SOUTHWEST FLORIDA WATER MANAGEMENT DISTRICT
WATER USE PERMIT
Individual
PERMIT NO. 20 011771.002

PERMIT ISSUE DATE: January 25, 2022 **EXPIRATION DATE: January 25, 2032**

The Permittee is responsible for submitting an application to renew this permit no sooner than one year prior to the expiration date, and no later than the end of the last business day before the expiration date, whether or not the Permittee receives prior notification by mail. Failure to submit a renewal application prior to the expiration date and continuing to withdraw water after the expiration date is a violation of Chapter 373, Florida Statutes, and Chapter 40D-2, Florida Administrative Code, and may result in a monetary penalty and/or loss of the right to use the water. Issuance of a renewal of this permit is contingent upon District approval.

TYPE OF APPLICATION:	Renewal
GRANTED TO:	Tampa Bay Water;/Attn: Warren Hogg 2575 Enterprise Road Clearwater, FL 33763
PROJECT NAME:	TBW-Consolidated Permit
WATER USE CAUTION AREA(S):	Northern Tampa Bay
COUNTY:	Pinellas, Hillsborough, Pasco

TOTAL QUANTITIES AUTHORIZED UNDER THIS PERMIT (in gallons per day)	
ANNUAL AVERAGE	90,000,000 gpd

ABSTRACT:
This is a renewal of an existing Water Use Permit for public supply use. The authorized quantity 90,000,000 gallons per day (gpd), is unchanged from the previous permit and is based on historic use and demand projections provided by the applicant. This permit, referred to as the “Consolidated Permit”, covers ten wellfields within the Northern Tampa Bay region that are collectively referred to as the “Central System” and are listed below:

1. Cosme-Odessa Wellfield
2. Cross Bar Ranch Wellfield
3. Cypress Bridge Wellfield
4. Cypress Creek Wellfield
5. Eldridge-Wilde Wellfield
6. Morris Bridge Wellfield
7. Northwest Hillsborough Regional Wellfield
8. Section 21 Wellfield
9. South Pasco Wellfield

The location of each permitted withdrawal at the above facilities is attached to this permit as Exhibit C.1. All tables and Exhibits to this Water Use Permit are incorporated herein by reference for all purposes.

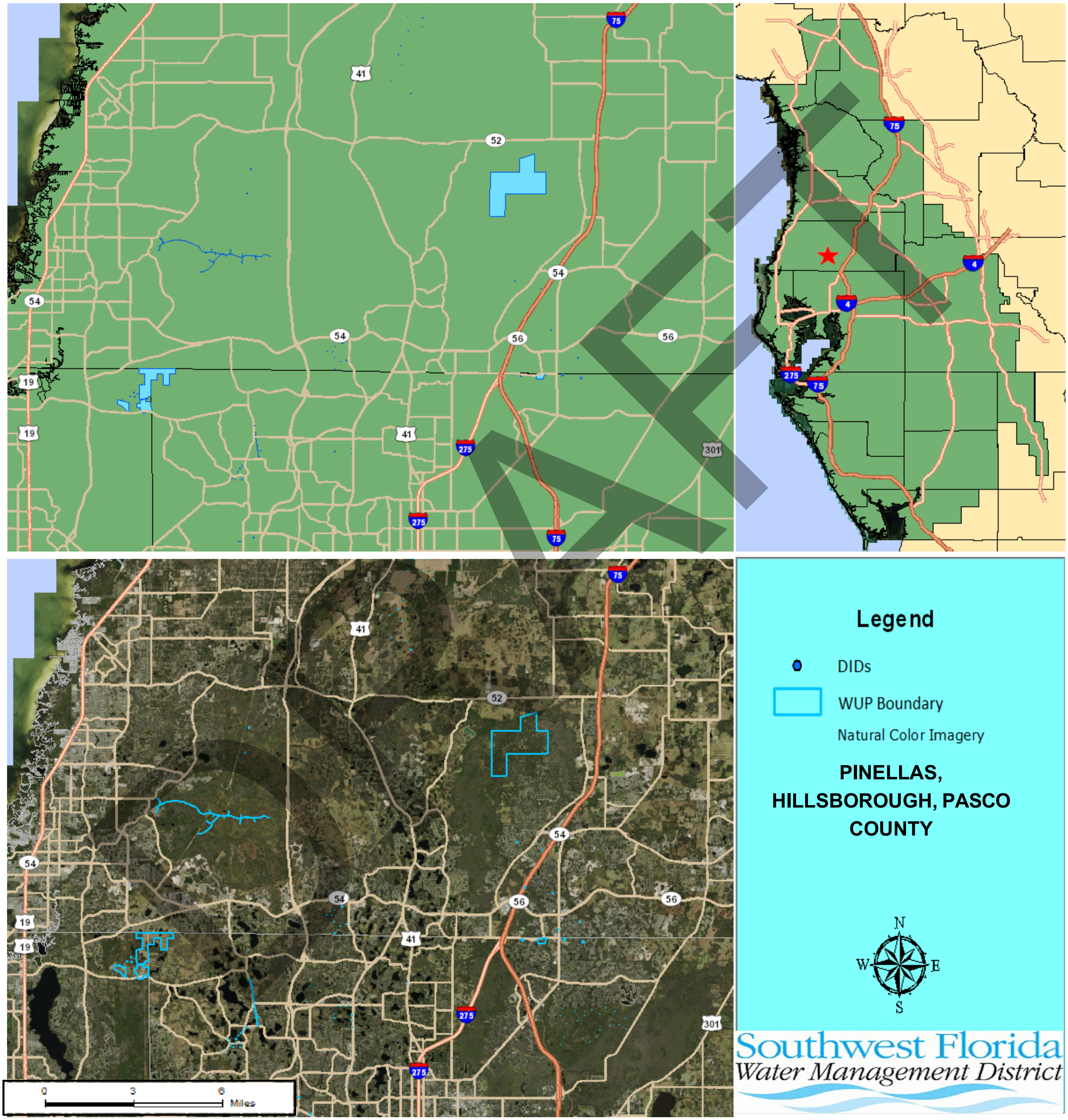
The application for this permit meets the conditions for issuance because reasonable assurances have been provided that demonstrate that water resources, existing legal users, offsite land uses, and surface water and groundwater quality will not be adversely impacted. The Permittee has demonstrated recovery from the environmental impacts that occurred historically in the region through a comprehensive resource recovery assessment and has provided reasonable assurance that recovery will be maintained through continued system operation under the Optimized Regional Operations Plan (OROP).

Special conditions of this permit include those that require the permittee to continue to manage withdrawals using the Operations Plan (Exhibit D) to define and control how wellfield withdrawal points from the Central System will be operated to avoid adverse environmental impacts, to continue to monitor water levels, vegetation, and water quality according to the Environmental Monitoring Plan (Exhibit E), and to submit annual reports as required herein.

Standard Conditions:

The Permittee shall comply with the Standard Conditions attached hereto, incorporated herein by reference as Exhibit A and made a part hereof.

Location Map
Tampa Bay Water;/Attn: Warren Hogg
WUP No. 20 011771.002



SPECIAL CONDITIONS:

All references to approval by or notification to the District shall be defined as the Executive Director or designee.

1. **SUBMISSION OF DATA AND REPORTS**
All reports and data required by condition(s) of the permit shall be submitted to the District according to the due date(s) contained in the specific condition. If a condition specifies that a District-supplied form is to be used, the Permittee shall use that form in order for its submission to be acknowledged in a timely manner. The only alternative to this requirement is to use the District Permit Information Center (www.swfwmd.state.fl.us/permits/epermitting/) to submit data, plans or reports online. There are instructions at the District website on how to register to set up an account to do so. If the report or data is received on or before the fifteenth day of the month following data collection, it shall be deemed a timely submittal.

All mailed reports and data are to be sent to:

Southwest Florida Water Management District
Tampa Service Office, Water Use Permit Bureau
7601 U.S. Hwy. 301 North
Tampa, Florida 33637-6759

Unless submitted online or as otherwise indicated in the special condition, all submittals shall be made in a format acceptable to the District such as, but not limited to, Microsoft EXCEL and WORD, other compatible software or ASCII format.

2. **WITHDRAWAL LIMITATIONS**
Total withdrawals from the Central System as metered at the individual production wells, shall not exceed 90 MGD on a 12-month running average basis. The locations of withdrawal points for this permit are found in Exhibit C.1.

3. **OPERATIONS PLAN - GENERAL REQUIREMENTS**
The Permittee shall continue to implement and refine, as needed, the Operations Plan (Exhibit D). Refinements and updates to the Operations Plan will be documented in Biennial Reports, the most recent of which is included in Exhibit D. The Operations Plan shall include the Permittee's OROP, input data sets, constraint data sets, and supporting models used in the development of a weekly rotation schedule for the Central System. The Operations Plan shall continue to be used to define and control how wellfield withdrawals from the Central System shall be optimized to avoid or minimize environmental stress. Throughout the term of this permit, any changes to the Operations Plan that could result in a change to the distribution of wellfield withdrawals will require District approval including the following:

A. Any change to the optimization formulation, implementation or software;
B. Any change to the Integrated Northern Tampa Bay (INTB) Model code and INTB model, or incorporation of new codes and models;
C. Any change to the Unit Response Matrix (URM), operating rule curves, or preferential weighting system;
D. Any change to the number and location of control points;
E. Any change to target aquifer levels at control points;
F. Any change to the number and location of the Upper Floridan aquifer monitor wells used in OROP; and
G. The addition of any new interconnected groundwater supply source.

If a change is proposed to the Operations Plan, except for routine updates of target levels and the addition or deletion of control point wells documented in the Biennial Reports, the Permittee shall submit an amended and restated version of the entire Operations Plan identifying the proposed change to the District. The restated report shall be submitted in an electronic format acceptable to the District such as, but not limited to, Microsoft Excel and Word, other compatible software or ASCII format. Approval must be obtained from the District prior to implementation of any changes by the Permittee. The Permittee shall begin implementation of the approved changes within 60 days of District approval.

The Operations Plan shall:

A. Define how the Permittee will operate the Central System;
B. Provide the protocol under which the Permittee will select among the production wells in the Central System to meet demand;
C. Provide the protocol under which the Permittee will rotate among the production wells in the Central System to avoid or minimize environmental stresses;
D. Rely upon ground water elevation target levels in the aquifer systems as a surrogate for water levels in wetlands and lakes, and flows in streams and springs at a specified set of existing and proposed monitor wells, to gage environmental stresses in and around the Central System wherein increased ground water elevations will denote reduced environmental stresses;
E. Include procedures for analyzing relationships between the distribution and rate of withdrawal at the well fields, flow rates in rivers and streams, and the associated Floridan and surficial aquifer system levels, using available models;
F. Include procedures for selecting optimal scenarios for the distribution and rate of ground water withdrawals from the well fields, using available mathematically-based optimization software, based on projected demand and operating system constraints, such that ground water levels in the surficial aquifer system are maximized according to a specified weighting/ranking system as a surrogate for water levels in wetlands and lakes and flow in rivers and streams;
G. Include in the optimization analysis a weighting/ranking system to enable priority factors to be applied to reduce environmental stress preferentially at selected locations, with such factors to be associated with the specified surficial aquifer monitor wells;
H. Propose a set of surficial aquifer monitor wells as well as a priority weighting system for those wells; and
I. Provide data and software for all models used in the OROP.

4. BIENNIAL OPERATIONS PLAN REPORTS

The Permittee shall submit to the District an Operations Plan Report for the previous 2 water years by July 1 of years 2022, 2024, 2026, 2028 and in conjunction with the application to renew the Consolidated Permit in 2031. This report is subject to District approval based upon conditions within this permit, the previously approved Operations Plan and the previously approved Biennial Report. The District shall respond in writing with approval or comments/questions. The Permittee shall respond in writing to any comments/questions from the District within sixty (60) days of receipt of the District letter and shall revise the Operations Plan Report to address the District's comments/ questions. The report shall include the following:

A. Summary of all changes to the Operations Plan (Exhibit D) that were approved by the District during the reporting period;
B. Description of any infrastructure changes during the reporting period that affect groundwater sources, including changes to withdrawal points, conveyance infrastructure and points of connection;
C. Review of Central System operations for the reporting period;
D. Discussion of how capital improvement projects (key infrastructure improvement projects) may affect operations of the Central System;
E. Review of hydrologic conditions relevant to recent/existing/future operations (regional rainfall, surface water flow, and OROP control point performance) describing how

hydrologic conditions affected the Operations Plan;

F. Discussion of groundwater quality, describing how water quality affects the use of Central System facilities;

G. Monthly average production for each of the Central System facilities for the reporting period;

H. Annual average and moving-annual average daily production from the Central System for the reporting period;

I. Discussion of groundwater facility shutdowns;

J. Water level hydrographs of regulatory wells and OROP control points;

K. Summary of the EMP/OROP Wetlands Referrals and subsequent actions;

L. Any reassessment of OROP control points, including location and target level adjustments;

M. Summaries of work plan activities for the reporting period, if any;

N. Summary information and data on operation activities during the preceding reporting period;

O. Proposed work plan activities for the next reporting period, if any; and

P. Any other information or analysis associated with District approved changes to the Operations Plan, as applicable.

5. OPERATIONS PLAN WEEKLY REPORTS

The Permittee shall submit to the District the following weekly reports as compliance reports:

A. Proposed weekly production schedule for all active production sources (groundwater, surface water and desalinated seawater), commonly referred to as the "OROP Consolidated Report". This report shall be provided to the District in the format that the report is automatically produced for the Permittee's internal use.

B. Weekly actual and forecasted demands, source availability, water use, and surface water allocation, commonly referred to as the "Weekly Demand and Supply Report". This report shall be provided to the District in the format that the report is automatically produced for the Permittee's internal use.

6. ENVIRONMENTAL MANAGEMENT PLAN

The Permittee shall monitor and assess environmental systems based on the Environmental Monitoring Plan (EMP) entitled **Environmental Management Plan for the Tampa Bay Water Central System Wellfields** (Exhibit E).

If a change is proposed to the EMP the Permittee shall submit a request in writing to the District. Approval must be obtained from the District prior to implementation of any such change. The Permittee shall begin implementation of the monitoring elements of the change within 60 days of District approval. These changes shall be reported in the subsequent Wellfield Annual Report required pursuant to Special Condition 13.

Reference and control sites proposed by the Permittee are provided as attachments to the EMP in Exhibit E.

7. ENVIRONMENTAL AUGMENTATION

When supplemental hydration is provided to sites described in Exhibit C.5, the specific augmentation shall be reported in the wellfield annual reports. The Permittee shall not make changes to Exhibit C.5 and items A-J below, as applicable, without District approval:

A. Location of a proposed augmentation site and its current condition;

B. Benefits of augmentation at the proposed location;

C. Source(s) of the augmentation water, e.g., surface water, groundwater, reclaimed water;

D. Estimated augmentation quantity expressed as gallons per day;

E. Proposed augmentation elevations and fluctuation schedule that will emulate similar natural systems;
F. Plan for monitoring water elevations and water quality;
G. The potential to provide supplemental hydration using sources other than groundwater;
H. Assessment of potential unacceptable adverse effects that might be attributable to the proposed augmentation;
I. Presence of any nuisance plants, coverage and the need for a maintenance control plan; and
J. Plan for monitoring of biota.

The Permittee shall submit a summary of its augmentation efforts for all augmented sites with each applicable Wellfield Annual Report. Information shall include augmentation quantities per site per month.

8. AERIAL PHOTOGRAPHY

The Permittee shall utilize aerial photographs of the wellfield areas to detect and document changes to the vegetation and/or the hydrology of wetlands, lakes or streams that occurred during the reporting period relative to the previous reporting period aerial photographs. Any aerial photographs taken by the Permittee in support of the aerial photographic analysis as well as the interpretation of the photographs shall be dated and submitted to the District. Wellfield Annual Reports submitted to the District by July 1 of the specified years, starting with reports submitted in 2022, will contain copies of the imagery if conducted by the Permittee. An interpretive analysis of aerial photography collected since the previous report, including an analysis of historical conditions, shall be submitted as a part of the Wellfield Annual Reports submitted in the years 2024, 2027 and 2030.

9. CONSERVATION AND CONSERVATION REPORTING

The Permittee shall not have water losses greater than 10% of total system output, as measured from the Permittee's points of withdrawal to the points of connection with its member governments. Actual water loss shall be reported in the Permittee's Meter Calibration, Testing, and Maintenance Program Annual Report, as required by Condition 10.K. Should water losses exceed 10% of total system output, the Permittee shall conduct a water audit by the following July 1, and the results shall be submitted by October 1 of the same year. The water audit report shall (1) evaluate the items set forth in Water Use Permit Applicant's Handbook – Part B Sections 2.3.7 and 4.4.8, as possible sources for the water losses, and (2) include a schedule for a remedial action plan to reduce the water losses to 10% or less.

10. DATA COLLECTION AND SUBMITTAL

Adherence to approved standards for the consistent and accurate collection of field data is a primary objective of this permit. Since collection of field data presents many challenges, it is critical such data is collected using properly installed and adequate field instrumentation, consistent data collection techniques, and appropriate quality control methods and that the data be readily available, comprehensive and well-documented.

A. If a change is proposed to the monitoring and augmentation sites in Exhibits C.2 - C.5, and flow metering devices for production wells in Exhibit C.1, the Permittee shall submit a request in writing to the District for approval of the specific change. For wetland water level readings, Tampa Bay Water may propose to the District the discontinuation of center well readings during times when water level readings can be made on the staff gage(s) if it can be demonstrated that the staff gage and center well readings are consistently equal (within 0.1 foot) over a reasonable length of time. Once demonstrated and approved by the District, data from such center wells need only be collected during times when the staff gage or gages are dry. Approval of any such change must be obtained from the District prior to implementation of any change by the Permittee. Changes approved by the District will be provided in written form and shall not constitute a modification of this permit. The Permittee shall begin implementation of the approved changes within 60 days of District approval, unless otherwise authorized by the District.

B. The Permittee shall collect field data and submit the data to the District in a timely manner. Exhibits C.1 - C.5 of this permit list the devices to be monitored, the parameters to be collected at each device, and the frequency of data collection at each device. For the purpose of this permit, devices include ground-water withdrawal wells including their associated monitoring devices, monitoring wells, staff gages, and transects for use in administering the Wetland Assessment Procedure.

C. The accurate analysis of field data requires accurate site information on each of the devices used to collect the data. All vertical and horizontal surveying shall be completed under the direct supervision of a Florida licensed Professional Surveyor and Mapper. Additionally, a list of site parameters must be submitted to the District with the establishment of any new District-approved monitoring devices or the change of any site information at existing sites within 90 days of the establishment or change. All monitoring sites identified in Exhibits C.1-C.5 shall be resurveyed one time during the term of this water use permit.

