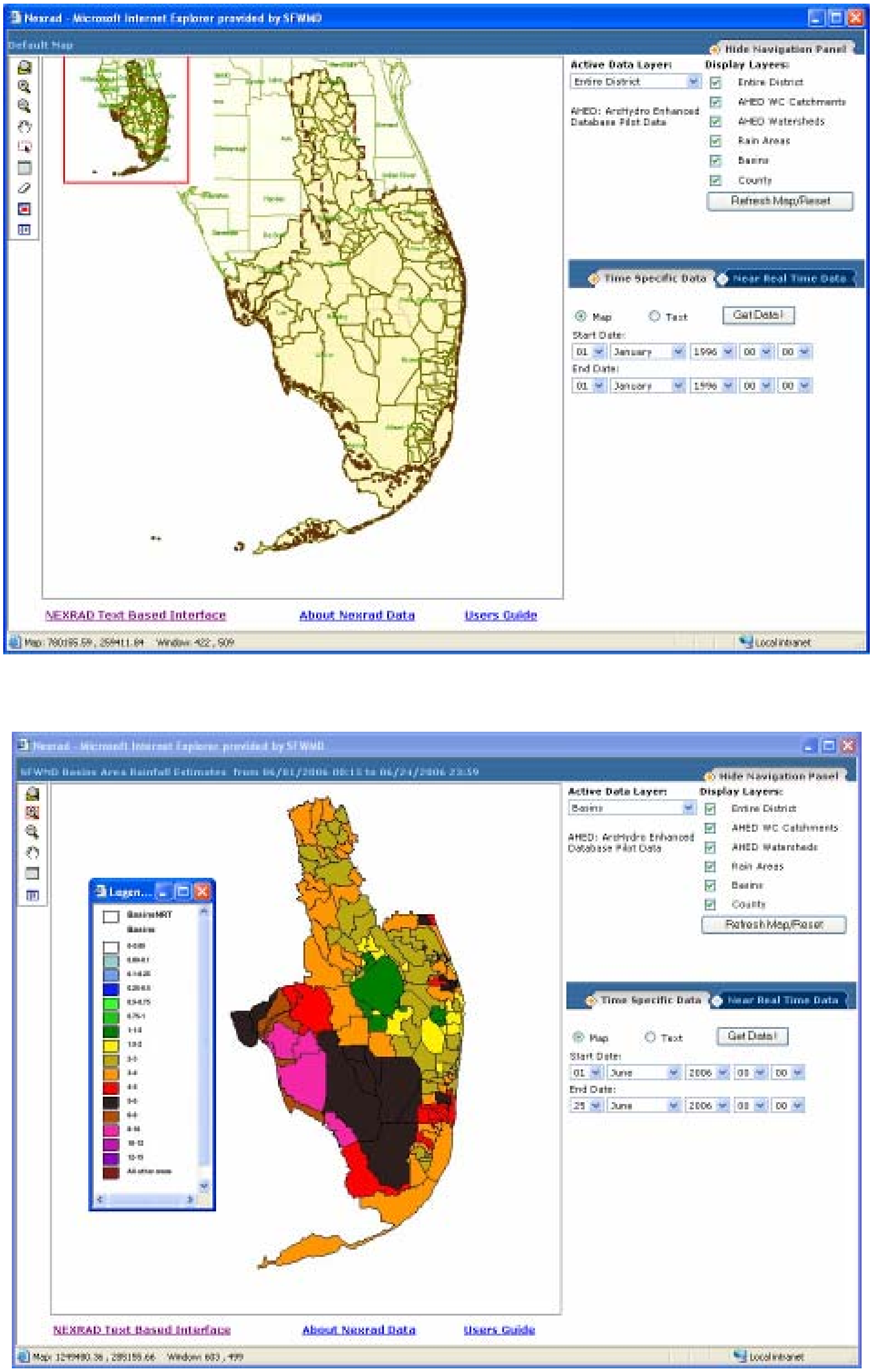

Figure 25. ArcMap-based NEXRAD data retrieval application: (A) input screen and (B) output.

D. Rain Gauge Data

The District operates an extensive network of 279 active rain gauges in order to obtain rainfall data necessary for use in operations, planning, and regulatory aspects of water management. The District's rain gauge network is shown in **Figure 26**. The rainfall data from 233 stations are available on breakpoint basis. The breakpoint data can be obtained in a format of 15-minute, hourly, and daily intervals from the DBHYDRO database. The rainfall data from the remaining 46 stations are available as daily rainfall (from non-recording rain gauges) in DBHYDRO database. Additionally, historical rainfall time series data from the District and other external government agencies are also available in DBHYDRO to both internal and external users.

Designation codes account for the different rain gauge reporter types used by the District (**Table 11**). **Table 12** provides the corresponding breakdown of the District's 279 current active rain gauge sites with respect to reporter type.

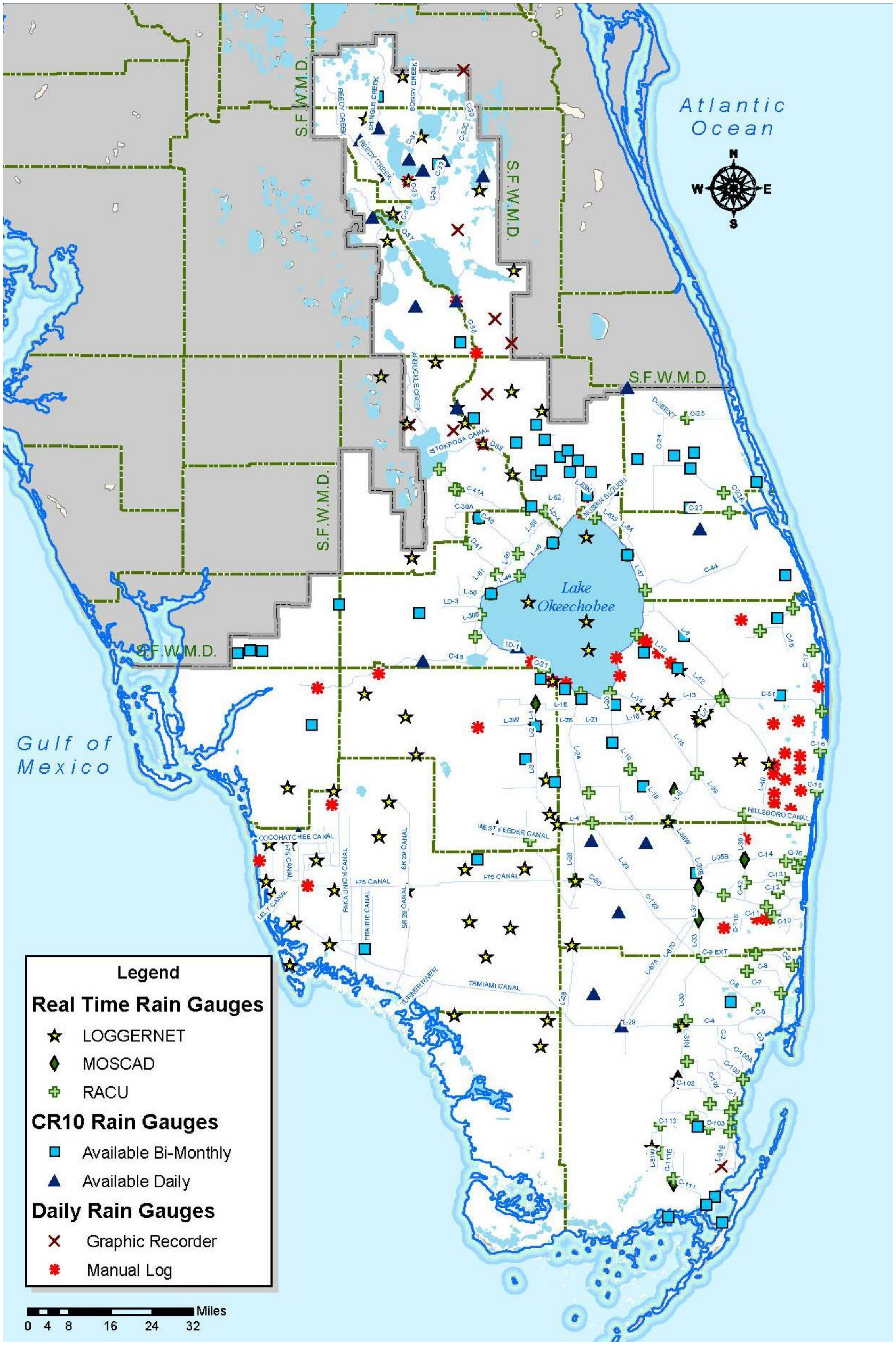

Figure 26. District rain gauge network.

Table 11. Rain gauge reporter codes and associated attributes.

Code	Reporter Type	Tipping Bucket Rain Gauge	Breakpoint Data	Reporting Time (EST)
SS ARDAMS	ARDAMS	Yes	Yes	Midnight-midnight
SS DMS	LoggerNet System	Yes	Yes	Midnight-midnight
SS CR10	CR10	Yes	Yes	Midnight-midnight
RACU	RACU	Yes	Yes	Midnight-midnight
MOSCAD	MOSCAD	Yes	Yes	Midnight-midnight
2A35 Graph and Weekly Graph	Graphic Chart	No	Yes	Midnight-midnight
CO-OP LOG	CO-OP LOG	No	No	7 AM - 7 AM

Table 12. Active 279 rain gauge station IDs and associated reporting attributes.

Break Point Data (233)						Daily Data (46)
Real-Time (144)			Received Daily (21)	Received Monthly (68)		
LoggerNet (66)	RACU (71)	MOSCAD (7)	ARDAMS (21)	CR10 (60)	Graphic Chart (8)	CO-OP LOG (46)
L005+R	CV5-R	S38-R	S78W+R	EAA2+R	MRF185	MRF101
L006+R	G56-R	G136-R	ENR308+R	FLYG+R	MRF187	MRF102
S5AY-R	S123-R	S34-R	951EXT+R	JBTS+R	MRF3	MRF114
LZ40+R	S124-R	S9-R	KREF+R	PALM+R	MRF190	MRF135
S65CW+R	S13-R	S331M-R	EXOT+R	RUCWF+R	MRF158	MRF137
BCSI+R	S131-R	G331D-R	ALL2+R	SCRG+R	MRF155	MRF138
CFSW+R	S153-R	S5AE-R	3AS+R	TPTS+R	MRF23	MRF213
S61W+R	S155-R		LOKEEM+R	MDTS+R	MRF123	MRF250
LXWS+R	S177-R		TOHO10+R	DAV2+R		MRF27
ENR203+R	S18C-R		TOHO2+R	LEHI+R		MRF285
ENR101+R	S2-R		3AS3W3+R	WHID+R		MRF299
ENR301+R	S20F-R		3ANW+R	OPAL+R		MRF300
S331W+R	S20G-R		S12D+R	WLNB+R		MRF301
L001+R	S21-R		3ANE+R	SIRG+R		MRF419
ENR106R	S26-R		KISSFS+R	SBAY+R		MRF5002
S59+R	S28Z-R		CREEKR+R	HOMEFS+R		MRF5004
S336+R	S29-R		INDLK+R	MIALCK+R		MRF5006
BELLW+R	S29Z-R		S65GW+R	PEL23+R		MRF5034
COCO1+R	S33-R		INRCTY+R	S5A+R		MRF5053
CORK+R	S352-R		ROCK+R	3A-36+R		MRF54
WCA1ME+R	S36-R		ACRA2+R	RITTA+R		MRF57
IMMOLF+R	S37A-R			TOWNSI+R		MRF63
COLSEM+R	S37B-R			ALICO+R		MRF78
COLGOV+R	S39-R			SIXL3+R		MRF81
WRWX+R	S40-R			S70+R		MRF90
FPWX+R	S41-R			S65E+R		MRF92
KRBN+R	S44-R			S135+R		MRF133

Table 12. (continued)

Break Point Data (233)						Daily Data (46)
Real-Time (144)			Received Daily (21)	Received Monthly (68)		
LoggerNet (66)	RACU (71)	MOSCAD (7)	ARDAMS (21)	CR10 (60)	Graphic Chart (8)	CO-OP LOG (46)
G600+R	S46-R			S127+R		MRF317
S7WX+R	S5A-R			S131+R		MRF85
S140W+R	S6-R			TCS2+R		MRF151
3ASW+R	G54-R			MOBL+R		MRF243
S6Z+R	S174-R			DUP3+R		MRF32
S65DW+R	S21A-R			MIAMI+R		MRF38
PC61+R	S8-R			DANHP+R		MRF93
BCA15+R	C18W-R			SVWX+R		MRF18
BCA16+R	S332-R			JDWX+R		MRF198
BCA17+R	S169-R			WPBFS+R		MRF212
BCA18+R	S70-R			FTPIER+R		MRF286
BCA19+R	S72-R			SCOTTO+R		MRF144
BCA20+R	S49-R			BLUEG+R		MRF5029
NAPCON+R	S97-R			BSET+R		MRF84
ENR401+R	S99-R			C24SE+R		MRF88
GOLDF2+R	S71-R			TOHO15+R		MRF303
S5AX+R	S68-R			BRD05R		MRF423C
KIRCOF+R	S83-R			RUCKGW+R		NSID1@R
SGGEW+R	S84-R			MICCO+R		RF376
BRYGR+R	S135-R			EAA4+R		
COCO3+R	S191-R			EAA5+R		
MARCO+R	S127-R			TICK+R		
ROOK+R	S129-R			OKEEFS+R		
OKALN+R	S133-R			COWCRK+R		
OKALS+R	S154-R			FLYGW+R		
FKSTRN+R	G57-R			STA5W+R		
L2GW+R	S47B-R			S75WX+R		
GRFFTH+R	S190-R			PAIGE+R		
AVONPK+R	S167-R			POPASH+R		
PEAVIN+R	S179-R			DCRK+R		
PINEIS+R	S165-R			GTRSLU+R		
SNIVLY+R	S30-R			BASING+R		
KENAN1+R	S334-R			WPBWCA+R		
TAFT+R	S335-R					
POINCI+R	S338-R					
LOTELA+R	S82-R					
SEBRNG+R	S75-R					
BCA4+R	S125-R					
VENUS+R	S7Z-R					
	S7-R					
	S27-R					
	S140-R					
	S3-R					
	G300-R					

1. *Rainfall Data Storage*

Rainfall data stored within DBHYDRO have been recorded since 1955 and includes breakpoint and non-breakpoint data. Breakpoint data are stored in DCVP database. Breakpoint data are accessible in 15-minute, 30-minute, hourly, and daily time intervals, while non-breakpoint data are available only as daily accumulation totals. Daily rainfall data are used most often at the District and represent the preferred time interval for many purposes, such as continuous simulation hydrologic modeling. This is because the daily rainfall time interval makes use of the full extent of rainfall data available through the rain gauge network, and also because daily rainfall data take up less storage volume in computer applications than data of smaller time increments.

Rainfall data codes, or tags, accompany daily rainfall data within DBHYDRO to provide users with an indication of rainfall data quality. A “null value” in the data code field corresponds to data that are missing. The “M” tag designates that rainfall data are missing, a code indicative of rain gauge equipment malfunction. The “X” data code designates that rainfall data are unknown. Rainfall data demonstrating the “X” tag are eventually followed with an “A” code, meaning that an accumulative amount of rainfall was measured over the time period indicated by the “X” tag. The complete record of DBHYDRO data codes used for rainfall and associated meanings are presented in **Table 1**.

2. *Data Quality Assurance/Quality Control*

The QA/QC post-processing analysis is a second set of operations, which extract pre-processed data from DBHYDRO for select stations to undergo further examination. Presently, data from approximately 20 District rain gauge stations receive additional processing due to legal mandates under the Florida Forever Act. Data that have undergone the additional scrutiny of the QA/QC post-processing analysis are known as “preferred data” and represent the “best available data” at the District (Sangoyomi and Dawkins, 2005).

E. Rain Gauge Network Optimization

The District performed a rain gauge network optimization study (SFWMD, 2006) to analyze the existing network and identify areas that have excess or deficiency of coverage. Specific recommendations were made for improvement of the existing rain gauge network that achieves a consistent level of accuracy across the District.

The optimization of an existing rain gauge network using NEXRAD radar rainfall data was performed within an optimal estimation framework that accounts for local rainfall patterns defined by spatial autocorrelation at hourly and daily timescales. The rain gauge network operates in combination with radar to produce the archival rainfall product for use in operational decision making. The methodology used the existing DBHYDRO rainfall data derived from the District’s rain gauge network and radar rainfall from calendar year 1995 to 2005 at a 2 km by 2 km resolution, which was the longest period available with a consistent method of estimation. The approach to network optimization was tailored to accomplish the District's objective of having an optimal rain gauge network that supports hydrologic monitoring at the hourly and daily intervals.

Rainfall measurement accuracy depends on statistical properties of the rainfall and its spatial distribution. A regular array of analysis blocks was used to account for variability in point rainfall processes from the rain gauge data and geo-spatial variability of the radar data. Using the optimal number of gauges per analysis block as a requirement, the existing gauge network was adjusted by recommending new, relocated, and removed gauges. The network design utilized existing gauges where possible, relocated gauges that were too closely spaced, and places additional gauges such that the optimal gauge number per analysis block was achieved.

The resulting network of 332 (154 proposed and 178 existing) gauges contained the number of gauges required to achieve the accuracy requirement of standard error of 0.3 inch, which was determined to be reasonable and acceptable to the District. Of the 154 proposed gauges, 133 are new and 21 are relocated. With the addition of new gauges in areas of insufficient coverage, removal of gauges from areas of excess coverage and relocation of existing gauges, the net increase will be 53 gauges. The proposed new network can be summarized as follows:

Proposed (new and relocated)	= 154
Existing Network	= 178
Resulting Network (total)	= 332

The proposed network with 332 rain gauges has an average spacing of 12.3 km, or 150.6 km^2 per gauge (**Figure 27**). The result of this analysis was a rain gauge network of variable density that takes into account rainfall statistical properties, and the covariance structure of the rainfall field. Implementing these recommendations will provide a network that has a more varied density and achieves a consistent level of accuracy across the District.

Follow up work of this study is expected to be performed in fiscal year 2007. In this second phase of the work effort, potential proposed locations of the new rain gauges will be identified. In addition, implementation strategy of the recommendations would be also developed.

