# OPERATIONS CONTROL & HYDRO DATA MANAGEMENT DEPARTMENT
## HYDRO DATA MANAGEMENT DIVISION
### Quality Assurance & Hydrology Section

**Procedure:** **Q200-001**

**Title:** **Quality Assurance Management for Hydrometeorological and Water Level Monitoring at the South Florida Water Management District**

## Revision Chart

| REV | DESCRIPTION | DATE | PREPARED BY | REVIEWED BY | APPROVED BY |
|---|---|---|---|---|---|
| 01 | Draft Issue | 4/24/10 | T. Sangoyomi/ S. Graham | S. Sylvester M. Ansar/ L. Deaton/ E. Ebanks/ C. Gomez/ J. Gonzalez/ J. Goodson/ J. Heron-Reid/ S. Huebner/ C. James/ L. Latour/ J. Lynch/ R. Musalem/ C. Pathak/ J. Raymond/ G. Ritchie/ L. Rodriguez/ T. Sangoyomi/ K. Smith/ J. Vincent/ M. Wilsnack/ G. Wu/ K. Stewart/ E. Damisse/ M. Chen/ D. Dawkins/ | S. Sylvester M. Ansar K. Smith C. James L. Deaton L. Lynch |
| - | Original Issue | 4/26/11 | C. Pathak/ L. Herlihy | C. Pathak | C. Pathak |

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# EXECUTIVE SUMMARY

The South Florida Water Management District (SFWMD or District) is a government agency responsible for managing and protecting water resources in 16 counties from central Florida near Orlando in the north to the Florida Keys in the south. This region covers approximately 18,000 square miles (46,439 square kilometers), and includes vast areas of agricultural lands, areas of urban growth and development, the Kissimmee River and Chain of Lakes, Lake Okeechobee, and the Southern Everglades.

The District collects, validates, and archives hydrologic data used for real-time water management and data analysis. This is accomplished through hydrometeorologic and hydraulic monitoring. The data are acquired from the collective monitoring networks of the District, and subsequently summarized, stored, and published. The data are stored in two different databases: breakpoint data are stored in the Data Collection/Validation Preprocessing (DCVP) database, while daily summary and 15-minute data are published in the DBHYDRO database.

Datasets generated from the District's monitoring include water levels (stage), water control structure operations (gate openings and pump speed), ground water elevations, flow (measured and computed), rainfall, radiation, evaporation and other meteorological data. Planners, scientists, engineers and water managers use these data in models and decision making processes to support the District's mission (e.g., operation of water control structures, hydrologic and hydraulic analyses and modeling, design of new structures, regulatory and/or permit compliance, etc.). Since these datasets are critical to achieving the District's mission, it is important that the quality assurance management requirements be documented for this monitoring. This document, *Quality Assurance Management for Hydrometeorological and Water Level Monitoring at the South Florida Water Management District* (Q200-001), sets forth those requirements.

The Operations Control and Hydro Data Management Department is responsible for hydrological and hydrometerological data collection and management. The Department is responsible for designing, installing, maintaining, and repairing environmental data recording instrumentation, and for producing, managing, and maintaining the highest quality operational and hydrometeorologic data. The quality assurance management requirements for all phases of the hydrometeorologic and hydraulic data monitoring are described in Q200-001, with references to supporting material given throughout for the expert-level reviewer. The Q200-001 document provides requirements for phases including project planning, training, site selection, sensor selection, installation, preventive maintenance, data management, flow measurement and computation, quality assurance/quality control, data change, and auditing.

# 1.0 PURPOSE

These guidelines support the Operations Control and Hydro Data Management Department (OCHDM), Hydro Data Management Division (HDM), the SCADA & Instrumentation Division (SIM), and Telemetry Spec and Support Division (TSS) of the Operations Control and Hydro Data Management Department (OCHDM). It specifies the Quality Assurance Management Requirements (QAMR) that will be used during training, project planning and review, site selection, sensor selection, installation, maintenance, data processing and archiving, flow-rating development, quality assurance, streamgauging, data change, and auditing/assessment. It also specifies the data objectives, which include accuracy, precision, sampling frequencies, availability, completeness and timeliness for hydrometeorological data. Data must be of the highest quality, consistency, and comparability to be defensible for scientific and legal purposes.

# 2.0 SCOPE

The goal of this document is to describe the District's *Quality Assurance Management for Hydrometeorological and Water Level Monitoring at the South Florida Water Management District* (Q200-001) for hydrometeorological and hydraulic data. Requirements and guidelines are provided for parameters including evaporation, evapotranspiration, air temperature, barometric pressure, solar radiation, net radiation, photosynthetic radiation, wind speed, wind direction, relative humidity, rainfall, surface water stage, groundwater stage, measured flows, computed flows, pump RPMs, and gate openings.

This document covers:

- Data quality objectives for accuracy, precision, sampling frequency, availability, completeness and timeliness
- Requirements and guidelines for site selection, sensor selection, installations, maintenance, and datum reference elevations
- Guidelines for training, project planning, and review
- Guidelines for data processing, quality assurance, flow rating development, and archiving
- Guidelines for audits of data production processes including installations, preventive maintenance, data processing, flow rating development, and quality assurance

This is intended to be a dynamic document that will be periodically reviewed and updated as new information becomes available or advances in technology are made.

# 3.0 RESPONSIBILITIES

## 3.1 Primary Responsibility for the Process and Procedures

**3.1.1** The Quality Assurance Officer of the OCHDM Department is responsible for the Quality Assurance Management Requirements and for the maintenance of this document.

**3.1.2** Awareness of and compliance with these guidelines are required by all applicable SFWMD organizations. This and all subsequent revisions of this procedure must have evidence of approval.

### 3.2 Secondary Responsibility

All technical staff, supervisors, and section leaders are responsible for reviewing and understanding these requirements, guidelines, and document contents. The supervisors and section leaders are also responsible for ensuring that personnel in their sections are trained in and comply with these guidelines as written.

## 4.0 DEFINITIONS

| | |
|---|---|
| Accuracy | Degree of closeness (variance) a measured or calculated quantity is to an actual or true value. |
| Availability | Percentage of time that a system or function is available for service according to established criteria. The key components of availability are reliability and maintainability. Availability can also denote the probability that a system is operating satisfactorily at any point in time, excluding times when the system is under repair. |
| Audit (Assessment) | A systematic and independent examination to determine whether quality activities and related results comply with planned arrangements and whether these arrangements are implemented effectively and are suitable to achieve objectives. |
| Breakpoint Data | The name given to real-time resolution data collected by the SFWMD. The term is used to describe data collected at random intervals throughout a given observed duration of hydrologic conditions. |
| CERP | Comprehensive Everglades Restoration Plan: The framework and guide for the restoration, protection, and preservation of the south Florida ecosystem. CERP also provides for water-related needs of the region, such as water supply and flood protection. |
| Completeness | Having all expected and necessary parts, elements or steps. Percentage of expected measurements that are reported successfully. |
| Data Collection | Refers to activities associated with obtaining meteorological, hydrologic, hydraulic, and water quality measurement and samples. |
| Data Processing | A set of activities that are performed on unprocessed time series data collected through the District’s monitoring network. |
| District or SFWMD | South Florida Water Management District |
| DCVP | The Data Collection/Validation Preprocessing System is used to process all of the raw data received through the various data collection methods used by the District. DCVP was developed to handle manually and electronically collected data. |
| DQO | Data Quality Objectives: Qualitative and quantitative statements that are used to define the study objectives, the appropriate type of data that should be collected, and to specify tolerable levels of decision errors. |

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| Flow (or Discharge) | The rate of water movement past a reference point, measured as volume per unit time, usually expressed as cubic feet per second. |
| Headwater | Headwater is water that is typically of higher elevation (with respect to tailwater) on the controlled side of a structure. |
| Maintainability | The ease with which a component can be modified to correct faults. The most common maintainability parameter is mean time of repair, which is the mean time it takes to repair a failed component. |
| OCHDM | Operations Control and Hydro Data Management |
| Precision | Also called reproducibility or repeatability, the degree to which further measurements or calculations will show the same or similar results. |
| QA | Quality Assurance: The utilization and evaluation of quality control results to verify that a system is operating within acceptable limits. Also, the procedures and practices developed and implemented to produce data of a required level of reliability. |
| Q200-001 | *Quality Assurance Management for Hydrometeorological and Water Level Monitoring at the South Florida Water Management District* |
| Reference Elevation | Represents the most recent surveyed elevation. Certified reference elevations of the First Order of accuracy are recommended for data processing purposes. |
| Reliability | Probability of a system performing a specified function without failure for a specified period of time; a failure occurs when a measurement or control action does not comply with established accuracy, completeness, or timeliness standards. The most common reliability parameter is the mean time between failures. |
| Resolution | The smallest detectable change an instrument can measure. |
| RPM | Revolutions per minute, for this document, rpms denote pump speed and, indirectly, volume of water being moved. |
| Sensor | A device used to record a specific data type. For purposes of data processing and station assignments, sensors may also be referred to as sensor-stations and have the same definition as the term station. |
| Site | A representative point used to designate one or more stations that are associated by proximity or project. Site level representation is to provide clarity for small scale mapping in lieu of displaying a high density of associated stations. A site should not be viewed as an area feature with specific boundaries but simply as a representative location of activities. |
| Stage | The height or level of the water surface above a given reference point at a particular location along the river, stream, or canal. Stage recorders monitor the depth of water at a gauging station. Because there is a relationship between discharge and stage at any point, stage can be used to calculate discharge. |
| SOP | Standard Operating Procedure: A written document that details the method for an operation, analysis, or action with thoroughly prescribed |

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| | techniques and steps, which is officially approved as the method for performing certain routine or repetitive tasks. |
| Station | A specific coordinate that indicates where data (observations, sampling or monitoring) are collected. A coordinate may have more than one station associated with it. The name given to a station has traditionally been similar to, or an exact duplicate of, the corresponding site name. |
| Streamgauging | The various operations necessary for measuring discharge. |
| Tailwater | Tailwater is water that is typically of lower elevation (with respect to headwater) or on the discharge side of a structure. |
| Time Series Data | A single data variable that changes with time. Examples of time series data are hourly precipitation, instantaneous river stage, flow, etc. |
| Timeliness | Promptness of reporting a measurement after it is made. |
| Telemetry | Transmission and collection of data obtained by sensing conditions in a real-time environment. |
| True North | The direction of the northern geographic pole. |
| TSS | Telemetry Spec and Support |

# 5.0 TRAINING

All personnel involved in data collection and data processing activities must have the necessary education, experience, and skills to perform their duties. Training activities and demonstration of capabilities must be documented. The training must include expectations regarding ethical behavior and data integrity. Training procedures, training records, and demonstration of capabilities must be documented indicating the specific tasks, date of training, and proper signatures.

## 5.1 Skills and Training

In order to meet the requirements of the OCHDM Department and ensure the validity of its results, all personnel should be properly trained in the monitoring processes in which they are involved. Personnel shall be trained in District-specified standard operating procedures (SOPs) for each defined process and maintain consistent documentation. The training shall include expectations regarding ethical behavior and data integrity to ensure that the data collected are of acceptable quality and are legally defensible. The level of training shall be documented. Training in new skills or methods may be conducted via a mentoring procedure, through formal classes, or by working with experienced colleagues, and must be properly documented.

Specifically, training will include a combination of formal classroom training, self-learning modules, discussions with immediate supervisor and/or project managers, field trips, and on-the-job training. The employee's immediate supervisor has the primary responsibility of ensuring that adequate training is provided.

### 5.2 Training Assessment Review

The Supervisors and Section Leads will evaluate the requirements for positions held by their staff within their areas of responsibility. They will also plan and facilitate any training necessary to meet those requirements.

### 5.3 Safety and Health

The Department is mandated through the Occupational Safety and Health Administration (OSHA) 29 CFR 1960, to establish policies, procedures, and requirements of managers and supervisors to provide training, a safe working environment, and proper equipment for employees to undertake field assignments with minimal chance of personal injury or infringement of the rights of others.

Since employees may be required to participate in numerous field activities ranging from routine meetings with cooperators, other federal and public officials, and private citizens to potentially hazardous assignments, such as measuring water control structure discharge, hurricane emergency preparedness, and making flood measurements, it is incumbent on the Department/Division to provide proper safety training for new employees and refresher courses for all employees.

Staff is required to be familiar with the District's established occupational safety and health policy, practices and procedures covering: (1) Motor Vehicle/Operations Safety, (2) First Aid and CPR, (3) Safe Boating, (4) Water Safety, (5) Field Safety, and (6) Boat Operation.