Site Information for Monitor Wells

1) Location (Latitude and Longitude)
2) Well diameter
3) Well depth
4) Casing depth and material
5) Liner Depth (if applicable)
6) Ground elevation
7) Measuring point description and elevation (NGVD 29/NAVD 88)
8) Aquifer(s) monitored
9) Well Completion Report No. (if available)
10) Well Construction Date and Chapter 40D-3, F.A.C., permit number
11) Information on recorder (if applicable)
12) Parameters sampled/measured
13) Sampling method/measurement technique
14) Sampling depth (if applicable)
15) Sampling frequency
16) Date of data collection start and (if applicable) end
17) Source and documentation for all horizontal and vertical surveys
18) Information on legal access/land owner for each site.

Detailed Site Information for Staff Gages

1) Location (Latitude and Longitude)
2) Ground elevation
3) Description of gage construction
4) Information on recorder (if applicable)
5) Sampling frequency
6) Date of data collection start and (if applicable) end
7) Source and documentation for all horizontal and vertical surveys
8) Information on legal access/land owner for each site.

Detailed Site Information for Wetland Monitoring and Augmentation Locations

1) Wetland Community Type per Environmental Management Plan (EMP)
2) Historic Normal Pool and method used (if applicable)
3) Details of WAP transect installation (if applicable)
4) Details of augmentation installation (if applicable)
5) Sampling frequency
6) Date of data collection start and (if applicable) end
7) Source and documentation for all horizontal and vertical surveys

8) Applicable documentation on benchmarks used

9) Information on legal access/land owner for each site.

D. The addition or subtraction of monitoring devices, changes in types of data collected at devices, and changes in data collection frequency shall require prior approval from the District, as set forth in Special Condition 10.A. If legal access is lost to a device, it is the Permittee's responsibility to re-acquire access to the device or propose an acceptable alternative to the District within 30 days of access loss to the original device. Acceptable alternatives may include, but are not limited to, acquiring a site in the same general vicinity, utilizing other existing or proposed sites, or justifying why not replacing a site is acceptable. The Permittee shall make a good faith effort to replace all devices for which it loses legal access. If loss of legal access or loss of devices is anticipated in the future, the Permittee shall inform the District in writing in a timely manner. All District approved changes to monitoring devices as set forth in Special Condition 10.A, including but not limited to, survey changes, measuring point changes and gage replacement, must be reported to the District within 30 days of such changes being implemented by the Permittee, and include any new site parameters (listed above).

E. All data shall be submitted to the District in an electronic format acceptable to the District.

F. A data value shall be collected for each parameter at the frequency specified in Exhibit C. If data cannot be collected for any parameter at the frequency specified, the Permittee shall indicate such in the regular submittal, along with an explanation of why the data could not be collected. Any long-term problems that prohibit the regular collection of data shall be rectified by the Permittee if feasible.

G. Water level data shall be referenced to National Geodetic Vertical Datum of 1929 (NGVD29) and submitted to the District on or before the 15th day of the following month from which it is collected. For sites with continuous recorders, the maximum of the 24 hourly values for each day shall be determined and only the maximum value for each day shall be reported to the District. Data collected manually (twice a month) shall be collected during the same weeks of each month.
Within six months from the date of issuance of this permit, the Permittee shall submit a plan for conversion of the vertical datum for all active monitoring sites included in this permit to North American Vertical Datum of 1988 (NAVD88). Water level data shall continue to be provided in NGVD29 until the conversion date identified in the plan.

H. Water quality data shall be submitted to the District on or before the 15th day of the following month from which it is collected. Water quality samples shall be collected from active production wells and monitor wells in accordance with the frequency identified in Exhibit C.2. For production wells that are temporarily out of service, water quality samples should not be separated by more than 180 days.

1) All field sampling of groundwater water quality data shall follow the applicable field collection, quality control and record-keeping requirements described in the Florida Department of Environmental Protection's (FDEP) Standard Operating Procedures (SOPs) (DEP-SOP-001/01 (effective December 3, 2008)), Rule 62- 160.800 F.A.C. The FDEP SOPs (specifically FD1000, FQ1000, FT1000 through FT1600, FS1000, FS2000, and FS2200) for collection, documentation, and quality assurance for required permit condition water quality parameters can be accessed at the FDEP website.

2) Laboratories utilized by the Permittee for analyzing water quality samples, and therefore generating environmental data for submission to the District, must hold National Environmental Laboratory Accreditation Conference (NELAC) certification from the Florida Department of Health - Drinking Water or Environmental Laboratory Certification Program for the parameters being tested (as required under Rule 62-160.300, F.A.C.).

3) The Permittee will permit the District, the FDEP, or any consultant operating on behalf of the District or FDEP, to conduct periodic audits of field and laboratory procedures or records to determine if approved protocols are being followed in accordance with Rule 62-160.650, F.A.C.

4) The Permittee shall submit all water quality data in a standardized electronic

format (available from the District) in accordance with Rule 62-40.540, F.A.C., and shall include the required data elements set forth in Rules 62-160.240 and 62-160.340, F.A.C.

I. Wetland Assessment Procedure (WAP) data, collected in accordance with Exhibit E, shall be submitted on or before the 15th day of October after the data were collected.

J. The Permittee shall meter withdrawals from the groundwater resources and meter readings from each withdrawal facility shall be recorded on a daily basis. Total ground- water flow shall be measured on a daily basis and reported on a weekly basis in an electronic format acceptable to the District. This data is currently and will continue to be posted to the Tampa Bay Water FTP site on a weekly basis for District access. Posting of this data on the Tampa Bay Water FTP site in a manner that provides direct access by the District constitutes full compliance with the requirements of this Special Condition 10.J. The mechanism of electronic data transfer may be modified with the mutual consent of the Permittee and the District and shall not constitute a modification of this permit. Flow metering shall be required for all withdrawal points identified in Exhibit C.1 and at all points at which water is discharged for environmental augmentation (Exhibit C.5). Recorded individual withdrawal records shall be final as determined by the Permittee and any corrections to the data will be included in the weekly data posting to the Tampa Bay Water FTP site.

K. The Permittee shall submit an Annual Report summarizing activities conducted under the Meter Calibration, Testing and Maintenance Program for the preceding water year. This report shall be submitted by July 1 of each year.

11. INVESTIGATION AND REMEDIATION OF WATER WITHDRAWAL COMPLAINTS

The Permittee shall expeditiously investigate and resolve complaints regarding an impact to a well in accordance with the following procedures:

A. The Well Complaint Mitigation Area (Mitigation Area) is defined as the area specified in Exhibit F. The Mitigation Area may be amended, as requested by the Permittee, subject to prior approval of the District.

B. Within 24 hours of complaint receipt by the Permittee, the Permittee shall make every reasonable effort to commence a preliminary investigation and determine whether the Permittee's withdrawals may have caused the problem. The preliminary investigation shall include contacting the complainant to determine the location of the complainant's withdrawal relative to the Mitigation Area, the nature of the problem (e.g., loss of water, loss of pressure, water quality), the uses for the complainant's withdrawal, and the date the complainant's withdrawal was initiated.

C. If this preliminary assessment indicates that the Permittee may be responsible for a water supply impact which represents a public health and safety problem, the Permittee shall, within 48 hours of complaint receipt, make available to the complainant any water necessary for health and safety purposes, such as drinking water.

D. The Permittee is currently investigating domestic well complaints pursuant to Ch. 49B- 3.005, F.A.C., and shall continue mitigating domestic wells during the term of this permit pursuant to this rule, as amended by the Permittee from time to time. However, in no case shall the Permittee's well mitigation be less stringent than as set forth in this special condition.

E. The Permittee may elect to mitigate the complaint after the preliminary investigation without further investigation or conduct a detailed investigation to determine if the Permittee caused the problem. This detailed investigation shall include, but not be limited to, an analysis of impacts at the complainant's well arising from the Permittee's pumpage, an analysis of water levels at the time of the complainant's problem, withdrawal and pump characteristics including depths, capacity, pump curves, and irrigation system requirements. If this detailed investigation confirms that the complainant's problem was caused by the Permittee's withdrawals, the complainant's problem shall be fully corrected. In cases where water is unavailable to the complainant for public health and safety purposes, the complainant's problem shall be corrected as soon as possible, with restoration of essential domestic water supply within 15 days, and fully corrected within 30 days of complaint receipt, unless an extension of time is granted by the District. In cases of complaints where water is available to the complainant for public health and safety purposes, the complainant's problem shall be fully corrected as soon as possible, and within no more than 30 days of complaint receipt, unless an extension of time is granted by the District.

F. Full correction shall be restoration of the complainant's water supply to pre-impact condition or better, including the aspects of pressure levels, water quality, and discharge quantity. Full correction may be accomplished by connecting a complainant to a public supply system, with the consent of the owner of the well. Produced or delivered water quality shall meet, at a minimum, the standards referenced below. If the water quality is found to exceed the standards referenced below, the Permittee shall propose alternative mitigation to resolve the complaint, with full correction completed within 45 days of water quality complaint receipt, unless an extension of time is granted by the District. If the water quality is found not to exceed the standards referenced below, mitigation shall be deemed complete.

Water Quality Constituents and Standards:
Constituents: Odor, Total Sulfides, Color, Coliform Bacteria, Iron, Turbidity, Nitrate, Chloride, Sulfate, Total Dissolved Solids. The maximum levels for these constituents in the complainant's well water sample shall not exceed any of the levels established by the Florida Department of Environmental Protection (FDEP) Secondary Drinking Water Standards [Ref: 62-550.320(1), F.A.C.], or any modified version thereof. Total Sulfides concentration must not exceed 0.20 milligrams/liter. This Total Sulfides concentration limit may be modified by the District on a case-by-case basis if necessary to protect existing legal water users. Such modifications shall be made only after consultation and discussion with the Permittee.

G. In those instances where a complainant's withdrawal is located outside of the Well Complaint Mitigation Area, as determined by the Permittee's preliminary investigation, the District shall deem a detailed investigation unnecessary if the prior 90-day withdrawal from the wellfield(s) closest to the location of the complainant's withdrawal has remained below the quantities used to develop the Well Complaint Mitigation Area and below the historic 90-day peak withdrawal for said wellfield(s). In such cases, the Permittee shall not be responsible for mitigation except as provided for in Special Condition 11.K.

H. If the detailed investigation determines that the Permittee was not responsible for the complainant's problem, the Permittee shall document the reasons for this determination and notify the District within 48 hours of the completion of the determination. The Permittee shall submit the findings of facts, all information collected during the investigation, and a summary explaining the Permittee's reasons for this determination. Upon concurrence by the District of the Permittee's determination, a copy of the report shall also be sent to the complainant. Should the District decide that water quality data should be collected for well complaints, or that well water quality complaints should be mitigated under the requirements of this permit, the District shall provide the Permittee written notification of these requirements after consultation and discussion with the Permittee.

I. The Permittee shall file a monthly summary report showing the ongoing complaint investigations and new complaints received during the previous month of operation.The report shall be submitted by the 15th day of the month following the reporting period, to the District for review. The report shall include, but not be limited to:

1) The name and address of each complainant;
2) The location of the complainant's withdrawal (latitude/longitude);
3) The date of complaint receipt and nature of the complaint (water level, water quality);
4) The status of the Permittee's investigation (mitigate, not mitigate, pending);
5) The name of the nearest wellfield included in this permit;
6) An explanation of reasons for not mitigating a complaint (outside mitigation area, pre-existing problem, not a legal existing user, no problem found, notcause of problem), including a summary of the Permittee's investigation if onewas performed;
7) Date complaint file closed.

J. In instances where a new well is constructed to replace an adversely impacted well, the Permittee shall properly abandon the impacted well in a timely manner in accordance with Department of Environmental Protection and District rules regarding well abandonment, currently Ch. 62-532.500(5), F.A.C., and Ch. 40D-3.531(2), F.A.C., as may be amended from time to time. Should the owner refuse to have the well abandoned, the Permittee shall report this situation to the District.

K. In instances where the District and the Permittee differ on the need for mitigation in response to complaints that may be received, the Permittee shall abide by the District's determination. Such determinations by the District shall be made only after consultation and discussion with the Permittee.

12. INVESTIGATION OF WATER RESOURCE AND LAND USE COMPLAINTS

With respect to complaints regarding water levels or flows in water bodies such as lakes, wetlands, springs, streams or other watercourses, damage to crops and other vegetation,damage to the habitat of endangered or threatened species, or damage to other offsite landuses, the following requirements apply:

A. The Permittee shall commence an investigation within 72 hours of receipt of thecomplaint by the Permittee and provide a summary report in the wellfield annual reports required by Condition 13 of this water use permit. The report shall include, but not belimited to:

1) The name and address of each complainant;
2) The date and nature of the complaint;
3) A summary of the Permittee's investigation to date, and, if the investigation is ongoing, an estimate of the time necessary to complete the investigation; and
4) A map showing the location of the water resource and land use impact complaints received, complaints mitigated, and complaints not mitigated thatare presented in the monthly summary report.

B. Within 90 days of complaint receipt, the Permittee shall submit a separate reportpresenting a summary of the Permittee's determinations, including whether thePermittee's withdrawals caused the problem, details of any mitigation or proposedmitigation activities and an estimate of the time necessary to complete mitigation, ifincomplete, and any additional information necessary to assess the impact and anynecessary mitigation. A copy of the report shall also be sent to the complainantconcurrent with the report submitted to the District.

C. The Permittee shall make all reasonable efforts to expeditiously mitigate water resource and land use impacts caused by the Permittee's withdrawals. Full mitigation shall not exceed 180 days from complaint receipt, unless additional time is granted by the District.

D. In instances where the District and the Permittee differ on the need for mitigation in response to complaints that may be received, the Permittee shall abide by the District's determination. Such determinations by the District shall be made only after consultation and discussion with the Permittee.

13. ANNUAL REPORT

The Permittee shall provide comprehensive and concise individual annual reports ("Wellfield Annual Reports") to the District which provide an assessment of the water resources and environmental systems of each of the facilities covered under this permit. Where wellfields are located in close proximity to each other, one Wellfield Annual Report may cover multiple wellfields (e.g., Northwest Hillsborough, Cosme-Odessa, Section 21, Eldridge Wilde, and South Pasco Wellfields). An assessment of the water resources and environmental systems in the area of each facility is required for all sections listed below. The Wellfield Annual Reports shall concisely summarize the elements listed below, and any other elements within this permit that require annual environmental reporting, with emphasis on the interactions between these elements, where appropriate. Data sources shall be referenced. Only essential text, graphs and tables should be included in the Wellfield Annual Reports. An electronic file in a format acceptable to the District such as, but not limited to, Adobe, Microsoft Excel, Word, other compatible software or ASCII format of each Wellfield Annual Report shall be submitted to the District by July 1 of each year. The Wellfield Annual Reports shall cover the preceding water year from October 1 to September 30.

The Annual Report shall include, at a minimum:

A. Executive Summary- Summarization of previous year's monitoring results;
B. Summary of District-approved changes to the monitoring devices (Exhibit C);
C. Production and Wetland Augmentation - Tabular representation of quantities by well or wetland site on average daily basis; meter calibration, testing and maintenance program results (may be submitted separately);
D. Listing of any reported or noted sinkholes and any subsequent investigations, if conducted;
E. Complaints - A summary of the investigations of all complaints concerning adverse impacts to existing legal users, land uses and environmental features, as well as all of the Permittee's efforts to mitigate such adverse impacts, shall be provided for each reporting period. This summary shall include:
    1) Number and type of complaint(s);
    2) Number and type of mitigation activity(ies);
    3) Number and type of complaint(s) which did not require mitigation activity; and
    4) The location of all water resource and land use impact complaints received, complaints mitigated and complaints not mitigated. This shall include a location map and may include ArcGIS coverage, if available;
F. Rainfall - Monthly totals per site for previous year and available period of record yearly totals;
G. Water Quality Monitoring Results - minimum, maximum and average values;
H. Floridan and Surficial Aquifer Water Levels - Hydrographs of monitoring sites, period of record and previous year;
I. Wetland Water Levels, Surface and Groundwater - Hydrographs showing levels in relation to approved reference elevations, ground surface and approved offset of monitoring sites, period of record and previous year;
J. Hydroperiods - Tabular representation of estimated days of surface water per wetland site;

K. Wetland Assessment Results and Data Sheets - Tabular representation of individual scoring categories for period of record. Copies of the WAP data sheets will be submitted separately in accordance with Special Condition 10.I of this permit.

L. Wildlife Usage - Summary of any listed, wetland dependent or exotic wildlife species observations noted throughout previous year;

M. MFL Sites Water Level Summaries - Calculation of median water levels for Chapter 40D- 8, F.A.C., listed sites;

N. OROP Referrals - Listing of wetland sites referred to OROP, period of record and previous year;

O. Aerial Photography Summaries - Consistent with Special Condition 8;

P. Ecological Site Descriptions - Detailed characterizations of wetland sites noting habitat type, significant natural features and any physical alterations;

14. MAINTENANCE OF ENVIRONMENTAL RECOVERY

The Permittee shall continue to manage pumping rate and distribution through the OROP in order to ensure that drawdown in the Upper Floridan aquifer does not cause adverse impacts to the environment. Long term deviation of water flows or levels below established MFLs due to groundwater withdrawals will be considered a violation of the terms of the permit and shall be corrected in a timely manner. Within 90 days of written notification by the District that an MFL has not been met due to groundwater withdrawals from the wellfields included in this permit, the Permittee shall provide a report documenting measures that will be taken to ensure the MFL is met. Any corrective measures proposed are subject to the written approval of the District prior to implementation.

Lakes, wetlands, rivers, and aquifers with MFLs at the time of issuance of this permit are provided in Exhibit C.6. In the event that the Minimum Levels for any of the lakes, wetlands, rivers, or aquifers provided in Exhibit C.6 are repealed from Rule Nos. 40D-8.041, 40D-8.623, 40D-8.624, or 40D-8.626, F.A.C., they shall also be considered null and void for compliance purposes with respect to this condition.

15. TIME EXTENSIONS

Unless specified otherwise, time extensions to condition deadlines will be considered upon written request to the District, provided that the request is made prior to the deadline, the Permittee has demonstrated a good faith effort in meeting the deadline set forth in the condition, and a reasonable modified deadline is proposed by the Permittee.

40D-2
Exhibit A

WATER USE PERMIT STANDARD CONDITIONS

1. With advance notice to the Permittee, District staff with proper identification shall have permission to enter, inspect, collect samples, take measurements, observe permitted and related facilities and collect and document any information deemed necessary to determine compliance with the approved plans, specifications and conditions of this permit. The Permittee shall either accompany District staff onto the property or make provision for access onto the property.

2. When necessary to analyze impacts to the water resource or existing users, the District shall require the Permittee to install flow metering or other measuring devices to record withdrawal quantities and submit the data to the District.