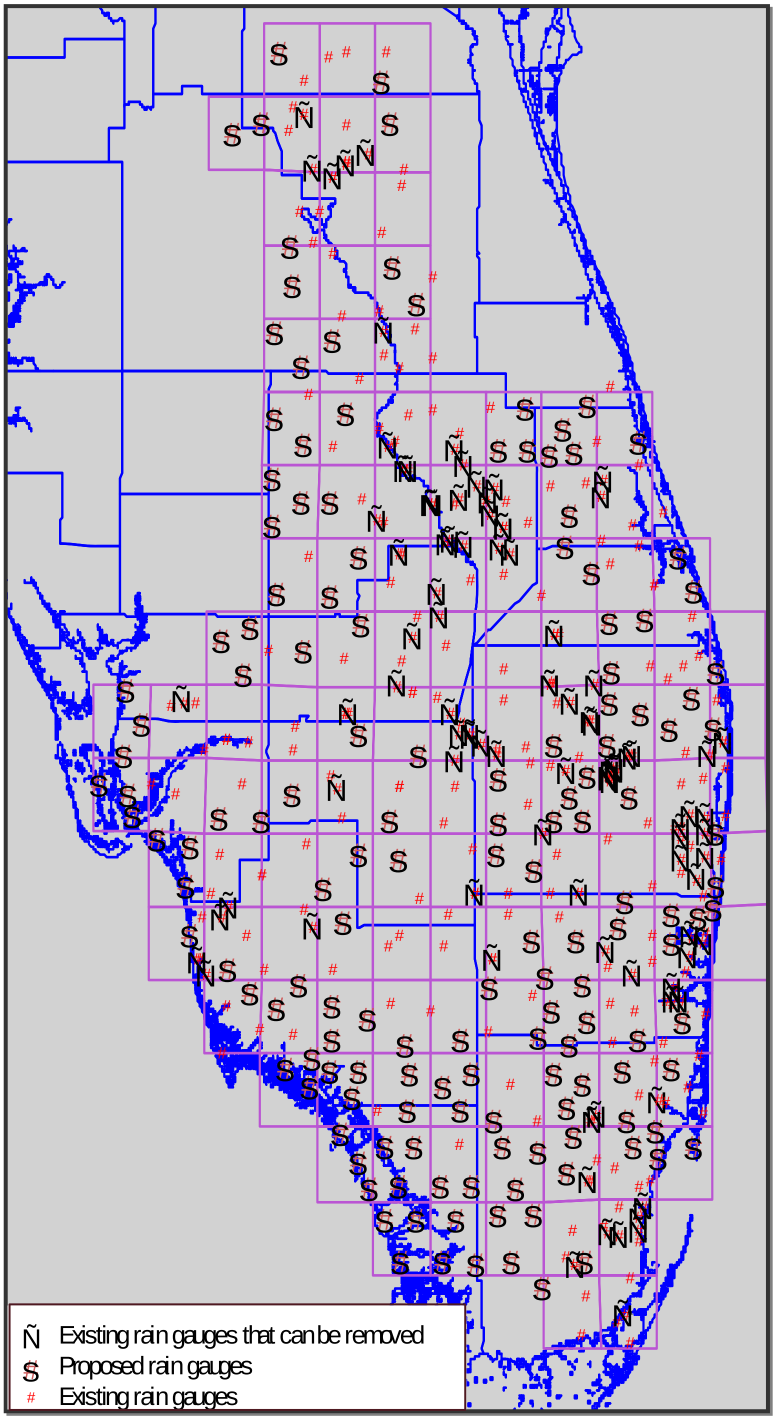

Figure 27. Proposed rain gauge network.

V. SURFACE WATER STAGE MONITORING NETWORK

By Chandra Pathak and Madhav Pandey

"Stage" is defined as the height (elevation) of the water surface above an established datum. Stage is usually expressed in units of feet or in meters above a datum (or point of reference). There are two vertical datums currently used in South Florida: the National Geodetic Vertical Datum of 1929 (NGVD 29) and the North American Vertical Datum of 1988 (NAVD 88). The District monitors both surface water and groundwater levels; however, this section only addresses surface water levels. Accurate water level data are used by engineers, scientists and water managers to make operational decisions (i.e., gate openings and pump activity). These data are also indispensable for estimating flows at hydraulic (water control) structures and other District flow-monitoring sites (SFWMD, 2004a).

Surface water levels (or stage) measurements are typically made in canals, lakes, rivers, springs, wetlands, reservoirs, estuaries, and water control structures. The term "stage" is synonymous with water level. The term "stage" is also used to reference the parameters of headwater (upstream) and tailwater (downstream) water levels at water control structures in the District's canal systems. Surface water data is recorded based on the elevation relative to a standard reference and expressed in units of feet. Surface water levels in a water body are influenced by the size of the contributing drainage basin, amount of rainfall in the basin, and inflow from groundwater withdrawals and groundwater recharge. Rainfall can increase water levels in the District canals significantly and trigger changes in water control structure operations (SFWMD, 2004a).

The actual accuracy and precision of stage measurements depends upon the instrumentation used. The stage of a water body can either be determined continuously (as a time series) from a variety of instruments that measure water-surface elevation, or intermittently by "systematic" manual observations of a non-recording staff gauge (SFWMD, 2004a).

Continuous water-level measurement devices include stage recorders that measure and record the surface elevation of the water. Water-level measurements require the use of "stilling wells" to accommodate the stage recorder, and to damp out natural oscillations of the water surface. Some stage recorders utilize a float on the surface of the water which is attached to a moveable gear in the recorder. A rise or fall of the water surface causes the float to rise or fall. This rotates the gear and the movement is recorded. Other stage recorders (or sensors) monitor either relative or absolute pressure at a point under the water surface. This pressure measurement can then be converted to the height of the water surface (SFWMD, 2004a).

A data collection platform (DCP) will store these data in a remote terminal unit and transmit the data through satellite transmission or phone modem to the District database. Non-recording gauges, such as a vertical staff gauge (**Figure 28**) are mostly installed adjacent to continuous recording gauges for use as an auxiliary reference (SFWMD, 2004a).

Figure 28. Stilling well and stage recorder (left) and vertical staff gauge (right).

A. Development of the Surface Water Stage Monitoring Network

Several manual surface water stage gauges were installed in various locations of South Florida in the early 1900s by the USGS. The District began operating its own surface water stage gauges after 1979, with the number of gauges growing since then. During that time, the stage gauges were added based on the project needs of the District. Additionally, during this time, many of the manual stage gauges were replaced by various recording devices that included varied levels of automation of stage data collection. **Table 13** shows the total number of stage gauges that were used in data collection on a decade basis with a significant increase after 1990.

Table 13. Total number of surface water stage gauges at the District between 1950-2005.

Years	Total Number of Stage Gauges
1950-1959	1
1960-1969	76
1970-1979	158
1980-1989	305
1990-1999	747
2000-2005	931

The existing stage gauge network was not designed, but it evolved based on the project needs of the District. The network contains several surface water stage gauges that are located in lakes, wetland areas, and upstream, and downstream of water control structures. The stage gauges have been used to operate water control structures that regulate flows from lakes and canals which in turn changes surface water stages in the hydraulically connected water bodies (SFWMD, 2004a).

B. Existing Surface Water Stage Network

1. Field Instrumentation at the Station

The accuracy and precision of stage measurements depends upon the instrumentation used. There are several types of water level/stage devices available, but the two basic types are recording and non-recording. Recording type instruments keep track of stage levels at preset intervals and non-recording gauges require a field observer to read stage height from a gauge.

Recording devices measure stage continuously (as time series data) with automatic sensors (float/counterweight, shaft encoders, pressure transducers, ultrasonic, acoustic, etc.) interfaced with RTUs. Stage measurements require the use of a stilling well to reduce errors induced by surges and wind wave action. A stilling well is a chamber that is hydraulically connected to the river through intake pipes. The stilling well eliminates turbulence that may occur in the river and the elimination of waves and surges results in more accurate readings. Measuring sensors are placed inside stilling wells to measure the water levels relative to a standard reference (**Figure 28**).

Recording devices can be grouped into one of the following categories: (1) mechanical, (2) electronic, or (3) combination. Mechanical types include digital punched paper tape and analog graphical strip chart recorders. Analog strip chart recorders convert rotational shaft positions into the position of an ink pen on a graphic chart. As the chart moves by the pen, an analog graph representing the action of the water level over time is generated. Punched paper tape recorders convert rotational shaft position into coded digital information and periodically record this information as punched holes in paper tape. Combination recording devices use both mechanical and electronic technology. The shaft is positioned mechanically, but the position of the shaft is sensed and recorded electronically. Totally electronic devices such as the acoustic transducers use the liquid/air interface as the measuring point and therefore require no mechanics. Both combination and electronic recording devices record water-level measurements digitally and store the values in the RTU (e.g., solid-state data logger) memory.

A simple non-recording gauge is the vertical staff gauge. Vertical staff gauges are commonly used as reference gauges in stilling wells; or could be attached to a bridge piling or other permanent, fixed structure, or in the river channel itself. Staff gauges require a field observer to take regular measurements. Staff gauges are usually used as reference gauges for setting a water level (stage) recorder. However, in some instances staff gauges are installed without a recording device, when the gauges are usually observed at a predetermined frequency (most often on daily time interval).

The District acquires stage data at various time intervals depending on the “type” of instrumentation actually installed at a specific location within the District’s stage monitoring network. District’s SCADA system acquires real-time data from Mototrola SCADA (MOSCAD) RTUs, Legacy Master Concentrator Unit/Remote Access and Control Units (RACU) RTUs and Campbell Scientific CR10X-TD (LoggerNet) RTUs. The District also receives breakpoint data from CR10X (ARDAMS) RTUs on a daily basis (mid-night to mid-night) via phone lines and radio frequency telemetry. Some stage data are acquired from the U.S. Geological Survey (USGS). The reasons for stage data problems and data changes are varied; among them are datum adjustments (reference elevation changes) and instrumentation and/or communication network problems.

2. Active Surface Water Stage Gauge Stations

Information on all the active surface water stage gauges was obtained from the DBHYDRO database. The stage gauge network has been expanding rapidly due to Acceler8 and CERP projects. If the stage gauge has been collecting the data as of December 31, 2005, it was considered as an active stage gauge. The surface water stage network was grouped into four groups – water control structures, wetland areas, lake areas and others (such as canals, small ponds, and other water bodies).

a. Surface Water Stage Gauges at Water Control Structures and Flow Monitoring Sites

A pair of stage gauges, both upstream and downstream of a water control structure, are used for estimating flow volumes that pass through the structure. The data from these gauges are used for water management purposes that vary with wet and dry seasons. Presently, there are 412 pairs of stage gauge stations located near 412 structures. These locations account for a combined 824 stage gauges. In addition to this total, there are 12 single stage gauges (located near two spillway structures, two weirs structures, and eight index-velocity meter stations) for a total of 836 stage gauges that are used in estimating flows at the flow monitoring sites. **Figure 29** shows the location of the stage monitoring stations at the flow monitoring sites.

b. Surface Water Stage Gauges in Wetland Areas

There are 53 stage gauges located in the wetland areas of the District. **Figure 30** shows the location of the stage monitoring stations within the wetland areas. The stage data collected from these stations are used for various purposes including hydrological, ecological, and biological conditions of the wetland areas.

c. Surface Water Stage Gauges in Lake Areas

In the lake areas of the District, there are 25 stage gauges. **Figure 31** shows the location of these stage monitoring stations within the lake areas. The stage data collected from these gauge stations are used for various purposes including hydrological, ecological, and biological conditions of the lake areas.

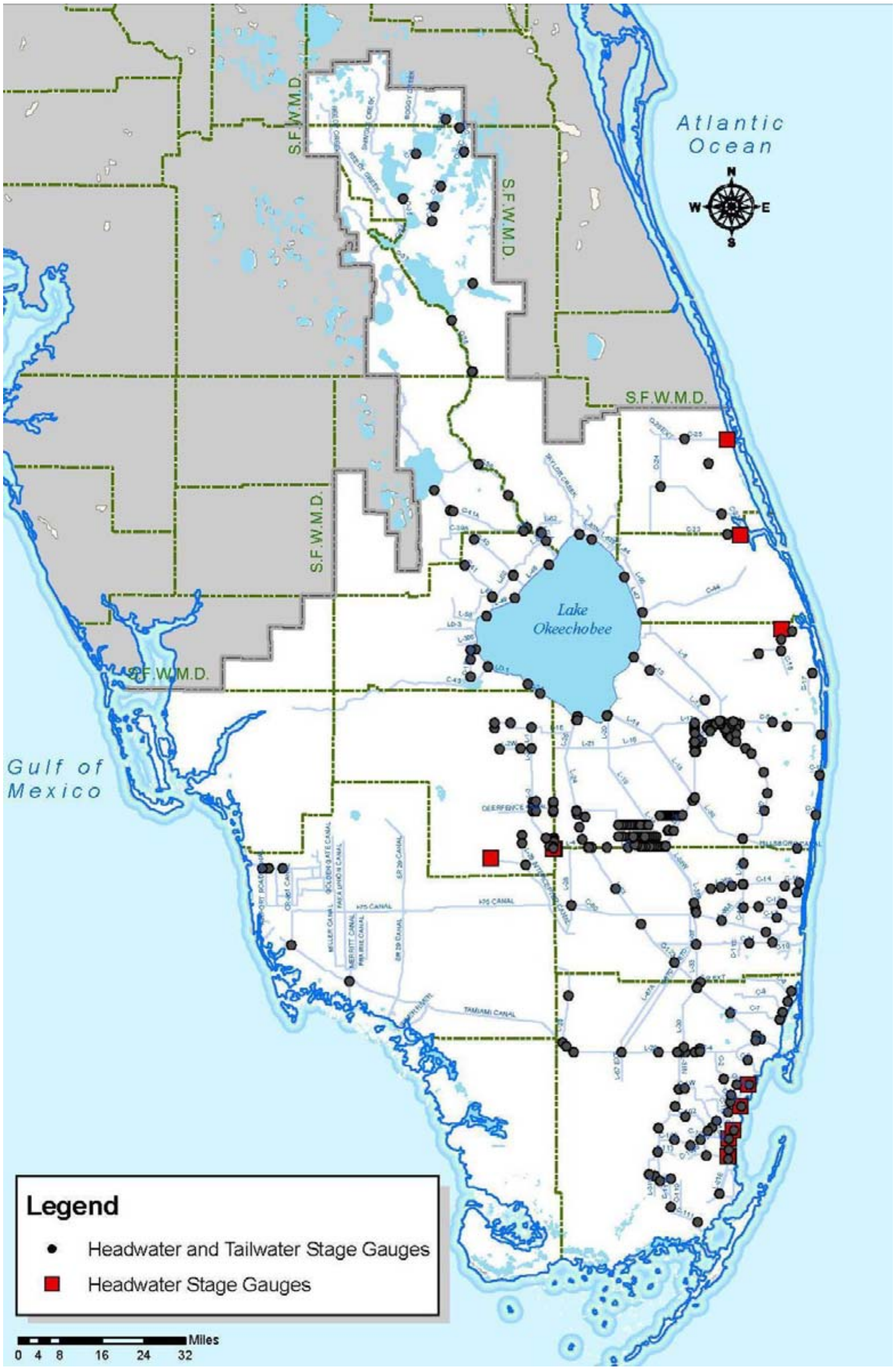

Figure 29. Location of stage monitoring gauges at the flow monitoring sites.

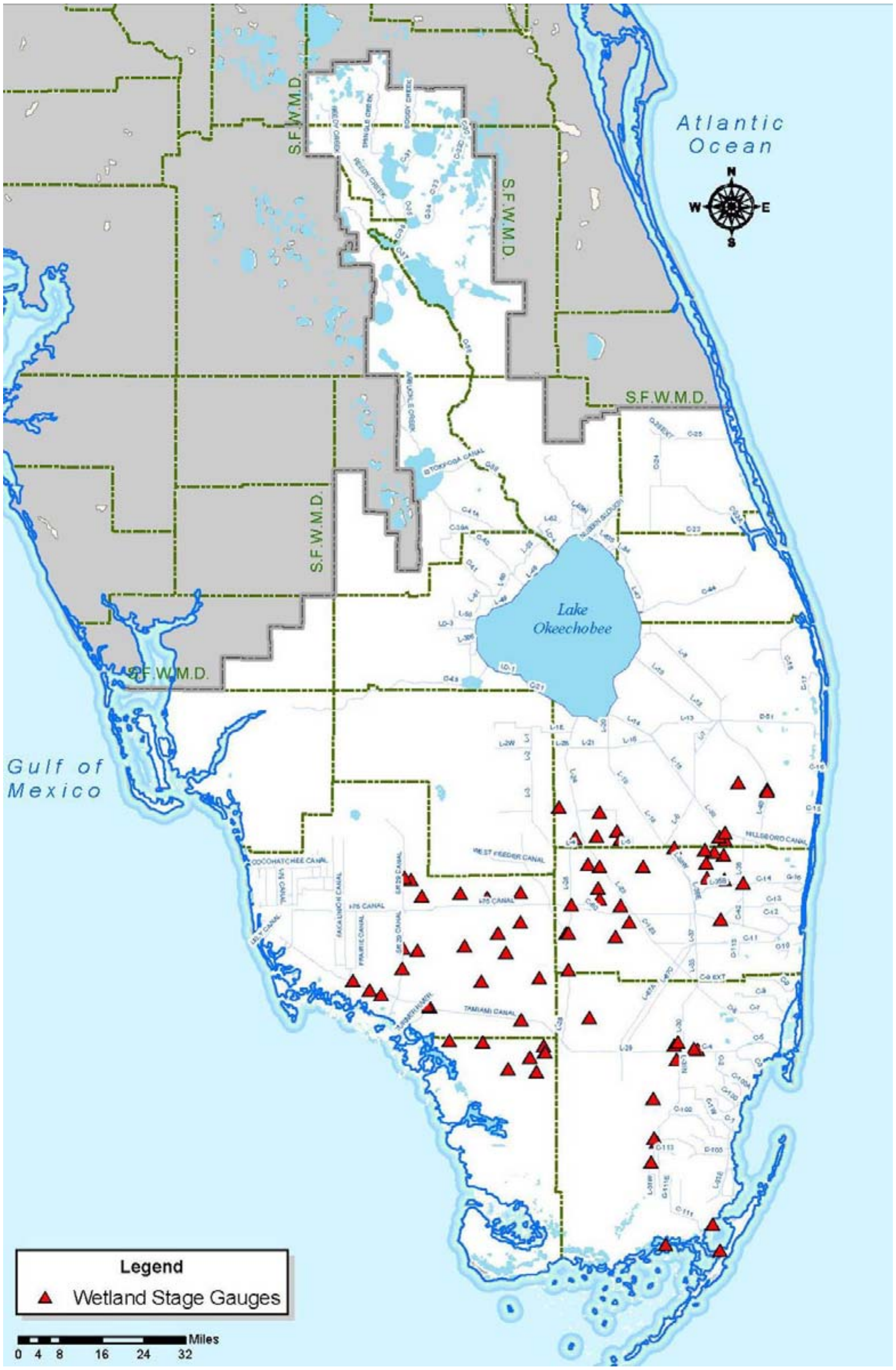

Figure 30. Location of stage monitoring gauges within wetland areas.