## 6.0 PROJECT PLANNING AND REVIEW

A monitoring project plan should be developed and subject to reviews prior to any monitoring implementation. CERP (2009) contains guidance and discussion on preparing a monitoring plan. The basic elements of the monitoring plan include the project introduction, data quality objectives (DQOs), data quality indicators, field activities (methodologies, equipment, instrumentation and maintenance procedures), documentation and record keeping requirements, reporting requirements, quality control requirements, data verification and validation procedures, and data management procedures. Appendix B of the *CERP Guidance Memorandum* (CGM 40.01) provides a Hydrometeorologic Monitoring Plan Template that should be used for preparing the monitoring plan. In addition, site selection criteria, preventive maintenance, sensor selections, installation requirements, and auditing/assessment requirements should be discussed in the project plan.

Prior to project planning, a clear monitoring need at the program level should be established. Examples of need may include mandates or permits, landscape-level changes, or enhancements of monitoring instruments.

## 7.0 DATA QUALITY OBJECTIVES

The DQO process is a planning approach for developing sampling designs for data collection that will be used in decision making. The DQOs are the qualitative and quantitative statements that are used to define the study objectives, the appropriate type of data that should be collected, and to specify tolerable levels of decision errors. General QASR guidelines for formulating project-specific DQOs are presented in CERP (2007) (Chapter 2, Section 2.5).

The seven steps in the DQO process are as follows:

1. State the problem
2. Identify the goal of the study
3. Identify inputs
4. Define boundaries
5. Develop a decision rule
6. Specify limits on decision errors
7. Develop the plan and optimize the design

Formulating project DQOs brings awareness to project participants of the minimum data quality required for a project. The DQO process is a tool used to define the type, quality, and quantity of data needed to make defensible decisions for a project. This process systematically defines the requirements for a field investigation and the limits on tolerable error rates. It also identifies the intended end use of the data, including decisions that may be made based on the results of a project.

The DQO process has both qualitative and quantitative components. The qualitative steps encourage logical and practical planning for environmental data collection activities, while the quantitative steps use statistical methods to design a data collection operation that will efficiently control the probability of making an incorrect decision.

The quantitative components of the DQO process (Step 6) for hydro-meteorological data monitoring include accuracy, precision, sampling frequency, reporting frequency, availability, completeness and timeliness. The District guidelines for these quality indicators are contained in SFWMD, 2009. A summary for the various hydrometeorological data types is provided in Table 6.1 of that document.

Each project should adequately select sensors or measurement devices to ensure that they are capable of meeting and complying with their accuracy and precision requirements and other quality indicators provided in **Table 1**.

**Table 1. Data Quality Objectives** (See SFWMD, 2009; CERP, 2007).

| PARAMETER | QUALITY DIMENSION[1] | | | | | |
|---|---|---|---|---|---|---|
| | Accuracy | Precision[6] | Sampling Frequency | Availability | Completeness | Reporting Frequency & Timeliness |
| **Evapotranspiration** | ±0.02 inches | N/A | 1 day | Reliability: 24 months<br>Maintainability[2]: 72 hours | 95%[3] | Reporting Frequency: 1 sample per day |
| **Air Temperature** | ±0.4 Celsius over full range<br>Reported resolution=0.1 °C<br>Instrument range: -33-48 °C | ±0.1 °C | 2 seconds to 15 minutes | Reliability: 24 months<br>Maintainability[2]: 72 hours | 95%[3] | Reporting Frequency: 4 samples per hour<br>Timeliness: max 15-minute real-time delay<br>Timeliness: max 1 day post-process delay |
| **Barometric Pressure** | ±0.375 mm Hg (millimeters Mercury)<br>Reported resolution=0.1 mm Hg<br>Measurement range: 600.35-795.475 mm Hg | ±0.75218 mm Hg | 20 seconds to 1 minute | Reliability: 12 months<br>Maintainability[2]: 72 hours | 95%[3] | Reporting Frequency: 4 samples per hour<br>Timeliness: max 15-minute real-time delay<br>Timeliness: max 1 day post-process delay |
| **Solar Radiation** | ±5% for readings > 0.0926 kW/$m^2$<br>±0.0046 kw/$m^2$ for readings < 0.0926 kW/$m^2$<br>Reported resolution=0.001 kW/$m^2$<br>Measurement range: 0-1.3 kW/$m^2$ | ±0.001 kW/$m^2$ | 1 minute | Reliability: 24 months<br>Maintainability[2]: 72 hours | | Reporting Frequency: 4 samples per hour<br>Timeliness: max 15-minute real-time delay<br>Timeliness: max 1 day post-process delay |
| **Net Radiation** | ±5% for readings > 0.0926 kW/$m^2$<br>±0.0046 kw/$m^2$ for readings < 0.0926 kW/$m^2$<br>Reported resolution=0.001 kW/$m^2$<br>Measurement range:<br>-0.1-1.0 kW/$m^2$ land-based station<br>-0.2-1.1 kW/$m^2$ wetland surrounded by open water | N/A | 1 minute | Reliability: 12 months<br>Maintainability[2]: 72 hours | 99%[3] | Reporting Frequency: 4 samples per hour<br>Timeliness: max 15-minute real-time delay<br>Timeliness: max 1 day post-process delay |
| **Photosynthetically Active Radiation** | ±5% in μmol/$m^2$/s<br>Reported resolution= 1 μmol/$m^2$/s<br>Measurement range: 0-2,500 μmol/$m^2$/s | N/A | 1 minute | Reliability: 24 months<br>Maintainability[2]: 72 hours | 99%[3] | Reporting Frequency: 4 samples per hour<br>Timeliness: max 15-minute real-time delay<br>Timeliness: max 1 day post-process delay |

**Table 1.** Continued.

| PARAMETER | QUALITY DIMENSION[1] | | | | | |
|---|---|---|---|---|---|---|
| | Accuracy | Precision[6] | Sampling Frequency | Availability | Completeness | Reporting Frequency & Timeliness |
| **Wind Speed** | ±1.1 mph < 22 mph<br>5% of readings > 22 mph<br>Reported resolution=0.2 mph<br>Measurement range: 0-155+ mph | ±1 mph | 1 second | Reliability = 24 months<br>Maintainability = 72 hours[2] | 95%[3] | Reporting Frequency: 4 samples per hour<br>Timeliness: max 15-minute real-time delay<br>Timeliness: max 1 day post-process delay |
| **Relative Humidity** | ±5%<br>Reported resolution=1%<br>Measurement range: 5-100% | ±1◦C and ±1% | 1 minute | Reliability: 6 months<br>Maintainability[2]: 72 hours | 95%[3] | Reporting Frequency: 4 samples per hour<br>Timeliness: max 15-minute real-time delay<br>Timeliness: max 1 day post-process delay |
| **Rainfall** | ±0.01 inches<br>Reported resolution=0.01 inches | ±0.01 inch | 15 minutes | Reliability: 24 months<br>Maintainability[2]: 72 hours | 99%[3]<br>(Jun-Oct)<br>95%<br>(Nov-May) | Reporting Frequency: 4 samples per hour<br>Timeliness: max 15-minute real-time delay<br>Timeliness: max 1 day post-process delay |
| **Surface Water Stage** | ±0.02 feet for critical sites<br>±0.03 feet for non-critical sites<br>Reported resolution=0.01 feet<br>Instrument range: 0-20 feet | ±0.01 feet | 2 seconds to 15 minutes | Reliability: 18 months<br>Maintainability[2]:<br>24 hours critical sites<br>72 hours non-critical sites | 95%[3] | Reporting Frequency: 4 samples per minute<br>Timeliness: max 15-minute real-time delay<br>Timeliness: max 1 day post-process delay |
| **Groundwater Stage** | ±0.03 feet<br>Reported resolution=0.01 feet<br>Instrument range: 0-30 feet | ±0.01 feet | 1 minute to 15 minutes | Reliability: 24 months<br>Maintainability[2]: 72 hours | 95%[3] | Reporting Frequency: 4 samples per hour<br>Timeliness: max 15-minute real-time delay<br>Timeliness: max 1 day post-process delay |

**Table 1.** Continued.

| PARAMETER | QUALITY DIMENSION[1] | | | | | |
|---|---|---|---|---|---|---|
| | Accuracy | Precision[6] | Sampling Frequency | Availability | Completeness | Reporting Frequency & Timeliness |
| **Gate Position** | ±0.05 feet<br>Reported resolution=0.01 feet<br>Gate position range: 0-75/0-550 inches | ±0.02% full stroke | N/A | Reliability:<br>24 months critical sites<br>18 months non-critical sites<br>Maintainability[2]:<br>24 hours critical sites<br>72 hours non-critical sites | 95%[3] | Reporting Frequency: 4 samples per hour<br>Timeliness: max 15-minute real-time delay<br>Timeliness: max 1 day post-process delay |
| **Pump RPM[4]** | ±25 RPM<br>Reported resolution=1 RPM<br>Pump RPM range: 0-3,000 RPMs | N/A | 10 samples per second | Reliability:<br>24 months critical sites<br>18 months non-critical sites<br>Maintainability[2]:<br>24 hours critical sites<br>72 hours non-critical sites | 95%[3] | Reporting Frequency: 1-360 samples per hour<br>Timeliness: max 15-minute real-time delay<br>Timeliness: max 1 day post-process delay |

[1] A definition for each Quality Dimension is available in SFWMD, 2009.
[2] Mean time to repair 95% of incidents
[3] The percentage of a site's reported samples actually received
[4] This standard applies to diesel pumps only
[5] Accuracy is correlated with flow; figures assume head differentials in the order of magnitude of 0.20 feet or higher
[6] Values from CERP (2007)
$kW/m^2$ - kilowatts per square meter
$\mu mol/m^2/s$ - microMols per square meter per second

# 8.0 EVAPOTRANSPIRATION

Evaporation occurs when water is changed into a gas and returned to the atmosphere. Transpiration is the process by which water vapor escapes from a living plant, usually the leaves. It is practically impossible to differentiate between evaporation and transpiration if the ground surface is covered by vegetation; hence, the two processes are commonly linked together and referred to as evapotranspiration. Evapotranspiration rates drawn from evaporation and transpiration measurements are used by the District for various water budgeting purposes (SFWMD, 2009). Only automated measurements are discussed within the scope of this document. For details on manual evaporation pan measurements, see Pathak and Pandey (2008).

## 8.1 Site Selection Requirements

A large, open, flat area of about 60 feet by 60 feet with low vegetation and a sky view open to lower angles of altitude above the horizon is generally recommended for weather station locations (U.S.D.C. *et al*., 2002). However, more stringent criteria are required for evaporation and evapotranspiration by the District because these values are calculated by the weather station (Campbell Scientific, 2005). In order to accurately describe monitored conditions, an area of 100 meters by 100 meters is recommended (ASCE, 2005) that represents the general area of interest (Campbell Scientific, 2005). All weather stations must be installed where shadows do not fall on the instrumentation during daylight hours. Vegetation and site configuration must be controlled to maintain the site's suitability for meteorological monitoring.

Overall, the meteorological monitoring network at the District was initially designed to assist in water structure operations, thus, weather stations were not placed with the specific intent to calculate evaporation and evapotranspiration. An effort to optimize the monitoring network and meet accuracy quality standards for all parameters is ongoing (Martin, 1997; Pathak and Pandey, 2008).

## 8.2 Sensor Selection Requirements

All monitoring sensors must meet or exceed current sensors on power use, durability, accuracy, maintainability, and sampling frequency. It is recommended that the customer requesting a new sensor submit specific requirements for monitoring needs, site conditions (if known), and instrumentation accuracy requirements to the Field Operations Center for actual product selection. If a new product is needed, instruments are tested first in laboratory conditions, and then in the field. Once selected, final instrumentation approval by both parties may provide the best overall quality step to ensure the sensor meets the monitoring needs of a given project. Ideally, sensors for meteorological monitoring will meet or exceed the criteria for DQOs established in **Table 1**.

Since evaporation and evapotranspiration values that are monitored automatically are calculated, sensor selection requirements include those for air temperature, relative humidity, wind speed, and radiation. See the respective parameter and *Sensor Selection Requirements* sections of this document for details on each sensor involved in the calculation. For data quality purposes, the specific instruments and station exposure (e.g., land or water) should be noted by the processing engineer so that adjustment factors can be controlled as needed (WMO, 1997).

## 8.3 Installation Requirements

For all installations, District engineers provide oversight and track contractor's work, and design (SFWMD, 2008d). Design drawings and work standards for contractors are set by District staff for internal and external customers. All new construction projects require a survey of Second Order accuracy for vertical control. Once all equipment has been installed, the installation engineer overseeing the project inspects the build and creates a punch list for follow up. The installation engineer then provides the initial calibrations for instrumentation. Finally, the receiving database must be configured for the new site (SFWMD, 2010e). Electrical connections, data connections, telemetry, and radio-antenna mounting are critical aspects of installation for data collection (SFWMD, 2007b).