3. A District identification tag shall be prominently displayed at each withdrawal point that is required by the District to be metered or for which withdrawal quantities are required to be reported to the District, by permanently affixing the tag to the withdrawal facility.

4. The Permittee shall mitigate any adverse impact to environmental features or offsite land uses as a result of withdrawals. When adverse impacts occur or are imminent, the District shall require the Permittee to mitigate the impacts. Examples of adverse impacts include the following:
   A. Significant reduction in levels or flows in water bodies such as lakes, impoundments, wetlands, springs, streams or other watercourses; or
   B. Damage to crops and other vegetation causing financial harm to the owner; and
   C. Damage to the habitat of endangered or threatened species.

5. The Permittee shall mitigate any adverse impact to existing legal uses caused by withdrawals. When adverse impacts occur or are imminent, the District may require the Permittee to mitigate the impacts. Adverse impacts include:

   A. A reduction in water levels which impairs the ability of a well to produce water;
   B. Significant reduction in levels or flows in water bodies such as lakes, impoundments, wetlands, springs, streams or other watercourses; or
   C. Significant inducement of natural or manmade contaminants into a water supply or into a usable portion of an aquifer or water body.

6. Permittee shall notify the District in writing within 30 days of any sale, transfer, or conveyance of ownership or any other loss of permitted legal control of the Project and / or related facilities from which the permitted consumptive use is made. Where Permittee's control of the land subject to the permit was demonstrated through a lease, the Permittee must either submit documentation showing that it continues to have legal control or transfer control of the permitted system / project to the new landowner or new lessee. All transfers of ownership are subject to the requirements of Rule 40D-1.6105, F.A.C. Alternatively, the Permittee may surrender the consumptive use permit to the District, thereby relinquishing the right to conduct any activities under the permit.

7. All withdrawals authorized by this WUP shall be implemented as conditioned by this permit, including any documents submitted as part of the permit application incorporated by reference in a permit condition. This permit is subject to review and modification, enforcement action, or revocation, in whole or in part, pursuant to Section 373.136 or 373.243, F.S.

8. This permit does not convey to the Permittee any property rights or privileges other than those specified herein, nor relieve the Permittee from complying with any applicable local government, state, or federal law, rule, or ordinance.

9. The Permittee shall cease or reduce surface water withdrawal as directed by the District if water levels in lakes fall below the applicable minimum water level established in Chapter 40D-8, F.A.C., or rates of flow in streams fall below the minimum levels established in Chapter 40D-8, F.A.C.

10. The Permittee shall cease or reduce withdrawal as directed by the District if water levels in aquifers fall below the minimum levels established by the Governing Board.

11. A Permittee may seek modification of any term of an unexpired permit. The Permittee is advised that section 373.239, F.S., and Rule 40D-2.331, F.A.C., are applicable to permit modifications.

12. The Permittee shall practice water conservation to increase the efficiency of transport, application, and use, as well as to decrease waste and to minimize runoff from the property. At such time as the Governing Board adopts specific conservation requirements for the Permittee's water use classification, this permit shall be subject to those requirements upon notice and after a reasonable period for compliance.

13. The District may establish special regulations for Water-Use Caution Areas. At such time as the Governing Board adopts such provisions, this permit shall be subject to them upon notice and after a reasonable period for compliance.

14. Nothing in this permit should be construed to limit the authority of the District to declare a water shortage and issue orders pursuant to chapter 373, F.S. In the event of a declared water shortage, the Permittee must adhere to the water shortage restrictions, as specified by the District. The Permittee is advised that during a water shortage, reports shall be submitted as required by District rule or order.

15. This permit is issued based on information provided by the Permittee demonstrating that the use of water is reasonable and beneficial, consistent with the public interest, and will not interfere with any existing legal use of water. If, during the term of the permit, it is determined by the District that a statement in the application and in the supporting data are found to be untrue and inaccurate, the use is not reasonable and beneficial, in the public interest, or does impact an existing legal use of water, the Governing Board shall modify this permit or shall revoke this permit following notice and hearing, pursuant to sections 373.136 or 373.243, F.S. The Permittee shall immediately notify the District in writing of any previously submitted information that is later discovered to be inaccurate.

16. All permits are contingent upon continued ownership or legal control of all property on which pumps, wells, diversions or other water withdrawal facilities are located.

Exhibit B
Instructions

METERING INSTRUCTIONS

The Permittee shall meter withdrawals from surface waters and/or the ground water resources, and meter readings from each withdrawal facility shall be recorded on a monthly basis within the last week of the month. The meter reading(s) shall be reported to the Water Use Permit Bureau on or before the fifteenth day of the following month for monthly reporting frequencies. For bi-annual reporting, the data shall be recorded on a monthly basis and reported on or before the fifteenth day of the month following the sixth month of recorded data. The Permittee shall submit meter readings online using the Permit Information Center at www.swfwmd.state.fl.us/permits/epermitting/ or on District supplied scanning forms unless another arrangement for submission of this data has been approved by the District. Submission of such data by any other unauthorized form or mechanism may result in loss of data and subsequent delinquency notifications. Call the Water Use Permit Bureau in Tampa at (813) 985-7481 if difficulty is encountered.

The meters shall adhere to the following descriptions and shall be installed or maintained as follows:

1. The meter(s) shall be non-resettable, totalizing flow meter(s) that have a totalizer of sufficient magnitude to retain total gallon data for a minimum of the three highest consecutive months permitted quantities. If other measuring device(s) are proposed, prior to installation, approval shall be obtained in writing from the Water Use Permit Bureau Chief.
2. The Permittee shall report non-use on all metered standby withdrawal facilities on the scanning form or approved alternative reporting method.
3. If a metered withdrawal facility is not used during any given month, the meter report shall be submitted to the District indicating the same meter reading as was submitted the previous month.
4. The flow meter(s) or other approved device(s) shall have and maintain an accuracy within five percent of the actual flow as installed.
5. Meter accuracy testing requirements:
   A. For newly metered withdrawal points, the flow meter installation shall be designed for inline field access for meter accuracy testing.
   B. The meter shall be tested for accuracy on-site, as installed according to the Flow Meter Accuracy Test Instructions in this Exhibit B, every five years in the assigned month for the county, beginning from the date of its installation for new meters or from the date of initial issuance of this permit containing the metering condition with an accuracy test requirement for existing meters.
   C. The testing frequency will be decreased if the Permittee demonstrates to the satisfaction of the District that a longer period of time for testing is warranted.
   D. The test will be accepted by the District only if performed by a person knowledgeable in the testing equipment used.
   E. If the actual flow is found to be greater than 5% different from the measured flow, within 30 days, the Permittee shall have the meter re-calibrated, repaired, or replaced, whichever is necessary. Documentation of the test and a certificate of re-calibration, if applicable, shall be submitted within 30 days of each test or re-calibration.
6. The meter shall be installed according to the manufacturer's instructions for achieving accurate flow to the specifications above, or it shall be installed in a straight length of pipe where there is at least an upstream length equal to ten (10) times the outside pipe diameter and a downstream length equal to two (2) times the outside pipe diameter. Where there is not at least a length of ten diameters upstream available, flow straightening vanes shall be used in the upstream line.
7. Broken or malfunctioning meter:
   A. If the meter or other flow measuring device malfunctions or breaks, the Permittee shall notify the District within 15 days of discovering the malfunction or breakage.
   B. The meter must be replaced with a repaired or new meter, subject to the same specifications given above, within 30 days of the discovery.
   C. If the meter is removed from the withdrawal point for any other reason, it shall be replaced with another meter having the same specifications given above, or the meter shall be reinstalled within 30 days of its removal from the withdrawal. In either event, a fully functioning meter shall not be off the withdrawal point for more than 60 consecutive days.
8. While the meter is not functioning correctly, the Permittee shall keep track of the total amount of time the withdrawal point was used for each month and multiply those minutes times the pump capacity (in gallons per minute) for total gallons. The estimate of the number of gallons used each month during that period shall be submitted on District scanning forms and noted as estimated per instructions on the form. If the data is submitted

by another approved method, the fact that it is estimated must be indicated. The reason for the necessity to estimate pumpage shall be reported with the estimate.

9. In the event a new meter is installed to replace a broken meter, it and its installation shall meet the specifications of this condition. The permittee shall notify the District of the replacement with the first submittal of meter readings from the new meter.

FLOW METER ACCURACY TEST INSTRUCTIONS

1. **Accuracy Test Due Date** - The Permittee is to schedule their accuracy test according to the following schedule:

   A. For existing metered withdrawal points, add five years to the previous test year, and make the test in the month assigned to your county.
   B. For withdrawal points for which metering is added for the first time, the test is to be scheduled five years from the issue year in the month assigned to your county.
   C. For proposed withdrawal points, the test date is five years from the completion date of the withdrawal point in the month assigned to your county.
   D. For the Permittee's convenience, if there are multiple due-years for meter accuracy testing because of the timing of the installation and/or previous accuracy tests of meters, the Permittee can submit a request in writing to the Water Use Permit Bureau Chief for one specific year to be assigned as the due date year for meter testing. Permittees with many meters to test may also request the tests to be grouped into one year or spread out evenly over two to three years.
   E. The months for accuracy testing of meters are assigned by county. The Permittee is requested but not required to have their testing done in the month assigned to their county. This is to have sufficient District staff available for assistance.

January	Hillsborough
February	Manatee, Pasco
March	Polk (for odd numbered permits)*
April	Polk (for even numbered permits)*
May	Highlands
June	Hardee, Charlotte
July	None or Special Request
August	None or Special Request
September	Desoto, Sarasota
October	Citrus, Levy, Lake
November	Hernando, Sumter, Marion
December	Pinellas

* The permittee may request their multiple permits be tested in the same month.

2. **Accuracy Test Requirements**: The Permittee shall test the accuracy of flow meters on permitted withdrawal points as follows:

   A. The equipment water temperature shall be set to 72 degrees Fahrenheit for ground water, and to the measured water temperature for other water sources.
   B. A minimum of two separate timed tests shall be performed for each meter. Each timed test shall consist of measuring flow using the test meter and the installed meter for a minimum of four minutes duration. If the two tests do not yield consistent results, additional tests shall be performed for a minimum of eight minutes or longer per test until consistent results are obtained.
   C. If the installed meter has a rate of flow, or large multiplier that does not allow for consistent results to be obtained with four- or eight-minute tests, the duration of the test shall be increased as necessary to obtain accurate and consistent results with respect to the type of flow meter installed.
   D. The results of two consistent tests shall be averaged, and the result will be considered the test result for the meter being tested. This result shall be expressed as a plus or minus percent (rounded to the nearest one-tenth percent) accuracy of the installed meter relative to the test meter. The percent accuracy indicates the deviation (if any), of the meter being tested from the test meter.

3. **Accuracy Test Report:** The Permittees shall demonstrate that the results of the meter test(s) are accurate by submitting the following information within 30 days of the test:

   A. A completed Flow Meter Accuracy Verification Form, Form LEG-R.101.00 (5/14) for each flow meter tested. This form can be obtained from the District's website (www.watermatters.org) under "ePermitting and Rules" for Water Use Permits.

B. A printout of data that was input into the test equipment, if the test equipment is capable of creating such a printout;

C. A statement attesting that the manufacturer of the test equipment, or an entity approved or authorized by the manufacturer, has trained the operator to use the specific model test equipment used for testing;

D. The date of the test equipment's most recent calibration that demonstrates that it was calibrated within the previous twelve months, and the test lab's National Institute of Standards and Testing (N.I.S.T.) traceability reference number.

E. A diagram showing the precise location on the pipe where the testing equipment was mounted shall be supplied with the form. This diagram shall also show the pump, installed meter, the configuration (with all valves, tees, elbows, and any other possible flow disturbing devices) that exists between the pump and the test location clearly noted with measurements. If flow straightening vanes are utilized, their location(s) shall also be included in the diagram.

F. A picture of the test location, including the pump, installed flow meter, and the measuring device, or for sites where the picture does not include all of the items listed above, a picture of the test site with a notation of distances to these items.

WATER QUALITY INSTRUCTIONS

The Permittee shall perform water quality sampling, analysis and reporting as follows:

1. The sampling method(s) from both monitor wells and surface water bodies shall be designed to collect water samples that are chemically representative of the zone of the aquifer or the depth or area of the water body.
2. Water quality samples from monitor wells shall be taken after pumping the well for the minimum time specified (if specified) or after the water reaches a constant temperature, pH, and conductivity.
3. The first submittal to the District shall include a copy of the laboratory's analytical and chain of custody procedures. If the laboratory used by the Permittee is changed, the first submittal of data analyzed at the new laboratory shall include a copy of the laboratory's analytical and chain of custody procedures .
4. Any variance in sampling and/or analytical methods shall have prior approval of the Water Use Permit Bureau Chief.
5. The Permittee's sampling procedure shall follow the handling and chain of custody procedures designated by the certified laboratory which will undertake the analysis.
6. Water quality samples shall be analyzed by a laboratory certified by the Florida Department of Health utilizing the standards and methods applicable to the parameters analyzed and to the water use pursuant to Chapter 64E-1, Florida Administrative Code, "Certification of Environmental Testing Laboratories."
7. Analyses shall be performed according to procedures outlined in the current edition of Standard Methods for the Examination of Water and Wastewater by the American Public Health Association-American Water Works Association-Water Pollution Control Federation (APHA-AWWA-WPCF) or Methods for Chemical Analyses of Water and Wastes by the U.S. Environmental Protection Agency (EPA).
8. Unless other reporting arrangements have been approved by the Water Use Permit Bureau Chief, reports of the analyses shall be submitted to the Water Use Permit Bureau, online at the District WUP Portal or mailed in hardcopy on or before the fifteenth day of the following month. The online submittal shall include a scanned upload of the original laboratory report. The hardcopy submittal shall be a copy of the laboratory's analysis form. If for some reason, a sample cannot be taken when required, the Permittee shall indicate so and give the reason in the space for comments at the WUP Portal or shall submit the reason in writing on the regular due date .
9. The parameters and frequency of sampling and analysis may be modified by the District as necessary to ensure the protection of the resource.
10. Water quality samples shall be collected based on the following timetable for the frequency listed in the special condition:

Frequency	Timetable
Weekly	Same day of each week
Quarterly	Same week of **March, June, September, December**
Semi-annually	Same week of **May, November**
Monthly	Same week of each month

Authorized Signature
SOUTHWEST FLORIDA WATER MANAGEMENT DISTRICT

This permit, issued under the provision of Chapter 373, Florida Statues and Florida Administrative Code 40D-2, authorizes the Permittee to withdraw the quantities outlined above, and may require various activities to be performed by the Permittee as described in the permit, including the Special Conditions. The permit does not convey to the Permittee any property rights or privileges other than those specified herein, nor relieve the Permittee from complying with any applicable local government, state, or federal law, rule, or ordinance.

Exhibit C.1
Individual Withdrawal Locations

EXHIBIT C.1

Consolidated Permit Individual Withdrawal Wells				
Permittee ID No.	**District ID No.**	**Status**	**Latitude**	**Longitude**
COS1C	1	Active	280550.77	823550.41
COS3A	3	Active	280606.51	823528.31
COS5	5	Active	280620.94	823513.00
COS6A	6	Active	280629.45	823507.43
COS7A	7	Active	280641.58	823455.44
COS8	8	Active	280648.54	823447.59
COS9A	9	Active	280635.66	823501.50
COS10	10	Active	280651.99	823415.43
COS12A	11	Active	280711.53	823412.23
COS16	12	Active	280603.65	823502.16
COS18	13	Active	280603.47	823520.47
COS20	15	Active	280616.56	823529.28
COS21	16	Active	280623.06	823536.22
COS24	18	Active	280725.06	823421.79
COS25	19	Active	280731.90	823422.93
COS30	20	Active	280813.03	823430.05
COS31	21	Active	280819.89	823431.18
COS32	22	Active	280826.72	823432.72
COS34	23	Active	280839.65	823438.39
CBR1	28	Active	282115.96	822741.70
CBR2	29	Active	282135.72	822753.42
CBR3	30	Active	282144.52	822833.00
CBR4	31	Active	282155.59	822800.81
CBR5	32	Active	282223.67	822805.34
CBR6	33	Active	282246.83	822814.66
CBR7	34	Active	282234.34	822839.46
CBR8	35	Active	282308.03	822807.54
CBR9	36	Active	282325.03	822817.82
CBR10	37	Active	282342.38	822748.01
CBR11	38	Active	282352.56	822710.90
CBR12	39	Active	282354.48	822641.22
CBR13	40	Active	282413.90	822710.89
CBR14	41	Active	282417.58	822640.59
CBR15	42	Active	282416.38	822749.67
CBR16	43	Active	282442.48	822732.03
CBR17	44	Active	282441.87	822650.82
CY1	111	Active	281355.02	822304.29
CY2	112	Active	281336.91	822155.13
CY4	113	Active	281159.02	822128.78

EXHIBIT C.1

Consolidated Permit Individual Withdrawal Wells				
Permittee ID No.	**District ID No.**	**Status**	**Latitude**	**Longitude**
CY5	114	Active	281210.40	822240.96
CY6	115	Active	281053.79	822017.00
CY7	116	Active	281035.07	822115.65
CYB	117	Active	281010.74	822247.06
CY9	118	Active	281008.18	822205.95
CY10	119	Active	281012.60	822058.00
CY11	120	Active	281006.29	822009.35
CC1	194	Active	281828.06	822235.00
CC2	195	Active	281812.89	822243.12
CC3	196	Active	281803.54	822249.39
CC4	197	Active	281752.74	822257.69
CC5	198	Active	281742.95	822309.13
CC6	199	Active	281737.56	822326.12
CC7	200	Active	281726.09	822336.95
CC8	201	Active	281710.53	822340.64
CC9	202	Active	281651.05	822339.19
CC10	203	Active	281641.41	822400.40
CC11	204	Active	281802.29	822237.61
CC12	205	Active	281753.24	822221.75
CC13	206	Active	281747.54	822206.08
ELW8S	267	Active	280852.01	823922.92
ELW101	268	Active	281022.04	823933.99
ELW102	269	Active	281012.45	823933.62
ELW103	270	Active	281021.50	823923.23
ELW104	271	Active	281011.37	823924.08
ELW105	272	Active	281019.39	823917.24
ELW106	273	Active	281022.55	823905.22
ELW107	274	Active	281013.66	823905.11
ELW109	275	Active	281002.65	823915.63
ELW110	276	Active	280952.72	823915.01
ELW112	278	Active	280958.21	823904.80
ELW113	279	Active	280946.54	823904.75
ELW114	280	Active	280932.26	823915.51
ELW115	281	Active	280944.69	823926.42
ELW116	282	Active	280938.62	823922.27
ELW120	286	Active	280916.38	823903.88
ELW121	287	Active	280928.84	823904.84
ELW122	288	Active	280938.14	823905.10
ELW131	289	Active	281024.08	823853.53
ELW134	290	Active	281023.81	823841.20
ELW135	291	Active	281011.01	823841.85
ELW136	292	Active	281023.57	823831.35
ELW137	293	Active	281012.55	823831.46