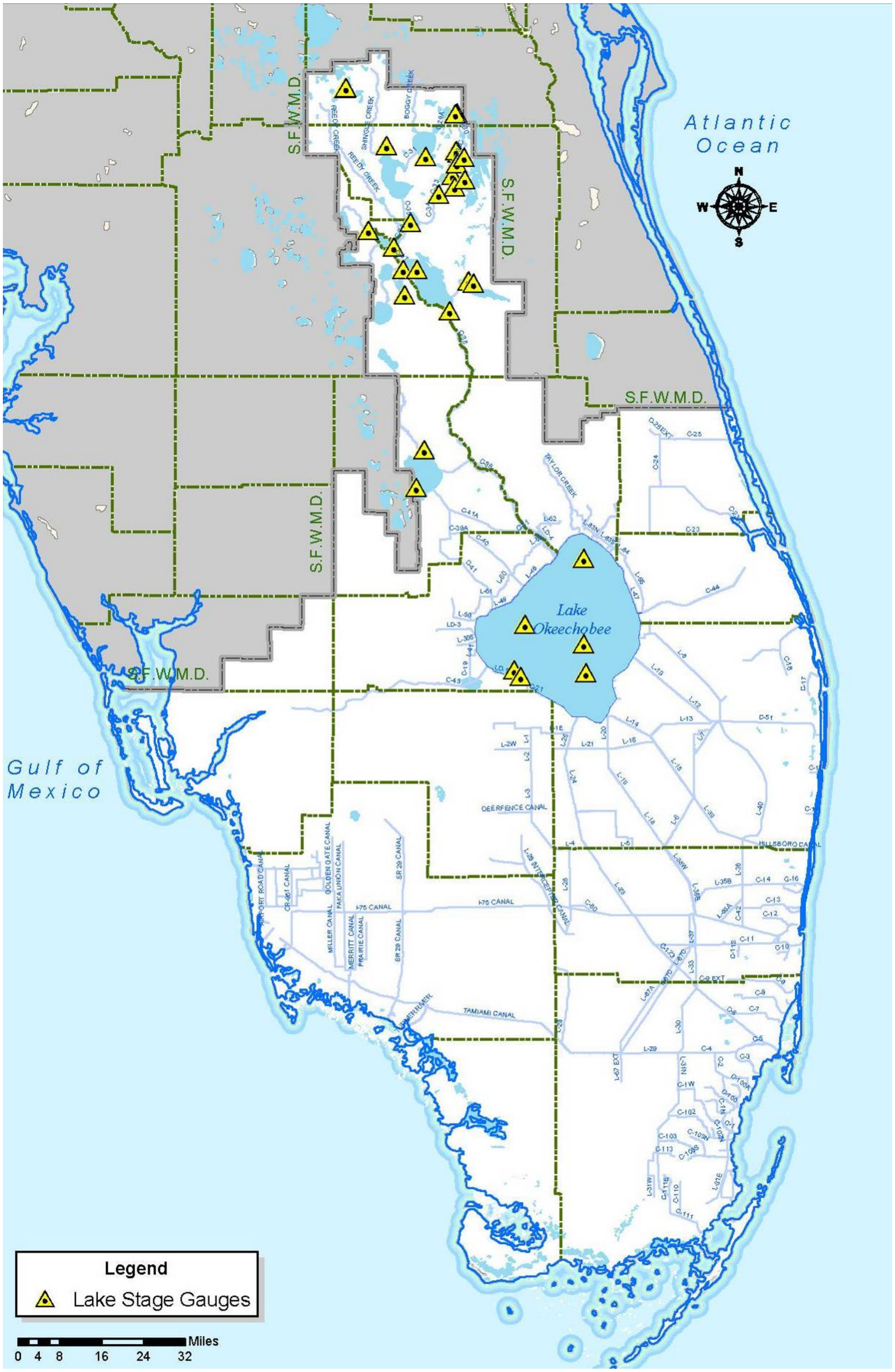

Figure 31. Location of stage monitoring gauges within lake areas.

d. Surface Water Stage Gauges in Other Water Areas

In addition to the stage gauges located in wetland and lake areas, there are 277 stage gauges in other water bodies of the District that include canals, detention facilities, and small ponds. The data collected from these gauge stations are also used for various purposes including operations and determining the hydrological condition of the areas. **Figure 32** shows the location of the 277 stage monitoring stations within the other water areas.

C. Surface Water Stage Data

The District operates an extensive network of 1,195 active surface water stage gauges in order to obtain stage data necessary for use in operations, planning, and regulatory aspects of water management (**Figure 33)**. The surface water stage data from 1,153 stations are collected from the recording type gauges. Therefore, the stage data are available on breakpoint basis. The breakpoint stage data can be obtained in 15-minute, hourly, and mean daily interval formats from DBHYDRO database. However, surface water stage data from 42 stations are collected as daily manual stage/staff readings and hence, the daily stage data are available in DBHYDRO database. Additionally, historical surface water stage time series data from the District and other external government agencies are available in DBHYDRO.

1. Stage Data Storage

Stage data stored and are available within DBHYDRO after 1959, and include breakpoint and non-breakpoint data. Breakpoint data are accessible in 15-minute, 30-minute, hourly, and daily time intervals, while non-breakpoint data are available only as daily values. Daily mean stage data are used most often at the District for hydrologic modeling, whereas breakpoint stage data are the preferred time interval for the support of water control structure operations in the District's OCC.

Stage data codes, or tags, accompany daily stage data within DBHYDRO in order to provide data users and analysts with an indication of data quality. A "null value" in the data code field corresponds to data that are missing. The "M" tag designates that stage data are missing, a code indicative of gauge equipment malfunction. The complete record of DBHYDRO data codes used for stage and associated definitions are presented in **Table 1**.

2. Data Quality Assurance/Quality Control

The QA/QC post-processing analysis is a second set of operations, which extract preprocessed data from DBHYDRO for select stations to undergo further examination. Presently, data from approximately 16 District stage gauge stations receive additional processing due to legal mandates under the Florida Forever Act. Data that have undergone the additional scrutiny of the QA/QC post-processing analysis are known as "preferred data" (PREF) and represent the "best available data" at the District.

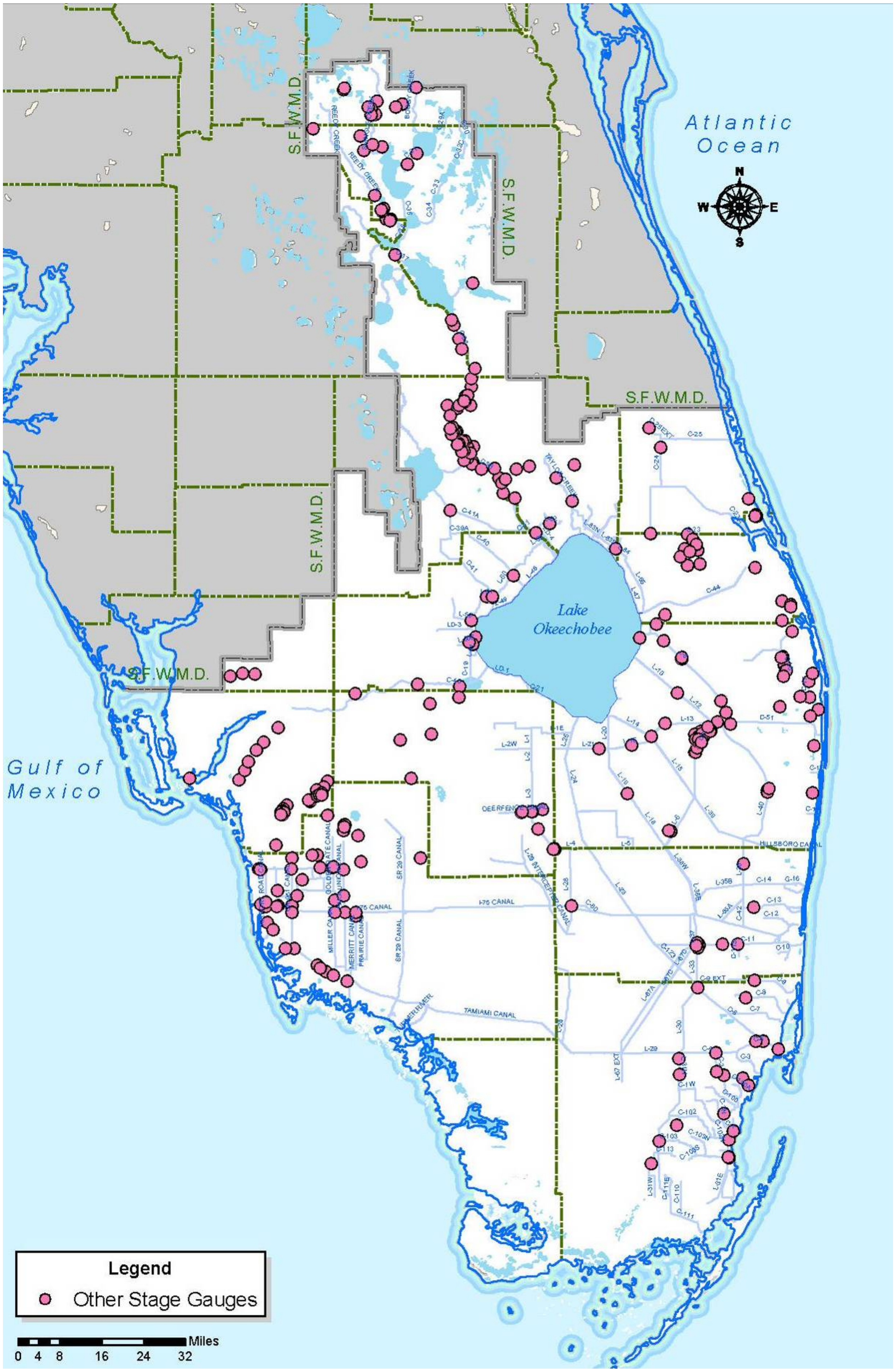

Figure 32. Location of stage monitoring gauges within other water bodies/areas.

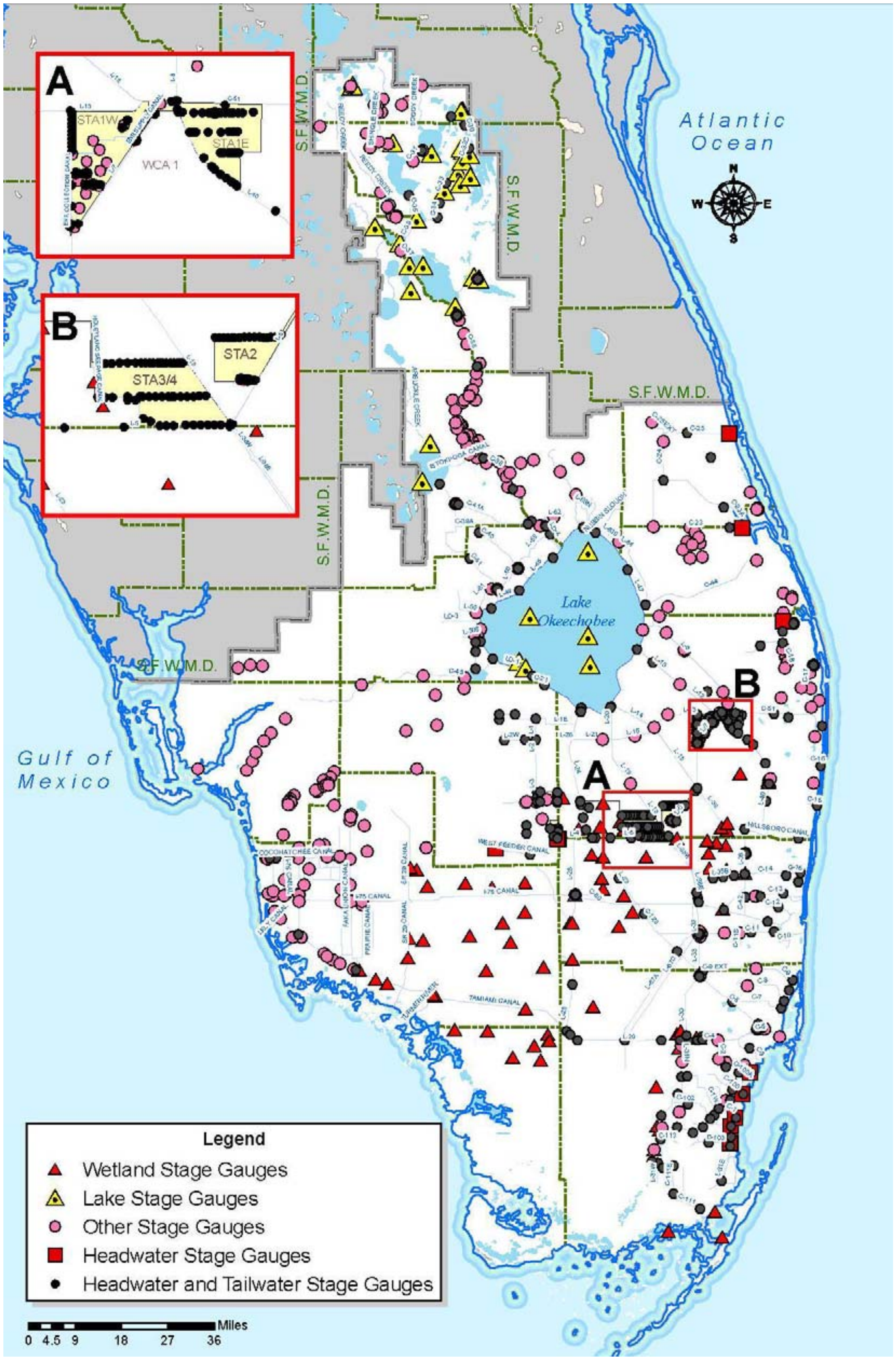

Figure 33. Surface water stage monitoring network in the District.

D. Surface Water Stage Network Optimization Study

In past, the District has not performed any network design or optimization study for the surface water stage network. However, during 2004 and 2005, two pilot studies on stage and flow network optimization were performed (SFWMD, 2004c; Martinez, 2006).

The first pilot study, conducted in 2004, looked at ways to enhance — via statistical and GIS tools — the stage monitoring network for a portion of the Everglades wetlands areas. The study also included tools and methodologies developed to enhance the design of stage monitoring networks. The publication "Enhancement of Stage Monitoring Network for Greater Everglades Wetland Areas" reports the details of this study (SFWMD, 2004c).

The second pilot study, conducted in 2005, addressed network optimization of monitoring stations located in lakes and streams (or canals) in selected drainage sub-basins of the Kissimmee River basin. The study provided a toolset for optimizing stage gauge stations in lakes. Another toolset was provided for optimizing stage gauge stations that are located upstream and downstream of the water control structure in the canal(s) and this pair of stage gauges is used for estimating flow volumes along the canal. The final report, "Pilot Study for Flow and Stage Network Optimization" (SFWMD, 2005; Martinez, 2006) includes user manuals for the two tools.

After completing these two pilot studies, follow up work efforts are expected to be performed in next few years, depending upon availability of funds at the District. These work efforts are divided into two projects and their details are provided below.

Project 1: Stage Network Optimization for the Everglades Wetlands Areas – This project involves the application of the stage network optimization methodology proposed in the publication "Enhancement of Stage Monitoring Network for Greater Everglades Wetland Areas" for the 52 Everglades wetland regions.

Project 2: Stage Network Optimization for Major Lake Areas – This project involves the application of the network optimization methodology and tools developed and presented in the publication "Pilot Study for Flow and Stage Network Optimization" (SFWMD, 2005; Martinez, 2006). Specifically, this task requires application of the methodologies and tools to the active stage network in two major lakes — Upper Chain of Lakes in Kissimmee River basin and Lake Okeechobee — within the District's boundaries.

VI. SURFACE WATER FLOW MONITORING NETWORK

By Zhiming Chen and Chandra Pathak

Surface water flow, or discharge flow rate, is the amount of surface water moved through a particular location per unit of time usually expressed in cubic feet per second (cfs) or cubic meters per second (cms). In scientific literature, flow and discharge are sometimes used interchangeably. Flow data are either measured or estimated using mathematical equations (SFWMD, 2004a).

The amount of flow in a river, creek, stream, or estuary is directly related to the amount of water moving off the watershed (river basin) into the stream channel. It is affected by weather, increasing during rainstorms and decreasing during dry periods. It also changes during different seasons of the year. In managed canal systems, released flow is affected by various water management policies and water quality and environmental constraints (SFWMD, 2004a).

Surface water flow data are critical for water management, operations of the water control structures, hydrological modeling, water balance analysis, flood control, hydrological analysis, and many other purposes. In South-Central Florida, flow monitoring is primarily the responsibility of the District. However, USGS continues to monitor some “designated” sites in cooperation with the District and USACE. The District works closely with the USGS, the USACE, and various local agencies in measuring and/or estimating flow through the District’s water control structures.

District’s water control structures are used to divert, restrict, stop, or otherwise manage the flow of water. Water control structures include pump stations, spillways, weirs, and culverts. District structures are typically designed to operate under a combination of water levels and operating conditions, which in turn result in different flow conditions. Flow that moves through the structure is estimated by using a rating equation appropriate for the flow conditions based on the structure’s static and dynamic data. The “static” data include the geometric characteristics of the structure, whereas the “dynamic” data comprise the prevailing headwater and tailwater stages and operating conditions (gate opening for spillways and culverts and pump speed for pumps) (SFWMD, 2004a).