A high quality installation of the automated weather station should include the following (Campbell Scientific, 2005):

- Unpack station and check carton contents for damage and completeness
- Collect tools and site information
- Assemble the data logger, communications devices, and power supplies and run checks in the lab to ensure everything works
- Complete a trial run of the tower or tripod assembly before taking to the site
- Repackage equipment with care for transport to the site
- Once the site is established, prepare the tower base, then install out-of-reach sensors and raise the tower
- Next, install the panel box that will hold the instrumentation and interface
- Finally, install the within-reach sensors and begin calibrations and field checks

See the respective parameter and *Sensor Selection Requirements* sections of this document for details on the installation requirements for each sensor involved in the calculation. For data quality purposes, the specific instruments and station exposure as a whole (e.g., land or water) should be noted by the processing engineer so that adjustment factors can be controlled as needed (WMO, 1997).

## 8.4 Preventive Maintenance Requirements

Regular maintenance for all equipment is required to produce accurate data without gaps. Along with sensor maintenance, connections to data loggers, antennae and other communication devices must be kept in good working condition (SFWMD, 2007). Weather station array sites must be maintained to ensure that shadows are not permitted to fall on the instrumentation during daylight hours. This maintenance includes vegetation management and care when making site configuration changes.

Evaporation is calculated every 24 hours by the weather station array at each monitoring site. General annual maintenance of the weather station includes cleaning the solar panel, checking structural integrity elements (bolts, level, and plumb) and power supply. A minimum annual inspection of the physical structure is required (SFWMD, 2007). Monthly maintenance requirements for accurate evaporation calculations include communication assessment and calibration of the air temperature, relative humidity, wind speed, and radiation sensors. For maintenance of each sensor, refer to each parameter's *Preventive Maintenance Requirements* section.

Quality maintenance depends heavily upon good judgment by the servicing technician. A minimum 4-6 month training period in the field is recommended for District staff. A formalized training program with documented sufficiency in each maintenance dimension by technicians is recommended.

Technicians must log all site visits, along with notes of condition, at each visit, into the workflow program relevant to that site that is accessible to data engineers (for example, the Campbell RTU Site Worksheet and Preventative Maintenance Report). If the site requires repair or vegetation maintenance, the appropriate check box in the workflow program to alert management should be selected. Photographs and extensive notes should be taken if the technician notices site configuration or access changes, degradation, or vandalism. One photo per year is required, with additional photos at intermediate visits for site changes (SFMWD, 2010).

# 9.0 AIR TEMPERATURE

Air temperature is defined as the temperature of the atmosphere near the Earth's surface – at a height from 4 feet through 6.5 feet above ground level (WMO, 1997). These measurements are usually taken at a specific location designated as the measurement site. The temperature probe used by the District contains a Platinum Resistance Temperature (PRT) detector and measures air temperature in degrees Celsius (ºC) (SFWMD, 2009).

## 9.1 Site Selection Requirements

A representative reading of the air temperature can be obtained only if the sensor is well protected from sunlight, sky, earth, and any surrounding objects. At the same time, the sensor should be adequately ventilated. The landscaping beneath the sensor should be representative of the surrounding area. Specifically, sensors should be located at least 30 meters away from large paved areas and at a distance of at least four times the height of any nearby obstructions. Short grass or natural earth area of at least 9 meters in diameter around the sensor provides an ideal site (SFWMD, 2009; Campbell Scientific, 2005).

## 9.2 Sensor Selection Requirements

For general guidelines applicable to all meteorological sensor selections, see the *Evapotranspiration, Sensor Selection Requirements* subsection of this document.

The sensor used to measure air temperature at the District must meet or exceed the following criteria (Campbell Scientific, 2009); however, an ideal sensor will meet the minimum criteria for DQOs established in **Table 1**.

- Accuracy not less than ±0.3°C in normal temperatures and ±0.4°C over the full range of measurement
- Precision of ±0.1°C

- Use 4 milliamperes current at 12 volts (or less); built-in switched voltage
- Tolerate power conservation measures such as on-off cycling of power
- Power up within 0.15 seconds from power-on mode
- User-defined lead length for flexible mounting
- Sized so that the unit will fit properly inside existing radiation shielding
- Have a measurement range encompassing all typical temperatures within District boundaries (-40°C through +60°C recommended)
- Minimum 0.2 μm filter of a corrosion and dirt resistant material
- Be capable of sampling at least every two seconds
- Have an output signal range of 0.008 to 1 volt direct current

## 9.3 Installation Requirements

Air temperature sensors should be installed on level ground where shading of the sensor does not occur during daylight hours. They must be installed a minimum of four times farther than the height of any obstructions (trees, fence, buildings, etc.) and at least 100 feet away from any area having extensive concrete or paved surfaces. These sensors must be installed inside a ventilated housing or shelter, which is designed specifically for the purpose of shielding against radiated heat energy at a recommended elevation of 2–3.0 meters (CERP, 2007; SFWMD, 2009; Campbell Scientific, 2009; WMO, 1997).

A combination sensor is used to measure air temperature and relative humidity. The general procedures for a successful installation on the weather station include (SFWMD, 2009a):

- The new probe should be securely inserted into the radiation shield
- Wiring should be run along the frame of the tower and secured with wire ties and enter the data logger housing through a sized compression fitting; any slack in the wire should be neatly coiled and tied
- All sensor wires must be secure in their respective wiring panel ports
- Field measurements of actual temperature and humidity should be used to test the sensor and ensure that data communication is active

## 9.4 Preventive Maintenance Requirements

For general guidelines applicable to the preventive maintenance of all meteorological instruments, see the *Evapotranspiration, Preventive Maintenance Requirements* subsection of this document.

Monthly maintenance requirements include physically inspecting the sensor and running calibration tests. Quarterly maintenance requirements for accurate evaporation calculations include communication assessment and calibration of the air temperature and relative humidity sensor. The air temperature/relative humidity sensor should be removed from the housing at least quarterly, inspected, cleaned, and documented. The expected range for air temperature during winter conditions is a minimum of -17.8°C (0°F) and during summer conditions, a minimum of 2.8°C (37°F), in general. Northern and southern portions of the District may have slightly different expected ranges. The technician should exercise good judgment when assessing initial temperature readings. If the sensor fails an air temperature accuracy standard of ±0.4°C over full range twice, the sensor must be replaced (SFWMD, 2007, 2010b).

# 10.0 BAROMETRIC PRESSURE

Barometric pressure (or atmospheric pressure) is the force per unit area exerted by the weight of the atmosphere on the Earth's surface. Hence, the pressure is equal to the weight of the vertical column of air above the surface. Air pressure measurement is considered to be static (little or no air movement) and is typically recorded in inches or millimeters of mercury (mm Hg), or hectoPascal [1 hPa is approximately 1 millibar (mb)]. The District measures barometric pressure in mm Hg as accurately as financial constraints and technology allow (SFWMD, 2009; WMO, 1997). Measurement and calibration requirements should be consistent with international standards for accurate climate prediction (WMO, 1997). Barometric pressure is critical for weather forecasting. In Florida, specifically, barometric pressure is an indicator of change in the state of tropical weather systems like hurricanes.

## 10.1 Site Selection Requirements

A barometer site should be clean, relatively dry, vibration free, maintained at as constant a temperature as is practical, and without direct sunlight on the instrument. The location must be free of drafts or the potential for hot-air currents or other causes of rapid temperature changes. The instrument must be situated away from any openings such as windows and doors or the windward and leeward sides of buildings that could cause changes in the static pressure due to wind eddy currents (CERP, 2007).

## 10.2 Sensor Selection Requirements

For barometers in general, temperature should not affect the barometric sensor's accuracy and that accuracy should be stable for long periods of time with small hysteresis effects. The probe should also be transportable with no loss of accuracy. Some probes at the District operate continuously or in power-down/power-up mode. Location and function in the network may determine which type is needed for a specific monitoring frequency.

The sensor used to measure air pressure at the District must meet or exceed the following criteria (Campbell Scientific, 2005a; WMO, 1997); however, an ideal sensor will meet the minimum criteria for DQOs established in **Table 1**:

- Overall accuracy of ±0.4 mb at 20°C, with hysteresis not to exceed ±0.03 mb (±2 standard deviation limits of pressure hysteresis error)
- Temperature dependence should be no more than ±0.02 mb/°C at 1,000 mb; ±0.08 mb/°C at 800 mb; and ±0.12 mb/°C at 600 mb
- Should reach accuracy within 2 seconds of power-on

- The systematic offset drift must be no greater than ±0.2 mb per year, with the effects of mechanical and thermal shocks impinging accuracy less than ±0.3 mb
- The measurement scale should be engraved on the barometer
- Maximum power consumption of 7 milliamperes at 11–30 volts direct current
- Output signal should be 0–2.5 volts
- Measurement ranges are 800-1,060 mb for pressure with a temperature range of -40°C to +60°C and non-condensing humidity range

## 10.3 Installation Requirements

Barometers should be installed at elevations as close to the same vertical datum as possible throughout the network, but height from the ground is relatively unimportant (WMO, 1997). However, the most recent vertical reference elevation should be used during installation, since barometric pressure is strongly affected by elevation and most sensors correct readings to sea level (Campbell Scientific, 1995). These instruments are subject to humidity, and must be installed inside the data logger housing with a desiccant.

A quality installation of a barometric pressure sensor includes (SFWMD, 2009a):

- Installing the new sensor in the mounting bracket within the data logger housing
- Ensuring the wire harness is securely reattached
- Updating correct trigger settings for the relevant site/program requirements
- Making sure desiccant is fresh
- Wiring the sensor to the monitoring panel, verifying operation, and testing to make sure the instrument is performing appropriately

## 10.4 Preventive Maintenance Requirements

The barometric pressure transducers used by the District contain no moving parts. Monthly and quarterly maintenance requirements for accurate barometric pressure measurements include verifying that the vent opening is unobstructed, active desiccant is stocked, wiring is connected securely, and domes are free of damage. A quarterly field test pass condition of the instrument would be a minimum accuracy of ± 0.375 mm Hg (SFWMD, 2010b; Campbell Scientific, 2005a) against a hand-held barometer. Field tests are conducted once, if the instrument passes. If the instrument fails the first test, the wiring harness should be rechecked for connectivity. If the wiring appears correct and the sensor fails a second test, the sensor must be replaced. Barometric pressure sensors must be replaced every two years or more frequently, as needed (SFWMD, 2007).

For general guidelines applicable to the preventive maintenance of all meteorological instruments, see the *Evapotranspiration, Preventive Maintenance Requirements* subsection of this document.

# 11.0 SOLAR RADIATION

Solar radiation is energy emitted by the sun. The sun radiates as a blackbody at a temperature of about 5,700 Kelvin; hence, about 99.9% of its energy output falls within the wavelength interval from 0.15–4.0 micrometers (μm), with peak intensity near 0.5 μm. Approximately 50% of the total energy in the solar beam is contained within the visible spectrum from 0.4–0.7 μm, and most of the other 50% lies in the near-infrared (longer wavelengths), with a small additional portion lying in the ultraviolet (shorter-than-visible wavelengths). The total downward radiation is the sum of downwelling shortwave and longwave radiation. The District uses total solar radiation as the downwelling shortwave radiation only and it is measured by pyranometer (SFMWD, 2009).

## 11.1 Site Selection Requirements

In order to accurately describe monitored conditions, including calculations made using observed solar radiation, a flat, open area of 100 meters by 100 meters is recommended (ASCE, 2005) that represents the general area of interest (Campbell Scientific, 2005).

For solar radiation, the site should first be easily accessible for maintenance since radiation sensors generally require frequent attention. It should also be free of obstructions above the plane of the sensing element and, ideally, be flat and horizontal with a slope of less than 2°. Surveying of the site is recommended so that station descriptions will contain the altitude of the sensor above sea level. Obstructions from west-northwest to east-northeast must be avoided as these obstructions tend to reflect and/or collect and re-radiate solar energy toward the sensor. Locations where shadows could be cast on the sensor and artificial radiation sources are nearby (e.g., smoke detectors) should also be avoided. The azimuth range for sunrise and sunset as seen by the sensor should have no obstructions exceeding an elevation angle of 5° above the horizon. Most radiation sensors are influenced by mechanical vibration and shock. This should be considered when site locations near roadways, railroads, or in industrial areas are necessary (SFWMD, 2007; Campbell Scientific, 2005; WMO, 1997; U.S.D.C. *et al*., 2002).