EXHIBIT C.1

Consolidated Permit Individual Withdrawal Wells				
Permittee ID No.	**District ID No.**	**Status**	**Latitude**	**Longitude**
ELW138	294	Active	281001.96	823826.01
ELW139	295	Active	280951.09	823824.91
ELW140	296	Active	281023.65	823820.30
ELW141	297	Active	281010.74	823819.83
ELW142	298	Active	281013.13	823809.95
ELW9	306	Active	280912.75	823912.45
ELW10A	307	Active	280920.94	823910.52
ELW11A	308	Active	280903.10	823911.01
ELW12	309	Active	280855.32	823904.16
ELW13	310	Active	280845.47	823903.83
ELW1S	311	Active	280852.60	824003.78
MBR150	388	Active	280717.16	822109.11
MBR151	389	Active	280734.67	822103.93
MBR153	391	Active	280706.27	822023.96
MBR154	392	Active	280718.39	822006.00
MBR155	393	Active	280731.74	821945.50
MBR156	394	Active	280722.18	821925.88
MBR158	396	Active	280728.47	821846.34
MBR159	397	Active	280700.59	822052.66
MBR160	398	Active	280628.40	822059.65
MBR164	402	Active	280630.28	821931.35
MBR165	403	Active	280645.41	821924.98
MBR166	404	Active	280654.11	821900.04
MBR167	405	Active	280647.90	821817.42
MBR168	406	Active	280657.30	821835.67
MBR169	407	Active	280711.74	821818.30
NWHNW1	559	Active	280336.14	823508.53
NWHNW2	561	Active	280345.88	823431.31
NWHNW3	562	Active	280358.68	823327.13
NWHNW4	563	Active	280409.59	823228.21
NWHNW5	564	Active	280323.59	823234.31
NWHNW6	565	Active	280328.97	823157.06
NWHNW7	566	Active	280746.22	823207.73

EXHIBIT C.1

Consolidated Permit Individual Withdrawal Wells				
Permittee ID No.	**District ID No.**	**Status**	**Latitude**	**Longitude**
S212	641	Active	280709.27	823059.12
S2110	642	Active	280649.91	823011.15
S219	643	Active	280736.44	823021.53
S218	644	Active	280718.28	823011.07
S215	645	Active	280738.59	823033.62
S216	646	Active	280738.55	823020.18
SP41	653	Active	281024.55	823057.64
SP43	654	Active	281042.37	823043.02
SP44	655	Active	281046.25	823027.37
SP46	656	Active	281051.51	823100.22
SP47	657	Active	281106.54	823104.92
SP48	658	Active	281107.17	823119.06
SP49	659	Active	281118.50	823058.65
SP50	660	Active	281126.42	823037.42
STK3	669	Active	281501.29	823846.15
STK4	670	Active	281526.60	823810.61
STK6	671	Active	281507.57	823625.36
STK7	672	Active	281450.63	823616.99
STK8	673	Active	281503.84	823534.50
STK9	674	Active	281447.22	823542.98
STK10	675	Active	281456.54	823504.26
STK12	677	Active	281439.13	823424.74
STK13*	678	Standby	281439.67	823632.34
STK14*	679	Standby	281411.02	823652.76
STK15	680	Active	281448.13	823348.14

*Standby wells are kept in readiness to serve in substitution of or in combination with another well or group of wells.

Exhibit C.2
Water Quality Monitoring Sites

Quarterly Sampling Frequency

Water quality samples are to be collected prior to the last day of the month specified in each quarterly sampling period listed below. A minimum of 31 days must separate consecutive sampling events.

Water quality monitoring will be required immediately in accordance with the frequency defined upon activation of standby wells.

Cosme-Odessa Wellfield

Permittee ID No.	District ID No.	Parameters	Frequency/Month
COS1C	1	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
COS3A	3	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
COS7	5	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
COS6A	6	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
COS7A	7	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
COS8	8	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
COS9A	9	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
COS10	10	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
COS12A	11	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
COS16	12	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
COS18	13	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
COS20	15	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
COS21	16	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
COS24	18	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
COS25	19	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
COS30	20	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
COS31	21	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
COS32	22	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
COS34	23	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec

Cypress Creek Wellfield

Permittee ID No.	District ID No.	Parameters	Frequency/Month
CC1	194	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CC2	195	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CC3	196	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CC4	197	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CC5	198	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CC6	199	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CC7	200	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CC8	201	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CC9	202	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CC10	203	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CC11	204	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CC12	205	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CC13	206	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CCWQ1	234	Chlorides, Sulfates, TDS, Conductivity	Quarterly@830'/Mar, Jun, Sept, Dec

Eldridge-Wilde Wellfield Production Wells

Permittee ID No.	District ID No.	Parameters	Frequency/Month
ELW8S	267	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
ELW101	268	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
ELW102	269	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
ELW103	270	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
ELW104	271	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
ELW105	272	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
ELW106	273	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
ELW107	274	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
ELW109	275	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
ELW110	276	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
ELW112	278	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
ELW113	279	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
ELW114	280	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
ELW115	281	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
ELW116	282	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
ELW120	286	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
ELW121	287	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
ELW122	288	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
ELW131	289	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
ELW134	290	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
ELW135	291	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
ELW136	292	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
ELW137	293	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
ELW138	294	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
ELW139	295	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
ELW140	296	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
ELW141	297	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
ELW142	298	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
ELW9	306	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
ELW10A	307	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
ELW11A	308	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
ELW12	309	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
ELW13	310	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
ELW1S	311	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec

Eldridge-Wilde Wellfield Monitor Wells

Permittee ID No.	District ID No.	Parameters	Frequency/Month
ELW5N	263	Chlorides, Sulfates, TDS, Conductivity	Quarterly@328'/Mar, Jun, Sept, Dec
ELW5N	263	Chlorides, Sulfates, TDS, Conductivity	Quarterly@703'/Mar, Jun, Sept, Dec
ELW5N	263	Chlorides, Sulfates, TDS, Conductivity	Quarterly@778'/Mar, Jun, Sept, Dec
ELW111	277	Chlorides, Sulfates, TDS, Conductivity	Quarterly@663'/Mar, Jun, Sept, Dec
ELW111	277	Chlorides, Sulfates, TDS, Conductivity	Quarterly@769'/Mar, Jun, Sept, Dec
ELW118	284	Chlorides, Sulfates, TDS, Conductivity	Quarterly@767'/Mar, Jun, Sept, Dec
ELW2A	312	Chlorides, Sulfates, TDS, Conductivity	Quarterly@443'/Mar, Jun, Sept, Dec
ELWN1 DSH	319	Chlorides, Sulfates, TDS, Conductivity	Quarterly@680'/Mar, Jun, Sept, Dec
ELWN1 DDP	321	Chlorides, Sulfates, TDS, Conductivity	Quarterly@1085'/Mar, Jun, Sept, Dec
ELWSW I1D	325	Chlorides, Sulfates, TDS, Conductivity	Quarterly@730'/Mar, Jun, Sept, Dec
ELWSW I1S	326	Chlorides, Sulfates, TDS, Conductivity	Quarterly@530'/Mar, Jun, Sept, Dec
ELWSW I2D	327	Chlorides, Sulfates, TDS, Conductivity	Quarterly@730'/Mar, Jun, Sept, Dec
ELWSW I2D	327	Chlorides, Sulfates, TDS, Conductivity	Quarterly@760'/Mar, Jun, Sept, Dec
ELWSW I3S	329	Chlorides, Sulfates, TDS, Conductivity	Quarterly@490'/Mar, Jun, Sept, Dec
ELWSW I3S	329	Chlorides, Sulfates, TDS, Conductivity	Quarterly@535'/Mar, Jun, Sept, Dec
ELWSW I3D	330	Chlorides, Sulfates, TDS, Conductivity	Quarterly@590'/Mar, Jun, Sept, Dec
ELWSW I3D	330	Chlorides, Sulfates, TDS, Conductivity	Quarterly@620'/Mar, Jun, Sept, Dec
ELWSW I4D	331	Chlorides, Sulfates, TDS, Conductivity	Quarterly@715'/Mar, Jun, Sept, Dec
ELWSW I4D	331	Chlorides, Sulfates, TDS, Conductivity	Quarterly@750'/Mar, Jun, Sept, Dec
ELW201 M	332	Chlorides, Sulfates, TDS, Conductivity	Quarterly@680'/Mar, Jun, Sept, Dec
ELW202 M	333	Chlorides, Sulfates, TDS, Conductivity	Quarterly@650'/Mar, Jun, Sept, Dec
ELW202 M	333	Chlorides, Sulfates, TDS, Conductivity	Quarterly@710'/Mar, Jun, Sept, Dec
ELWSW I5S	334	Chlorides, Sulfates, TDS, Conductivity	Quarterly@770'/Mar, Jun, Sept, Dec
ELWSW I5D	335	Chlorides, Sulfates, TDS, Conductivity	Quarterly@840'/Mar, Jun, Sept, Dec
ELWSW I5D	335	Chlorides, Sulfates, TDS, Conductivity	Quarterly@910'/Mar, Jun, Sept, Dec
ELWSW I6S	336	Chlorides, Sulfates, TDS, Conductivity	Quarterly@570'/Mar, Jun, Sept, Dec
ELWSW I6S	336	Chlorides, Sulfates, TDS, Conductivity	Quarterly@600'/Mar, Jun, Sept, Dec
ELWSW I6D	337	Chlorides, Sulfates, TDS, Conductivity	Quarterly@650'/Mar, Jun, Sept, Dec
ELWSW I6D	337	Chlorides, Sulfates, TDS, Conductivity	Quarterly@700'/Mar, Jun, Sept, Dec
ELWSW I7D	338	Chlorides, Sulfates, TDS, Conductivity	Quarterly@690'/Mar, Jun, Sept, Dec
ELWSW I7D	338	Chlorides, Sulfates, TDS, Conductivity	Quarterly@730'/Mar, Jun, Sept, Dec
ELWSW I11D	367	Chlorides, Sulfates, TDS, Conductivity	Quarterly@890'/Mar, Jun, Sept, Dec
ELWUF 3	368	Chlorides, Sulfates, TDS, Conductivity	Quarterly@250'/Mar, Jun, Sept, Dec
ELW203 M	369	Chlorides, Sulfates, TDS, Conductivity	Quarterly@1230'/Mar, Jun, Sept, Dec

Permittee ID No.	District ID No.	Parameters	Frequency/Month
ELWUF 2	370	Chlorides, Sulfates, TDS, Conductivity	Quarterly@250'/Mar, Jun, Sept, Dec
ELWUF 2	370	Chlorides, Sulfates, TDS, Conductivity	Quarterly@390'/Mar, Jun, Sept, Dec
ELWSW I18S	371	Chlorides, Sulfates, TDS, Conductivity	Quarterly@600'/Mar, Jun, Sept, Dec
ELWSW I18D	372	Chlorides, Sulfates, TDS, Conductivity	Quarterly@710'/Mar, Jun, Sept, Dec
ELWSW I18D	372	Chlorides, Sulfates, TDS, Conductivity	Quarterly@770'/Mar, Jun, Sept, Dec
ELWSW I12D	373	Chlorides, Sulfates, TDS, Conductivity	Quarterly@715'/Mar, Jun, Sept, Dec
ELWSW I12D	373	Chlorides, Sulfates, TDS, Conductivity	Quarterly@740'/Mar, Jun, Sept, Dec
ELWSW I10S	374	Chlorides, Sulfates, TDS, Conductivity	Quarterly@665'/Mar, Jun, Sept, Dec
ELWSW I10D	375	Chlorides, Sulfates, TDS, Conductivity	Quarterly@870'/Mar, Jun, Sept, Dec
ELWUF 1	376	Chlorides, Sulfates, TDS, Conductivity	Quarterly@120'/Mar, Jun, Sept, Dec
ELWUF 1	376	Chlorides, Sulfates, TDS, Conductivity	Quarterly@400'/Mar, Jun, Sept, Dec
ELWUF 30	377	Chlorides, Sulfates, TDS, Conductivity	Quarterly@420'/Mar, Jun, Sept, Dec
ELWUF 30	377	Chlorides, Sulfates, TDS, Conductivity	Quarterly@470'/Mar, Jun, Sept, Dec
ELWUF 27	378	Chlorides, Sulfates, TDS, Conductivity	Quarterly@125'/Mar, Jun, Sept, Dec
ELWUF 27	378	Chlorides, Sulfates, TDS, Conductivity	Quarterly@310'/Mar, Jun, Sept, Dec
ELWM7	379	Chlorides, Sulfates, TDS, Conductivity	Quarterly@250'/Mar, Jun, Sept, Dec
ELWSW I8D	380	Chlorides, Sulfates, TDS, Conductivity	Quarterly@780'/Mar, Jun, Sept, Dec
ELWSW I15D	381	Chlorides, Sulfates, TDS, Conductivity	Quarterly@680'/Mar, Jun, Sept, Dec
ELWSW I15D	381	Chlorides, Sulfates, TDS, Conductivity	Quarterly@730'/Mar, Jun, Sept, Dec
ELWUF 18	382	Chlorides, Sulfates, TDS, Conductivity	Quarterly@100'/Mar, Jun, Sept, Dec
ELWUF 19	383	Chlorides, Sulfates, TDS, Conductivity	Quarterly@200'/Mar, Jun, Sept, Dec
ELWUF 19	383	Chlorides, Sulfates, TDS, Conductivity	Quarterly@260'/Mar, Jun, Sept, Dec
ELWUF 16	384	Chlorides, Sulfates, TDS, Conductivity	Quarterly@140'/Mar, Jun, Sept, Dec
ELWUF 16	384	Chlorides, Sulfates, TDS, Conductivity	Quarterly@340'/Mar, Jun, Sept, Dec
ELWUF 21	385	Chlorides, Sulfates, TDS, Conductivity	Quarterly@390'/Mar, Jun, Sept, Dec
ELWSW I17D	386	Chlorides, Sulfates, TDS, Conductivity	Quarterly@650'/Mar, Jun, Sept, Dec
ELWSW I17D	386	Chlorides, Sulfates, TDS, Conductivity	Quarterly@730'/Mar, Jun, Sept, Dec
ELWUF 26	387	Chlorides, Sulfates, TDS, Conductivity	Quarterly@350'/Mar, Jun, Sept, Dec
ELWUF 26	387	Chlorides, Sulfates, TDS, Conductivity	Quarterly@440'/Mar, Jun, Sept, Dec
ELWUF 28R	1974	Chlorides, Sulfates, TDS, Conductivity	Quarterly@490'/Mar, Jun, Sept, Dec

Morris Bridge Wellfield

Permittee ID No.	District ID No.	Parameters	Frequency/Month
MBR150	388	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
MBR151	389	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
MBR153	391	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
MBR154	392	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
MBR155	393	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
MBR156	394	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
MBR158	396	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
MBR159	397	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
MBR160	398	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
MBR164	402	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
MBR165	403	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
MBR166	404	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
MBR167	405	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
MBR168	406	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
MBR169	407	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
MBR3CDP	414	Chlorides, Sulfates, TDS, Conductivity	Quarterly @1000'/Mar, Jun, Sept, Dec

North Pasco Wellfield

Permittee ID No.	District ID No.	Parameters	Frequency/Month
NPMW2	617	Chlorides, Sulfates, TDS, Conductivity	Quarterly@830'/Mar, Jun, Sept, Dec
NPMW14D	626	Chlorides, Sulfates, TDS, Conductivity	Quarterly@630'/Mar, Jun, Sept, Dec

Section 21 Wellfield

Permittee ID No.	District ID No.	Parameters	Frequency/Month
S2110	642	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
S219	643	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
S218	644	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
S215	645	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
S216	646	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec

South Pasco Wellfield

Permittee ID No.	District ID No.	Parameters	Frequency/Month
SP41	653	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
SP43	654	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
SP44	655	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
SP46	656	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
SP47	657	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
SP48	658	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
SP49	659	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
SP50	660	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
SPE105	664	Chlorides, Sulfates, TDS, Conductivity	Quarterly@1330'/Mar, Jun, Sept, Dec

Starkey Wellfield

Permittee ID No.	District ID No.	Parameters	Frequency/Month
STK3	669	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
STK4	670	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
STK6	671	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
STK7	672	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
STK8	673	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
STK9	674	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
STK10	675	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
STK12	677	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
STK13*	678	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
STK14*	679	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
STK15	680	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
STKMW1C	702	Chlorides, Sulfates, TDS, Conductivity	Quarterly@890'/Mar, Jun, Sept, Dec
STKMW2B	703	Chlorides, Sulfates, TDS, Conductivity	Quarterly@620'/Mar, Jun, Sept, Dec
STKMW3C	708	Chlorides, Sulfates, TDS, Conductivity	Quarterly@890'/Mar, Jun, Sept, Dec
STKDP2C	716	Chlorides, Sulfates, TDS, Conductivity	Quarterly@650'/Mar, Jun, Sept, Dec
STKTR1621	719	Chlorides, Sulfates, TDS, Conductivity	Quarterly@80'/Mar, Jun, Sept, Dec
STKTR162E	719	Chlorides, Sulfates, TDS, Conductivity	Quarterly@360'/Mar, Jun, Sept, Dec

* Standby wells

Cypress Bridge Wellfield

Permittee ID No.	District ID No.	Parameters	Frequency/Month
CY1	111	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CY2	112	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CY4	113	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CY5	114	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CY6	115	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CY7	116	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CY8	117	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CY9	118	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CY10	119	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CY11	120	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CYWQ1	162	Chlorides, Sulfates, TDS, Conductivity	Quarterly@980'/Mar, Jun, Sept, Dec