A. Development of the Surface Water Flow Monitoring Network

Surface water flow data were estimated at various locations within South-Central Florida in the early 1900s by the USGS. The District began operating its own surface water flow monitoring sites after 1950, with the number of sites growing since then. The flow monitoring sites were added at the new water control structures that were constructed in the District.

Table 14 shows the total number of surface water flow monitoring sites. The number of surface flow monitoring sites grew within the District over the years, especially after 1969. This reflects the increasing demand for flow data within the District. As of March

2005, 45 percent of flow monitoring stations are located in the STAs with the remaining sprawled throughout the other areas of the District (Pathak and Chen, 2005). These structures are grouped into culverts (58 percent), spillways (25 percent), pump stations (13 percent), and weirs (4 percent). Most surface water flow monitoring sites are located in east coastal areas and Kissimmee Basin, around Lake Okeechobee, and Water Conservation Areas (WCAs). With Kissimmee Basin and Everglades ecosystem restoration efforts under way, it is expected that many more surface flow monitoring sites will be added to the network in the coming years.

Table 14. Total number of surface flow monitoring stations in the District.

Years	Total Number of Stations
1950–1959	1
1960–1969	76
1970–1979	158
1980–1989	287
1990–1999	527
2000–2005	572

Prior to 1990s, the District surface water flow monitoring sites have been primarily used for flood control and structure operation purposes that did not require very accurate estimation of flow data. However, since 1990, demand for accurate flow data has increased significantly for estimating pollutant loadings. In turn, there is now an increased need for more stream gauging data to improve flow equations for each water control structure. In 1995, the District began to install flow meters at structures and in canals and rivers. The flow meters generally provide more accurate flow data, especially for complex flow conditions and flows under small head difference between headwater and tailwater.

B. Existing Surface Water Flow Network

1. Field Instrumentation at the Station

At surface water flow monitoring telemetry sites, an electronic supervising control and data acquisition system (SCADA) collects current headwater and tailwater stage and a structure’s operation data from the field sensors. The details of the stage recording devices are presented in Section V. The structure’s gate opening data and pump’s operation speed data are recorded by various automated electronic recording devices. However, at few select sites the data are recorded manually.

The recorded data from the sensors are transmitted using one of the four types of remote terminal units (RTUs): Remote Acquisition Control Unit (RACU), traditional CR10 configuration, LoggerNet CR10, and Motorola SCADA (MOSCAD). The RACU system provides real-time water level data when it is polled from OCC and has no local memory to store data. This system is primarily used at structures where control of gates and/or pump stations is needed. Data from the units of the traditional CR10 configuration are collected either manually once a month or daily by telemetry through the Automatic

Remote Data Acquisition and Monitoring System (ARDAMS). Data is routinely collected via telephone lines or telemetry on a daily basis. This system is used primarily where only monitoring, and no gate and/or pump control, is needed. The LoggerNet system uses a terminal server to poll all RTUs within its range, and collects new data recorded in the RTU. All traditional RTUs on the ARDAMS system will eventually be replaced by LoggerNet RTUs. They are used primarily where only monitoring, and no gate or pump control, is needed. The MOSCAD system uses a scheme called "report by exception" to report water level and operation data. The MOSCAD RTU polls each sensor, continuously in less than a second, and when it detects a change of state of ± 0.01 foot, it automatically bursts the data back to OCC. In next few years, the MOSCAD system will be eventually replace the old RACU system.

Besides telemetry data, the District currently receives manually observed stage, gate, pump, and flashboard data from a small number of non-recording stations throughout the District. The manual data are systematically collected by District's field personnel and volunteers such as ranchers, lock-tenders, landowners, and other agencies through cooperative (co-op) agreements with the District.

The data collected from the field are examined following a structured QA/QC procedure (see Section V) to ensure that stage data collected are of best possible quality before they are used for flow computation purposes.

2. Active Flow Monitoring Sites

Information on all of the active surface flow stations was obtained from the DBHYDRO database. A surface flow site is considered to be active if it has been collecting data as of December 31, 2005. The District surface flow monitoring sites can be divided into five types: pump, spillway, culvert, weir, and index velocity meter. The location of each type of surface flow monitoring sites is shown on the maps that follow the discussions.

a. Flow Monitoring Sites at Pump Stations

Pumps lift water from a lower to a higher elevation (**Figure 34**). There are 60 flow monitoring sites located at pump stations (**Figure 35)**. Most of the pumps are located around Lake Okeechobee, the WCAs, and in east coastal areas. In order to compute flow at pump stations, headwater and tailwater stages, and pump speed are required.

Figure 34. Pump station.

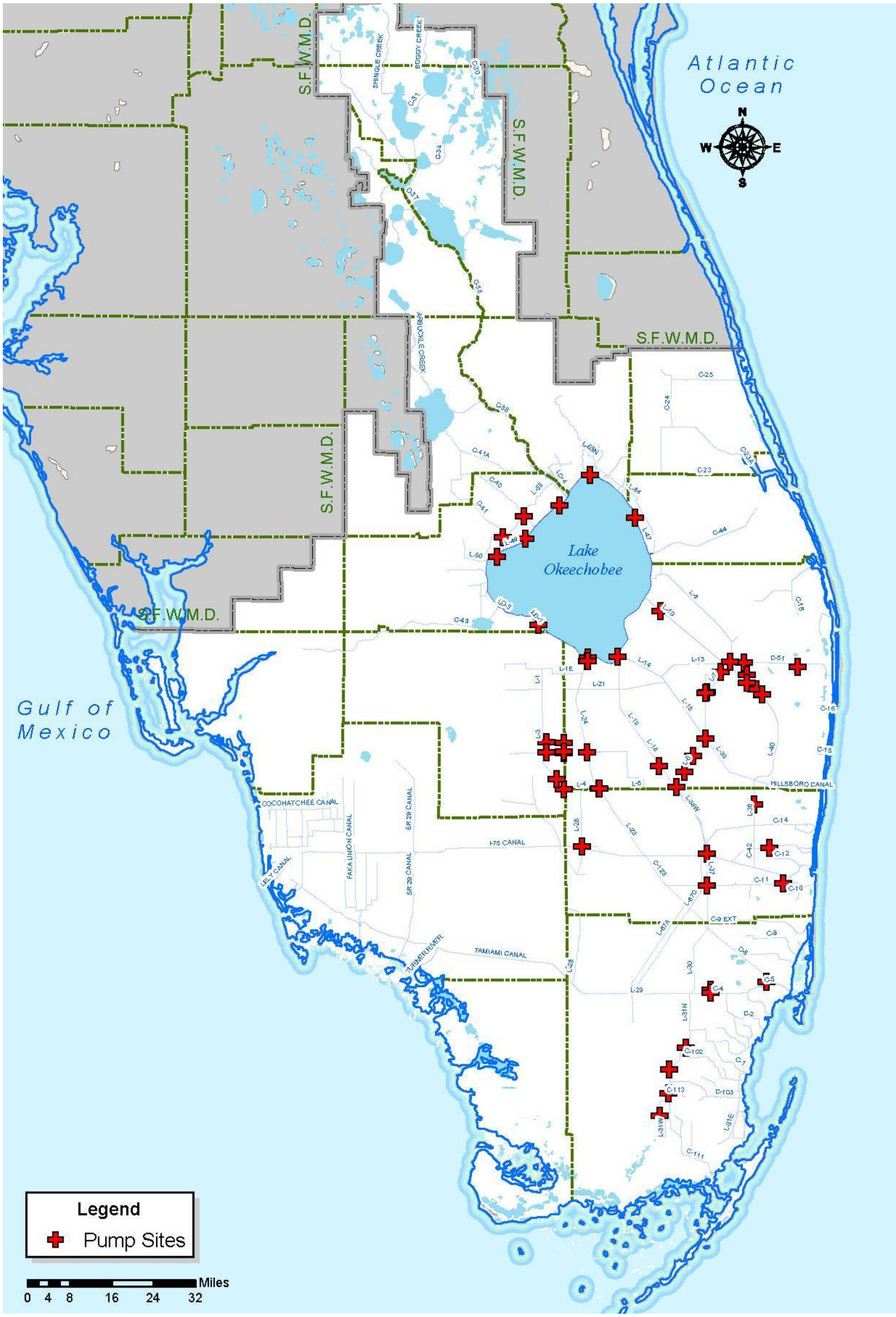

Figure 35. Location of flow monitoring sites at pump stations.

b. Flow Monitoring Sites at Spillways

A spillway is a gated structure over which flow is discharged from a reservoir or a canal (**Figure 36**). The purpose of a spillway is to control the stage and/or flow of water. As of December 31, 2005, the District monitored flow at 96 spillways (**Figure 37)**. The spillways are mostly located around Lake Okeechobee, WCAs, and the Kissimmee Basin and coastal areas. Flow computation at spillways requires headwater and tailwater stage measurements and gate opening data.

Figure 36. Spillway.

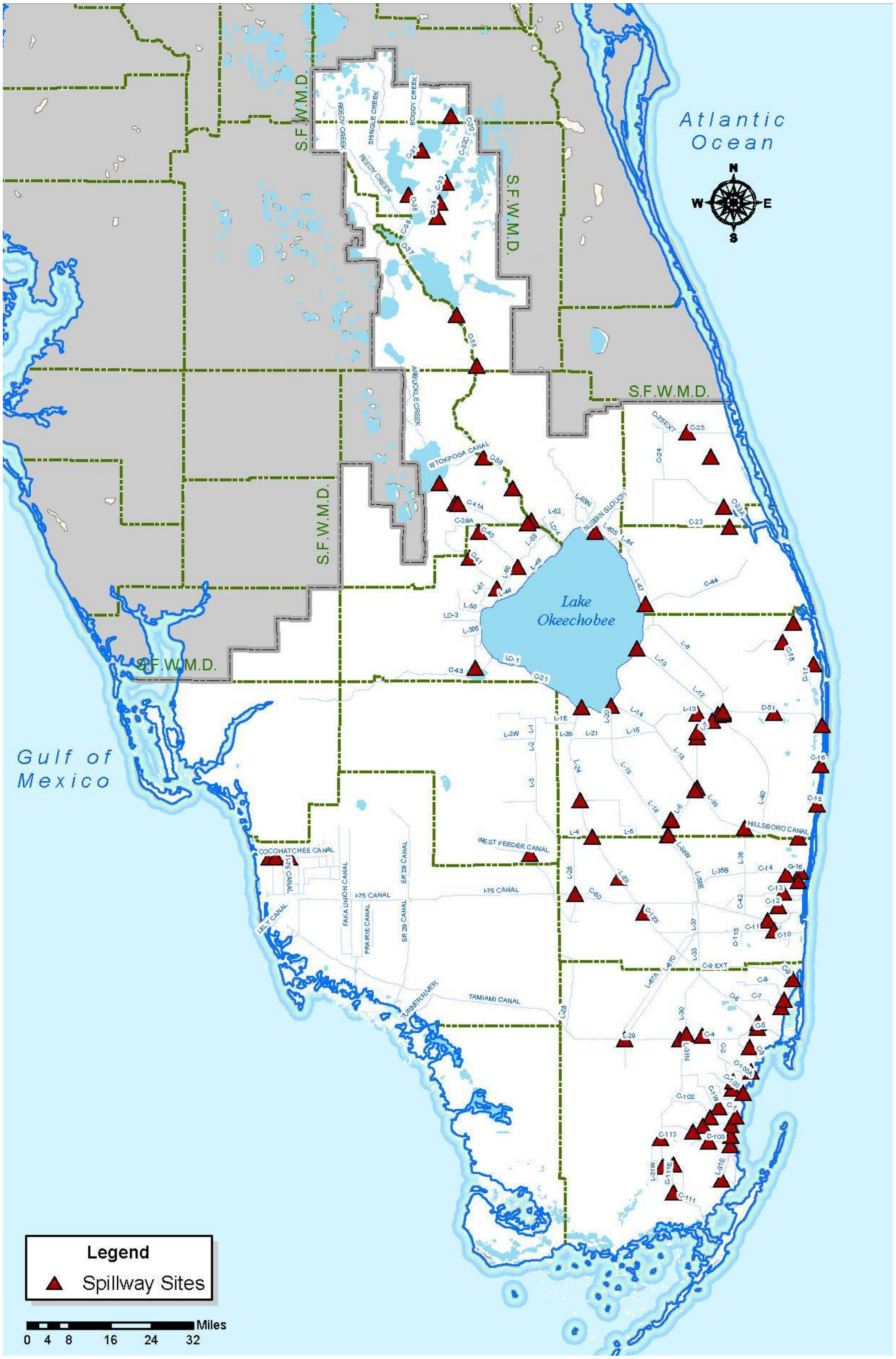

Figure 37. Location of flow monitoring sites at spillways.

c. Flow Monitoring Sites at Weirs

A weir is a structure (without a gate) over which flow is discharged from a reservoir or a canal (**Figure 38**). The District monitors flow at 14 weirs (**Figure 39)**. Flow computation at weirs usually requires headwater and tailwater stage measurements. However, if flow is free, i.e., tailwater does not affect flow, discharge can be estimated from headwater stage measurements and weir static information.

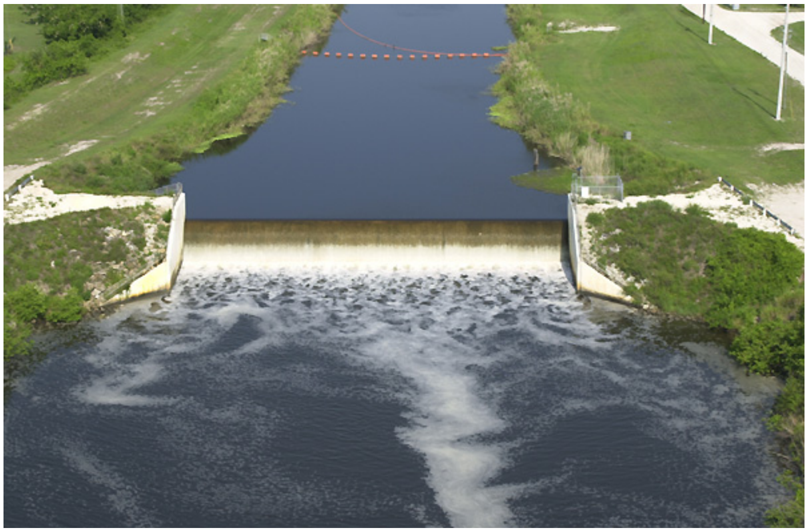

Figure 38. Weir.

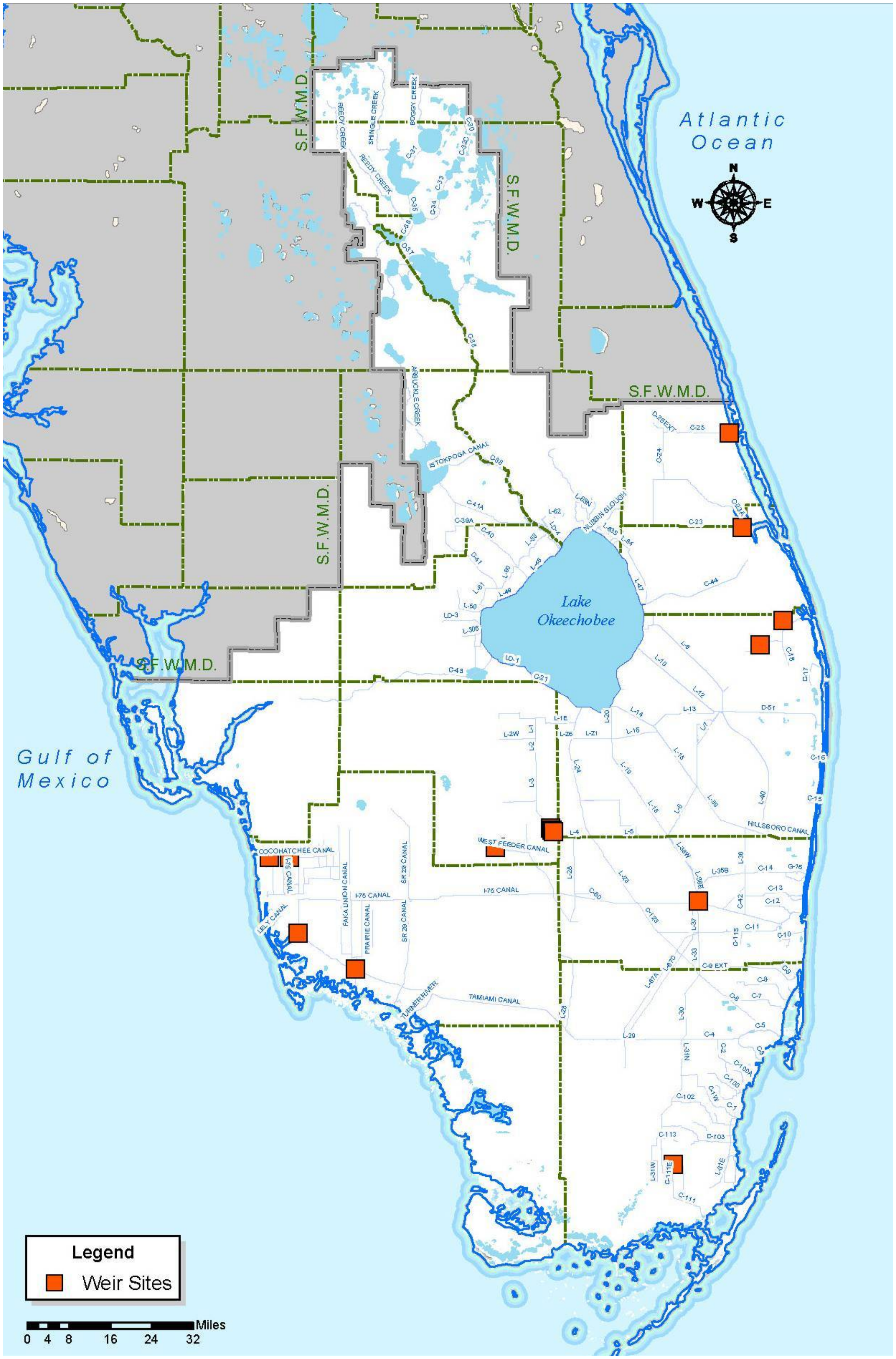

Figure 39. Location of flow monitoring sites at weirs.

d. Flow Monitoring at Culverts

Culverts are a closed conduit for conveyance of water (**Figure 40**). In the District, the culverts may be either circular or rectangular in cross section. Culverts may have gates. Culverts provide a means for water to pass underground from one location to another.