## 11.2 Sensor Selection Requirements

For general guidelines applicable to all meteorological sensor selections, see the *Evapotranspiration, Sensor Selection Requirements* subsection of this document. The sensor used to measure solar radiation at the District must meet or exceed the following criteria (Campbell Scientific, 2008); however, an ideal sensor will meet the minimum criteria for DQOs established in **Table 1**:

- The sensor should exhibit less than ±2% change over a one-year period
- 5% maximum error in daylight
- Maximum temperature dependency of 0.15% per degree Celsius
- Factory-calibrated for the daylight spectrum (400 to 1,100 nanometers)
- Operate normally from -40°C to +65°C
- Cosine corrected up to 80°

- Sensor housing should allow ventilation, prevent re-radiation events, and be weatherproof
- Response time minimum is 10 micro seconds
- Output signals should be proportional to the incoming radiation with the current able to be converted into voltages readable by the data logger

### 11.3 Installation Requirements

Mount the instrument such that, except for aircraft and clouds, no shadow will ever be cast upon the sensor and the sensor is never exposed to any artificial radiation sources; this includes making sure the sensor is not shadowed by the weather station itself. To ensure no error is introduced by wave motion or vibration, the pyranometers must be installed with special attention paid to leveling. The sensor should be installed at a height of 3 meters or less for easy access, and such that the cable is pointed to the north (CERP, 2007; Campbell Scientific, 2008). In addition, the following criteria for installation apply (SFWMD, 2009a):

- Install the sensor in the saddle and tighten connection
- Remove the red cap used for shipping
- Rewire the new sensor and check site/program information for correct trigger setting
- Secure sensor cable to the tower with wire tires and use the correct compression fitting for entry into the panel box
- Verify operation, perform field test of actual temperature and compare with new sensor

### 11.4 Preventive Maintenance Requirements

The pyronometers used by the District contain no moving parts. Monthly and quarterly maintenance requirements for accurate solar radiation measurements include verifying that the sensor is level and secured tightly, free of dust and debris, and the drain hole is unobstructed. A soft brush or compressed air should be used to clean the sensor to avoid scratching. Calibration by the manufacturer is required every two years at a minimum, but annual calibration is recommended (Campbell Scientific, 2008; CERP, 2007). A monthly field test should be conducted, and the pass condition of the instrument would be a minimum accuracy of ±5% (SFWMD, 2007). Field tests are conducted once if the instrument passes. If the instrument fails the second test, the sensor must be replaced (SFWMD, 2007).

For general guidelines applicable to the preventive maintenance of all meteorological instruments, see the *Evapotranspiration, Preventive Maintenance Requirements* subsection of this document.

## 12.0 NET RADIATION

Net radiation is the difference between absorbed and emitted radiation and is commonly used to refer to the surface radiation budget. Major components of the surface radiation budget are downward shortwave (direct plus diffuse solar radiation), upward shortwave (reflected), downward longwave (emitted from different levels of the atmosphere), and upward longwave (emitted from the surface). Therefore, net radiation = downward shortwave radiation – reflective shortwave radiation + downward longwave radiation – upward longwave radiation (SFWMD, 2009). Net radiation is measured with a net radiometer, which is a type of actinometer. Actinometers are instruments used to measure the heating power of radiation.

## 12.1 Site Selection Requirements

In order to accurately describe monitored conditions, including calculations made using net radiation, a flat, open area of 100 meters by 100 meters is recommended (ASCE, 2005) that represents the general area of interest (Campbell Scientific, 2005).

The site should first be easily accessible for maintenance. It should also be free of obstructions above the plane of the sensing element and, ideally, be flat and horizontal with a slope of less than 2°. The sensor should be installed such that the radius of the surface below is at least 10 times the mounting height, and that the upper portion of the instrument has a true 180° field of view. Locations where shadows could be cast on the sensor and artificial radiation sources are nearby are unacceptable. This includes locations where fast-growing canopy trees are within shadow range at any time of day. Most radiation sensors are influenced by mechanical vibration and shock. This should be considered when site locations near roadways, railroads, or in industrial areas are necessary (SFWMD, 2007; Campbell Scientific, 2005; Campbell Scientific, 2006; WMO, 1997; U.S.D.C. *et al*., 2002).

## 12.2 Sensor Selection Requirements

For general guidelines applicable to all meteorological sensor selections, see the *Evapotranspiration, Sensor Selection Requirements* subsection of this document. The sensor used to measure net radiation at the District must meet or exceed the following criteria (Campbell Scientific, 2008; Campbell Scientific, 1996; SFWMD, 2009); however, an ideal sensor will meet the minimum criteria for DQOs established in **Table 1**:

- Thermopile design with serial thermocouples; generates voltage through the radiant energy being measured, so no power supply to the sensor needed
- Spectral range should be at least 0.2–100 micrometers; response 0.25–60 micrometers
- Directional error should be <30 Watts per square meter within the 0–60° angle of incidence at 1,000 Watts per square meter
- Sensitivity should be the same for solar and infrared radiation
- Correction for wind speed in the existing network will be required to ensure accuracy
- The sensor should operate at temperatures from -30°C to +70°C and the maximum temperature dependence ≤ 0.12% per degree Celsius
- Minimum 30 second time constant
- If applicable, easily accessible desiccant with color-coded obsolescence
- If applicable, non-pressurized domes (easily replaced)

- If applicable, ventilation to prevent dew formation on sensor parts
- Durable black coating on upper and lower collection apparatus

## 12.3 Installation Requirements

Net radiation sensors may have domes or be undomed. Both sensor types must be mounted with care to not damage fragile radiation-collecting surfaces. A high quality installation of both types of sensors includes the following (SFWMD, 2009a; Campbell Scientific, 2006; SFWMD, 2007):

- Sensor should be installed pointing south at a height of at least 1.5 meters from the ground surface
- Net radiation sensors should be mounted separately, at least 25 feet from the weather station
- The sensor head should not be directly manipulated, and directional rotations conducted using the mounting arm
- Desiccant and bird-repelling sticks should be used as needed
- Sensor cables should enter data logger housing through compression fittings
- The sensor must be leveled (with a bubble level)
- Care should be taken to ensure that the serial number, calibration, and sensitivity values are recorded with the correct calibration factors entered into the data logger during installation
- Wind speed correction factors should also be entered as needed
- The high and low readings marked on each instrument by the calibrating technician should also be recorded
- Operation must be verified and field testing performed to ensure sensor is functioning properly and that data is being sent

## 12.4 Preventive Maintenance Requirements

Both domed and undomed radiometers are used at the District. Monthly and quarterly maintenance requirements for net radiation measurements include verifying that the sensors are level and secured tightly, active desiccant maintained, domes undamaged (replaced quarterly or as needed), sensors are clear of insects and debris, and that bird deterrents are still effective. Each sensor has a specific calibration certificate from the manufacturer that must be used in field tests, but the expected value of net radiation during normal daylight conditions is about 1,000 Watts per square meter, so the technician’s reasonable judgment must be used in initial assessments.

A monthly field test pass condition of the instrument is determined individually to predetermined criteria at a factor of 5 percent (SFWMD, 2007). Field tests are conducted once if the instrument passes. If the instrument fails the first test, desiccant, level, leaks (for domed instruments), condition of the black collection surfaces, and cleanliness of the radiometer should all be examined carefully (SFWMD, 2007). If the instrument fails a second test, it must be replaced.

For general guidelines applicable to the preventive maintenance of all meteorological instruments, see the *Evapotranspiration, Preventive Maintenance Requirements* subsection of this document.

# 13.0 PHOTOSYNTHETIC ACTIVE RADIATION

Photosynthetically active radiation (PAR) is the electromagnetic energy in the 400–700 nanometer (nm) wavelength range that is useful to terrestrial plants. PAR is measured as the photosynthetic photon flux (PPF) in quanta per second per square meter, or mole of quanta per second per square meter, or photosynthetic irradiance (PI) in watts per square meter for the specified wavelength band. PAR is measured with quantum sensors at the District (SFWMD, 2009).

## 13.1 Site Selection Requirements

PAR measurement sensors should be easily accessible for maintenance. Sites selected should be free of obstructions above the plane of the sensing element and, ideally, be flat and horizontal with a slope of less than 2°. The sensor should be installed such that the radius of the surface below is at least 10 times the mounting height, and that the upper portion of the instrument has a true 180° field of view. Locations where shadows could be cast on the sensor and artificial radiation sources are nearby are unacceptable. This includes locations where fast-growing canopy trees are within shadow range at any time of day. Most radiation sensors are influenced by mechanical vibration and shock. This should be considered when site locations near roadways, railroads, or in industrial areas are necessary (SFWMD, 2007; Campbell Scientific, 2005; Campbell Scientific, 2006; WMO, 1997; U.S.D.C. *et al*., 2002).

## 13.2 Sensor Selection Requirements

For general guidelines applicable to all meteorological sensor selections, see the *Evapotranspiration, Sensor Selection Requirements* subsection of this document. The sensor used to measure quantum radiation at the District must meet or exceed the following criteria (Campbell Scientific, 2008a; SFWMD, 2009); however, an ideal sensor will meet the minimum criteria for DQOs established in **Table 1**:

- Accuracy change of ≤ 2% over a one-year period
- Sensitivity of 5 microamperes per 1,000 moles per second per square meter
- Response time of 10 microseconds
- Calibrated to within 5% traceable to the U.S. National Institute of Standards Technology
- Maximum ±0.15% per degree Celsius temperature dependence
- Cosine corrected up to 80° angle of incidence
- Operates at a temperature range of -40°C to +65°C and 0–100% relative humidity
- Monitors the waveband from 400–700 nanometers
- Has a 0.35-second response time

- Samples at a maximum 1-second interval

### 13.3 Installation Requirements

The quantum sensor cable should be installed pointing north, and the sensor mounted so as to be free from shadows during daylight hours. A mounting height below 3 meters is recommended for ease of maintenance. The sensor must be level for accurate readings. The calibration constant is determined for each instrument individually, thus, the serial number and calibration constant must be recorded accurately and used to determine the multiplier. The correct multiplier for measurement must be used once the instrument is installed (SFWMD, 2007; Campbell Scientific, 2008a). Quantum sensors are generally installed in the same manner as pyranometers. For more specific details, see the *Solar Radiation, Installation Requirements* section of this document.

### 13.4 Preventive Maintenance Requirements

Quarterly maintenance requirements for quantum sensors include visual inspection and cleaning, as well as ensuring level and wiring connectivity. A quarterly field test pass condition of the instrument is required. Each instrument has an individual calculation value for pass-fail condition based on its initial calibration constant (factory determined), with an accuracy requirement of ±5% micromoles per square meter per second (Campbell Scientific, 2008a). Field tests are conducted once if the instrument passes. If the instrument fails the first test, the test is repeated. If the instrument fails a second test, it must be replaced (SFWMD, 2007).

For general guidelines applicable to the preventive maintenance of all meteorological instruments, see the *Evapotranspiration, Preventive Maintenance Requirements* subsection of this document.

## 14.0 WIND SPEED

Wind speed is the ratio of the distance covered by the air to the time taken to cover it. The extent to which wind is characterized by rapid fluctuations is referred to as gustiness. Gusts that persist for about three seconds correspond to a "wind run" of the order of 64–328 feet (50–100 meters) in strong wind conditions (WMO, 1986). This is sufficient to engulf structures of ordinary size and expose them to the full load of potentially damaging gusts. Wind observations at the District are part of the criteria for estimating evaporation, can be used to estimate wind damage, and are a general descriptive part of overall weather monitoring (SFWMD, 2009; WMO, 1997).

### 14.1 Site Selection Requirements

Surface wind sensing equipment should be placed 10 meters above the ground on a well exposed tower over terrain that is level and free from obstructions that may cause turbulence. Sensors should be located at a distance of at least 10 times the height of any nearby obstruction (see Campbell Scientific, 2005). Ideally, wind sensors will be the highest object within a 300-meter radius (Vaisala, 2009a). Sites where topography and/or obstructions are known to create eddy currents or other adverse wind effects should be avoided. If instrument exposure must be compromised, the sensor should be installed at least 4 meters above any obstruction lying within 30 meters and at least as high as any obstruction between 30 and 60 meters of the instruments. Supporting towers should be small and not of such size as to create any appreciably detrimental effect on the pattern of wind flow (CERP, 2007).