Northwest Hillsborough Regional Wellfield

Permittee ID No.	District ID No.	Parameters	Frequency/Month
NWHNW1	559	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
NWHNW2	561	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
NWHNW3	562	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
NWHNW4	563	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
NWHNW5	564	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
NWHNW6	565	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
NWHNW7	566	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
NWHSRCL	570	Chlorides, Sulfates, TDS, Conductivity	Quarterly@970'/Mar, Jun, Sept, Dec
NWHRMP9D	589	Chlorides, Sulfates, TDS, Conductivity	Quarterly@725'/Mar, Jun, Sept, Dec
NWHRMP10	591	Chlorides, Sulfates, TDS, Conductivity	Quarterly@765'/Mar, Jun, Sept, Dec
NWHRMP13D	597	Chlorides, Sulfates, TDS, Conductivity	Quarterly@109'/Mar, Jun, Sept, Dec
NWHRMP15DA	601	Chlorides, Sulfates, TDS, Conductivity	Quarterly@104'/Mar, Jun, Sept, Dec
NWHRMP15D	601	Chlorides, Sulfates, TDS, Conductivity	Quarterly@164'/Mar, Jun, Sept, Dec
NWHRMP16D	603	Chlorides, Sulfates, TDS, Conductivity	Quarterly@330'/Mar, Jun, Sept, Dec
NWHRMP13PZ	607	Chlorides, Sulfates, TDS, Conductivity	Quarterly@614'/Mar, Jun, Sept, Dec
NWHRMP19D	609	Chlorides, Sulfates, TDS, Conductivity	Quarterly@680'/Mar, Jun, Sept, Dec
NWHRMP1D	757	Chlorides, Sulfates, TDS, Conductivity	Quarterly@470'/Mar, Jun, Sept, Dec
NWHSWMW1D	758	Chlorides, Sulfates, TDS, Conductivity	Quarterly@903'/Mar, Jun, Sept, Dec
NWHSWMW3D	759	Chlorides, Sulfates, TDS, Conductivity	Quarterly@905'/Mar, Jun, Sept, Dec
NWHSWMW4D	760	Chlorides, Sulfates, TDS, Conductivity	Quarterly@425'/Mar, Jun, Sept, Dec
NWHSWMW5D	1637	Chlorides, Sulfates, TDS, Conductivity	Quarterly@1045'/Mar, Jun, Sept, Dec

Cross-Bar Wellfield

Permittee ID No.	District ID No.	Parameters	Frequency/Month
CBR1	28	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CBR2	29	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CBR3	30	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CBR4	31	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CBR5	32	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CBR6	33	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CBR7	34	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CBR8	35	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CBR9	36	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CBR10	37	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CBR11	38	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CBR12	39	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CBR13	40	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CBR14	41	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CBR15	42	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CBR16	43	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec
CBR17	44	Chlorides, Sulfates, Conductivity	Quarterly/Mar, Jun, Sept, Dec

Exhibit C.3
Aquifer Level Monitoring Sites

Eldridge Wilde Wellfield

Permittee ID No.	District ID No.	Aquifer	Frequency	Program
ELWNIDSH	319	Floridan	Twice Monthly	
ELWNIDDP	321	Floridan	Twice Monthly	
ELWSWI1D	325	Floridan	Twice Monthly	
ELWSWI1S	326	Floridan	Twice Monthly	
ELWSWI2D	327	Floridan	Twice Monthly	
ELWSWI2S	328	Floridan	Twice Monthly	
ELWSWI3S	329	Floridan	Twice Monthly	
ELWSWI3D	330	Floridan	Twice Monthly	
ELWSWI4D	331	Floridan	Twice Monthly	
ELW201M	332	Floridan	Twice Monthly	
ELW202M	333	Floridan	Twice Monthly	
ELWSWI5S	334	Floridan	Twice Monthly	
ELWSWI5D	335	Floridan	Twice Monthly	
ELWSWI6S	336	Floridan	Twice Monthly	
ELWSWI6D	337	Floridan	Twice Monthly	
ELWSWI7D	338	Floridan	Twice Monthly	
ELWEWMW2SH	339	Surficial	Twice Monthly	
ELWEWMW2DP	340	Floridan	Twice Monthly	
ELWEWMW7SH	341	Surficial	Twice Monthly	
ELWEWMW7DP	342	Floridan	Twice Monthly	
ELWGJ4	343	Surficial	Twice Monthly	
ELWSM1	351	Surficial	Twice Monthly	
ELWSM3	352	Surficial	Twice Monthly	
ELWSM4	353	Surficial	Twice Monthly	
ELWSM5	354	Surficial	Twice Monthly	
ELWSM6	355	Surficial	Twice Monthly	
ELW11SAR	1625	Surficial	Continuous	OROP
ELWSM12	357	Surficial	Twice Monthly	
ELWSM13	358	Surficial	Twice Monthly	
ELWSM14	359	Surficial	Twice Monthly	
ELWSM15SAR	1626	Surficial	Continuous	OROP
ELWSM19	361	Surficial	Twice Monthly	
ELWSM20	362	Surficial	Twice Monthly	
ELW118	284	Floridan	Twice Monthly	
ELWSM24	364	Surficial	Twice Monthly	
ELWSM28SAR	1627	Surficial	Continuous	OROP
ELWSWI11D	367	Floridan	Twice Monthly	
ELWUF3	368	Floridan	Twice Monthly	
ELW203M	369	Floridan	Twice Monthly	
ELWUF2	370	Floridan	Twice Monthly	
ELWSWI18S	371	Floridan	Twice Monthly	
ELWSWI18D	372	Floridan	Twice Monthly	
ELWSWI12D	373	Floridan	Twice Monthly	
ELWSWI10S	374	Floridan	Twice Monthly	
ELWSWI10D	375	Floridan	Twice Monthly	
ELWUF1	376	Floridan	Twice Monthly	
ELWUS30	377	Floridan	Twice Monthly	
ELWUS27	378	Floridan	Twice Monthly	
ELWM7	379	Floridan	Twice Monthly	
ELWSWI8D	380	Floridan	Twice Monthly	
ELWSWI15D	381	Floridan	Twice Monthly	
ELWUF18	382	Floridan	Twice Monthly	
ELWUF19	383	Floridan	Twice Monthly	
ELWUF16	384	Floridan	Twice Monthly	
ELWUF21	385	Floridan	Twice Monthly	
ELWSWI17D	386	Floridan	Twice Monthly	
ELWUF26	387	Floridan	Twice Monthly	
ELWUF28R	1974	Floridan	Twice Monthly	

Morris Bridge Wellfield

Permittee ID No.	District ID No.	Aquifer	Frequency	Program
MBR2DP	411	Floridan	Twice Monthly	
MBR3ADP	412	Floridan	Continuous	SWFWMD*
MBR3CDP	414	Floridan	Continuous	SWFWMD*
MBR2SHSAR	1623	Surficial	Continuous	OROP
MBR10DP	432	Floridan	Twice Monthly	SWFWMD*
MBR11DP	433	Floridan	Continuous	
MBR13DP	436	Floridan	Continuous	
MBR17DP	440	Floridan	Twice Monthly	
MBR537DP	446	Floridan	Continuous	SWFWMD*
MBR537SH	467	Surficial	Continuous	OROP
MBR9DP	468	Floridan	Twice Monthly	
MBR9SH	469	Surficial	Twice Monthly	
MBR516DP	470	Floridan	Twice Monthly	
MBR516SH	471	Surficial	Twice Monthly	
MBR17SH	472	Surficial	Twice Monthly	
MBR18SH	473	Surficial	Twice Monthly	
MBR20SH	475	Surficial	Twice Monthly	
MBR21SH	476	Surficial	Twice Monthly	
MBR22SH	477	Surficial	Twice Monthly	
MBR23SH	478	Surficial	Continuous	OROP
MBR24SH	479	Surficial	Continuous	OROP
MBR25SH	480	Surficial	Twice Monthly	
MBR27SH	481	Surficial	Twice Monthly	
MBR3aSH	483	Surficial	Continuous	SWFWMD*
MBR11SH	484	Surficial	Continuous	
MBR13SH	485	Surficial	Continuous	SWFWMD*
MBRSGW1SAR	1624	Surficial	Continuous	OROP
MBR12SAR	1868	Surficial	Twice Monthly	
MBR2SAR	1869	Surficial	Twice Monthly	

Northwest Hillsborough Regional Wellfield

Permittee ID No.	District ID No.	Aquifer	Frequency	Program
NWHSRM1	571	Floridan	Continuous	
NWHRMP1D	572	Floridan	Continuous	SWFWMD*
NWHRMP1S	573	Surficial	Continuous	SWFWMD*
NWFSRCL	570	Floridan	Continuous	
NWHRMP3D	576	Floridan	Continuous	SWFWMD*
NWHRMP3S	577	Surficial	Continuous	SWFWMD*
NWHRMP5D	580	Floridan	Continuous	SWFWMD*
NWHRMP5S	581	Surficial	Continuous	SWFWMD*
NWHRMP19D	609	Floridan	Continuous	
NWHRMP6S	583	Surficial	Twice Monthly	
NWHRMP7D	584	Floridan	Continuous	SWFWMD*
NWHRMP7S	585	Surficial	Continuous	
NWHRMP8D	586	Floridan	Continuous	SWFWMD*
NWHRMP8PZ	587	Floridan	Continuous	
NWHRMP8S	588	Surficial	Continuous	OROP/SWFWMD*
NWHRMP9S	590	Surficial	Twice Monthly	SWFWMD*
NWHRMP13D	597	Floridan	Continuous	SWFWMD*
NWHRMP13S	598	Surficial	Continuous	OROP
NWHRMP15D	601	Floridan	Continuous	
NWHRMP15S	602	Surficial	Twice Monthly	
NWHRMP16S	604	Surficial	Twice Monthly	SWFWMD*
NWHRMP18D	606	Floridan	Continuous	
NWHRMP13PZ	607	Floridan	Continuous	SWFWMD*
NWHSWMW1D	757	Floridan	Twice Monthly	
NWHSWMW1S	771	Surficial	Twice Monthly	
NWHSWMW2D	758	Floridan	Twice Monthly	
NWHSWMW2S	772	Surficial	Twice Monthly	
NWHSWMW3D	759	Floridan	Twice Monthly	
NWHSWMW3S	773	Surficial	Twice Monthly	
NWHSWMW4D	760	Floridan	Twice Monthly	
NWHSWMW5S	1636	Surficial	Twice Monthly	
NWHSWMW5D	1637	Floridan	Twice Monthly	

Cypress Creek Wellfield

Permittee ID No.	District ID No.	Aquifer	Frequency	Program
CCTB9	219	Surficial	Twice Monthly	
CC829D	224	Floridan	Twice Monthly	
CC829S	220	Surficial	Twice Monthly	
CCPD9	227	Surficial	Twice Monthly	
CC826D	223	Floridan	Twice Monthly	
CC831D	226	Floridan	Twice Monthly	
CYCT2DSAR	1854	Surficial	Twice Monthly	
CCSR2	213	Surficial	Twice Monthly	
CCSR3	214	Surficial	Twice Monthly	
CCTB22SAR	1639	Surficial	Continuous	OROP
CCSR5	216	Surficial	Twice Monthly	
CCSR4	217	Surficial	Twice Monthly	
CYC821SAR	1848	Surficial	Twice Monthly	
CYC824SAR	1849	Surficial	Twice Monthly	
CC826S	237	Surficial	Twice Monthly	
CYC827SAR	1850	Surficial	Twice Monthly	
CC831S	239	Surficial	Twice Monthly	
CYCE106SAR	1851	Surficial	Twice Monthly	
CCE107S	241	Surficial	Twice Monthly	
CCHR2S	243	Surficial	Twice Monthly	
CCMW24S	245	Surficial	Twice Monthly	
CYCPF1SAR	1852	Surficial	Twice Monthly	
CYCPF2SAR	1853	Surficial	Twice Monthly	
CYCTB10SAR	1855	Surficial	Twice Monthly	
CYCTB13SAR	1856	Surficial	Twice Monthly	
CCTB14S	252	Surficial	Twice Monthly	
CYCVF1SAR	1857	Surficial	Twice Monthly	
CC821D	259	Floridan	Twice Monthly	
CCE107D	258	Floridan	Continuous	
CCMW24D	260	Floridan	Continuous	
CCWQ1	234	Floridan	Continuous	
CYC-TMR-3SAR	1694	Surficial	Continuous	
CYC-TMR-4SAR	1695	Surficial	Continuous	
CYC-W56B	1895	Surficial	Continuous	OROP
CYC-EHRENS-D	2051	Floridan	Continuous	
CYC-EHRENS-S	2052	Surficial	Continuous	

Cross Bar Wellfield

Permittee ID No.	District ID No.	Aquifer	Frequency	Program
CBRNRWD	52	Floridan	Continuous	
CBRNERWD	57	Floridan	Continuous	
CBRSERWD	50	Floridan	Continuous	
CBRSERWS	49	Surficial	Continuous	OROP/SWFWMD*
CBRSRWD	55	Floridan	Continuous	
CBRSRWS	54	Floridan	Continuous	OROP
CBRWRWD	48	Floridan	Continuous	
CBRB1	46	Floridan	Twice Monthly	
CBRB2D	92	Floridan	Continuous	
CBRC1D	94	Floridan	Twice Monthly	
CBRNWO2D	82	Floridan	Twice Monthly	
CBRNOW2D	83	Floridan	Twice Monthly	
CBRA1D	85	Surficial	Continuous	
CBRA1SR	1632	Surficial	Continuous	OROP
CBR1SWD	96	Floridan	Continuous	SWFWMD*
CBR1SWS	97	Surficial	Continuous	SWFWMD*
CBR1NED	98	Floridan	Continuous	SWFWMD*
CBR1NES	99	Surficial	Continuous	
CBR2ED	100	Floridan	Continuous	SWFWMD*
CBR2ES	101	Surficial	Continuous	
CBRCBM1	102	Surficial	Twice Monthly	
CBRCBM2	103	Surficial	Twice Monthly	
CBRCBM4	105	Surficial	Twice Monthly	
CBRB2SAR	1860	Surficial	Twice Monthly	
CBRC1SAR	1861	Surficial	Twice Monthly	
CBRCBM3-SAR2	1862	Surficial	Twice Monthly	
CBRNERWSAR	1863	Surficial	Continuous	
CBRNOW2SAR	1864	Surficial	Twice Monthly	
CBRNRWSAR	1865	Surficial	Continuous	
CBRS1SAR	1866	Surficial	Continuous	
CBRWRWSAR	1867	Surficial	Continuous	

Cypress Bridge Wellfield

Permittee ID No.	District ID No.	Aquifer	Frequency	Program
CYWT5500AR	1697	Surficial	Continuous	
CYFL5500R	1698	Floridan	Continuous	
CYFL51950	123	Floridan	Continuous	
CYFL21000	124	Floridan	Continuous	
CYWT21000	125	Surficial	Continuous	
CYFL7200	126	Surficial	Continuous	
CYWQ1	162	Floridan	Twice Monthly	
CYFL55000	163	Floridan	Continuous	
CYWT240	164	Surficial	Twice Monthly	
CYWT2500	165	Surficial	Continuous	OROP
CYWT5200	172	Surficial	Continuous	OROP
CYWT51950	173	Surficial	Continuous	
CYWT52900A	1635	Surficial	Twice Monthly	
CYWT55000	175	Surficial	Continuous	
CYWT72000	176	Surficial	Continuous	
CYWT9100	177	Surficial	Continuous	
CYWT9500	178	Surficial	Continuous	OROP
CYX2FL	182	Floridan	Continuous	
CYX2WT	183	Surficial	Continuous	
CYX3AP	184	Floridan	Continuous	
CYX3SUW	185	Floridan	Continuous	SWFWMD*
CYX3WT	186	Surficial	Continuous	
CYX4FL	187	Floridan	Continuous	
CYX4WT	188	Surficial	Continuous	
CYPEBCRK	193	Floridan	Twice Monthly	

Starkey Wellfield

Permittee ID No.	District ID No.	Aquifer	Frequency	Program
STKEMW1	681	Surficial	Twice Monthly	
STKEMW3	683	Surficial	Twice Monthly	
STKEMW4SAR	1841	Surficial	Twice Monthly	
STKEMW5	685	Surficial	Twice Monthly	
STKEMW6SAR	1842	Surficial	Twice Monthly	
STKEMW7SAR	1843	Surficial	Twice Monthly	
STKEMW8SAR	1844	Surficial	Continuous	OROP
STKEMW9	689	Surficial	Twice Monthly	
STKEMW10	690	Surficial	Continuous	
STKEMW11SAR	1846	Surficial	Twice Monthly	
STKEMW13	692	Surficial	Twice Monthly	
STKEMW14	693	Surficial	Twice Monthly	
STKEMW15	694	Surficial	Twice Monthly	
STKEMW8ASAR	1845	Surficial	Twice Monthly	
STKWT15	697	Surficial	Continuous	OROP
STKSTARKEY10	698	Floridan	Continuous	
STKSTARKEY20	699	Surficial	Continuous	OROP
STKPZ1	700	Floridan	Continuous	
STKPZ3	701	Floridan	Continuous	
STKMW1	702	Floridan	Twice Monthly	
STKMW2	703	Floridan	Twice Monthly	
STKEMW12SAR	1847	Surficial	Twice Monthly	
STKMW3A	708	Floridan	Continuous	
STKPZ4D	721	Floridan	Continuous	SWFWMD*
STKPZ5D	722	Floridan	Continuous	SWFWMD*
STKEMW16S	723	Surficial	Continuous	OROP
STK731S	724	Surficial	Twice Monthly	
STKBEX1S	725	Surficial	Continuous	

North Pasco Wellfield

Permittee ID No.	District ID No.	Aquifer	Frequency	Program
NPMW1	616	Floridan	Continuous	
NPMW2	617	Floridan	Twice Monthly	
NPMW3	620	Floridan	Twice Monthly	
NPMW4	621	Surficial	Twice Monthly	
NPMW5	622	Surficial	Continuous	
NPMW6	623	Surficial	Twice Monthly	
NPMW7D	627	Floridan	Continuous	
NPMW7S	628	Surficial	Continuous	OROP
NPMW8S	629	Surficial	Continuous	OROP
NPMW9S	630	Surficial	Continuous	OROP
NPMW10D	631	Floridan	Continuous	
NPMW10S	632	Surficial	Continuous	
NPMW11D	633	Floridan	Continuous	
NPMW11S	634	Surficial	Continuous	
NPMW12D	635	Floridan	Continuous	
NPMW12S	636	Surficial	Continuous	
NPMW13D	637	Floridan	Continuous	
NPMW13S	638	Surficial	Continuous	

Cosme-Odessa Wellfield

Permittee ID No.	District ID No.	Aquifer	Frequency	Program
COSJAMES10	763	Surficial	Continuous	SWFWMD/OROP*
COS20S	1638	Surficial	Continuous	OROP
COSKETST36SAR	1858	Surficial	Continuous	OROP

Section 21 Wellfield

Permittee ID No.	District ID No.	Aquifer	Frequency	Program
S21HILL13SR	1628	Surficial	Continuous	OROP
S21JACK26ASR	1629	Surficial	Continuous	OROP
S21LUTZP40SAR	1859	Surficial	Continuous	OROP

South Pasco Wellfield

Permittee ID No.	District ID No.	Aquifer	Frequency	Program
SPHARRYMSAR2	768	Surficial	Continuous	OROP
SPNORTHSHR	1634	Surficial	Continuous	OROP
SP47SR	1633	Surficial	Continuous	OROP

*Data will be collected by the District at these sites but shall be incorporated into annual reports and hydrogeologic analyses by the Permittee. Monthly submittal of these data by the Permittee to the District is not required, except in the event that the District ceases collection of data at these sites, at which time the Permittee shall commence collection of this data and monthly submittal to the District.