Figure 40. Culvert.

The District monitors flow at 247 culverts (**Figure 41)**. The figure shows that most culverts are located in Stormwater Treatment Areas (STAs), WCAs, and lower east coastal areas. Culverts usually pass smaller flows compared with spillways. Flow computation for culverts requires headwater and tailwater stage measurements, and gate opening, if gates are located in the culverts.

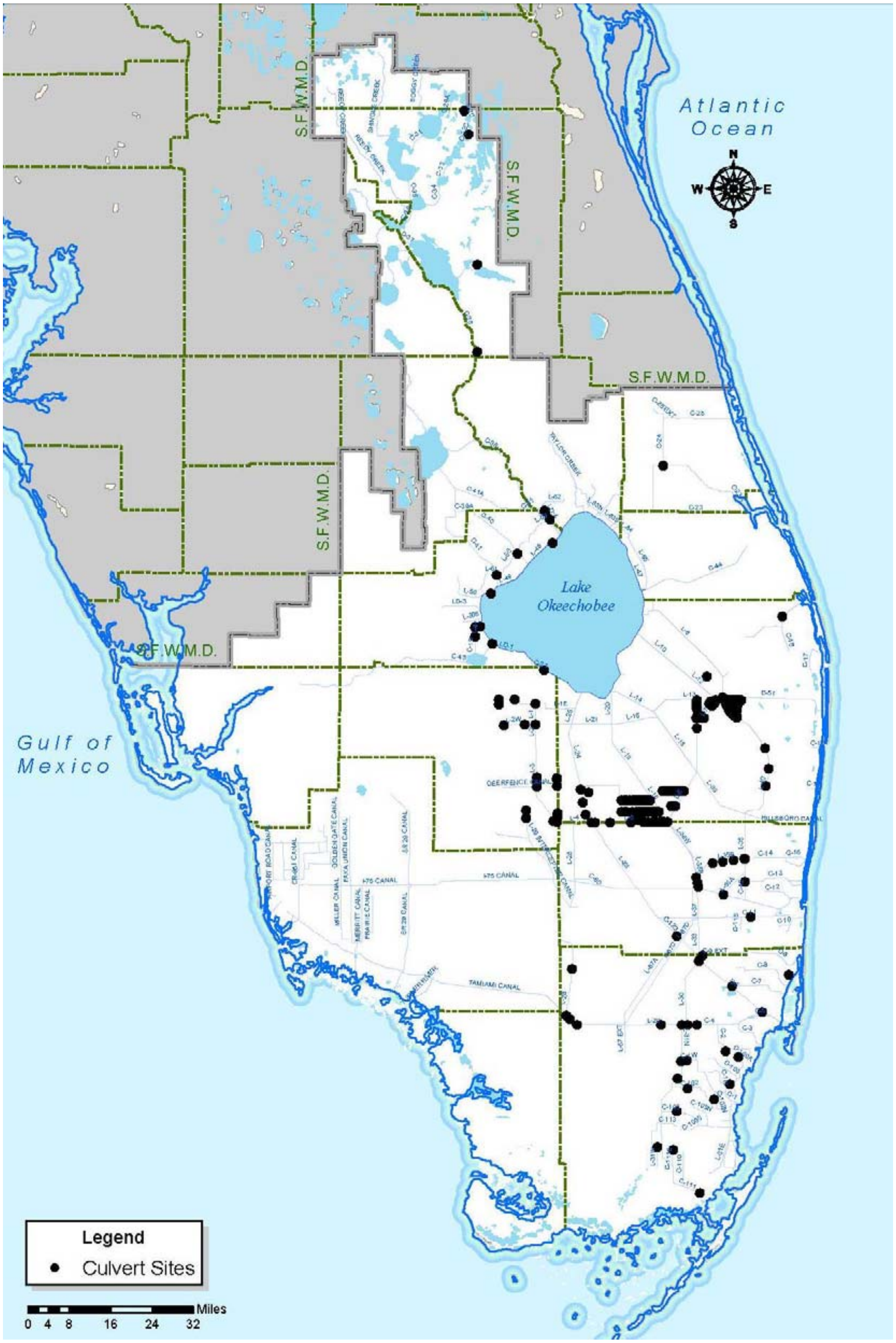

Figure 41. Location of flow monitoring sites at culverts.

e. Flow Monitoring Sites with Index Velocity Meters

Acoustic index velocity meters enable direct, continuous, non-contact measurements of velocity in open channel and closed conduits. The water velocity measured by these instruments is used as an estimator, or "index," of the mean cross sectional velocity. The mean velocity is then calculated from the index velocity through a rating equation and is used to predict flows at the cross section. District index meters include Ultrasonic Velocity Meter (UVM), Argonaut Side-Looking (Argonaut-SL), and Argonaut Shallow Water (Argonaut-SW).

Figure 42 shows a flow monitoring site with an index meter. Flow data at 18 index velocity meter sites (**Figure 43)** are published in DBHYDRO. Among them, eight index velocity meters are in canals or streams and 10 are in culverts. The District has installed index flow meters at many important sites, and flow data at these sites will be available soon from DBHYDRO. Installation of more index meters in critical streams and structures has been planned. For index velocity meter sites, stage and index velocity measurements are required.

Figure 42. Index velocity meter site.

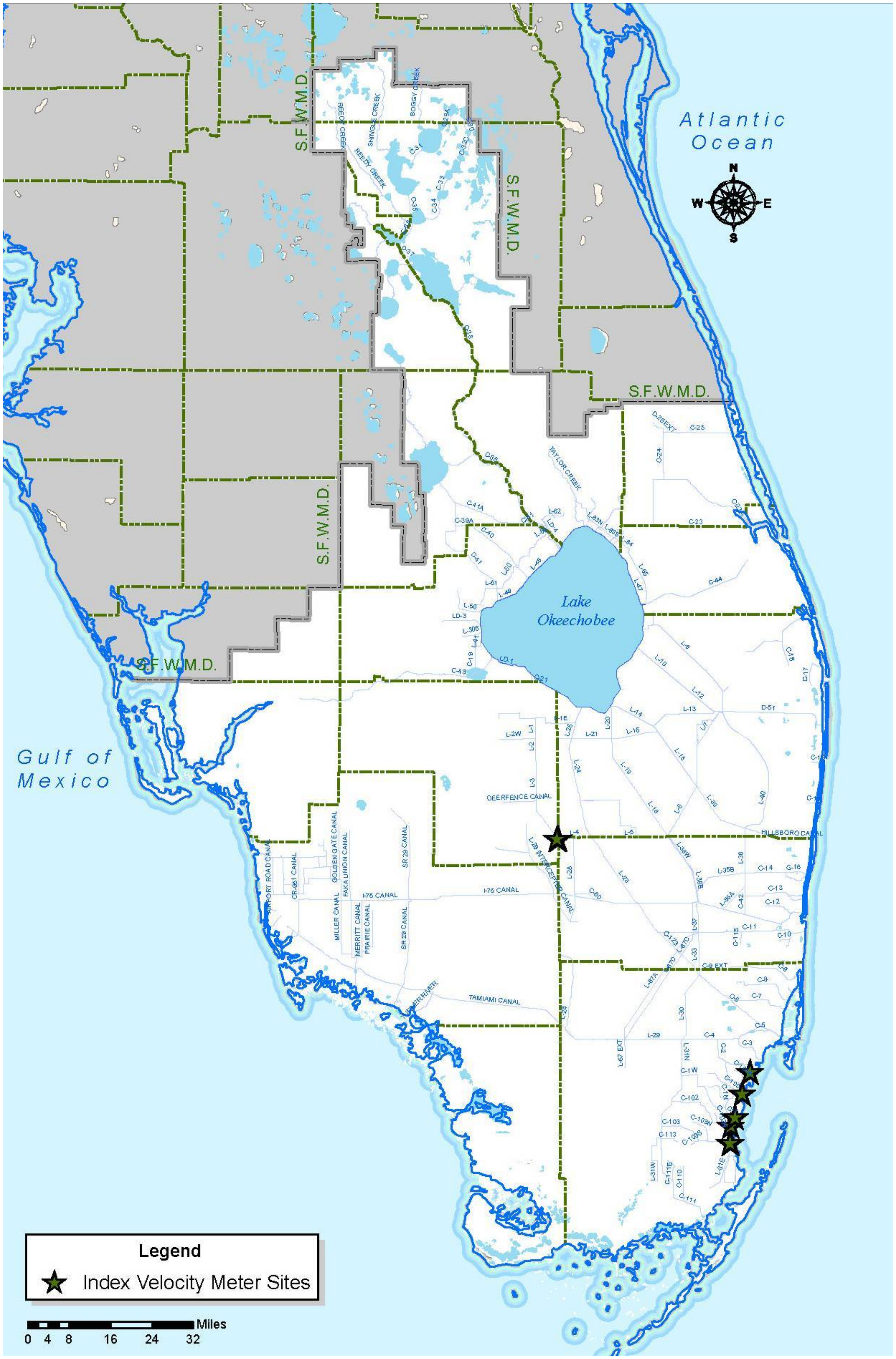

Figure 43. Location of flow monitoring at index velocity meter sites.

C. Surface Water Flow Data

1. Stream Gauging Data

Stream gauging is the process of measuring the flow rate of water at a cross section in a river, canal, creek, stream, estuary, or a culvert. The acquired data in stream gauging are used to verify, calibrate, and validate flow rating equations. The flow rating equations are used to compute flow rate at a cross section in a canal, stream, river or a culvert. The accuracy of the flow data is dependent upon the accuracy of the flow ratings, which are in turn largely dependent on accuracy of stream gauging flow measurements (OHDM, 2004).

Historically, flow measurements were made with a Price AA current meter (**Figure 44**) or other mechanical instruments. The Price meter measures the flow velocity at several locations of a vertical of a cross section. Velocity measurements in several verticals of a cross section are usually required for accurate flow estimation at a cross section. The discharge at a cross section is then computed from the measured velocities and their representative areas. This area-velocity method is labor-intensive and time consuming.

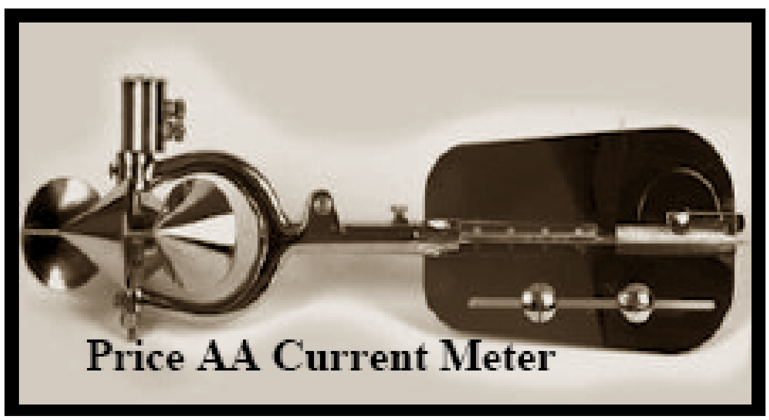

Figure 44. Price AA current meter.

Starting early part of 1990s, new field flow measurement instruments were developed. These instruments include Acoustic Doppler Current Profilers (ADCPs) (**Figure 45**), Acoustic Doppler Flow Meters (ADFMs), Acoustic Doppler Veloci-meters (ADVs), and many other instruments. These new instruments are based on acoustic doppler principle. These new acoustic instruments provide much more detailed flow data in terms of frequency and/or velocity distribution than a Price meter or other mechanical instruments.

Figure 45. An acoustic doppler current profiler (ADCP).

Currently, the most commonly used flow measurement (**Figure 46**) instrument in the field is an ADCP. An ADCP provides flow velocity distribution of a cross section when the ADCP moves along a transect (usually perpendicular of the stream flow). ADCP flow measurements are cost effective and provide accurate flow measurement data.

In shallow water, flow measurement can be performed with a StreamPro – a micro ADCP mounted on a small boat (**Figure 47**). StramPro can measure flow in streams from 15 to 200 cm in depth. Data is collected in real-time and transmitted via a wireless data link to a convenient palm PC loaded with a user friendly software. In many swamps or small streams, StreamPro may be the only solution for flow data collection.

Figure 46. StreamPro.

In pressurized pipes and culverts, Acoustic Doppler Flow Meters (ADFMs) are often used for flow data collection. The ADFM can be installed in the culverts and is capable of collecting a large mount of flow data with the accuracy needed for calibrating culverts operating under free-surface flow and pressured conditions. The ADFM is a quasi-direct velocity meter that relies on theoretical consideration application to fully developed flow. Thus, the applicability of the ADFM for measuring flows in culverts in a great extent depends on the velocity distribution in the culvert.

Figure 47. An ADFM.

Stream gauging data are checked following a QA/QC procedure before being input into a stream gauging database (known as the QMEAS database) for calibration or verification of flow ratings. The details of the QA/QC procedure for stream gauging data can be found in the document "QA/QC of Flow Data Procedures" (Sangoyomi et al., 2005).

Figure 48. Flow measurement with a StreamPro.

2. Flow Equations (Flow Ratings) Used in Computing Flow Data

At pump stations, spillways, weirs, and culverts, flow is estimated using flow equations. The flow equations use headwater, tailwater, and operation data (gate opening or pump speed) to compute flow. In the flow equations, some parameters are associated with local flow conditions and are usually calibrated or verified using streamgauging data collected at the structure. If the computed discharges using the calibrated flow rating equation do not agree with the flow measurements, development of a new flow equation may be required. **Figure 49** shows schematically the streamgauging data are used in calibration or verification of a rating. At index velocity meter sites, flow is estimated from measured index velocity and stage. The index velocity is used to compute mean cross sectional velocity through rating, and the stage is used to compute cross sectional area through relationship between stage and area.

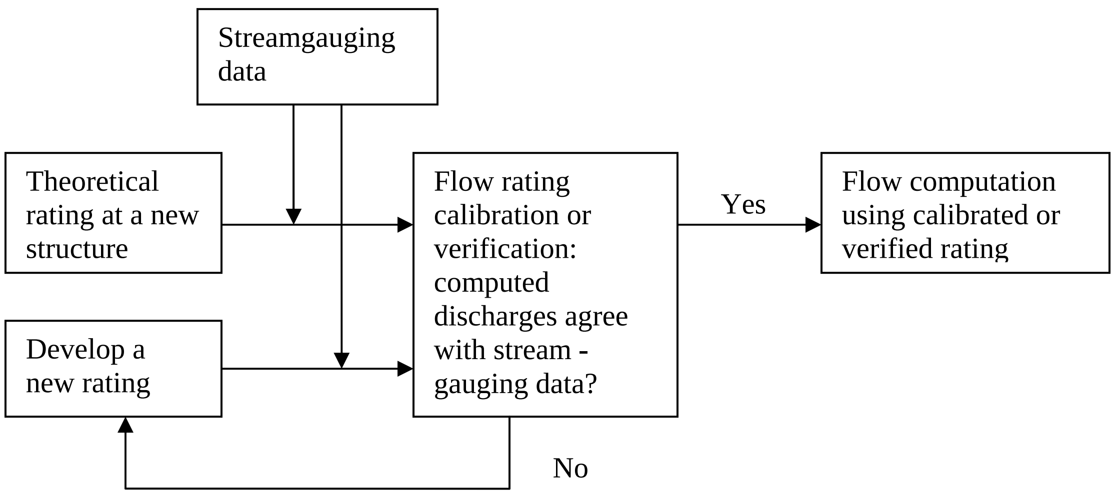

Figure 49. Flow ratings used in flow computation.

Originally, the USACE developed and calibrated the rating equations for most of the pumps in the District (Otero, 1995). The flow equations used for computing flow at culverts were developed by Fan (1985). The flow equations for spillways and weirs were based on experimental work from the 1960s by the USACE (Grace, 1963). These flow equations sometimes provide erroneous flow estimation and were later revised by the District.

The District has been working on improving the flow equations and has made significant progress. The new flow equations for pumps were developed (Damisse, 2000; Imru and Wang, 2003). Significant efforts have been made on improving spillway flow computation by Ansar et al. (2002, 2003a, 2003b, 2005) and Chen et al. (2006a). Nair (2003) and Damisse and William (2006) proposed new flow equations for culverts. Chen et al. (2006b) improved flow computation for several culverts that are located in the STA-3/4. The new flow equations for pump stations, culverts, spillways, and weirs significantly improve flow computation for some flow conditions. Some of these newly developed flow equations have been implemented in the District flow computation program. The remaining will be implemented in the District's new FLOW computation program (software application) that is currently being developed. The existing and/or improved flow equations are examined before they are used for flow computation. The District has established guidelines for QA/QC of flow equations.

At index velocity meter sites, the relationship is established between cross-sectional mean velocity obtained from the stream gauging data and the velocity measured with the index meter. Once the relationship is developed, the flow through the cross section is computed from the measured index velocity and the cross-sectional area derived from the relationship between stages and cross-sectional areas.

3. Surface Water Flow Data

The flow computation is performed by the FLOW program, a FORTRAN-based application developed by the District approximately 25 years ago. The FLOW program uses rating equations for various flow regimes to compute flow. A flow rating equation is the relationship between the flow, the stage level (headwater and tailwater elevations) and the operating status (gate openings, pump speed, weir crest elevations, etc.). Rating equations are defined for each type of structure and each potential flow case. For example, rating equations are defined for each of the 5 cases of flow through a "gated spillway": (1) controlled submerged flows, (2) controlled free flows, (3) uncontrolled submerged flows, (4) uncontrolled free flows, and (5) over-the-top flows.

The computed flow data are scrutinized using the District's QA/QC before they are published in DBHYDRO. The QA/QC procedure uses statistical analysis and hydraulic principles to check the accuracy of the computed discharges and investigate questionable values.