## 14.2 Sensor Selection Requirements

For general guidelines applicable to all meteorological sensor selections, see the *Evapotranspiration, Sensor Selection Requirements* subsection of this document. The sensor used to measure wind speed at the District must meet or exceed the following criteria (Vaisala, 2009; SFWMD, 2009); however, an ideal sensor will meet the minimum criteria for DQOs established in **Table 1**:

- Accuracy at 0-65 meters per second (m/s): ±0.135 m/s (±0.3 miles per hour, ±0.26 knots) or 3% of the reading, whichever is greater
- Resolution of 0.1 miles per hour
- Has a 0.35-second response time and samples at a maximum 1-second interval
- Multiple transducer layout to capture the 3-dimensional nature of wind
- Signal output up to 144 miles per hour
- 10-15 volts direct current required for power supply
- Operates at temperatures of -40°C to +55°C

## 14.3 Installation Requirements

Wind direction and speed are monitored through a combination sensor at the District. Wind sensors must be handled with care during unpacking and assembling so as to not damage the transducers or twist the arms of the sensor. The sensor may be mounted upright or inverted as long as it is properly aligned for wind speed and direction measurements. The transducer arms are marked to be aligned along a north-south axis, as close to true north as possible. Marking the sensor body so that the north-south arms are visible from the ground is recommended. A fused 12-volt battery with a solar panel or trickle charger is recommended. Direct current power sources that cause ripple in the output should be avoided, as these can affect measurement accuracy (Vaisala, 2009). In addition to the manufacturer's recommendations, the District uses the following criteria for a quality installation (SFWMD, 2009a):

- The tower should be lowered for wind sensor replacement (tower must not be climbed); this will require additional personnel
- New sensor must be vertically plumb and is mounted to the top of the tower
- Bird deterrent should be installed
- The north arm of the sensor should be aligned to true north
- Wires should enter data logger housing through a compression fitting and wiring configured as needed for a new install
- A handheld anemometer should be used for field measurements of wind speed

- The new sensor should register between 0–60 miles per hour (in normal conditions)
- A compass should be used for field measurement of wind direction
- The wind direction's expected range is 0°–360°
- The old sensor should be carefully repacked as it can be returned to the manufacturer for repair

### 14.4 Preventive Maintenance Requirements

The wind sensor has no moving parts and is corrosion resistant, so only quarterly maintenance is required. Quarterly maintenance requirements for accurate wind speed measurements include wiring checks and an orientation assessment with correction if needed. Calibrations must be done by the manufacturer. The expected range for wind speed is 0-60 miles per hour in normal conditions with accuracy of ±3% at <110 miles per hour (normal conditions) (SFWMD, 2010b). A failed test with large errors requires replacement of the sensor (SFWMD, 2007).

For general guidelines applicable to the preventive maintenance of all meteorological instruments, see the *Evapotranspiration, Preventive Maintenance Requirements* subsection of this document.

## 15.0 WIND DIRECTION

Wind is the air (atmosphere) in motion relative to the surface of the Earth. Wind direction is defined as the direction from which the wind is blowing relative to true north.

The extent to which wind is characterized by rapid fluctuations is referred to as gustiness. Gusts that persist for about three seconds correspond to a "wind run" of the order of 64–328 feet (50–100 meters) in strong wind conditions (WMO, 1986). This is sufficient to engulf structures of ordinary size and expose them to the full load of potentially damaging gusts.

### 15.1 Site Selection Requirements

See the *Wind Speed, Site Selection Requirements* section of this document for details.

### 15.2 Sensor Selection Requirements

For general guidelines applicable to all meteorological sensor selections, see the *Evapotranspiration, Sensor Selection Requirements* subsection of this document. The sensor used to measure wind speed at the District must meet or exceed the following criteria (Vaisala, 2009; SFWMD, 2009); however, an ideal sensor will meet the minimum criteria for DQOs established in **Table 1**:

- Accuracy of ±2% when wind is blowing at >1 mile per hour
- Measurement range from 0-360° with a resolution of 1°
- Multiple transducer layout to capture the 3-dimensional nature of wind
- 10-15 volts direct current required for power supply

### 15.3 Installation Requirements

A combination instrument is used at the District to measure wind speed and direction (Vaisala, 2009). For installation details, see the *Wind Speed, Installation Requirements* section of this document.

### 15.4 Preventive Maintenance Requirements

Maintenance requirements for accurate wind direction measurement include wiring checks and an orientation assessment with correction if needed on a quarterly basis. Orientation should be corrected so that when the nose cone or counterweight is aimed at true north, the datalogger registers zero degrees (Campbell Scientific, 2005). Field point measurement is done with a hand-held meter whose axis is kept within 20° of the estimated direction of the wind. Orientation changes generally require two technicians to complete and the sensor itself should not be rotated or bent; only the mounting arms should be moved to realign the sensor. Calibrations must be done by the manufacturer. The expected range for wind direction is 0-360°, with an accuracy requirement of ±2° (SFMWD, 2010b). A failed test with large errors requires replacement of the sensor (SFWMD, 2007).

For general guidelines applicable to the preventive maintenance of all meteorological instruments, see the *Evapotranspiration, Preventive Maintenance Requirements* subsection of this document.

## 16.0 RELATIVE HUMIDITY

Relative humidity is the ratio in percent of the observed vapor pressure (absolute measure of vapor in the air) to the saturation vapor pressure (maximum amount of water the air can hold at the current temperature) with respect to water at the same temperature and pressure. Relative humidity is reported as the humidity of the air near the Earth's surface. Humidity measurements are used in forecasting, meteorological analysis, hydrology, and environmental studies and describe the state of water in the atmosphere (WMO, 1997; Campbell Scientific, 2009).

### 16.1 Site Selection Requirements

Relative humidity sensors should be located at least 30 meters away from large paved areas and at a distance of at least four times the height of any nearby obstructions. The landscaping beneath the sensor should be representative of the surrounding area. Short grass or natural earth area of at least 9 meters in diameter provides an ideal site (SFWMD, 2009; Campbell Scientific, 2005).

### 16.2 Sensor Selection Requirements

For general guidelines applicable to all meteorological sensor selections, see the *Evapotranspiration, Sensor Selection Requirements* subsection of this document. The sensor used to measure relative humidity at the District must meet or exceed the following criteria (Campbell Scientific, 2009); however, an ideal sensor will meet the minimum criteria for DQOs established in **Table 1**:

- Accuracy not less than ±2% at 20°C in conditions of 0-90% humidity; and ±3% at 20°C in conditions of 90-100% humidity
- Temperature dependence not to exceed ±0.05% relative humidity per 1°C
- Respond to relative humidity changes 90% of the time at normal temperatures within 15 seconds if a membrane filter is used
- Use 4 milliamperes current at 12 volts (or less); built-in switched voltage
- Tolerate power conservation measures such as on-off cycling of power
- Power up within 0.15 seconds from power-on mode
- User-defined lead length for flexible mounting
- Sized so that the unit will fit properly inside existing radiation shielding
- Have a measurement range of 0-100% relative humidity
- Have an output signal range of 0.008 to 1 volt direct current
- Long-term stability should be at least 1% relative humidity per year

## 16.3 Installation Requirements

Air temperature sensors should be installed on level ground where shading of the sensor does not occur during daylight hours. They must be installed a minimum of four times farther than the height of any obstructions (trees, fence, buildings. etc.) and at least 100 feet away from any area having extensive concrete or paved surfaces. These sensors must be installed inside a ventilated housing or shelter, which is designed specifically for the purpose of shielding against radiated heat energy at a recommended elevation of 2-3.0 meters (CERP, 2007; SFWMD, 2009; Campbell Scientific, 2009; WMO, 1997).

A combination sensor is used to measure air temperature and relative humidity. For details, please see the *Air Temperature, Installation Requirements* section of this document.

## 16.4 Preventive Maintenance Requirements

Monthly maintenance requirements include inspecting sensors and running calibration tests. Humidity sensors may be removed from the housing and rinsed in distilled water. This cleaning is especially important in monitoring stations near salt water to remove salt build-up (Campbell Scientific, 2009). Quarterly maintenance requirements for accurate evaporation calculations include cleaning (WMO, 1997), communication assessment, and calibration. The air temperature/relative humidity sensor should be removed from the housing at least quarterly, inspected, and cleaned. The expected range for relative humidity in south Florida is 20%-103%, with an accuracy of ±2% when the relative humidity is 0-90%, and ±3% when the relative humidity is 90-100% (SFWMD, 2010b). The technician should exercise good judgment when assessing initial relative humidity readings. If the sensor fails the relative humidity accuracy standard twice, the sensor must be replaced (SFWMD, 2010).

For general guidelines applicable to the preventive maintenance of all meteorological instruments, see the *Evapotranspiration, Preventive Maintenance Requirements* subsection of this document.

# 17.0 RAINFALL

Rainfall is the amount of water that has fallen to the ground as precipitation and is reported by the District in inches. While this section only discusses ground monitoring of rainfall, the District may use radar/satellite data from national networks to complement rain gauge data for analyses. Engineers must familiarize themselves with rainfall sites since metadata describing the circumstances of ground-based rainfall measurements (site location, wind conditions, and topography) are particularly useful.

The District's network uses tipping buckets for rainfall recording and this type of data is being homogenized to a single sensor type. Quality guidelines for rainfall can be applied to numerous time intervals (15-minute, 24-hour, etc.) provided those intervals do not exceed a maximum frequency of 15-minutes (WMO, 1997; SFWMD, 2009).

## 17.1 Site Selection Requirements

In a situation of ideal gauge exposure, the rain catch would represent the precipitation falling at that point as well as the surrounding area. Ideally, rain gauges should be located on horizontal ground with a less than 19° slope and at a minimum distance of four times the height of any obstructions above the top of the gauge. Exposure to strong winds and slopes should be avoided (Hydrological Services, 1994).

Objects that individually, or in groups, reduce the wind speed, turbulence, and eddy currents in the vicinity of the gauge may provide for a more accurate catch, as long as they do not obstruct rain. A wind shield may be employed, if necessary. The best exposures are often found in clearings of forests, as long as the dimensions of the clearing meet the preferable height/distance requirements. Rain gauges placed in such clearings should be installed so that surrounding tree tops and other obstructions are outside the imaginary 45° cone radiating upward from the receiver. Short grass and gravel make ideal landscape for rain gauges, and the lowest possible mounting that avoids splashing from the ground is also recommended. Sites on the roofs of buildings or that are heavily sloped should be avoided (SFWMD, 2009; CERP, 2007; Campbell Scientific, 2005; WMO, 1997; U.S.D.C. *et al*., 2002).

Rainfall monitoring has been historically guided by individual project needs, and the extensive network remains somewhat heterogeneous across the District's area. However, since rainfall is the most important contributor for runoff, stream flow, and aquifer recharge, new installations should ideally balance the recommendations made in a 2006 optimization study, with a continuing effort to address mandated needs for monitoring (Pathak and Pandey, 2008).

## 17.2 Sensor Selection Requirements

For general guidelines applicable to all meteorological sensor selections, see the *Evapotranspiration, Sensor Selection Requirements* subsection of this document. The automated sensor used to measure rainfall at the District must meet or exceed the following criteria (Hydrological Services, 1994); however, an ideal sensor will meet the minimum criteria for DQOs established in **Table 1**:

- Accuracy of ±2% for intensities from 25–500 millimeters per hour
- One-tip sensitivity
- Measuring range of 0–700 millimeters per hour accumulation
- 200 millimeter diameter (±0.3 millimeter) receiving rim
- Bucket capacity of 0.01 inch of rainfall
- Operates at a temperature range of -20°C to +70°C and humidity of 0–100%
- Dual-reed switch contact system
- Siphon capacity of rainfall of 0.4 mm made from non-corroding material
- Bucket balanced to ±0.05 grams
- Bull's-eye levels attached to base
- Corrosion-proof pivots and stainless steel mesh screens at small enough grade to prevent insect intrusion

## 17.3 Installation Requirements

The rain gauge must be installed above the maximum expected rainfall or surface water height, but low enough such that the rain does not splash up into the receiver (WMO, 1997). These distances are determined on a site-by-site basis consistent with the surrounding topography. The outer funnel of the rain gauge must be level and all data connections secure. Once assembled, the bucket should be manually tipped to ensure data is recording properly. For annual replacement of tipping bucket rain gauges, the following general guidelines should be observed (SFWMD, 2009a):

- Before installation, the calibration and installation date should be recorded on the label
- The sponge used for shipping must be removed from the tipping mechanism
- The new rain gauge should be placed in the same place as the old one and leveled
- Once the gauge is wired properly, a tip test should be performed (11 tips) to ensure that the correct count is showing up on the data logger
- Once testing is complete, the rain gauge housing should be replaced and secured with correctly sized bolts

## 17.4 Preventive Maintenance Requirements

A minimum quarterly inspection of the physical condition, wiring, and conduit is required for rain gauges. Annual maintenance of rain gauges includes replacement of the gauge unit if it has been in use more than one year (SFWMD, 2007). For the best accuracy, monthly maintenance of rain gauges would be ideal.

Since metadata describing the circumstances of rainfall measurements are particularly useful for data processors, overall site documentation is of particular importance (WMO, 1997). Photographs and extensive notes should be taken if the technician notices site configuration or access changes, degradation, vandalism, or vegetative growth at the site. One photo per year is required, with additional photos as needed for site changes (SFMWD, 2010).

Monthly maintenance consists of wiring checks, tip tests, catch filter and funnel inspection, oiling and cleaning of the tipping mechanism, and bird deterrent assessment. Tipping bucket rain gauge instruments should be cleaned once a month during the dry season and twice a month during the wet season. The expected range for the tip test, which is conducted twice in succession and coordinated with the control room, is 82 ±2 tips (SFWMD, 2010; Hydrological Services, 1994). If the gauge does not meet this standard, it is replaced.