Exhibit C.4
Ecological Monitoring Sites

Wellfield Code	Wetland ID	District ID	Permittee Name	Monitor Type	Frequency	Latitude	Longitude
COS	103	1702	SG-COS-102717-CG	Surface Water	Twice Monthly	28.15741116	-82.59782005
		1703	WE-COS-102717-CW2	Well	Twice Monthly	28.15765445	-82.59798017
		N/A	TR-COS-102717	Transect	Annually		
COS	104	1719	SG-COS-162717-CG	Surface Water	Twice Monthly	28.13104048	-82.61595602
		1720	WE-COS-162717-CW2	Well	Twice Monthly	28.13105192	-82.61596271
		N/A	TR-COS-162717	Transect	Annually		
COS	105	1727	SG-COS-C042817-CG	Surface Water	Twice Monthly	28.07644469	-82.6054248
		1728	WE-COS-C042817-CW2	Well	Twice Monthly	28.0764679	-82.60534445
		1729	WE-COS-C042817-UW	Well	Twice Monthly	28.07627889	-82.60597707
		N/A	TW-COS-C042817	Transect	Annually		
COS	106	1704	SG-COS-C142717-CG	Surface Water	Twice Monthly	28.13603236	-82.57651821
		1705	WE-COS-C142717-CW2	Well	Twice Monthly	28.13603425	-82.57651113
		1706	WE-COS-C142717-UW	Well	Twice Monthly	28.1360042	-82.57710785
		N/A	TR-COS-C142717	Transect	Annually		
COS	107	1721	SG-COS-EC222717-CG	Surface Water	Twice Monthly	28.12127102	-82.58894065
		1722	WE-COS-EC222717-CW2	Well	Twice Monthly	28.12127166	-82.58894963
		N/A	TR-COS-EC222717	Transect	Annually		
COS	108	1712	SG-COS-EC332717-CG	Surface Water	Twice Monthly	28.09250818	-82.60009857
		1713	WE-COS-EC332717-CW2	Well	Twice Monthly	28.09253016	-82.60010817
		N/A	TR-COS-EC332717	Transect	Annually		
COS	110	1707	SG-COS-NC262717-CG	Surface Water	Twice Monthly	28.11385678	-82.57221319
		1708	WE-COS-NC262717-CW2	Well	Twice Monthly	28.11388783	-82.5723124
		2064	SG-COS-NC262717-EG	Surface Water	Twice Monthly	28.11405425	-82.57243917
		N/A	TR-COS-NC262717	Transect	Annually		
COS	112	1714	SG-COS-NW332717-CG2	Surface Water	Twice Monthly	28.09412723	-82.61281872
		1715	WE-COS-NW332717-CW2	Well	Twice Monthly	28.09413234	-82.61281962
		N/A	TR-COS-NW332717	Transect	Annually		
COS	1842	3088	SG-COS-RAMBLEWOOD-CG	Surface Water	Twice Monthly	28.1326217	-82.55785925
		3094	WE-COS-RAMBLEWOOD-CW	Well	Twice Monthly	28.13261108	-82.5578506
		3095	WE-COS-RAMBLEWOOD-UW	Well	Twice Monthly	28.13280541	-82.55815993
		N/A	TR-COS-RAMBLEWOOD	Transect	Annually		

Wellfield Code	Wetland ID	District ID	Permittee Name	Monitor Type	Frequency	Latitude	Longitude
COS	114	1725	SG-COS-SC332717-CG2	Surface Water	Twice Monthly	28.08543227	-82.60950053
		1726	WE-COS-SC332717-CW2	Well	Twice Monthly	28.08542325	-82.60951733
		N/A	TR-COS-SC332717	Transect	Annually		
COS	116	1716	SG-COS-SE142717-CG	Surface Water	Twice Monthly	28.12921598	-82.57047945
		1717	WE-COS-SE142717-CW2	Well	Twice Monthly	28.129245	-82.5704919
		1718	WE-COS-SE142717-UW	Well	Twice Monthly	28.12917213	-82.5711038
		N/A	TR-COS-SE142717	Transect	Annually		
COS	118	1710	SG-COS-W272717-CG2	Surface Water	Twice Monthly	28.10163462	-82.59482433
		2065	SG-COS-W272717-EG2	Surface Water	Twice Monthly	28.10227299	-82.59480504
		3096	SG-COS-W272717-EG3	Surface Water	Twice Monthly	28.10223610	-82.5947250
		N/A	TR-COS-W272717	Transect	Annually		
COS		3121	SG-COS-CHURCH-CG1	Surface Water	Daily	28.1005580	-82.5953440
CBR	1	N/A	TR-CBR-Q01	Transect	Annually		
CBR	2	2053	SG-CBR-Q02-CG	Surface Water	Twice Monthly	28.35315672	-82.47663762
		1901	WE-CBR-Q02-CW	Well	Twice Monthly	28.3532045	-82.47645713
		N/A	TR-CBR-Q02	Transect	Annually		
CBR	3	1177	SG-CBR-Q03-CG	Surface Water	Twice Monthly	28.36271343	-82.47764477
		1216	WE-CBR-Q03-CW	Well	Twice Monthly	28.36208811	-82.47784761
CBR	4	1178	SG-CBR-Q04-CG2	Surface Water	Twice Monthly	28.36637357	-82.46737659
		N/A	TR-CBR-Q04/Duck Pond Marsh	Transect	Annually		
CBR	5	1179	SG-CBR-Q05-CG	Surface Water	Twice Monthly	28.37325463	-82.46964546
		1903	WE-CBR-Q05-CW2	Well	Twice Monthly	28.3732567	-82.46965138
		1219	WE-CBR-Q05-UW	Well	Twice Monthly	28.37400238	-82.46866307
		N/A	TR-CBR-Q05	Transect	Annually		
CBR	6	1180	SG-CBR-Q06-CG	Surface Water	Twice Monthly	28.38386233	-82.45430461
		1905	WE-CBR-Q06-CW	Well	Twice Monthly	28.38393102	-82.45426913
		1221	WE-CBR-Q06-UW	Well	Twice Monthly	28.38396982	-82.45422322
		N/A	TR-CBR-Q06	Transect	Annually		
CBR	7	1181	SG-CBR-Q07-CG	Surface Water	Twice Monthly	28.37922737	-82.48148758
		1907	WE-CBR-Q07-CW2	Well	Twice Monthly	28.37923271	-82.48148586
		2054	SG-CBR-Q07-EG	Surface Water	Twice Monthly	28.3792906	-82.48049725
		N/A	TR-CBR-Q07	Transect	Annually		

Wellfield Code	Wetland ID	District ID	Permittee Name	Monitor Type	Frequency	Latitude	Longitude
CBR	8	1182	SG-CBR-Q-08CG2	Surface Water	Twice Monthly	28.37492976	-82.48751744
		1224	WE-CBR-Q08-CW	Well	Twice Monthly	28.37490258	-82.48752214
		2055	SG-CBR-Q08-EG	Surface Water	Twice Monthly	28.37484482	-82.48855497
		1225	WE-CBR-Q08-UW	Well	Twice Monthly	28.37473999	-82.4874246
		N/A	TR-CBR-Q08	Transect	Annually		
CBR	9	1183	SG-CBR-Q10-CG	Surface Water	Twice Monthly	28.3521516	-82.49534601
		1910	WE-CBR-Q10-CW	Well	Twice Monthly	28.35215608	-82.49535394
		1911	WE-CBR-Q10-UW	Well	Twice Monthly	28.35188642	-82.49560077
		N/A	TR-CBR-Q10	Transect	Annually		
CBR	11	1185	SG-CBR-Q14-CG	Surface Water	Twice Monthly	28.3402117	-82.41727675
		1230	WE-CBR-Q14-CW	Well	Twice Monthly	28.34022008	-82.41727987
		1912	WE-CBR-Q14-UW	Well	Twice Monthly	28.34091225	-82.41787402
		N/A	TR-CBR-Q14	Transect	Annually		
CBR	12	1186	SG-CBR-Q15-CG	Surface Water	Twice Monthly	28.34964543	-82.42998686
		1913	WE-CBR-Q15-CW	Well	Twice Monthly	28.34964055	-82.42999228
		1233	WE-CBR-Q15-UW	Well	Twice Monthly	28.3492491	-82.42957612
		N/A	TR-CBR-Q15	Transect	Annually		
CBR	13	1187	SG-CBR-Q16-CG	Surface Water	Twice Monthly	28.37749996	-82.44748278
		1915	WE-CBR-Q16-CW	Well	Twice Monthly	28.37761256	-82.44765736
		2056	SG-CBR-Q16-EG	Surface Water	Twice Monthly	28.37749996	-82.44748278
		1234	WE-CBR-Q16-UW	Well	Twice Monthly	28.37749221	-82.44748871
		N/A	TR-CBR-Q16	Transect	Annually		
CBR	14	1188	SG-CBR-Q17-CG	Surface Water	Twice Monthly	28.38380361	-82.427937
		1236	WE-CBR-Q17-CW	Well	Twice Monthly	28.38277711	-82.42777711
		3082	SG-CBR-Q17-EG	Surface Water	Twice Monthly	28.38349098	-82.4279434
		N/A	TR-CBR-Q17	Transect	Annually		
CBR	17	1916	WE-CBR-Q20-UW	Well	Twice Monthly	28.35610096	-82.50022459
		3060	SG-CBR-Q20-CG2	Surface Water	Twice Monthly	28.35614935	-82.50054224
		N/A	TR-CBR-Q20	Transect	Annually		
CBR	18	1192	SG-CBR-Q21-CG	Surface Water	Twice Monthly	28.40939368	-82.46420519
		1917	WE-CBR-Q21-UW	Well	Twice Monthly	28.40965325	-82.46454138
		N/A	TR-CBR-Q21	Transect	Annually		

Wellfield Code	Wetland ID	District ID	Permittee Name	Monitor Type	Frequency	Latitude	Longitude
CBR	23	1196	SG-CBR-Q26-CG	Surface Water	Twice Monthly	28.36285455	-82.4950853
		1243	WE-CBR-Q26	Well	Twice Monthly	28.36285863	-82.495084
		3097	WE-CBR-Q26-UW	Well	Twice Monthly	28.36295226	-82.49528351
		3098	SG-CBR-Q26-EG	Surface Water	Twice Monthly	28.36289751	-82.49521396
		N/A	TR-CBR-Q26	Transect	Annually		
CBR	31	2060	SG-CBR-Q31-CG	Surface Water	Twice Monthly	28.42957022	-82.38587529
		2061	SG-CBR-Q31-EG	Surface Water	Twice Monthly	28.42947015	-82.38589843
CBR	32	1204	SG-CBR-Q35-CG	Surface Water	Twice Monthly	28.38491675	-82.48788774
		1246	WE-CBR-Q35-CW	Well	Twice Monthly	28.38493165	-82.48789037
		3099	SG-CBR-Q35-EG	Surface Water	Twice Monthly	28.38526984	-82.48806494
CBR	33	1205	SG-CBR-Q36-CG	Surface Water	Twice Monthly	28.37977754	-82.46882042
		1247	WE-CBR-Q36_CW	Well	Twice Monthly	28.37978353	-82.46882067
CBR	34	1206	SG-CBR-T01-CG	Surface Water	Twice Monthly	28.38149186	-82.46443416
		1248	WE-CBR-T01-I_CW	Well	Twice Monthly	28.38149677	-82.46443083
		N/A	TR-CBR-T01	Transect	Annually		
CBR	35	1207	SG-CBR-T02A-CG	Surface Water	Twice Monthly	28.36503039	-82.43686466
		1249	WE-CBR-T02A-CW	Well	Twice Monthly	28.36514924	-82.43561533
		1926	WE-CBR-T02A-UW	Well	Twice Monthly	28.36627525	-82.43758703
		N/A	TR-CBR-T02A	Transect	Annually		
CBR	37	1209	SG-CBR-T04-CG	Surface Water	Twice Monthly	28.35511426	-82.46852638
		1253	WE-CBR-T04-CW	Well	Twice Monthly	28.35797341	-82.46733641
		1252	WE-CBR-T04-UW	Well	Twice Monthly	28.35741725	-82.46657367
		N/A	TR-CBR-T04	Transect	Annually		
CBR	38	1210	SG-CBR-T08A-CG	Surface Water	Twice Monthly	28.37079329	-82.48008768
		1255	WE-CBR-T08A-CW	Well	Twice Monthly	28.37070444	-82.48004953
		1254	WE-CBR-T08A-UW	Well	Twice Monthly	28.37201918	-82.47978173
		N/A	TR-CBR-T08A	Transect	Annually		
CBR	39	1212	SG-CBR-T10-CG	Surface Water	Twice Monthly	28.33916493	-82.42232548
		2062	WE-CBR-T10-CW2	Well	Twice Monthly	28.33917853	-82.4222000
		1928	WE-CBR-T10-UW	Well	Twice Monthly	28.33968431	-82.42213778
		N/A	TR-CBR-T10	Transect	Annually		

Wellfield Code	Wetland ID	District ID	Permittee Name	Monitor Type	Frequency	Latitude	Longitude
CBR	542	3055	SG-CBR-LOST LAKE	Surface Water	Twice Monthly	28.37608882	-82.45683548
CBR	543	3056	SG-CBR-STAFF14-SPRING LAKE	Surface Water	Twice Monthly	28.35850101	-82.48514455
CBR	544	3057	SG-CBR-CROSSBAR-6	Surface Water	Twice Monthly	28.37633878	-82.47814011
CBR		3058	SG-CBR-CROSSBAR-8	Surface Water	Twice Monthly	28.3858987	-82.46803571
		3122	SG-CBR-CROSSBAR-8-EG2	Surface Water	Twice Monthly	28.38601894	-82.4684485
CYB	121	1261	SG-CYB-01-CG3	Surface Water	Twice Monthly	28.2221785	-82.36863019
		2077	WE-CYB-01-CW	Well	Twice Monthly	28.22214953	-82.36855467
		N/A	TR-CYB-01	Transect	Annually		
CYB	122	1262	SG-CYB-02-CG	Surface Water	Twice Monthly	28.22550871	-82.36770568
		2078	WE-CYB-02-CW	Well	Twice Monthly	28.22550039	-82.36770362
		N/A	TR-CYB-02	Transect	Annually		
CYB	123	1263	SG-CYB-03-CG	Surface Water	Twice Monthly	28.22705838	-82.3648781
		1301	WE-CYB-03-CW	Well	Twice Monthly	28.22705332	-82.36487552
		N/A	TR-CYB-03	Transect	Annually		
CYB	124	N/A	TR-CYB-4	Transect	Annually		
CYB	125	1265	SG-CYB-05-CG	Surface Water	Twice Monthly	28.23355221	82.36289741
		1303	WE-CYB-05-CW	Well	Twice Monthly	28.23354297	-82.3628886
		2079	SG-CYB-05-EG	Surface Water	Twice Monthly	28.23329965	-82.36252516
CYB	126	1266	SG-CYB-06-CG	Surface Water	Twice Monthly	28.20078805	-82.35435686
		1304	WE-CYB-06-CW	Well	Twice Monthly	28.20079462	-82.35439231
		N/A	TR-CYB-06	Transect	Annually		
CYB	127	2080	SG-CYB-09-CG	Surface Water	Twice Monthly	28.204425	-82.37536171
		1305	WE-CYB-09-CW	Well	Twice Monthly	28.204326	-82.37533405
		N/A	TR-CYB-09	Transect	Annually		
CYB	128	3080	SG-CYB-11-CG	Surface Water	Twice Monthly	28.20096491	-82.35640011
		2081	WE-CYB-11-CW	Well	Twice Monthly	28.20097156	-82.35639503
CYB	130	2082	SG-CYB-13-CG	Surface Water	Twice Monthly	28.20053086	-82.36921468
		1308	WE-CYB-13-CW	Well	Twice Monthly	28.2005316	-82.36920707
		2083	SG-CYB-13-EG	Surface Water	Twice Monthly	28.2002865	-82.36917873
		N/A	TR-CYB-13	Transect	Annually		

Wellfield Code	Wetland ID	District ID	Permittee Name	Monitor Type	Frequency	Latitude	Longitude
CYB	131	1309	WE-CYB-14-CW	Well	Twice Monthly	28.20607402	-82.37012351
		1271	SG-CYB-14-EG	Surface Water	Twice Monthly	28.20595905	-82.37037738
		3081	SG-CYB-14-CG2	Surface Water	Twice Monthly	28.20606952	-82.37012467
		N/A	TR-CYB-14	Transect	Annually		
CYB	132	2084	SG-CYB-15-CG2	Surface Water	Twice Monthly	28.20693626	-82.3755652
		2085	WE-CYB-15-CW	Well	Twice Monthly	28.2069301	-82.37558145
		N/A	TR-CYB-15	Transect	Annually		
CYB	133	N/A	TR-CYB-16	Transect	Annually		
CYB	135	1275	SG-CYB-18-CG	Surface Water	Twice Monthly	28.19545957	-82.35598848
		1314	WE-CYB-18-CW	Well	Twice Monthly	28.19546404	-82.35599873
CYB	138	2086	SG-CYB-21-CG3	Surface Water	Twice Monthly	28.17624618	-82.35482728
		2087	WE-CYB-21-CW	Well	Twice Monthly	28.17625399	-82.35482834
		N/A	TR-CYB-21	Transect	Annually		
CYB	139	1279	SG-CYB-22-CG	Surface Water	Twice Monthly	28.17271426	-82.36070379
		2088	WE-CYB-22-CW	Well	Twice Monthly	28.17271311	-82.36069977
CYB	140	1280	SG-CYB-23-CG	Surface Water	Twice Monthly	28.17278509	-82.35926429
		2089	WE-CYB-23-CW	Well	Twice Monthly	28.17278689	-82.35927532
		N/A	TR-CYB-23	Transect	Annually		
CYB	142	N/A	TR-CYB-30	Transect	Annually		
CYB	143	1283	SG-CYB-26-CG	Surface Water	Twice Monthly	28.19858828	-82.37898971
		1322	WE-CYB-26-CW	Well	Twice Monthly	28.19856676	-82.37897989
CYB	145	1285	SG-CYB-28-CG	Surface Water	Twice Monthly	28.19071877	-82.36719629
		1324	WE-CYB-28-CW	Well	Twice Monthly	28.19088351	-82.36681306
		2090	SG-CYB-28-EG	Surface Water	Twice Monthly	28.19087788	-82.36681931
CYB	147	1287	SG-CYB-30-CG2	Surface Water	Twice Monthly	28.20887195	-82.35535194
		1326	WE-CYB-30-CW	Well	Twice Monthly	28.20884108	-82.35534906
		2091	SG-CYB-30-EG	Surface Water	Twice Monthly	28.20908996	-82.35539816
		N/A	TR-CYB-30	Transect	Annually		
CYB	148	1288	SG-CYB-31-CG	Surface Water	Twice Monthly	28.16776566	-82.36402897
		1327	WE-CYB-31-CW	Well	Twice Monthly	28.16776063	-82.36402639
CYB	149	N/A	TR-CYB-32	Transect	Annually		