Flow computation for each structure is based on available static and dynamic data. The District determines the static structure information from the "as-built" drawings of structures, and this information is stored in the DBHYDRO database. However, this static structure information is often not of sufficient quality to compute flow accurately in certain hydraulic conditions, and in some cases, the information is erroneous or out of date. To address this issue, the STRucture Information VErification (STRIVE) project was initiated to verify static structure information. As of March 2005, field surveys for 367 water control structures have been completed. The flow data for 168 of these structures have been adjusted and archived in DBHYDRO (Pathak and Chen, 2005).

4. Flow Data Availability

The District operates an extensive network of 425 active flow monitoring sites that are used in operations, planning, and regulatory aspects of water management. The District's flow monitoring network is shown in **Figure 50**. The flow data from 425 sites are available on breakpoint basis. The breakpoint stage data can be obtained in 15-minute, hourly, and mean daily format from the DBHYDRO database. Historical flow time series data from the District and other external government agencies are also available in DBHYDRO.

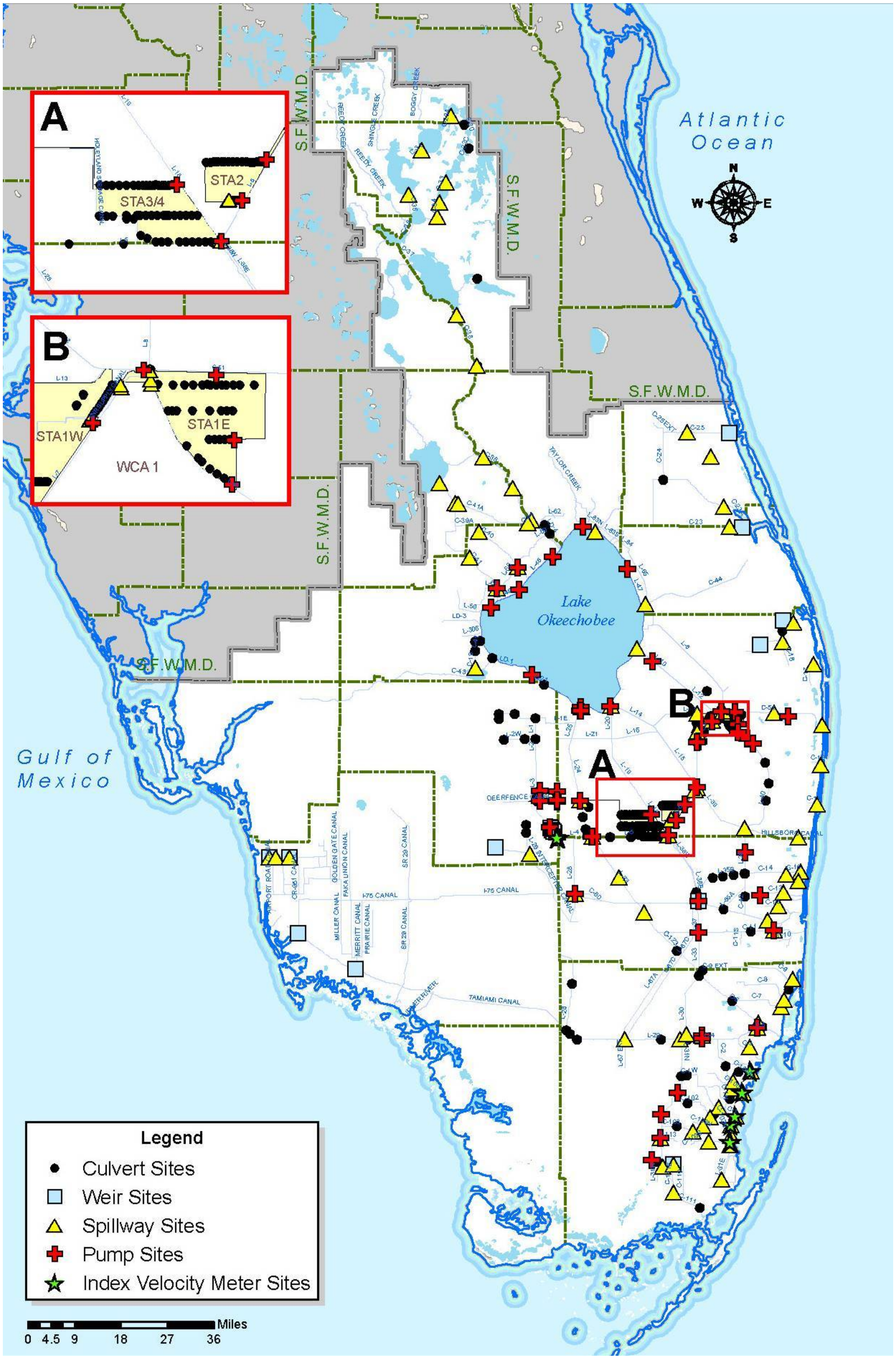

Figure 50. District flow monitoring network.

Hydraulic structure information and flow data can also be obtained using the application called Web Atlas, a web-based GIS interface. From Web Atlas, structure photos, structure static information (including structure geometry and discharge coefficients that are used in the structure's flow equations), historical daily and breakpoint flow data, and real-time flow data are available. **Figure 51** shows a screenshot of the Web Atlas interface.

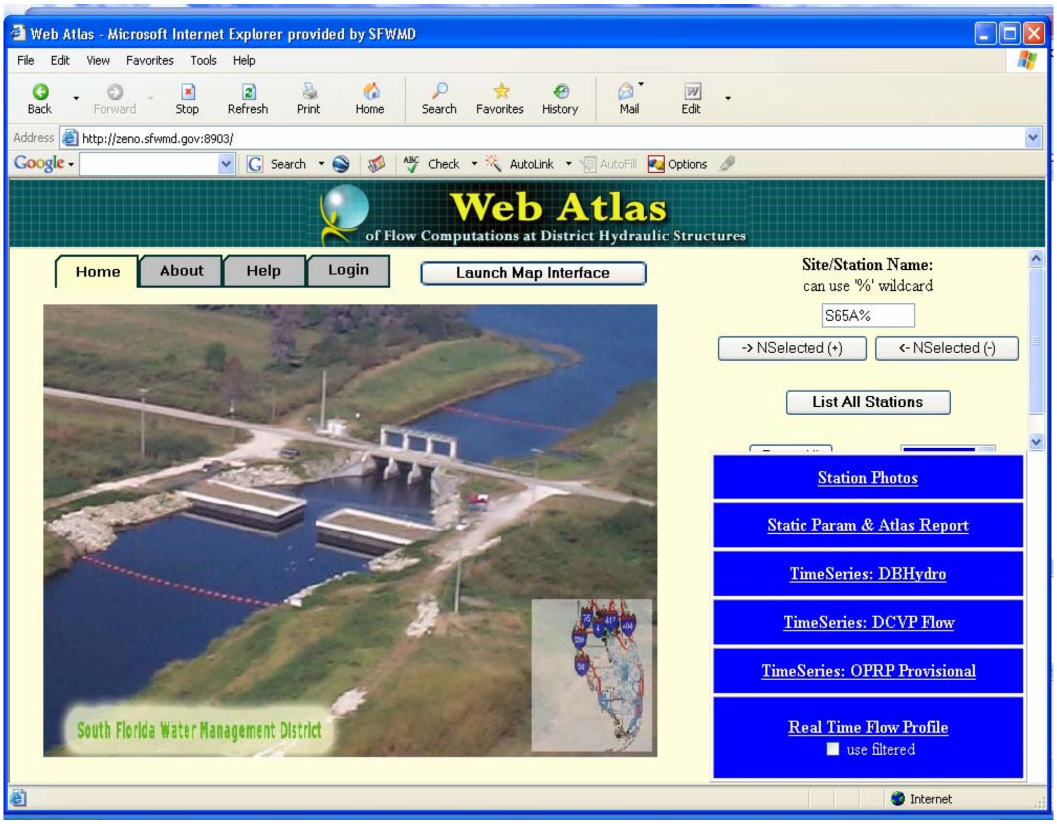

Figure 51. Screenshot of the Web Flow Atlas for Hydraulic Structures and Flow Data.

a. Flow Data Storage

Flow data are stored and are available in DBHYDRO. Data include breakpoint and non-breakpoint data. Breakpoint flow data are accessible in 15-minute, 30-minute, hourly, and daily time intervals, while non-breakpoint data are available only as daily values. Daily mean flow data are used most often at the District for hydrologic and ecological data analyses, whereas breakpoint stage data are the preferred time interval for the support of water control structure operations, hydrologic and hydraulic modeling, and various other purposes.

Flow data are tagged within DBHYDRO in order to provide information on the quality of the data. A "null value" in the data code field corresponds to data that are missing. The "M" tag designates that stage data are missing, a code indicative of gauge equipment and/or communication network malfunction. The complete record of DBHYDRO data codes used for flow and associated meanings are presented in **Table 1**.

b. Flow Data Quality Assurance/ Quality Control

The QA/QC processing further examines the flow data quality, including checking and analyzing data (including headwater, tailwater, operational data) from difference sources, and performing statistical, hydrological, and hydraulic analysis. Presently, data from approximately 161 District flow sites receive this additional processing due to legal mandates under the Florida Forever Act. Data that have undergone this additional scrutiny of the QA/QC Post-Processing Analysis is known as "preferred data" and represent the "best available data" at the District (Sangoyomi et al., 2005).

D. Surface Water Flow Network Optimization

During 2005, a pilot study on stage and flow network optimization was performed. The study addressed network optimization of monitoring stations located in lakes and streams (or canals) in selected drainage sub-basins of the Kissimmee River basin. The study provided a toolset for optimizing stage gauge stations that are located and upstream and downstream of the water control structure in the canal(s) and this pair of stage gauges is used for estimating flow volumes along the canal. The final report, "Pilot Study for Flow and Stage Network Optimization" (SFWMD, 2005 and Martinez, 2006), includes user manuals for the tool. Follow up work efforts based on the pilot study are expected to be performed in the next few years, depending upon availability of funds at the District. These work efforts are divided into two projects:

Project 1: Flow and Stage Network Optimization for Active Water Control Structures in the Central and Southern Florida (C&SF) System. This project involves the application of the network optimization methodology and tools developed and presented in the publication "Pilot Study for Flow and Stage Network Optimization." Specifically, this task requires application of the methodologies and tools to the approximately 232 water control structures in the District's C&SF system.

Project 2: Flow and Stage Network Optimization for Water Control Structures in the Storm Water Treatment Areas (STAs). This project involves the same application as for Project 1. However, this task differs by requiring the application of the methodologies and tools to the approximately 191 water control structures in five STAs — STA-1W, STA-2, STA-3/4, STA-5, and STA-6 — within the District's boundaries.

VII. GROUNDWATER MONITORING NETWORK

By Taiye Sangoyomi and Anthony Larenas

Groundwater is water below the earth's surface in underground streams and aquifers. Groundwater level or head for a water table (unconfined) aquifer is simply the elevation of the upper surface that indicates the uppermost extent of groundwater, and is usually expressed in units of feet or meters above an established datum. For a confined aquifer, the groundwater is under pressure and the groundwater level or head is the elevation that coincides with the piezometric or hydraulic head in the confined aquifer, which may be above the land surface (**Figure 52**).

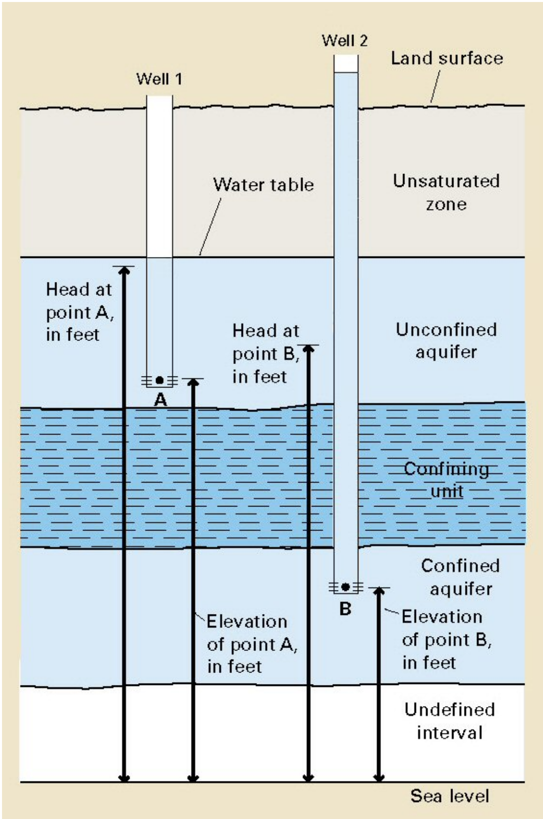

Figure 52. Groundwater level or head in a well in an unconfined aquifer (Well 1) and a confined aquifer (Well 2) (source: modified from Taylor and Alley, 2001).

The aquifers in the District are classified into three general groups — surficial aquifer system, intermediate aquifer system, and Floridan aquifer system. The surficial aquifer system is a water table aquifer system that includes the Biscayne Aquifer, Lower Tamiami Aquifer, and all of the otherwise undefined aquifers that are present at the land surface and are generally under unconfined, or water table, conditions. The surficial aquifer system is typically less than 50 feet deep in most areas but can range up to 400 feet deep in Indian River and St. Lucie counties (http://www.dep.state.fl.us/swapp/Aquifer.asp).

Aquifers between the surficial and Floridan aquifer systems are collectively referred to as the intermediate aquifer system, and consist of one or more water-bearing units separated by confining units. The intermediate aquifer system is present only in southwestern Florida. This system includes the Sandstone and Mid-Hawthorn aquifers.

The Floridan aquifer system underlies the entire District region and includes the Lower Hawthorn aquifer, Suwannee aquifer, and Ocala group. **Table 15** provides a summary of the aquifer system and their thicknesses. **Figure 53** provides a three dimensional view of the aquifer system over Florida.

Table 15. Aquifer systems of the District.

Aquifer System	Aquifer Unit	Thickness (feet)
Surficial	Water Table Biscayne Lower Tamiami	40 to 400[a]
Intermediate	Sandstone Mid-Hawthorn	0 to 260[b]
Floridan	Lower Hawthorn Suwannee Ocala Group	1,800 to 3,600[c]

(a) http://www.dep.state.fl.us/swapp/Aquifer.asp
(b) Tables 3 to 5, SFWMD, 2000
(c) Figure on page 50, Fernald and Purdum, 1998

The remainder of this section is organized into four parts: (1) the development of the groundwater monitoring network and history and evolution of the network; (2) the existing groundwater network, as of December 2005, with maps showing the locations of the wells by aquifer system; (3) the QA/QC procedures for the water level data and data availability; and (4) the future groundwater network design

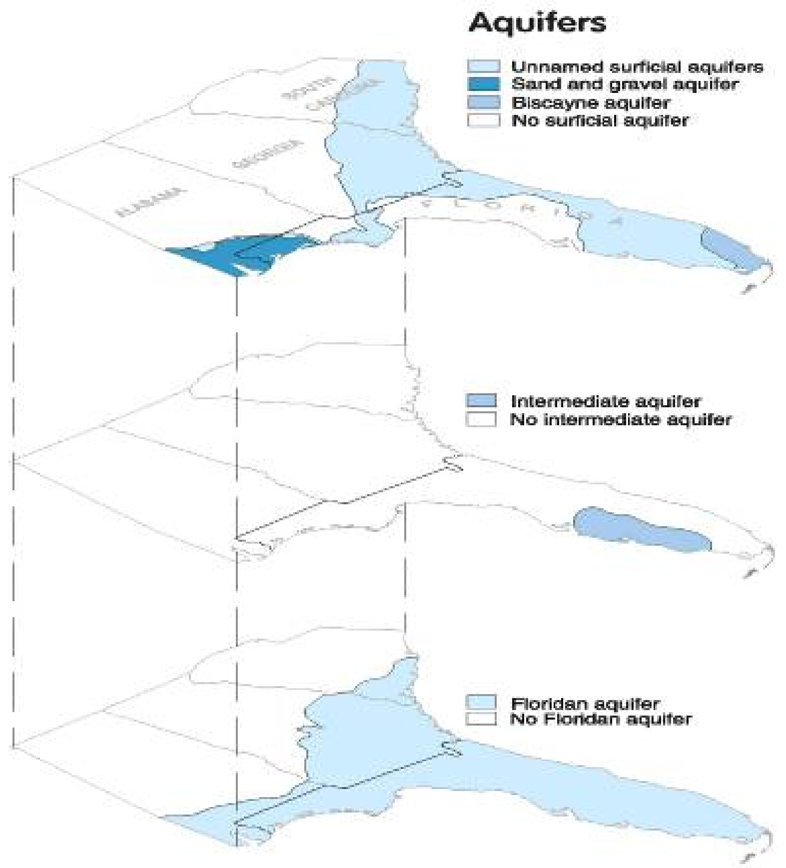

Figure 53. Three-dimensional view of the aquifer system in Florida (Berndt, 1998).

A. Development of the Groundwater Monitoring Network

The District's groundwater network consists of wells that have data publicly available through the District's DBHYDRO database but also in other databases not publicly accessible (these are mostly project specific). There are ongoing plans to migrate non-publicly accessible data into the DBHYDRO database. The groundwater network also consists of wells monitored by the USGS through a cooperative agreement with the District. Most of the data on these wells are also available in DBHYDRO, but some can only be assessed from the USGS's ADAPS database.

The District has managed and/or funded the groundwater monitoring network within and near the District boundaries since 1955. **Table 16** below shows the total number of monitoring wells available on a decadal basis since 1950.

Table 16. Total number of groundwater monitoring wells at the District from 1950 to 2005.

Years	Total Wells	USGS Wells	District Wells
1950–1959	311	311	0
1960–1969	286	282	4
1970–1979	1,562	1,540	22
1980–1989	1,724	1,551	173
1990–1999	616	314	302
2000–2005	975	362	613

The benefits from funding this long-term groundwater-monitoring network for the District include the following (Lukasiewicz et al., 2002):

- To provide a means of assessing long-term trends in groundwater availability
- To develop, verify, and calibrate groundwater flow models from groundwater data collected
- To provide data to regularly assess temporal groundwater conditions during droughts
- To provide data for water use permit application evaluations
- To assist the District in legal proceedings involving regulatory and other groundwater disputes
- To determine background conditions for use in design and performance evaluation of various District projects

Groundwater data archived by the District are also accessible to the public, consulting firms, and staff from other governmental agencies. Uses of the data include developing the appropriate scientific and technical understanding required by District rules to support applications for Environmental Resource Permits, Consumptive Use Permits, and other purposes applicable to the District's mission.