# 18.0 SURFACE WATER STAGE

Accurate water level data are needed by research scientists in regional modeling development and by water managers to make operational decisions (e.g., gate openings, flashboard openings, pump activity, etc.). Surface water levels in a water body are influenced by the size of the contributing drainage basin, amount of precipitation (rainfall) in the basin, and inflow from groundwater withdrawals and groundwater recharge. 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 stage is reported as the distance above or below a reference point, such as the top of a recorder shelf, in a stilling well for lakes, rivers, or other open body of water. These measurements are usually taken at a specific location designated as the measurement site. In order for surface water stage data to be comparable between measuring sites, both sites must be referenced to the same elevation datum. Most sites currently use mean sea level, also known as the National Geodetic Vertical Datum of 1929 (NGVD29) as a reference datum. The District, however, is in the process of transitioning to the more accurate North American Vertical Datum of 1988 (NAVD 88).

## 18.1 Site Selection Requirements

There is a constant need to add new sites/stations with sensors/instruments for hydrologic data collection within the District, and this need will grow faster as new projects are implemented. Surface water stage monitoring sites may be added, removed, re-surveyed, re-instrumented, or upgraded according to project monitoring needs.

Stilling wells and accompanying instrumentation must be located such that the well does not interfere with structure operation, and in such a way that the equipment captures the high and low fluctuations of the water level being measured. Locations will vary with geographic area type (e.g., wetland, estuaries, and canals).

## 18.2 Sensor Selection Requirements

All monitoring sensors must meet or exceed current sensor specifications with regard to power use, durability, accuracy, maintainability, and sampling frequency. An engineering change request process should be used to ensure that new sensors do meet minimum requirements. For automated surface water monitoring, stilling well systems are used. Stilling well monitoring consists of a tape, float, and shaft encoder array. Both the physical aspects of the system and the sensor itself must meet accuracy requirements. Two task categories are needed to fulfill accuracy and precision requirements: (1) installation with high workmanship standards, and (2) maintenance and calibration by an experienced technician.

It is recommended that the customer requesting a new sensor submit specific requirements for monitoring needs, site conditions (if known), and instrumentation accuracy requirements to the Field Operations Center for actual product selection. If a new product is needed, instruments are tested first in laboratory conditions, and then in the field. Once selected, final instrumentation approval by both parties may provide the best overall quality step to ensure the sensor meets the monitoring needs of a given project.

The shaft encoders used to measure surface water stage at the District must meet or exceed the following criteria (DAA, 2002); however, an ideal sensor will meet the minimum criteria for DQOs established in **Table 1**:

- Meets current data logging application requirements
- Corrosion resistant housing, sealed bearings
- Battery powered with a minimum 10-year lifespan
- Current operation of 150 microamperes (sleep mode) to 40 milliamperes (reporting/reading)
- Absolute shaft position not lost if power fails
- Scales encoder position in desired unit of measurement (feet)
- Optical encoding measuring absolute shaft position from 0-360°
- Continuous, legible, accurate display showing last measured value with a configuration capacity of ±199.99 to ±19,999 feet
- Configurable for interval, polled recording, or continuous recording
- Resolution of 0.000015 feet with a 1.0 foot circumference pulley
- Accuracy of 0.00024 feet with a 1.0 foot circumference pulley
- Operates at temperatures from -40°C to +60°C and humidity from 0-100%

## 18.3 Installation Requirements

Once the location is determined, the installer must notify the Control Center to place the site in Test Mode. Upon arrival at the site, a physical inspection and minor repairs to the physical condition should be conducted. Any sensor currently in the well must be removed prior to installation of a replacement.

Shaft encoders should be installed in a protected area, preferably bolted to a shelf that is located above the highest expected water level, with the tape and float protruding over the shelf. The housing must be leveled and the tape and pulley should not rub on any obstructions. In addition, a length of tape should be installed perpendicular to the sensor as a safety net to prevent the float and counterweight from falling into the well should they be knocked off the pulley.

The use of an automated data command to calibrate the sensor is recommended (SFWMD, 2007); however a staff gauge or other verified datum may also be used to set the encoder to the correct current stage. Upper and lower analog limits must also be set using predetermined criteria to give the expected measurement range for the instrument. The float and counter weight on the pulley must also be evaluated to ensure that clockwise staff rotations are reading as positive values. Care must be taken during these steps since the instrument is not able to be reset once installed and calibrated. When installation is complete, a manual pulley rotation test is recommended to verify readings (SFWMD, 2010; DAA, 2002).

Once the instrument is calibrated, the site should be returned to the original monitoring condition and the Control Center notified.

## 18.4 Datum References Elevation Requirements

Accurate vertical control is critical to the operations of water structures and the movement of water through the water management system. For example, water control structures and pumps are triggered into operation when surface water reaches specified levels for flood control purposes. The same benchmark established at a site should be used at all times when making changes to that site so that error is not introduced; changes include replacement and calibration of sensors, or new sensor installations. As a quality target, the District is making an ongoing effort to provide benchmarks at all hydrological monitoring sites, and requires that new sites be installed with certified (not estimated) elevation, unless emergency conditions exist for water control structure operation. A valid benchmark should be located within 100 feet of any stilling well or groundwater well.

Monitoring network elevations should have First Order reference mark accuracy, which requires the use of highly qualified and equipped contractors. This ensures that the base is consistent throughout the District (see Keith and Schnars, 2007; NMI, 2006). For operations and some internal applications, Third Order or better is required. Level run accuracy is determined by project needs. A stipulation in contracts for an accurate survey is recommended for all site changes or new sites.

All vertical data is currently collected in the North American Vertical Datum of 1988 (NAVD 88) as the primary source, with conversion to the National Geodetic Vertical Datum of 1929 (NGVD 29) at the data processing level to accommodate the historical record of the District. VERTCON conversions from the NGS web site are less precise than other methods, and should be used only at the project manager's best judgment.

All vertical elevation control starts and ends on a National Geodetic Survey (NGS) First Order Class II or better vertical control monument. These documents are available on the NGS web site at http://www.ngs.noaa.gov/cgi-bin/datasheet.prl. A minimum of two different NGS benchmarks that are at least one-half mile apart should be used. The two monuments must be close to each other (CERP, 2007).

All control surveys methods shall meet NGS Third Order accuracy and procedural standards or better and procedural methods shall comply with applicable USACE engineering manuals. All conventional vertical control (double run forward and back) established shall be a closed level loop without spur lines, with a minimum of NGS Third Order accuracy. All vertical control along with baseline layouts, sketches and pertinent data shall be entered in field books (CERP, 2007). The Florida minimum technical standards (MTS) for land surveying include the stipulation that the level run will close to 0.05 feet times the square root of the distance in miles. The District generally exceeds this standard with more stringent criteria that are project specific, for example, 0.03 feet times the square root of the distance in miles (SFWMD, 2010c).

Only the most current NGS vertical control monuments and data should be used for establishing the vertical control monuments at a monitoring site. Control points established or recovered with no description or out-of-date (5 years or older) description should be described with sketches for future recovery use (CERP, 2007). Stage sensors should be placed on a rotation so that each site is resurveyed and benchmarked a minimum of every five years.

The contractor will report to NGS through the online reporting system, the status of the marks used. If a monument does not exist at the site, the contractor will establish one standard NGS stainless steel rod class “B” (stability). The contractor will provide a North American Datum 1983/1990 Adjustment (NAD83/90) x, y coordinates with a positional accuracy of ±3 feet using differentially corrected GPS on this point and/or the site benchmark.

Horizontal data at the District is used descriptively and does not have submeter accuracy. Only spatial locations for geographical information systems (GIS) mapping is required. For example, streamgaugers may use already mapped GIS data such as Google™ earth to describe locations in general terms, but for operations and data processing, accurate vertical datum are required so that all sensors throughout the network read from the same base. Stage sensors have estimated ranges for monitoring, and, ideally, should be calibrated as needed to the most recent relevant benchmark.

For the best quality data, timely synchronization between the most recent accurate survey data and installations/calibration activities is recommended. A formalized program within the agency and the establishment of a data steward for vertical control data management may be needed. See Waltman (2005) for a business process example.

## 18.5 Preventive Maintenance Requirements

Surface water flow monitoring equipment includes a stilling well, multiple moving parts, associated constructed framework and access points, as well as the sensor’s assemblies themselves. Quality maintenance depends heavily upon good judgment by the servicing technician. A minimum 4-6 month training period in the field is recommended. Two years’ field experience maintaining and troubleshooting electronic equipment is required for data logger maintenance for surface water and groundwater monitoring (SFWMD, 2007). A formalized training program with documented sufficiency in each maintenance dimension by technicians is recommended.

Annual inspections and cleaning of all surface water monitoring equipment is required, including confirming correct reference elevation tagging, structural inspections such as checking for damage to wells and well mountings, site security (e.g., gates locked, stilling well covers locked), checking conditions of walkways, cleaning off debris and dirt, and checking for animal activity. Certain sensors are replaced annually.

Additionally, stilling wells should be flushed annually so that the transfer tube is clear of debris and is functional. Precautions like submerging the discharge tube of the sump pump so it does not damage the sensor, and making sure the sensor is not submerged during pumping are critical for success. The discharge rate for a successful flush is about 1 foot per minute. If after three attempts, the discharge rate is still slower than 1 foot per minute, a diving team will need to be called in to clean out the transfer tube.

Quarterly maintenance includes general physical condition inspections, wiring checks, lubrication, leak repairs, and reference elevation confirmation. If a well elevation certification stamp is out of date more than 3 years, the technician should check for a processed elevation addendum. If an addendum exists, but the well has not been stamped, this should be noted by the technician.

All surface water sensors are tested for physical operability on a monthly basis (SFWMD, 2007). Monthly calibration checks are recommended for the highest data quality, but may not be possible due to budget constraints. For stilling wells, the technician must be experienced enough to evaluate the overall physical condition of the well. These requirements include assessing for shifting or damage (e.g., by construction vehicles banging into wells), broken brackets on walkways, readability and currency of elevations, removing animals from floats and tapes, and making sure the tape is installed correctly on the pulley.

Shaft encoders should be replaced annually, or when the accuracy (distance to water value) is off more than ±0.02 foot. For replacement procedures, see the *Surface Water Stage, Installation Requirements* section of this document or SFWMD (2010). Pressure transducers may also be used in surface water stilling wells. For replacement procedures of pressure transducers, see the *Groundwater Stage, Installation Requirements* section of this Procedure.

Photographs and extensive notes should be taken if the technician notices high water marks, site configuration or access changes, degradation, or vandalism. One photo per year is recommended, with additional photos for site changes (SFMWD, 2010).

# 19.0 GROUNDWATER STAGE

Groundwater stage is reported as the distance above or below a measuring point such as the top of a well casing for a groundwater site, or the water head height for an artesian well. District monitored wells penetrate the principal aquifer systems in Florida. The principal aquifers monitored are the Floridan Aquifer System, the Surficial Aquifer System, and the Intermediate Aquifer System. Sangoyomi and Larenas, 2008, provide a detailed description of the groundwater monitoring network at the District.

In order for groundwater stage data to be comparable between measurement sites, both sites must be referenced to the same elevation datum. Most sites currently use mean sea level (MSL), also known as the National Geodetic Vertical Datum of 1929 (NGVD29) as a reference datum. Groundwater stage is therefore defined as the measured level, expressed in feet, of the column of water in a well referenced to a geodetic datum.

Groundwater level measurements are made on static and artesian wells. These wells are usually small in diameter and require a slender sensor for submergence in static wells and a screw-on sensor that can be attached to the outside of artesian wells. Groundwater data are recorded in feet and/or psi. Metadata such as well diameter for groundwater measurements are of particular concern for data engineers, and a familiarity with individual wells is recommended.

## 19.1 Site Selection Requirements

Site conditions and characteristics can affect data collected from a well, or can produce an intended or unintended bias in interpreting the data being collected. Site selection is influenced by the purpose of the well, specifically, whether it is intended for collecting water levels, water quality data or geophysical logs.

Lapham *et al.,* (1997) discuss site selection criteria for wells collecting water quality data. Site selection must incorporate the effects of natural and anthropogenic processes, which can occur seasonally, continuously, or catastrophically. Examples include tides, agricultural practices, nearby well fields, and industrial discharges.

Sites must be selected such that the water quality samples or water level is of the hydrogeologic unit targeted for the study. The surficial and depth distribution at the site should conform to the conceptual or statistical design developed for the study. The site characteristics and potential influences on groundwater chemistry should also be considered.

## 19.2 Sensor Selection Requirements

All new monitoring sensors must meet or exceed current sensor specifications with regard to power use, durability, accuracy, maintainability, and sampling frequency. These requirements will vary based on monitoring location and sensor type. An engineering change request process should be used to ensure that new sensors do meet minimum requirements. Only automated recording devices are covered by this document.