Wellfield Code	Wetland ID	District ID	Permittee Name	Monitor Type	Frequency	Latitude	Longitude
CYB	150	2092	WE-CYB-33-CW	Well	Twice Monthly	28.16912764	-82.37920933
		3101	SG-CYB-33-CG	Surface Water	Twice Monthly	28.16913211	-82.37921344
		N/A	TR-CYB-33	Transect	Annually		
CYB	151	1291	SG-CYB-34-CG	Surface Water	Twice Monthly	28.1705343	-82.34891608
		2093	WE-CYB-34-CW	Well	Twice Monthly	28.17044419	-82.34843107
		N/A	TR-CYB-34	Transect	Annually		
CYB	152	1292	SG-CYB-37-CG	Surface Water	Twice Monthly	28.16949148	-82.33754865
		2094	WE-CYB-37-CW	Well	Twice Monthly	28.16960271	-82.33745314
CYB	153	N/A	TR-CYB-A	Transect	Annually		
CYB	154	1293	SG-CYB-C10-CG	Surface Water	Twice Monthly	28.16032701	-82.39857443
		1332	WE-CYB-C10-CW	Well	Twice Monthly	28.16032449	-82.39857443
CYB	155	1294	SG-CYB-C12-CG	Surface Water	Twice Monthly	28.16105354	-82.39624853
CYB	156	2095	SG-CYB-C16-CG2	Surface Water	Twice Monthly	28.18488285	-82.43347307
		2096	WE-CYB-C16-CW	Well	Twice Monthly	28.18488299	-82.43346262
		1296	SG-CYB-C16-EG	Surface Water	Twice Monthly	28.18502055	-82.43380979
		N/A	TR-CYB-C16	Transect	Annually		
CYB	157	1297	SG-CYB-C18-CG	Surface Water	Twice Monthly	28.18816933	-82.45426611
		1684	WE-CYB-C18-CW	Well	Twice Monthly	28.18800844	-82.45399384
CYC	161	1337	SG-CYC-C03A-CG2	Surface Water	Twice Monthly	28.28395154	-82.43821198
		1421	WE-CYC-C03-CW	Well	Twice Monthly	28.28325748	-82.43697734
		3102	SG-CYC-C03A-EG3	Surface Water	Twice Monthly	28.28326399	-82.43697746
		N/A	TR-CYC-C03	Transect	Annually		
CYC	162	1339	SG-CYC-C06-	Surface Water	Twice Monthly	28.30354427	-82.42928477
		1422	WE-CYC-C06-CW	Well	Twice Monthly	28.30344721	-82.42930623
		N/A	TR-CYC-C06	Transect	Annually		
CYC	164	1426	WE-CYC-C11C-CW	Well	Twice Monthly	28.30129564	-82.33708162
		1341	SG-CYC-C11-CG2	Surface Water	Twice Monthly	28.3012983	-82.33707499
		1427	WE-CYC-C11D-UW	Well	Twice Monthly	28.30147223	-82.33733516
		N/A	TR-CYC-C11	Transect	Annually		

CYC	165	1344	SG-CYC-C13 17/18 WATERCOURSE-CG3	Surface Water	Twice Monthly	28.3115493	-82.33754188
		1870	WE-CYC-C13-CW	Well	Twice Monthly	28.31154325	-82.33754167
CYC	166	1344	SG-CYC-C14A-CG2	Surface Water	Twice Monthly	28.29880542	-82.33759638
		1871	WE-CYC-C14A-CW	Well	Twice Monthly	28.29880968	-82.3375785
		N/A	TR-CYC-C14	Transect	Annually		
CYC	169	3103	SG-CYC-C19A-CG3	Surface Water	Twice Monthly	28.2350822	-82.41125189
		1872	WE-CYC-C19A-CW	Well	Twice Monthly	28.23507906	-82.41129493
CYC	170	2098	SG-CYC-C20A-CG	Surface Water	Twice Monthly	28.25317873	-82.44065623
		2099	WE-CYC-C20-CW	Well	Twice Monthly	28.25318148	-82.44065624
		1349	SG-CYC-C20-EG	Surface Water	Twice Monthly	28.25188674	-82.44036302
		N/A	TR-CYC-C20	Transect	Annually		
CYC	174	1438	WE-CYC-C24A-CW	Well	Twice Monthly	28.26289233	-82.380049
		1351	SG-CYC-C24-CG	Surface Water	Twice Monthly	28.2628913	-82.38004182
		1437	WE-CYC-C24-UW	Well	Twice Monthly	28.26272027	-82.37997434
		N/A	TR-CYC-C24	Transect	Annually		
CYC	16	3000	WE-CYC-C25A-UW	Well	Twice Monthly	28.32121955	-82.43931196
		3090	SG-CYC-C25-CG	Surface Water	Twice Monthly	28.32119445	-82.44093812
		1190	SG-CYC-C25-EG	Surface Water	Twice Monthly	28.32140792	-82.44089504
		3104	WE-CYC-C25-CW	Well	Twice Monthly	28.321144	-82.441176
		N/A	TR-CYC-C25	Transect	Annually		
CYC	176	3001	SG-CYB-33-CG/SG-CYC-C33B-CG	Surface Water	Twice Monthly	28.34075866	-82.35777135
		1875	WE-CYC-C33B-CW	Well	Twice Monthly	28.34074124	-82.35775273
CYC	177	1355	SG-CYC-C39-CG2	Surface Water	Twice Monthly	28.21414451	-82.39048139
CYC	178	1356	SG-CYC-C40-CG	Surface Water	Twice Monthly	28.2743384	-82.38407541
		1444	WE-CYC-C40A-CW	Well	Twice Monthly	28.27434089	-82.38407065
CYC	179	1357	SG-CYC-C100-CG	Surface Water	Twice Monthly	28.23335474	-82.41416623
		1445	WE-CYC-C100-CW	Well	Twice Monthly	28.23335086	-82.41416591
CYC	180	1389	SG-CYC-W25-CG	Surface Water	Twice Monthly	28.26000046	-82.41330938
		1494	WE-CYC-W25B-CW	Well	Twice Monthly	28.25998687	-82.41330223
		1388	SG-CYC-W25-EG1	Surface Water	Twice Monthly	28.25944549	-82.41266387

Wellfield Code	Wetland ID	District ID	Permittee Name	Monitor Type	Frequency	Latitude	Longitude
CYC	181	1447	WE-CYC-C101A-UW	Well	Twice Monthly	28.36169046	-82.33845952
		1359	SG-CYC-C101A-CG	Surface Water	Twice Monthly	28.36198113	-82.33874361
		1448	WE-CYC-C101D-CW2	Well	Twice Monthly	28.3619852	-82.33874368
		3002	SG-CYC-C101A-EG	Surface Water	Twice Monthly	28.36185649	-82.33863177
		N/A	TR-CYC-C101	Transect	Annually		
CYC	182	N/A	TR-CYC-C102	Transect	Annually		
CYC	183	1451	WE-CYC-C103-CW	Well	Twice Monthly	28.25481354	-82.39981485
		1361	SG-CYC-C103-CG2	Surface Water	Twice Monthly	28.25457879	-82.39995817
CYC	187	3003	SG-CYC-W01A-CG	Surface Water	Twice Monthly	28.31030248	-82.38594035
		3105	SG-CYC-W01-CG	Surface Water	Twice Monthly	28.31027889	-82.38593517
		1456	WE-CYC-W01-CW	Well	Twice Monthly	28.31031879	-82.38596925
CYC	189	1880	WE-CYC-W03A-CW	Well	Twice Monthly	28.30350991	-82.3776008
		1368	SG-CYC-W03B-CG	Surface Water	Twice Monthly	28.30354829	-82.37771106
		N/A	TR-CYC-W03	Transect	Annually		
CYC	190	N/A	TR-CYC-W04	Transect	Annually		
CYC	191	1370	SG-CYC-W05-CG2	Surface Water	Twice Monthly	28.30507303	-82.38190931
		3005	WE-CYC-W05A-CW	Well	Twice Monthly	28.30506886	-82.38191648
		1461	WE-CYC-W05-UW	Well	Twice Monthly	28.30458371	-82.3815186
CYC	193	1882	SG-CYC-W09A-CG2	Surface Water	Twice Monthly	28.3018998	82.38120592
		1466	WE-CYC-W09A-CW	Well	Twice Monthly	28.30189321	-82.38120522
		1465	WE-CYC-W09-UW	Well	Twice Monthly	28.30179086	-82.38098289
		N/A	TR-CYC-W09	Transect	Annually		
CYC	194	1376	SG-CYC-W10B-CG	Surface Water	Twice Monthly	28.2904689	-82.38398731
		1469	WE-CYC-W10B-CW	Well	Twice Monthly	28.29047269	-82.3839825
		1467	WE-CYC-W10-UW	Well	Twice Monthly	28.29111164	-82.3837333
		3106	SG-CYC-W10B-EG	Surface Water	Twice Monthly	28.29057291	-82.38397868
		N/A	TR-CYC-W10	Transect	Annually		
CYC	195	N/A	TR-CYC-W11	Transect	Annually		
CYC	196	N/A	TR-CYC-W12	Transect	Annually		
CYC	197	1476	WE-CYC-W14A-CW2	Well	Twice Monthly	28.29768321	-82.39831233
		1380	SG-CYC-W14-CG	Surface Water	Twice Monthly	28.29768802	-82.39830757
		3107	WE-CYC-W14-CW	Well	Twice Monthly	28.29769739	-82.39835744

Wellfield Code	Wetland ID	District ID	Permittee Name	Monitor Type	Frequency	Latitude	Longitude
CYC	198	N/A	TR-CYC-W16	Transect	Annually		
CYC	199	N/A	TR-CYC-W17	Transect	Annually		
CYC	200	1483	WE-CYC-W19B-CW	Well	Twice Monthly	28.27833898	-82.39773252
		1383	SG-CYC-W19-CG	Surface Water	Twice Monthly	28.27834138	-82.39772598
		1481	WE-CYC-W19-UW	Well	Twice Monthly	28.27807777	-82.39752683
		N/A	TR-CYC-W19	Transect	Annually		
CYC	201	1485	WE-CYC-W20A-CW	Well	Twice Monthly	28.27852285	-82.39406533
		1384	SG-CYC-W20-CG	Surface Water	Twice Monthly	28.27852073	-82.39405992
		1484	WE-CYC-W20-UW	Well	Twice Monthly	28.27875484	-82.39430282
		N/A	TR-CYC-W20	Transect	Annually		
CYC	204	1489	WE-CYC-W23A-CW	Well	Twice Monthly	28.27293271	-82.40743866
		1889	WE-CYC-W23-UW	Well	Twice Monthly	28.27260013	-82.40750726
		3073	SG-CYC-W23-CG23	Surface Water	Twice Monthly	28.27289669	-82.40708566
		N/A	TR-CYC-W23	Transect	Annually		
CYC	205	1496	WE-CYC-W27A-CW	Well	Twice Monthly	28.29923116	-82.38046539
		1390	SG-CYC-W27-CG	Surface Water	Twice Monthly	28.29954801	-82.38090729
		1495	WE-CYC-W27-UW	Well	Twice Monthly	28.29939798	-82.38111204
		N/A	TR-CYC-W27	Transect	Annually		
CYC	206	1391	SG-CYC-W29-CG	Surface Water	Twice Monthly	28.29945782	-82.38800777
		1497	WE-CYC-W29A-CW	Well	Twice Monthly	28.29944998	-82.38801183
		1498	WE-CYC-W29B-UW	Well	Twice Monthly	28.29976856	-82.38831472
		N/A	TR-CYC-W29	Transect	Annually		
CYC	207	1392	SG-CYC-W30-CG	Surface Water	Twice Monthly	28.29949986	-82.37571859
		1890	WE-CYC-W30N-CW	Well	Twice Monthly	28.29956141	-82.37565855
		1499	WE-CYC-W30-UW	Well	Twice Monthly	28.29912966	-82.37528995
CYC	208	1393	SG-CYC-W30S-CG	Surface Water	Twice Monthly	28.29931762	-82.37604644
		1891	WE-CYC-W30S-CW	Well	Twice Monthly	28.29933027	-82.37597904
CYC	209	1394	SG-CYC-W31-CG2	Surface Water	Twice Monthly	28.27593539	-82.3966766
		3074	SG-CYC-W31-EG2	Surface Water	Twice Monthly	28.27602869	-82.39662758
		1500	WE-CYC-W31-UW	Well	Twice Monthly	28.2761763	-82.39655356
		1501	WE-CYC-W31-CW2	Well	Twice Monthly	28.27593921	-82.39666155
		N/A	TR-CYC-W31	Transect	Annually		

Wellfield Code	Wetland ID	District ID	Permittee Name	Monitor Type	Frequency	Latitude	Longitude
CYC	210	1503	WE-CYC-W32A-CW	Well	Twice Monthly	28.29352658	-82.38911876
		1396	SG-CYC-W32-CG	Surface Water	Twice Monthly	28.29353169	-82.38911445
		1502	WE-CYC-W32-UW	Well	Twice Monthly	28.29372444	-82.38886106
		N/A	TR-CYC-W32	Transect	Annually		
CYC	211	1505	WE-CYC-W33A-CW	Well	Twice Monthly	28.27634182	-82.39291366
		1397	SG-CYC-W33-CG	Surface Water	Twice Monthly	28.27629931	-82.39293749
		1504	WE-CYC-W33-UW	Well	Twice Monthly	28.2767299	-82.39280177
		N/A	TR-CYC-W33	Transect	Annually		
CYC	213	1509	WE-CYC-W36A-CW	Well	Twice Monthly	28.29475625	-82.36968483
		1399	SG-CYC-W36-CG	Surface Water	Twice Monthly	28.29475922	-82.36968325
		1508	WE-CYC-W36-UW	Well	Twice Monthly	28.29544609	-82.37021614
		N/A	TR-CYC-W36	Transect	Annually		
CYC	214	1511	WE-CYC-W37A-CW	Well	Twice Monthly	28.29596622	-82.37089432
		1401	SG-CYC-W37B-CG	Surface Water	Twice Monthly	28.29597257	-82.37090293
		N/A	TR-CYC-W37	Transect	Annually		
CYC	215	1513	WE-CYC-W39A-UW	Well	Twice Monthly	28.29524822	-82.38865361
		3006	SG-CYC-W39-CG2	Surface Water	Twice Monthly	28.29585142	-82.38850164
		1512	WE-CYC-W39-CW	Well	Twice Monthly	28.29577188	-82.3886433
		N/A	TR-CYC-W39	Transect	Annually		
CYC	216	N/A	TR-CYC-W40	Transect	Annually		
CYC	217	N/A	TR-CYC-W41	Transect	Annually		
CYC	220	1522	WE-CYC-W43A-CW	Well	Twice Monthly	28.28916788	-82.3782552
		1406	SG-CYC-W43-CG	Surface Water	Twice Monthly	28.28921911	-82.37826484
		3108	SG-CYC-W43-EG	Surface Water	Twice Monthly	28.28860277	-82.37863157
CYC	222	N/A	TR-CYC-W45	Transect	Annually		
CYC	223	N/A	TR-CYC-W46	Transect	Annually		
CYC	226	N/A	TR-CYC-W50	Transect	Annually		
CYC	228	1417	SG-CYC-W52S-CG	Surface Water	Twice Monthly	28.3124391	-82.37678746
		1542	WE-CYC-W52S-CW	Well	Twice Monthly	28.31243044	-82.37684691
		1540	WE-CYC-W52-UW	Well	Twice Monthly	28.31257636	-82.37689138
		N/A	TR-CYC-W52	Transect	Annually		

Wellfield Code	Wetland ID	District ID	Permittee Name	Monitor Type	Frequency	Latitude	Longitude
CYC	229	1419	SG-CYC-W55-CG	Surface Water	Twice Monthly	28.28825942	-82.38239772
		1546	WE-CYC-W55B-CW	Well	Twice Monthly	28.28826556	-82.38238926
		N/A	TR-CYC-W55	Transect	Annually		
CYC	230	N/A	TR-CYC-W56	Transect	Annually		
CYC	231	3043	WE-CYC-W57A-CW	Well	Twice Monthly	28.2977923	-82.3621813
		1896	SG-CYC-W57A-CG2	Surface Water	Twice Monthly	28.29778474	-82.36218529
		3075	SG-CYC-W57-EG	Surface Water	Twice Monthly	28.29734008	-82.36209631
CYC	232	3007	SG-CYC-W58-CG	Surface Water	Twice Monthly	28.2612762	-82.40303097
		3008	WE-CYC-W58-CW	Well	Twice Monthly	28.26127303	-82.40302361
		N/A	TR-CYC-W58	Transect	Annually		
ELW	1841	3109	BCP-SITE3-MW-3	Well	Twice Monthly	28.14439583	-82.65649734
		3110	BCP-SITE3-PZ-1	Well	Twice Monthly	28.14487096	-82.65660455
		3111	BCP-SITE3-SG-1	Surface Water	Twice Monthly	28.14475874	-82.65639375
		3112	BCP-SITE3-SG2-CG	Surface Water	Twice Monthly	28.14457672	-82.65647628
		3113	BCP-SITE3-SG3-EG	Surface Water	Twice Monthly	28.14440016	-82.65648156
ELW	243	1787	SG-ELW-C132716-CG	Surface Water	Twice Monthly	28.13701441	-82.66157429
		1788	WE-ELW-C132716-CW2	Well	Twice Monthly	28.13702029	-82.6615821
		1789	WE-ELW-C132716-UW	Well	Twice Monthly	28.13665406	-82.66113566
		1059	ELW-C132716-EG	Surface Water	Twice Monthly	28.13687957	-82.66138528
		N/A	TR-ELW-C132716	Transect	Annually		
ELW	244	N/A	TR-ELW-EC112716	Transect	Annually		
ELW	245	N/A	TR-ELW-NC222716	Transect	Annually		
ELW	246	N/A	TR-ELW-NNW122716	Transect	Annually		
ELW	247	N/A	TR-ELW-NW062716	Transect	Annually		
ELW	248	N/A	TR-ELW-NW052717	Transect	Annually		
ELW	249	N/A	TR-ELW-NW062717	Transect	Annually		
ELW	250	N/A	TR-ELW-NW122716	Transect	Annually		
ELW	251	N/A	TR-ELW-SC272716	Transect	Annually		