The coverage provided by the groundwater monitoring network is constantly being evaluated. The USGS and District cooperative wells are evaluated annually to identify redundant wells that could be removed from the network. New wells are being added to the network to fill data gaps for improved groundwater modeling. In 1996 the District completed a rigorous statistical analysis of the groundwater network in southwestern Florida (Switanek, 1999). This optimization study was an effort to determine how to optimize the cost effectiveness of the network. It was concluded that 41 wells could be removed from the network without significantly decreasing spatial coverage. With this conclusion, the District and USGS staff met to review non-statistical considerations for these 41 wells to determine how to discontinue monitoring without a significant loss of information. The criteria used for discontinuation included historic record, sensitive water shortage areas, and multi-agency studies of these wells. Another factor in the network's reduction was a change in the District's permit criteria. The new criteria mandated that public water supply utilities provide groundwater level data to the District on a monthly basis; this eliminated the need for wells located near reporting utilities. As a result, it was concluded that 24 of the 41 wells would be removed from the network within the Lower West Coast Planning Area.

In a separate District analysis, Lukasiewicz et al. (2002) concluded that 15 additional wells could be removed and 54 new wells should be installed to the network. At the time of the report approximately 20 percent of the groundwater network's 669 wells were being continuously recorded with automated equipment. The report recommended that an additional 40 percent of the wells should have automated monitoring equipment installed. Many of the recommendations from this report were implemented and the groundwater network increased in size.

B. Existing Groundwater Network

A total of 975 wells were monitored on a regular basis (15-minute continuous, monthly, or greater than 1 month intervals) as of December 2005. The District is solely responsible for monitoring, maintenance, QA/QC, data archival, and funding for 613 of these wells. The remaining 362 wells are monitored and QA/QC by the USGS under cooperative agreements with the District.

1. Location of Wells by Aquifer

The locations of the District wells are shown in maps on **Figures 54** through **56**, corresponding to the three aquifer systems. **Figure 54** shows the location of the wells in the surficial aquifer system, **Figure 55** shows the wells in the intermediate aquifer system, and **Figure 56** shows the wells in the Floridan aquifer system.

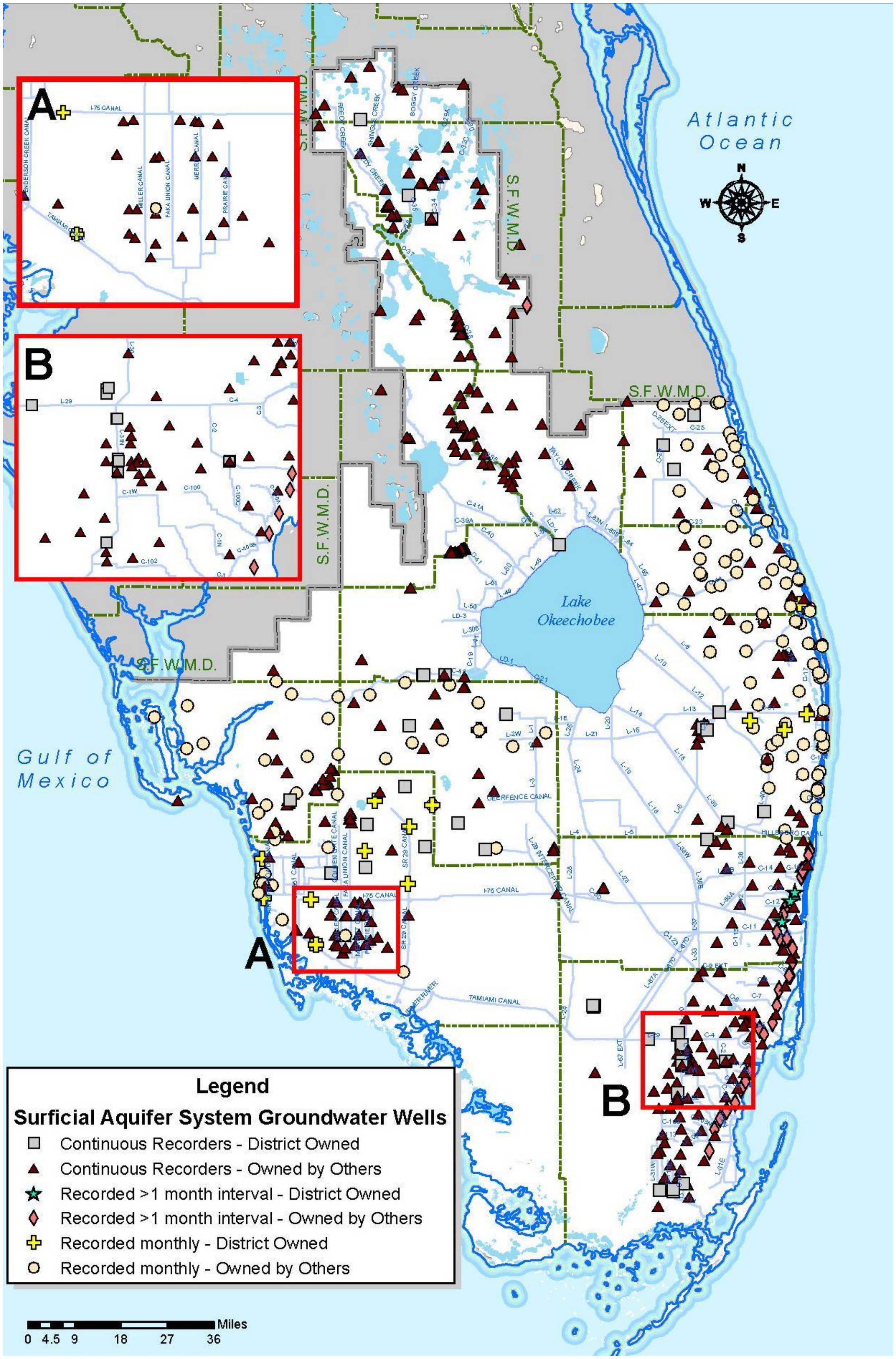

Figure 54. Surficial aquifer system wells.

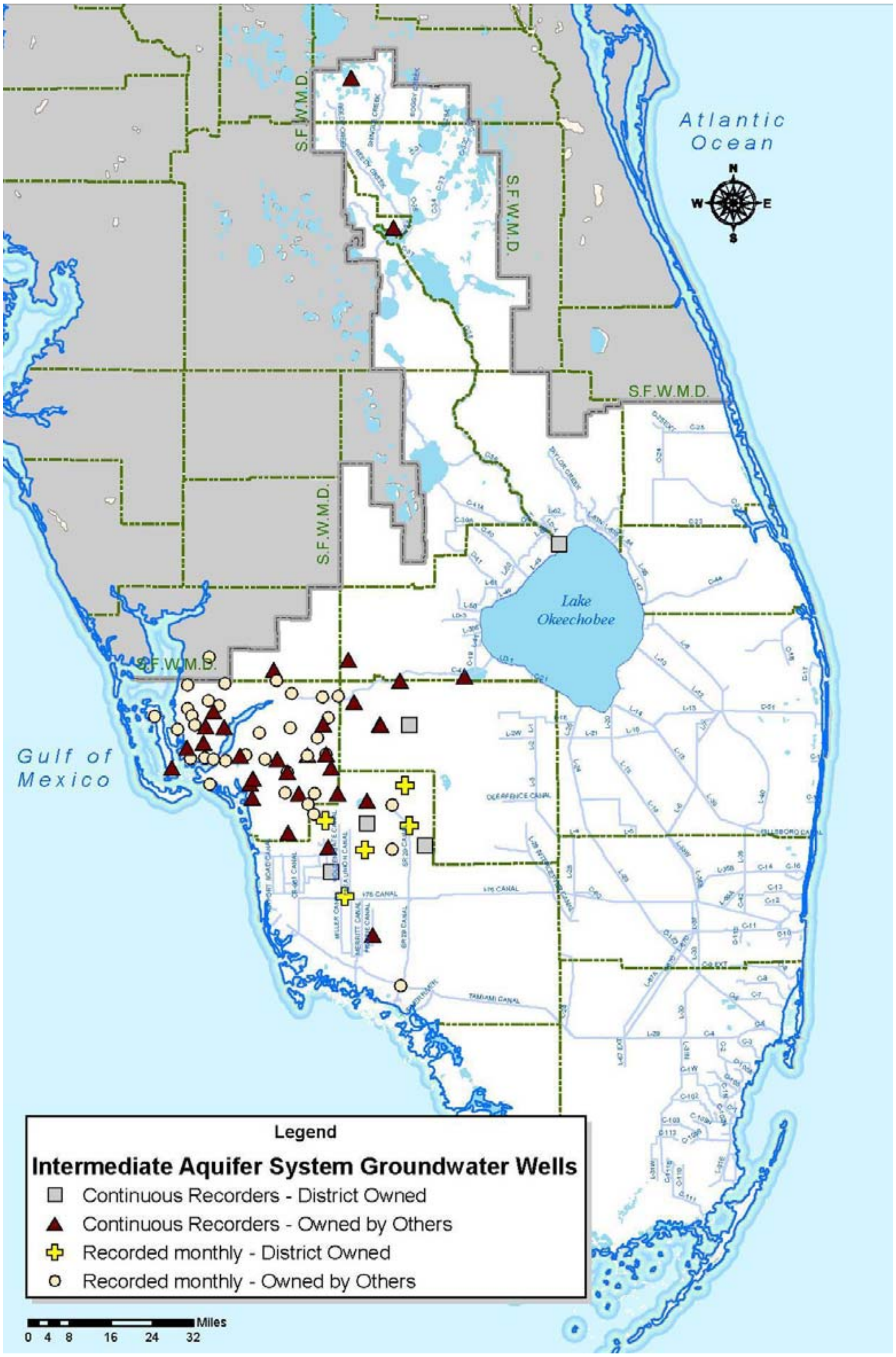

Figure 55. Intermediate aquifer system wells.

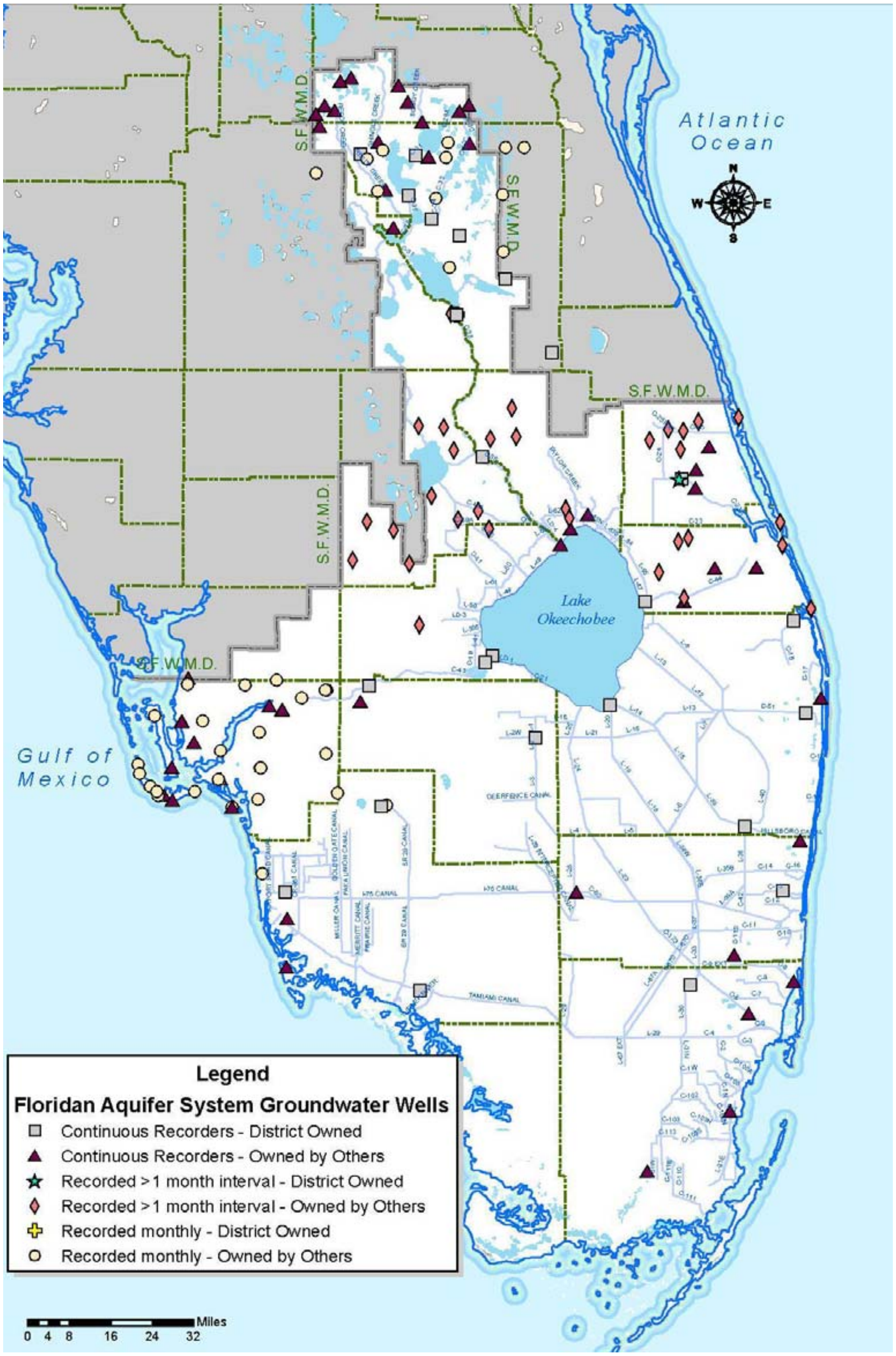

Figure 56. Floridan aquifer system wells.

2. Field Instrumentation Used at the Sites

The District measures groundwater levels by using a pressure transducer, typically connected to a Campbell Scientific® CR10 data logger (**Figure 57)**. In-Situ® Level Troll pressure transducers are commonly used in non-artesian or water table aquifer wells (**Figure 58)**. The In-Situ® Level Troll pressure transducer is a fully submersible instrument that measures accurate head pressures (water levels) above the sonde.

Artesian or confined aquifer wells are typically equipped with Rittmeyer® pressure transducers (**Figure 59)**. The Rittmeyer® pressure transducers are installed at the top of the wellhead and measure head pressure. The transducers communicate with the CR10 data loggers through an electronic cable. The data logger then converts measured pressure values into water levels and records these data for subsequent downloads via laptop computers. Alternatively, data from some of the wells connected to the CR10s are sent via telemetry to the District's headquarters. A non-artesian well site that transmits data via telemetry is shown on **Figure 60.**

Figure 57. A Campbell Scientific® CR10 data logger (attached to pressure transducer in a non-artesian well).

Figure 58. An In-Situ® Level Troll pressure transducer.

Figure 59. Rittmeyer® pressure transducers connected to a Floridan Aquifer System dual-zone well.

Figure 60. A non-artesian well site connected via telemetry.

Some wells in the groundwater network are measured by a well sounder, an instrument that measures water levels by means of an electronic sensor (**Figure 61)**. The sensor is lowered into the well, and a light and buzzer indicate when contact between the sensor and water is made. Along the sensor cable are permanently stamped depth markings to indicate the depth of the water from the top of casing (TOC). To obtain a water level elevation, the depth measurement is subtracted from the TOC elevation. An example of a well measured with a well sounder is shown in **Figure 62**.

Figure 61. Electronic well sounder used for measuring groundwater levels.

Figure 62. An un-instrumented groundwater monitoring well (typically measured with a well sounder).

The USGS measures and records groundwater levels during the last four days of each month. The majority of USGS groundwater wells are equipped with continuous recorders such as the Sutron® 8400 automated data recorders, Stevens® automated data recorders, or data collection platforms. With the exception of data collection platforms, these recorders measure daily groundwater levels at 1-hour frequencies. Data collected by data collection platforms use the Geostationary Operational Environmental Satellite (GOES), which permits water levels to be transmitted to the USGS on a near real-time basis. All data collection platforms are linked to the Internet (http://www.sflorida.er.usgs.gov) and allow users to query the data and produce hydrographs.

3. Frequency of Water Level Measurements

The frequency of water level measurements is not the same at all wells. About 67 percent are fitted with continuous recorders, about 26 percent have measurements taken monthly, and about 7 percent have measurements taken at more than one month intervals. **Table 17** shows the frequency of water level measurements of the wells and is classified by aquifer system. **Table 18** shows the frequency of water level measurements classified by county and aquifer system. **Figures 63** through **65** show the location of the wells by frequency of water level measurements: continuous, monthly, and greater than 1 month, respectively.