For automated groundwater monitoring, artesian well systems are used. Deep wells are drilled into the Floridan aquifer, which contains water confined under pressure (SJRWMD, 2001). These wells create natural pressure upward if properly installed. Measurements of the pressure at the well head provide engineering values to estimate the level and flow of the aquifer beneath.

Both the physical aspects of the well system (such as well diameter) and the sensor itself must meet accuracy requirements. Two task categories are needed to fulfill accuracy and precision requirements: (1) installation with high workmanship standards, and (2) maintenance and calibration by an experienced technician.

It is recommended that the customer requesting a new sensor submit specific requirements for monitoring needs, site conditions (if known), and instrumentation accuracy requirements to the Field Operations Center for actual product selection. If a new product is needed, instruments are tested first in laboratory conditions, and then in the field. Once selected, final instrumentation approval by both parties may provide the best overall quality step to ensure the sensor meets the monitoring needs of a given project.

The pressure transducers used to measure groundwater stage at the District must meet or exceed the following criteria (Pressure Systems, 2006; In-Situ, 2009);

however, an ideal sensor will meet the minimum criteria for DQOs established in **Table 1**:

- Maximum standby power 0.5 milliamperes
- Lithium-ion or other long-life (5-year minimum), low-power battery
- Accuracy above 10 feet of water ±0.05% full scale
- Accuracy below 10 feet ±0.1% full scale
- Resolution ±0.005 full scale
- Temperature compensation for accuracy at ranges from 0°C–50°C
- Temperature accuracy ±0.1°C, resolution ±0.01°C
- Configurable to output data according to data logger requirements
- Operates at voltage range from 8-36 volts direct current
- Operates at temperature range 0°C–80°C
- Logging and output rates of 1–2 per second

## 19.3 Datum References Elevation Requirements

Accurate vertical control is critical to the operations of water structures and the movement of water through the water management system. The requirements for groundwater stage elevation accuracies are the same as those listed for *Surface Water Stage, Datum References Elevation Requirements*.

## 19.4 Installation Requirements

For installing groundwater monitoring equipment or wells, special attention must be paid to relevant mandates concerned well drilling, materials, and location, in addition to meeting quality requirements for data gathered from the monitoring site.

Artesian wells should be drilled entirely through the geological formations above the aquifer, set into the surrounding clay, and casings constructed from corrosion-resistant materials. Plugs, valves, and any other applicable methods must be used to prevent the uncontrolled movement of water. Casings and materials that may adversely affect water quality parameters may not be used. During construction, care must be taken to avoid contaminating the source water of the well. All wells should be fitted with tamper-resistant covers (SFWMD, 2005).

Submersible transducers should be installed vertically, with the sensor facing down. The instrument must be lowered gently into position and protected from excessive pressure and impact. A perforated still well or suspension from a cable may be used for different applications. Clamping the transducer to a stable surface where it can receive flow and be protected from sharp-force trauma events is also acceptable. If the installation is a replacement, the depth of the sensor being removed should be noted so that the new sensor can be installed at the same depth following an on-time/off-time procedure. The nonfunctioning sensor's depth should be measured through a distance-to-water from the most accurate reference elevation available. The cable must be handled with care since it should remain water-tight during installation and monitoring.

Looping excess cable instead of cutting at the potted end is recommended. Once the cable and all wiring are connected, the new sensor must be tested and calibrated (Pressure Systems, 2006; SFMWD, 2007).

### 19.5 Preventive Maintenance Requirements

Pressure transducer sensors and the wells they monitor both require preventive maintenance to ensure that data is as accurate as possible. Submersible pressure transducers are replacing older models at the District as needed. Two years' field experience maintaining and troubleshooting electronic equipment is required for data logger maintenance for surface water and groundwater monitoring (SFWMD, 2007).

Artesian wells must be maintained at least annually. Physical condition, high water events, encroaching vegetation, leaks, and security of the well cover are the most salient dimensions of well maintenance. Quality maintenance of wells depends heavily upon good judgment by the servicing technician. A minimum 4-6 month training period in the field is recommended. A formalized training program with documented proficiency in well maintenance parameters is recommended. Photo documentation and extensive notes should be taken if the technician notices high water marks, site configuration changes, access changes, degradation, or vandalism of the site. One photo per year is recommended, with additional photos for site changes (SFMWD, 2010).

Above-ground pressure sensors should be calibrated annually regardless of test status, or more frequently if the measured value during maintenance differs more than ±0.05 feet from the majority of sensors being verified. Submersible sensors require calibration annually or if the measured distance-to-water is off by more than ±0.02 feet. Desiccant inside the sensors must also be replaced annually, or with calibration. Filtering systems that allow air flow over the desiccant should also be checked regularly and replaced as needed. Calibration must be performed on equilibrated thread-mount sensors or cleaned and properly positioned submersible serial data interface (SDI) pressure transducers. SDI sensors may be used to test calibration of thread-mount, above-ground sensors attached to wells in the field, while pressure calibrators are used for submersible sensors. Care must be taken to ensure that SDI pressure sensors used as calibration standards are not damaged by accumulated hard water deposits or jolts during travel. If any of the pressure sensors fail to calibrate, they must be replaced with SDI sensors. Failure to equilibrate is an indication of failure in a thread-mount sensor, but an errant temperature reading may be a good indication of sensor failure for SDI sensors (SFWMD, 2007, 2010a; Pressure Systems, 2006).

On a quarterly basis, pressure sensors must be removed from the wells, inspected and cleaned. Calibration tests must be performed, the sensor calibrated at least annually, and the well and well site observed with any changes noted and photographed (SFWMD, 2007, 2010a).

## 20.0 GATE POSITION

A gate is a control device installed at a District water control structure (e.g., spillway, pump station, culvert, weir and navigational lock) for controlling the rate of water discharge (flow) into or from a canal and/or water body. Gate position is the measurement that determines the opening between the gate sill and the bottom of the gate. Gate position is based on the distance between the sensor and the point where the cable is attached to the gate. Accuracy in gate position measurements directly affects gate control. Gate position is sensed by the transducer and recorded every 15 minutes by the remote terminal unit, unless the gate is in motion. During gate operation, one RTU updates position based on pre-programmed change-of-state parameters, while the other unit provides position updates once per minute (SFWMD, 2009).

## 20.1 Site Selection Requirements

All gated sites at the District are monitored for operational purposes. Gate selection locations are project- and mandate-driven.

## 20.2 Sensor Selection Requirements

All monitoring sensors must meet or exceed current sensor specifications with regard to power use, durability, accuracy, maintainability, and sampling frequency. An engineering change request process should be used to ensure that new sensors do meet minimum requirements. It is recommended that the customer requesting a new sensor submit specific requirements for monitoring needs, site conditions (if known), and instrumentation accuracy requirements to the Field Operations Center for actual product selection. Once selected, final instrumentation approval by both parties may provide the best overall quality step to ensure the sensor meets the monitoring needs of a given project.

Gate position sensors used at the District must meet or exceed the following criteria (Celesco 2006, 2007); however, an ideal sensor will meet the minimum criteria for DQOs established in **Table 1**:

- Accurate to minimum ±0.05 foot
- Precision ±0.02% full stroke
- Resolution of ±0.01 foot
- Measuring length adequate for gate application, generally 0–550 inches or 0–75 inches
- Operates at temperature from -40°C to +90°C and humidity 0–100%
- Withstands vibration up to 2,000 Hertz
- Adjustable cable exit position
- Customizable cable length, potentiometer life cycle, sensing circuit, and power

## 20.3 Installation Requirements

For any gate installation, the Control Room must be notified and the gate placed in the local/off mode, and then locked out for full manual control. Gate sensor installations require pre-arrangement with the project manager, a two-person team, safety harness, and hydraulic lifts. Safety is the main concern for gate sensor installations.

Initial physical inspection of the gate and related mechanical features should be made, with minor repairs made as needed prior to installation of a new sensor. Cable-extension transducers (also known as string pots or linear position sensors) are used for gate position monitoring at the District.

Before installation, the old sensor must be removed. A string should be tied to the end of the existing cable where it is attached to the gate before the cable is disconnected so that the retraction of the cable can be controlled. This will prevent damage to the sensor and the technician. Once the cable is retracted, the sensor can be removed and the new sensor installed. Serial numbers and sensitivity information from the old and new sensors must be recorded.

The new sensor should be mounted in the same location as the old sensor, which should be a flat, stable surface. A string attached to the cable end should be used to extend the cable to the eye bolt of the gate; tension on the cable should be maintained at all times. The technician must ensure that the cable will reach the gate's eye bolt when the gate is closed. If not, an extension can be added.

Once attached to the gate, the cable must not vary more than 5° in any direction from its entry angle into the sensor. Changing the cable position in the field to accommodate new mountings or excessive misalignment is not recommended. Once installed, the sensor must be calibrated and the sensitivity figure entered in the data logging application. Adjustments must be made until the accuracy of ±0.05 foot is met.

Upon completion, the Control Room must be notified and the gate switched back into normal operating mode (SFWMD, 2007, 2009a; Celesco, 2006, 2007).

## 20.4 Preventive Maintenance Requirements

For safety purposes, gates should be set for manual operation once the technician arrives on the site. Gate sensor calibrations require additional safety protocols and generally require pre-arrangement with the project manager, a two-person team, safety harness, and hydraulic lifts.

Gate position monitoring includes observations of the gate drop-down and the physical condition of the string pot on a monthly basis. Spider webs on the cable are particularly troublesome and should be completely cleaned off during each field visit, as needed.

Seepage of water under the gate and how far the gate bottom drops relative to recorded position are evaluated. If the gate position accuracy falls above or below 0.05 foot, calibration is required. This accuracy standard is based on reference staff gauges at each site, which are marked to the tenth of a foot. Gate sensors are calibrated with the bottom-most position set to a zero value for vertical gates, and with the gate open for horizontal gates. For gates with excessive seepage, field notes are taken and the local field office notified. Wiring inspections and mounting hardware are checked on a quarterly basis, with repairs as needed.

Annual maintenance events service all the major elements of gate position sensor operations. In addition to the examinations and repairs to the physical structure at monthly and quarterly checks, annual maintenance includes a sensor test across its full range, multiplier verification appropriate for the sensor ratings, and an examination of the cable's full span.

Photo documentation and extensive notes should be taken if the technician notices high water marks, site configuration changes, access changes, degradation, or vandalism of the site. One photo per year is recommended, with additional photos for site changes (SFMWD, 2010).

# 21.0 PUMP RPM

Hydraulic pumps are used at the District to maintain water levels throughout the landscape in response to urban, agricultural, and ecological needs. Pump RPM is the measurement of the number of revolutions per minute (RPM) of a pump shaft or motor of a water pump, and is used in flow calculations to estimate the volume of water being moved. Programmable meters are placed on the pump housing and count the revolutions (SFWMD, 2009).

## 21.1 Site Selection Requirements

All hydraulic pumps at the District are monitored for operational purposes including flood control, water supply for urban and agricultural needs, and ecological restoration. Pumping station site selection is project-driven and usually the result of a mandate or permit condition.

The creation of pump stations is a major construction effort. Stations are designed through a formal process and built to last a minimum of 50 years. For details on pump station design, see SFWMD (2008a).

## 21.2 Sensor Selection Requirements

All monitoring sensors must meet or exceed current sensor specifications with regard to power use, durability, accuracy, and sampling frequency. Pump RPM monitoring consists of a sensing meter with a programmable control module that serves as the measurement device. An engineering change request process should be used to ensure that new sensors do meet minimum requirements, and that data processing engineers are notified of sensor changes.

It is recommended that the customer requesting a new sensor submit specific requirements for monitoring needs, site conditions (if known), and instrumentation accuracy requirements to the Field Operations Center for actual product selection. Once selected, final instrumentation approval by both parties may provide the best overall quality step to ensure the sensor meets the monitoring needs of a given project.

Control modules used to measure pump RPM at the District must meet or exceed the following criteria (Texmate, Inc., 2009), however, an ideal sensor will meet the minimum criteria for DQOs established in **Table 1**:

- Accuracy ±0.0001% of reading (analog)
- Resolution ±0.7 nanoseconds through ±1 second
- Minimum 10 samples per second, customizable to 960 samples per second
- Configurable hysteresis
- Control output minimum of 10 milliseconds
- Carrier-board options to accommodate existing installation conditions
- Operates at temperatures from 0°C to 70°C
- Operates in relative humidity to 95% (non-condensing) at 40°C
- Minimum and maximum memory
- Tare, compensation, and calibration on demand

- Easy-to-read 5-digit display panel showing current pump speed
- Configurable, weatherproof case for mounting in various conditions
- Custom macro configuration capability
- Endless loop recording and removable memory options

### 21.3 Installation Requirements

Pump RPM sensors must be placed downstream of the clutch on pumps to ensure that readings are only taken when the clutch is engaged and water being moved. Only in direct-drive engines should the sensor be mounted above the clutch.

### 21.4 Preventive Maintenance Requirements

No maintenance is performed. Sensors are installed and replaced when not functioning, or functioning outside accuracy parameters. For pump RPM, there are different values for accuracy between data processing needs and practical pump applications for flood control/water level management. For data processing, and as a performance goal, ±0.02 ft accuracy is desired.

Sensors should not be relocated on the pump housing unless customers have been notified. A formal process for this notification, modeled after the data change process notification system (Procedure Q100-001) is recommended. This will avoid the introduction of errors for flow computations due to an undocumented change in flow recording.

## 22.0 DATA MANAGEMENT

The creation and implementation of structures, policies, and procedures that manage data through a full life cycle is needed to ensure the highest quality data products. Data management generally encompasses collection requirements, storing, quality assurance (processing and post-processing), and change requests, among other factors. The data management program at the District encompasses all the steps required for accurate data to be loaded into DBHYRDO (SFWMD, 2008).

Data collection requirements, such as siting and maintaining automated sensors are given in earlier sections of this document. A change requests process outline and quality assurance requirements are given in the *Data Change Requirements* and *Quality Assurance/Quality Control* section of this document, respectively. In addition, detailed processes at the enterprise level are given in SFMWD (2009b), and include steps such as establishing data management roles and access rights, reviewing statements of work, establishing studies and systems of record, submission/receipt of data, documentation of quality, correcting validated data, etc.

### 22.1 Data Use, Accessibility, and Ownership

The District uses meteorological and hydraulic data to manage water resources in the south Florida region, including mandated ecological restoration, and urban and agricultural water supply needs. Data that have been processed by the SCADA & Hydro Data Management Department is available to the public on the Internet through DBHYRDO at http://my.sfwmd.gov/dbhydroplsql/show_dbkey_info.main_menu. Unprocessed data is available through public information request.

## 22.2 Unprocessed Data

Unprocessed data is considered to be any directly observed data reported by instrumentation; some instrumentation may discard outliers during sampling (see the *Measured and Computed Flows* section of this document), and some instrumentation may report calculated values (see the *Evaporation and Evapotranspiration* section of this document). Unprocessed data is considered to be less reliable since it has not been validated or analyzed (CERP, 2007). This data is also generally not considered useful for describing change in systems, as much of it is collected from a single sampling event, and therefore is not descriptive. However, all analysis begins with unprocessed data, so the data must be preserved. At the District, meteorological and hydraulic breakpoint data are kept in the DCVP system. For further details on how reporting to the database occurs, see CERP (2007).

## 22.3 Metadata

Metadata provides the context for collected data values and may include things like site photos, site change notations, maintenance logs, well diameter, and project design schematics. Many of these documents are available to District staff through the SCADA server at \\focproj1\Eng\, \\focproj1\Maint\, and \\focproj1\proj\ or in Documentum (once access is obtained) at https://webtop.cerpzone.org/webtop/. Additionally, metadata for wells can be found in the Hydrogeologic Data section of the DBHYDRO browser. Since metadata can be of critical importance in evaluating datasets, familiarity with the contents of these directories is recommended, as are field visits, if possible. For example, engineers can find statements of work, pictures, and site setup notes at \\focproj1\maint\contracts for review before approaching a site's actual numbers. As part of database management practices, a common, single source for metadata may be useful for future initiation (see U.S.D.A., 1999).

## 22.4 Data Archiving Requirements

Archival records are those records determined to have long-term historical, research or other continuing value. The term usually refers to records no longer required for current use that have been selected for permanent preservation because of their enduring value. This data consists of all documents, paper records (e.g., charts, logs, CR10 information/verification sheets, etc.), letters, emails, digital tapes, microfilm, and electronic telemetry records from data collection sites/stations within the SFWMD regional area. The permanent retention schedule assigned to this historical data is based upon analysis of the records' compliance with legal retention requirements, historical requirements and values.

In general, processed electronic data should be archived in DBHYDRO in a usable format specific to parameter type and project needs. Breakpoint data is maintained in DCVP. Plan documents should specify where data will be stored.

Compact disk backup of datasets should also be conducted regularly and stored as long as required by specific project needs.

# 23.0 QUALITY ASSURANCE/QUALITY CONTROL

The quality of all hydrometeorological data generated and processed must be appropriate for their intended use, scientifically valid, of known precision and accuracy, of acceptable completeness, representativeness, and comparability, and, where appropriate, legally defensible. Data quality is achieved through adherence to protocols, standards, and practices at all levels of data collection and data processing. The protocols, standards, and practices defined in this document and supporting references outline what is acceptable for data quality objectives. The quality of the QA/QC function is maintained through employee training, observation monitoring review, and program oversight and coordination.

## 23.1 Data Processing

Data processing should be approached with the same high accuracy standards for all sites, regardless of mandate or permit conditions. Flow and meteorological data must be summarized or derived through review, analysis, and interpretation before they can be placed in any meaningful context, then published in the DBHYRDO database (see \\Dataserv\570\5730\5732\Donna_Master_Documentation\OHDP_sops\Master_ISO Procedures for specific processing procedures. ) Acquisition, validation, evaluation, and review are all components of sound data processing (Pathak and Pandey, 2008). Numerous Standard Operating Procedures have been developed for data processing at the District. These include Procedures Q100 through Q116. An example of the steps needed to extract data from DCVP is also detailed by Haller (2007).

## 23.2 Data Post-Processing QA

Post-processing QA at the District is mainly used to create preferred datasets. Preferred datasets have been rigorously examined to determine, and possibly improve, its quality. Post-processing is done after initial processing and takes into consideration the measure, collection, transmission, processing, and computations (Sangoyomi, 2005). Post-processing of select monitoring stations is conducted monthly, quarterly or yearly accordingly to published schedules, and may be used in mandated permits and/or reporting such as Everglades Agricultural Area Rulemaking and Stormwater Treatment Area performance. In addition, carefully vetted datasets are used for day-to-day operational decision-making (Sangoyomi, 2005; Q201).

Post-processing QA involves the use of graphical plotting tools to view the data, gaps, overlaps, relationships, and inconsistencies in data. It also involves the use of statistical analysis to analyze the reliability of the data, such as outlier and water budget analyses, and historical comparisons to give the data context. In general, the engineer should examine the dataset for problems (e.g., outliers, missing data, vertical datum, duplicated information) and work to rectify such problems, e.g., estimating the missing data (Sangoyomi, 2005; Q201). In addition, post-processing QA involves using engineering professional judgment in applying QA methods, for example, if the data reads negative flow, is negative flow possible at the collection site?

Each measured parameter at the District has a specific set of procedures that should be applied. For details, see Procedures Q201–Q205.

All quality assurance data validation and statistical analyses activities must be documented. The quality records required to conduct the analysis, as well as the reviewing documentation must be maintained at least five years beyond the life of the program or project. The quality records may be stored on a short-term basis on the QA/QC engineer's work station computer; and then elevated to a network attached storage server for long-term data storage.

### 23.3 Continuous Quality Improvement

The process of continuous quality improvement leads to the development of a better and more responsive QA/QC Program. Quality improvements generally result from activities that:

- Prevent or minimize problems that may affect the quality of the results,
- Detect and correct problems;
- Review existing performance and identify opportunities for quality improvement,
- Develop and implement data review criteria and assessment deliverable,
- Develop and implement QA/QC tools which will increase efficiency and result in time saving.

## 24.0 DATA CHANGE REQUIREMENTS

This section discusses data change requirements needed for the District's environmental database, DBHYDRO.

### 24.1 Data Quality Needs

Data change is a critical process that could induce additional burdens on the District. The safe design of water control structures depends to a large extent on available historical data. A strong rationale must, therefore, be established prior to a decision to change data. Even when justified, the process for data change should be well documented, easily understood, and restricted to a few staff members designated with the authority to change data. Data change must be considered as a security issue and editing permissions should be restricted to authorized users.

The primary objective of changing data will be to resolve inconsistencies so that the accuracy, precision, and reliability of the data are increased, thereby increasing the confidence of customers. It is expected that much of the uncertainty associated with acquisition, archiving, and changing water data can be reduced through the use of standard operating procedures.

### 24.2 Reasons for Data Changes

Possible reasons for data problems and data changes are: (1) data processing errors due to anomalies in data recording media, mechanical or calibration problems; (2) site or station registration problems (wrong mapping of stage sensors, operations data stream loaded to the incorrect station identification, etc.), (3) datum adjustments/corrections that change stage reference elevations (and affects data points such as flow estimates); (4) changes in calculation methodology (such as flow rating improvements), software, or water control structure reconfiguration.

### 24.3 Criteria for Data Change

Data changes in DBHYDRO are inevitable. A DBHYDRO reload may be necessary whenever the time-series data can be substantially improved. The improvement in the accuracy of the data may be the result of a new or improved flow rating, correction of errors in the collection, processing or flow computation applications, or a change in the reference elevation or structure configuration. However, the historical data should not be changed unless the new dataset represents a major improvement over the existing dataset. Specific criteria for changing the historical record are detailed in Procedure Q100-001.

### 24.4 Data Change Process

The data change process consists of the following steps as detailed in Procedure Q100-001:

- Problem notification
- Remedy incident request (create/assign/handle)
- Investigating and diagnosing a problem
- Internal approval
- Determine whether time-series record is Historical or Provisional
- Customer notification–pending data change
- Further investigation
- Data change approval
- Review period
- Designated staff with authority to change data
- Data change implementation

## 25.0 AUDITING/ASSESSMENT REQUIREMENTS

Audits are designed to ensure that all required tasks are being performed. Audits are documented quality assurance activities performed to determine compliance with SOPs and guidelines and the effectiveness of their implementation. Audits include observing and validating streamgauging data collection activities, preventive maintenance, installations, flow development activities, data processing activities, archival activities, and post-processing QA/QC activities. Audits are also performed to determine if District staff is producing the correct/right amount of data in the time frame required.

Audits and assessments require the use of a third-party auditor. Detailed steps for the audit process are provided in SFMWD, 2008b, c, d, and AHT, 2009. The audit process begins with the acquisition of all relevant documentation including SOPs, guidelines, notes, maintenance logs, flow calculation methods, etc. The auditor reviews these documents and then prepares an assessment checklist that will be used in the audit process. The checklist is then used to carry out the audits (SFWMD, 2007b).

Once the audits have been completed, the auditor prepares a draft report that should include reasonable and economical recommendations for corrective actions. The draft report is provided to the audited group for response. The response should address areas that the audited group agrees to and those that they do not. It should also include timelines for implementing the corrective actions which are agreed to. The auditor will then incorporate the audited group's response into a final report. In some cases, a second or third round of audits may be required.

## 26.0 REFERENCES

| Procedure | Title |
|---|---|
| Q100-001 | Operations & Hydrologic Data Processing Section Change Management Procedures for Hydrometeorological Data |
| Q100 | OHDM Hydrologic Data Processing & Streamgauging Policy |
| Q101 | Data Records Management Procedures (Archives, Retrieval, Record Keeping, Data Logging and Distribution) |
| Q102 | Site/Station Assignment Procedure |
| Q103 | Microwave Telemetry Network Data Loading Procedure |
| Q104 | ARDAMS RF Telemetry & Manually Collected CR10 Data Loading Procedure |
| Q105 | Site Registration Procedure |
| Q106 | Stevens A35 and 2A35 Graphic Chart Processing Procedure |
| Q107 | Belfort Weekly Rainfall Graphic Processing Procedure |
| Q108 | Stevens Digital Punch-Tape Processing Procedure |
| Q109 | Manually Observed Rainfall and Evaporation Logs (RF3) Processing Procedure |
| Q110 | ARDAMS/LoggerNet Radio Frequency (RF) Telemetry & Manually Collected CR10 (SG3) Processing Procedure |
| Q111 | Microwave Telemetry (SG4) Processing Procedure |
| Q112 | Data Request Report Generation Procedure |
| Q113 | Manually Observed Data: Stage, Gate, Pump and Flashboard (SG3) Processing Procedure |
| Q114 | Shark River Report |
| Q115 | Meteorological (Weather) Data Processing Procedure |
| Q116 | Graphical Verification Analysis User's Guide |
| Q201 | OHDM & QA/QC Section QA/QC of Stage Data Procedures |
| Q202 | OHDM & QA/QC Section QA/QC of Rainfall Data Procedures |
| Q203 | OHDM & QA/QC Section QA/QC of Flow Data Procedures |
| Q204 | OHDM & QA/QC Section QA/QC of Meteorological and Evapotranspiration Data Procedures |
| Q205 | OHDM & QA/QC Section QA/QC of Groundwater Level Data Procedures |

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