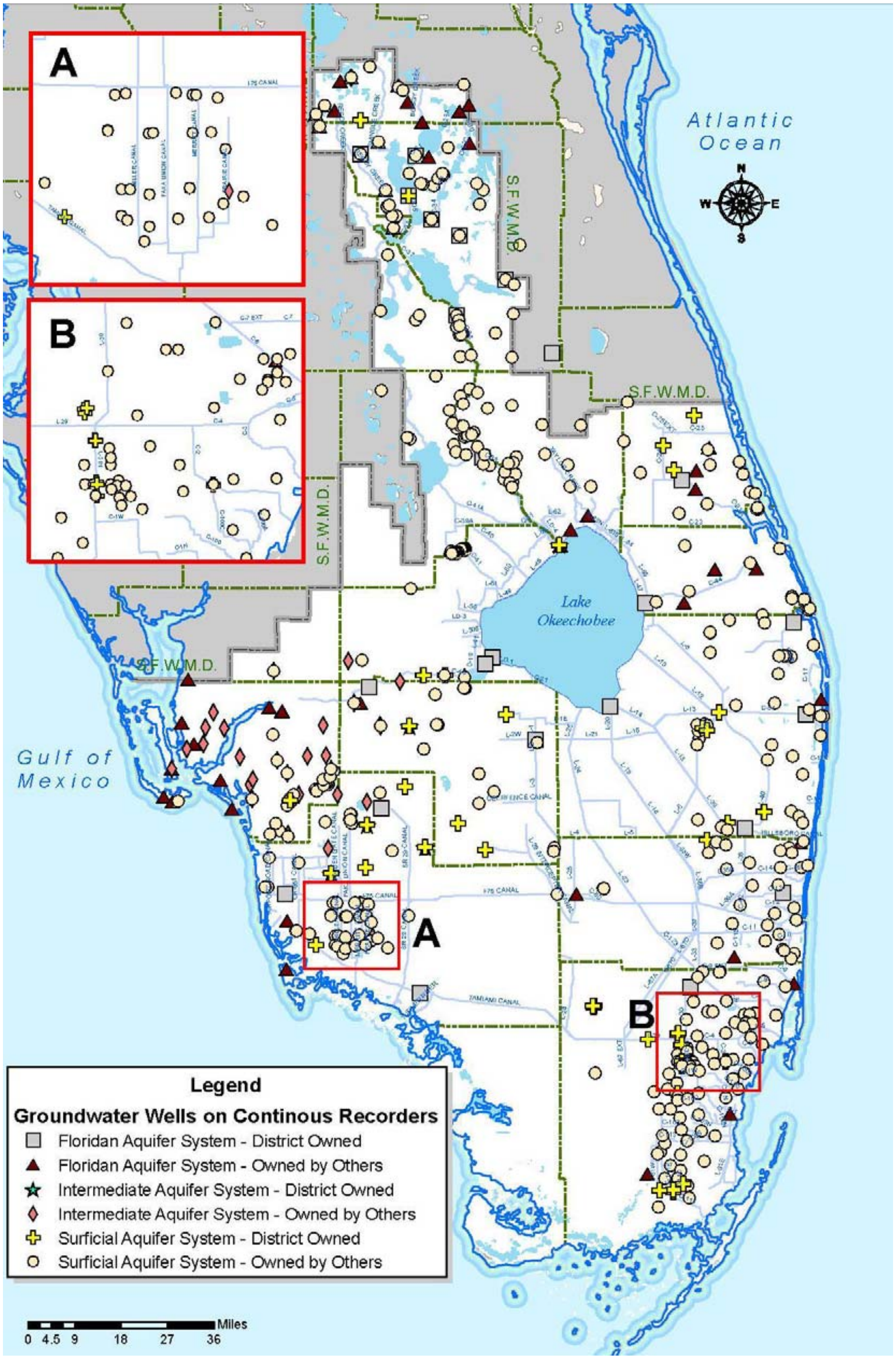

Figure 63. Location of wells on continuous recorders.

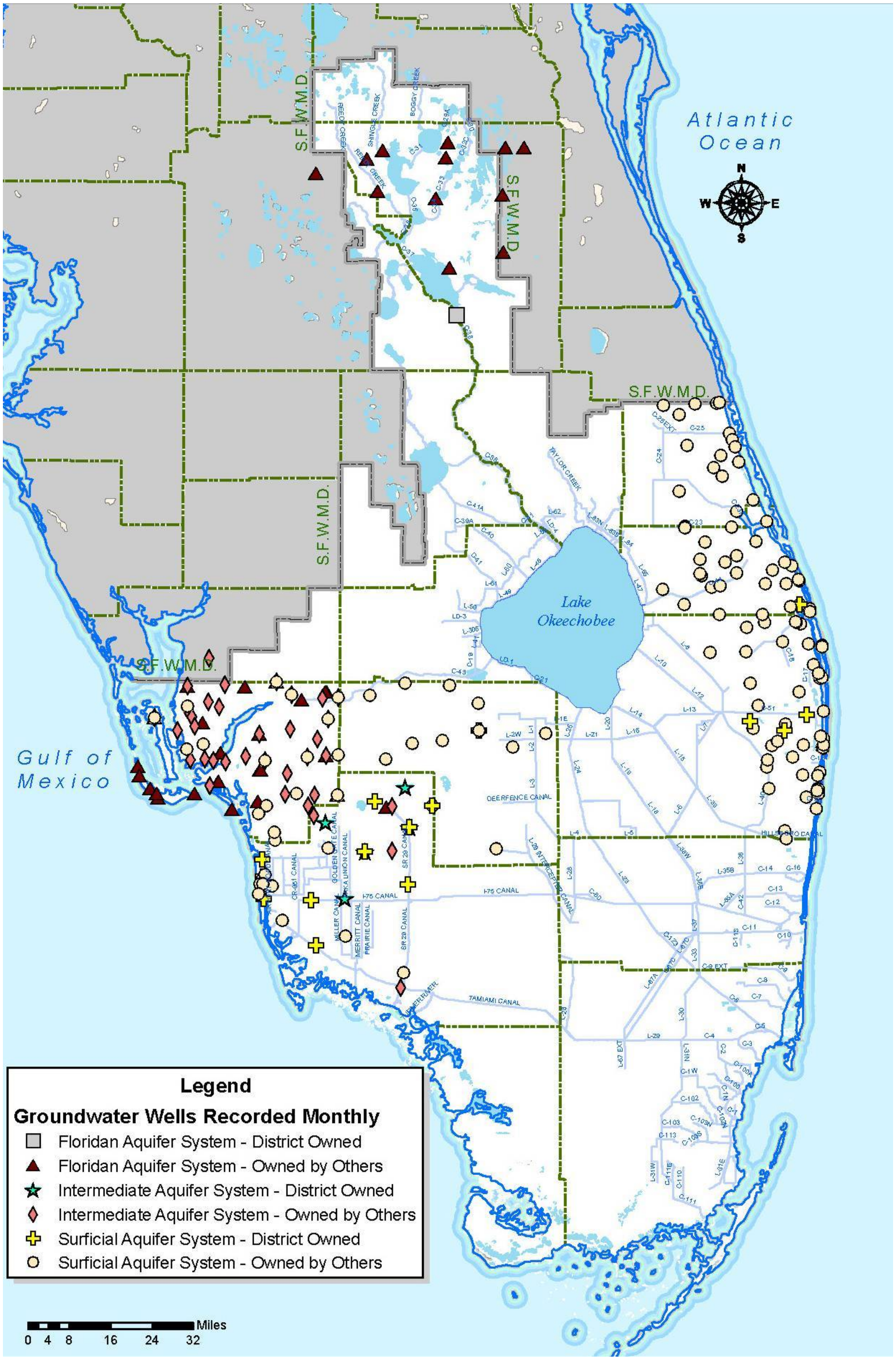

Figure 64. Location of wells recorded monthly.

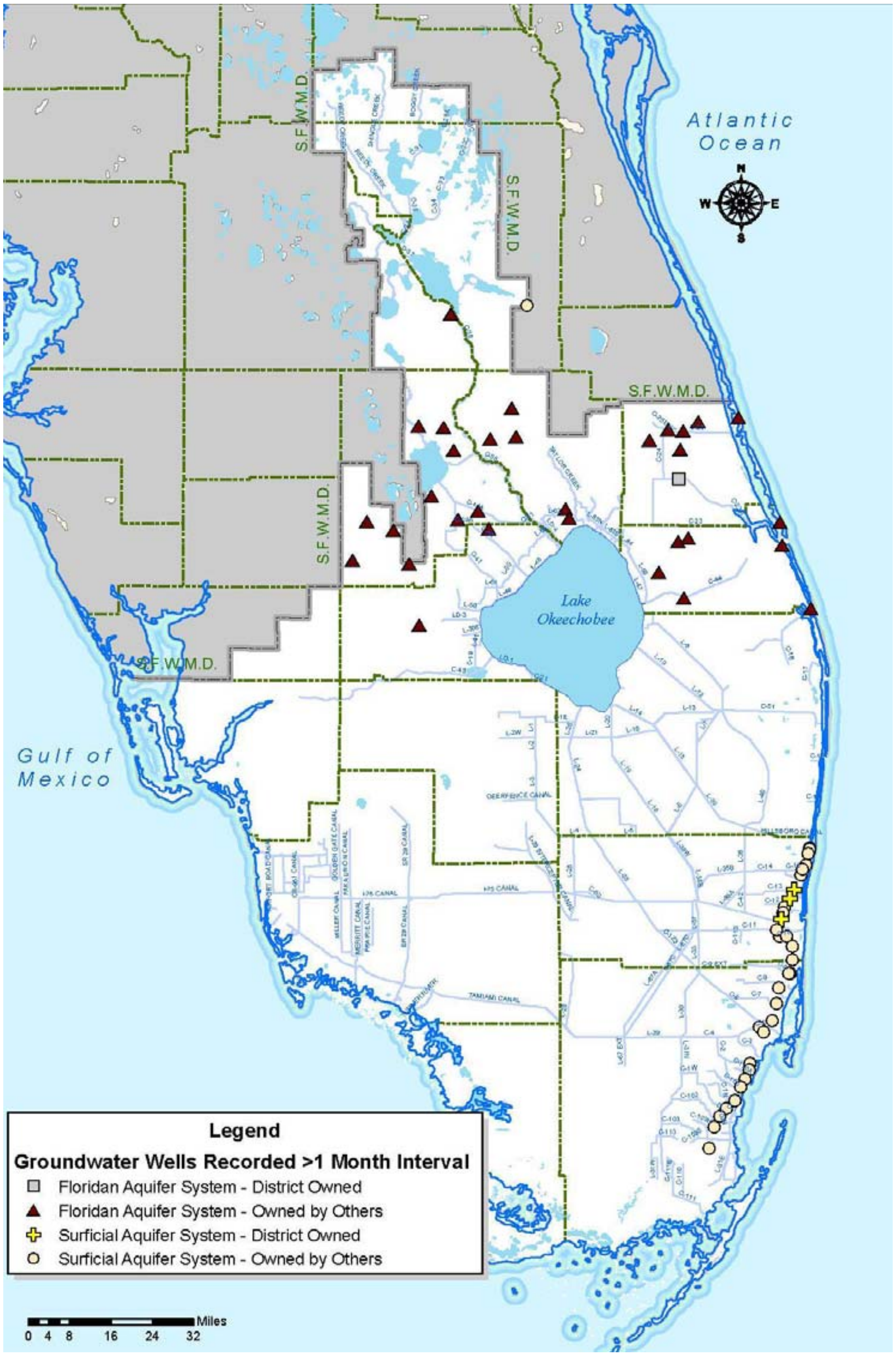

Figure 65. Location of wells recorded at > 1-month intervals.

Table 17. Wells classified by frequency of water level measurements and aquifer system.

Aquifer System	Aquifer Unit	Number of Wells by Frequency of Measurements			Total Number	% of Total
		Continuous	Monthly	>1 Month		
Surficial	Water Table Biscayne Lower Tamiami	537	173	33	743	76
Intermediate	Sandstone Mid-Hawthorn	40	42	N/A	82	8
Floridan	Lower Hawthorn Suwannee Ocala Group	79	39	32	150	15
Total Number		656	254	65	975	100
% of Total		67	26	7	100	100

N/A Not available

Table 18. Wells classified by county, frequency of water level measurements, and aquifer system.

County	County Total	Surficial Aquifer System				Intermediate Aquifer System			Floridan Aquifer System			
		Continuous	Monthly	>1 month	*Total*	Continuous	Monthly	*Total*	Continuous	Monthly	>1 month	*Total*
Broward	**58**	36	1	16	***53***				5			***5***
Charlotte	**4**	1			***1***	1	1	***2***	1			***1***
Collier	**102**	55	24		***79***	7	9	***16***	5	2		***7***
Glades	**20**	12			***12***	4		***4***	2		2	***4***
Hendry	**52**	30	13		***43***	5		***5***	4			***4***
Highlands	**59**	49			***49***						10	***10***
Lee	**136**	30	17		***47***	21	32	***53***	12	24		***36***
Martin	**58**	14	34		***48***				4		6	***10***
Miami-Dade	**133**	112		16	***128***				5			***5***
Monroe	**1**								1			***1***
Okeechobee	**47**	38			***38***				4		5	***9***
Orange	**20**	9			***9***	1		***1***	10			***10***
Osceola	**78**	52		1	***53***				13	12		***25***
Palm Beach	**127**	56	64		***120***				6		1	***7***
Polk	**29**	25			***25***	1		***1***	1	1	1	***3***
St. Lucie	**51**	18	20		***38***				6		7	***13***
Grand Total	**975**	537	173	33	***743***	40	42	***82***	79	39	32	***150***

C. Groundwater Data

1. Data QA/QC Procedures

The District's SCADA and Hydrologic Data Management (SHDM) Department collects, processes, and archives groundwater data from 419 wells. This department includes the SCADA and Instrumentation Management (SIM) Division and the Operations and Hydrologic Data Management (OHDM) Division. The SIM Division is responsible for installing and maintaining groundwater instrumentation, and ensuring that appropriate data are collected. The OHDM Division is responsible for processing and archiving the groundwater data into the DBHYDRO database.

Groundwater data collected by the SIM Division are reviewed and processed by the OHDM Division following established standard operating procedures (Sangoyomi and Lambright, 2006). Data review includes examination of groundwater data plots using a graphical verification analysis program. Data anomalies, if observed, are reported to the SIM Division for further evaluation. If anomalous data are identified, a request for maintenance and repair (Maintenance Inventory Recorder Malfunction Aid [MIRMAID]) report can be generated. This report triggers an email sent to SIM to request review of the suspect data. The email is assigned to an individual who typically must visit the monitoring site to investigate the problem.

A consultant is performing additional QA/QC to groundwater data series used in support of the District's reporting, modeling, and regulatory programs. The consultant will evaluate groundwater level measurements, perform temporal and spatial statistical analyses of the data, verify reference elevations, fill missing data, resolve hydrogeologic problems, and document all analyses in technical reports. This groundwater data will be assigned a new dbkey that indicates that it has gone through more thorough QA/QC procedures. This project is anticipated to be completed by September 2006.

The USGS is responsible for the monitoring and QA/QC of 362 wells in the groundwater network. Of these wells, 333 are part of the original 2006 cooperative agreements with the District and the USGS. Per this agreement, an additional 29 wells were added for semiannual water level measuring.

Many USGS wells are automated and equipped with automatic data recorders. Other USGS wells are manually measured with well sounders or pressure gauges. The USGS groundwater data resides in the Automated Data Processing System (ADAPS) database on Data General hardware. The USGS archives the data in their corporate database and portions of the data are migrated into DBHYDRO via an automated download.

2. Groundwater Data Availability

Groundwater data are available in the DBHYDRO database. If some wells do not have active dbkeys, then the Excel spreadsheet file in the appendices shows notes regarding when active dbkeys may become available.

a. Wells to be added to database

Hydrologic On-line Well Inventory (HOWDI) Wells

The District's Water Supply Department collects, processes, and archives groundwater data from 120 surficial aquifer wells located in Palm Beach, Martin, St. Lucie, and Hendry counties that are part of the HOWDI network. The USGS had been responsible for water level collection and data management for these HOWDI wells until 1995. Since that time, various District departments have taken responsibility for the HOWDI well network. Currently the Resource Evaluation and Sub-Regional Modeling Division of the Water Supply Department maintains responsibility of the HOWDI well network. The Division archives the groundwater data and manages contractors who perform monthly manual water level measurements. The HOWDI well data are located in an Oracle database not linked to DBHYDRO. Plans to migrate the HOWDI well data to DBHYDRO include surveying all the HOWDI wells and assigning dbkeys to store historic and future data. These data should be included in DBHYDRO by January 2007.

USGS/District Cooperative Wells

Less than half of the groundwater data currently collected from the USGS/District cooperative agreement are being transferred from ADAPS into DBHYDRO. Two alternatives to accessing ADAPS are being considered: (1) assign Dbkeys to the remaining wells and transfer all the ADAPS data into DBHYDRO or (2) provide links from the dbkey to the data located at the USGS website. However, a date for completion of these alternatives was not available at the time of this report.

3. Existing Groundwater Data from Project, Regulation, and Injection Wells

Groundwater data not included in DBHYDRO were collected as part of specific District projects independent of the SHDM Department. Although such projects may involve data collection and processing similar to that performed by SHDM, the data may have quality concern issues. However, a portion of this data could undergo QA/QC procedures and be included in DBHYDRO.

A large amount of groundwater data from regulation wells is submitted to the Water Use Regulation Division by approximately 100 permit holders with Water Use Permits issued by the District. While the actual data are collected by the permit holders, the District archives the data. Many permit holders that possess Individual or major General Water Use permits are required to develop and implement groundwater-monitoring programs as conditions of their permits. The objective of these permit conditions is to provide a means of evaluating whether permitted withdrawals may be causing adverse impacts to water resources, protected users, or protected environmental species.

Monthly or quarterly water-level measurements of monitoring wells and/or production wells are typically required of the permit holders. These data are evaluated to ensure compliance with permit conditions. Quality assurance is solely the responsibility of the permit holders; hence, the quality of data in this category may vary and is not included in

DBHYDRO. However, future data collected may be added to the DBHYDRO database as more QA/QC procedures are implemented.

The Florida Department of Environmental Protection (FDEP) maintains an injection well groundwater database. Data from this database would be ideal for inclusion into DBHYDRO as it includes deeper portions of the Floridan Aquifer System not normally monitored by District wells. However, the District will need to work with the FDEP to resolve QA/QC and data dissemination concerns before such inclusion takes place.

D. Groundwater Monitoring Network Design

The purpose of groundwater wells was to obtain groundwater quantity and quality information for various water supply related projects. While the existing groundwater network has evolved over several decades, the design of the network was not performed. However, in 2001, the District's groundwater monitoring network was assessed (Lukasiewicz et al., 2002). In 2004, the District and USGS discussed the possibility of developing a groundwater monitoring network design project. This project is expected to be performed in the next few years depending upon availability of funds at the District and USGS.

1. Proposed Groundwater Wells

a. Floridan Aquifer System wells – South of Lake Okeechobee

Because there is sparse coverage in this region, more wells will need to be installed to monitor the effects of increased Floridan aquifer system use and upcoming aquifer storage and recovery projects in the region. These additional wells will support modeling efforts by providing data to determine circulation and boundary conditions of the Floridan aquifer system.

b. Surficial Aquifer System wells – Interior District Region

The interior portions of the District, away from the heavily populated coasts, have sparse surficial aquifer system coverage. As the District proceeds with designing and implementing the CERP and Acceler8 programs, these areas will need more Surficial Aquifer System wells to monitor progress of these projects.

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