Wellfield Code	Wetland ID	District ID	Permittee Name	Monitor Type	Frequency	Latitude	Longitude
ELW	252	1802	SG-ELW-SW062717-CG	Surface Water	Twice Monthly	28.16250123	-82.6503262
		2066	WE-ELW-SW062717-CW2	Well	Twice Monthly	28.162496	-82.6503271
		3083	SG-ELW-SW062717-EG	Surface Water	Twice Monthly	28.16247466	-82.65046904
		1803	WE-ELW-SW062717-UW	Well	Twice Monthly	28.16292169	-82.65052789
		N/A	TR-ELW-SW062717	Transect	Annually		
ELW	254	N/A	TR-ELW-SW272716	Transect	Annually		
ELW	255	1776	SG-ELW-WC102716-CG	Surface Water	Twice Monthly	28.150723	-82.69507117
		1777	WE-ELW-WC102716-CW2	Well	Twice Monthly	28.15073979	-82.69501714
		3114	SG-ELW-WC102716-EG	Surface Water	Twice Monthly	28.15080478	-82.69518771
		N/A	TR-ELW-WC102716	Transect	Annually		
MBR	257	1975	SG-MBR-09-CG	Surface Water	Twice Monthly	28.11412477	-82.33648302
		1563	WE-MBR-09-CW	Well	Twice Monthly	28.11412037	-82.3364849
		1562	WE-MBR-09-UW	Well	Twice Monthly	28.11455669	-82.33700833
MBR	258	1976	SG-MBR-10-CG	Surface Water	Twice Monthly	28.12412765	-82.3340681
		1582	WE-MBR-20S-UW	Well	Twice Monthly	28.12315352	-82.33422706
		3078	WE-MBR-10-CW3	Well	Twice Monthly	28.12413673	-82.33430368
		N/A	TR-MBR-10	Transect	Annually		
MBR	259	1550	SG-MBR-11-CG	Surface Water	Twice Monthly	28.12498868	-82.32344341
		1978	WE-MBR-11-CW2	Well	Twice Monthly	28.12498503	-82.32343417
		1977	WE-MBR-11-UW	Well	Twice Monthly	28.1243384	-82.32361499
MBR	259	N/A	TR-MBR-11	Transect	Annually		
MBR	260	N/A	TR-MBR-14	Transect	Annually		
MBR	261	N/A	TR-MBR-16	Transect	Annually		
MBR	262	N/A	TR-MBR-29	Transect	Annually		
MBR	263	1553	SG-MBR-30-CG	Surface Water	Twice Monthly	28.10698973	-82.33817764
		1587	WE-MBR-25S-UW	Well	Twice Monthly	28.10712621	-82.33713804
		1592	WE-MBR-30-W-CW	Well	Twice Monthly	28.10700994	-82.33813918
		N/A	TR-MBR-30	Transect	Annually		
MBR	265	1989	SG-MBR-36-CG	Surface Water	Twice Monthly	28.11976117	-82.3080284
		1596	WE-MBR-36-CW	Well	Twice Monthly	28.11976195	-82.30802335
		1595	WE-MBR-36-UW	Well	Twice Monthly	28.11923019	-82.30775788

Wellfield Code	Wetland ID	District ID	Permittee Name	Monitor Type	Frequency	Latitude	Longitude
MBR	266	1990	SG-MBR-37-CG	Surface Water	Twice Monthly	28.11976117	-82.3080284
		1598	WE-MBR-37-CW	Well	Twice Monthly	28.11445803	-82.31263951
		1597	WE-MBR-37-UW	Well	Twice Monthly	28.11494076	-82.31261888
		N/A	TR-MBR-30	Transect	Annually		
MBR	270	1556	SG-MBR-80-CG3	Surface Water	Twice Monthly	28.1167419	-82.31611795
		1605	WE-MBR-80-CW	Well	Twice Monthly	28.11674526	-82.31611387
		1584	WE-MBR-22S-UW	Well	Twice Monthly	28.11757561	-82.31686529
MBR	273	N/A	TR-MBR-88	Transect	Annually		
MBR	274	N/A	TR-MBR-89	Transect	Annually		
MBR	275	1558	SG-MBR-90-CG	Surface Water	Twice Monthly	28.12102151	-82.29353151
		1613	WE-MBR-90-CW	Well	Twice Monthly	28.12102376	-82.29353562
		1612	WE-MBR-90-UW	Well	Twice Monthly	28.12077758	-82.29337074
		N/A	TR-MBR-90	Transect	Annually		
MBR	276	2002	SG-MBR-91-CG	Surface Water	Twice Monthly	28.10987492	-82.34745106
		3079	WE-MBR-91-CW3	Well	Twice Monthly	28.10987884	-82.34744406
		N/A	TR-MBR-91	Transect	Annually		
MBR	277	2004	SG-MBR-93-CG	Surface Water	Twice Monthly	28.09486766	-82.31794116
		1615	WE-MBR-93-CW	Well	Twice Monthly	28.09486994	-82.3179304
		2003	WE-MBR-93-UW	Well	Twice Monthly	28.09526729	-82.31807943
		N/A	TR-MBR-93	Transect	Annually		
MBR	278	1559	SG-MBR-94-CG	Surface Water	Twice Monthly	28.09154625	-82.31710208
		2005	WE-MBR-94-CW	Well	Twice Monthly	28.09156347	-82.31710079
		1617	WE-MBR-94-UW	Well	Twice Monthly	28.09223337	-82.31781066
		N/A	TR-MBR-94	Transect	Annually		
MBR	280	2008	SG-MBR-97-CG	Surface Water	Twice Monthly	28.11905037	-82.35891751
		2007	WE-MBR-97-CW	Well	Twice Monthly	28.11905345	-82.35892798
		2006	WE-MBR-97-UW	Well	Twice Monthly	28.11877002	-82.35903093
		N/A	TR-MBR-97	Transect	Annually		
MBR	281	1561	SG-MBR-98-CG	Surface Water	Twice Monthly	28.1193505	-82.36034004
		2009	WE-MBR-98-CW	Well	Twice Monthly	28.11934741	-82.36032836
		3071	WE-MBR-18S-UW-2	Well	Twice Monthly	28.11942886	-82.35982197
		N/A	TR-MBR-98	Transect	Annually		

Wellfield Code	Wetland ID	District ID	Permittee Name	Monitor Type	Frequency	Latitude	Longitude
MBR	283	2014	SG-MBR-102-CG	Surface Water	Twice Monthly	28.12537684	-82.34299132
		2013	WE-MBR-102-CW	Well	Twice Monthly	28.1253649	-82.34299198
		2012	WE-MBR-102-UW	Well	Twice Monthly	28.12519839	-82.34274543
MBR	284	2015	SG-MBR-103-CG	Surface Water	Twice Monthly	28.13199938	-82.36113657
		1568	WE-MBR-103-UW	Well	Twice Monthly	28.1320629	-82.36156161
MBR	285	2017	SG-MBR-104-CG4	Surface Water	Twice Monthly	28.09571952	-82.35243593
		1570	WE-MBR-104-UW	Well	Twice Monthly	28.0954113	-82.35235725
MBR	286	2019	SG-MBR-105-CG	Surface Water	Twice Monthly	28.10459425	-82.34850712
		1572	WE-MBR-105-CW	Well	Twice Monthly	28.10459562	-82.34850803
		2018	WE-MBR-105-UW	Well	Twice Monthly	28.10455457	-82.34892696
MBR	287	2022	SG-MBR-106-CG	Surface Water	Twice Monthly	28.11045092	-82.31937873
		2021	WE-MBR-106-CW	Well	Twice Monthly	28.11045535	-82.31938063
		2020	WE-MBR-106-UW	Well	Twice Monthly	28.11027243	-82.32086664
NOP	338	N/A	TR-NOP-NOP-3	Transect	Annually		
NOP	339	1021	SG-NOP-4-CG	Surface Water	Twice Monthly	28.30710294	-82.58735393
		3049	WE-NOP-04-CW	Well	Twice Monthly	28.30710525	-82.58734834
		N/A	TR-NOP-04	Transect	Annually		
NOP	340	1022	SG-NOP-5-CG3	Surface Water	Twice Monthly	28.30620709	-82.57883204
		3009	WE-NOP-05-CW	Well	Twice Monthly	28.306201	-82.57883654
		1948	WE-NOP-05-UW	Well	Twice Monthly	28.3061421	-82.57910901
		N/A	TR-NOP-05	Transect	Annually		
NOP	342	1024	SG-NOP-7-CG2	Surface Water	Twice Monthly	28.2898495	-82.58301533
		3010	WE-NOP-07-CW	Well	Twice Monthly	28.28984777	-82.58302449
		N/A	TR-NOP-07	Transect	Annually		
NOP	344	1026	SG-NOP-9-CG2	Surface Water	Twice Monthly	28.28413668	-82.5648515
		3011	WE-NOP-09-CW	Well	Twice Monthly	28.28412042	-82.56483895
		3115	WG-NOP-09-EG1	Surface Water	Twice Monthly	28.28405776	-82.56511662
		N/A	TR-NOP-09	Transect	Annually		
NOP	345	1005	SG-NOP-10-CG2	Surface Water	Twice Monthly	28.27941575	-82.58745148
		3012	WE-NOP-10-CW	Well	Twice Monthly	28.27940705	-82.58741473
		1933	WE-NOP-10-UW	Well	Twice Monthly	28.27929668	-82.58785837
		N/A	TR-NOP-10	Transect	Annually		

Wellfield Code	Wetland ID	District ID	Permittee Name	Monitor Type	Frequency	Latitude	Longitude
NOP	346	1006	SG-NOP-11-CG3	Surface Water	Twice Monthly	28.3247572	-82.58221322
		3013	WE-NOP-11-CW	Well	Twice Monthly	28.32424439	-82.58223843
		1934	WE-NOP-11-UW	Well	Twice Monthly	28.32449148	-82.58186473
		N/A	TR-NOP-11	Transect	Annually		
NOP	350	3014	SG-NOP-17-CG2	Surface Water	Twice Monthly	28.30198567	-82.57433627
		3015	WE-NOP-17-CW	Well	Twice Monthly	28.30197193	-82.57435799
		1937	NOP-NPEM-17-UW	Well	Twice Monthly	28.30186029	-82.57486828
		N/A	TR-NOP-17	Transect	Annually		
NOP	351	3016	SG-NOP-18-CG3	Surface Water	Twice Monthly	28.30175331	-82.56805745
		3017	WE-NOP-18-CW	Well	Twice Monthly	28.30177094	-82.56803981
		1938	NOP-NPEM-18-UW	Well	Twice Monthly	28.30215587	-82.5677726
		3016	SG-NOP-18-CG2	Surface Water	Twice Monthly	28.302074	-82.5679666
		N/A	TR-NOP-18	Transect	Annually		
NOP	352	N/A	TR-NOP-21	Transect	Annually		
NOP	353	3018	SG-NOP-22-CG2	Surface Water	Twice Monthly	28.29287201	-82.57143823
		3019	WE-NOP-22-CW	Well	Twice Monthly	28.29287964	-82.57143887
		1014	SG-NOP-22-EG	Surface Water	Twice Monthly	28.2930901	-82.57141462
		N/A	TR-NOP-22	Transect	Annually		
NOP	358	1019	SG-NOP-30-CG3	Surface Water	Twice Monthly	28.2738706	-82.55519836
		3020	WE-NOP-30-CW	Well	Twice Monthly	28.27386432	-82.55518731
		1940	NOP-NPEM-30-UW	Well	Twice Monthly	28.27419525	-82.55534362
		3116	SG-NOP-30-EG1	Surface Water	Twice Monthly	28.27406783	-82.5553163
		N/A	TR-NOP-30	Transect	Annually		
NOP	362	3023	SG-NOP-36-CG	Surface Water	Twice Monthly	28.30480593	-82.55625346
		3025	WE-NOP-36-CW	Well	Twice Monthly	28.3047816	-82.55607514
		3024	SG-NOP-36-EG	Surface Water	Twice Monthly	28.30490373	-82.55638007
		1944	NOP-NPEM-36-UW	Well	Twice Monthly	28.30493694	-82.55653582
		N/A	TR-NOP-36	Transect	Annually		
NOP	364	3021	SG-NOP-31-CG	Surface Water	Twice Monthly	28.30642203	-82.56725847
		3022	SG-NOP-31-EG	Surface Water	Twice Monthly	28.30654199	-82.56715522
		1942	WE-NOP-31-UW	Well	Twice Monthly	28.30644168	-82.56747384
		N/A	TR-NOP-Ryals Lake	Transect	Annually		

Wellfield Code	Wetland ID	District ID	Permittee Name	Monitor Type	Frequency	Latitude	Longitude
NWH	366	N/A	TR-NWH-132817	Transect	Annually		
NWH	367	1820	SG-NWH-142817-CG	Surface Water	Twice Monthly	28.0413954	-82.58240578
		1821	WE-NWH-142817-CW2	Well	Twice Monthly	28.04139679	-82.58241319
		1822	WE-NWH-142817-UW	Well	Twice Monthly	28.0416549	-82.58247164
		N/A	TR-NWH-142817	Transect	Annually		
NWH	372	1830	NWH-EC072818-CG2	Surface Water	Twice Monthly	28.06146106	-82.53908781
		1831	WE-NWH-EC072818-CW2	Well	Twice Monthly	28.0613548	-82.53913352
		N/A	TR-NWH-EC072818	Transect	Annually		
NWH	377	3117	SG-NWH-NW012817-SG5	Surface Water	Twice Monthly	28.07851311	-82.56530912
NWH	378	1830	SG-NWH-NW072818-CG	Surface Water	Twice Monthly	28.06368201	-82.54843904
		1833	WE-NWH-NW072818-CW2	Well	Twice Monthly	28.06372289	-82.54836374
		N/A	TR-NWH-NW072818	Transect	Annually		
NWH	379	1827	SG-NWH-SC042818-CG	Surface Water	Twice Monthly	28.06973637	-82.50752259
		1828	WE-NWH-SC042818-CW2	Well	Twice Monthly	28.06964112	-82.50755675
		N/A	TR-NWH-SC042818	Transect	Annually		
NWH	380	1829	SG-NWH-SC062818-CG3	Surface Water	Twice Monthly	28.07034778	-82.54152862
NWH	381	1834	SG-NWH-SW082818-CG	Surface Water	Twice Monthly	28.05557136	-82.53292712
		1835	WE-NWH-SW082818-CW2	Well	Twice Monthly	28.05558864	-82.53298827
		1156	SG-NWH-SW082818	Surface Water	Twice Monthly	28.05549491	-82.53253708
		N/A	TR-NWH-SW082818	Transect	Annually		
NWH	382	1816	SG-NWH-WC102817-CG	Surface Water	Twice Monthly	28.0600757	-82.58604326
		1817	WE-NWH-WC102817-CW2	Well	Twice Monthly	28.05968832	-82.58622188
		N/A	TR-NWH-WC102817	Transect	Annually		
S21	368	1811	SG-NWH-202718-CG	Surface Water	Twice Monthly	28.12707398	-82.52777475
		1812	WE-NWH-202718-CW2	Well	Twice Monthly	28.12710844	-82.52775155
		2067	SG-NWH-202718-EG	Surface Water	Twice Monthly	28.12713075	-82.52761519
		1813	WE-NWH-202718-UW	Well	Twice Monthly	28.12724609	-82.5273053
S21	371	1809	SG-NWH-E182718-CG	Surface Water	Twice Monthly	28.13265374	-82.53531869
		1810	WE-NWH-E182718-CW	Well	Twice Monthly	28.13254454	-82.53549326
		N/A	TR-NWH-E181718	Transect	Annually		

Wellfield Code	Wetland ID	District ID	Permittee Name	Monitor Type	Frequency	Latitude	Longitude
S21	383	2068	SG-S21-272718-S1-CG	Surface Water	Twice Monthly	28.10481912	-82.49179447
		2069	WE-S21-272718-W2-CW2	Well	Twice Monthly	28.10481436	-82.49179435
		N/A	TR-S21-272718	Transect	Annually		
S21	384	3026	SG-S21-322718-CG	Surface Water	Twice Monthly	28.09413961	-82.52274962
		3027	WE-S21-322718-CW2	Well	Twice Monthly	28.09413893	-82.52283408
S21	385	N/A	TR-S21-CW212718	Transect	Annually		
S21	387	1745	WE-S21-EC222718-CW2	Well	Twice Monthly	28.11807914	-82.48630674
		N/A	TR-S21-EC222718	Transect	Annually		
S21	388	1732	SG-S21-NC092718-CG2	Surface Water	Twice Monthly	28.1562157	-82.50521958
		1733	WE-S21-NC092718-CW2	Well	Twice Monthly	28.1562216	-82.50521589
		N/A	TR-S21-NC092718	Transect	Annually		
S21	376	1807	SG-NWH-NE132717-CG	Surface Water	Twice Monthly	28.14161768	-82.55136506
		1808	WE-NWH-NE132717-CW	Well	Twice Monthly	28.14161673	-82.55135554
		3086	SG-NWH-NE132717-EG	Surface Water	Twice Monthly	28.14139353	-82.55101131
		N/A	TR-S21-NE132717	Transect	Annually		
S21	390	1739	SG-S21-NE212718-CG	Surface Water	Twice Monthly	28.12746006	-82.50482478
		1740	WE-S21-NE212718-CW2	Well	Twice Monthly	28.12746862	-82.50480263
		2072	SG-S21-NE212718-EG	Surface Water	Twice Monthly	28.12758047	-82.50475348
		3089	SG-S21-NE212718-EG2	Surface Water	Twice Monthly	28.12765288	-82.50495376
		N/A	TR-S21-NE212718	Transect	Annually		
S21	392	1741	SG-S21-NW212718-CG4	Surface Water	Twice Monthly	28.12242396	-82.51193135
		N/A	TR-S21-NW212718	Transect	Annually		
S21	393	2073	SG-S21-SE212718-CG	Surface Water	Twice Monthly	28.11564954	-82.50558738
		1647	WE-S21-SE212718-CW2	Well	Twice Monthly	28.1156306	-82.50560337
		3118	SG-S21-SE212718-EG	Surface Water	Twice Monthly	28.11557757	-82.50554113
		N/A	TR-S21-SE212718	Transect	Annually		
S21	394	1742	SG-S21-SW292718-CG	Surface Water	Twice Monthly	28.1025314	-82.5296684
		1746	WE-S21-SW292718-CW2	Well	Twice Monthly	28.10250596	-82.52959001
		N/A	TR-S21-SW292718	Transect	Annually		
S21	395	2074	SG-S21-WC212718-S1-CG	Surface Water	Twice Monthly	28.11974311	-82.51561268
		2075	WE-S21-WC212718-CW2	Well	Twice Monthly	28.119694	-82.51565574
		N/A	TR-S21-WC212718	Transect	Annually		

Wellfield Code	Wetland ID	District ID	Permittee Name	Monitor Type	Frequency	Latitude	Longitude
S21	396	1743	SG-S21-WC342718-CG	Surface Water	Twice Monthly	28.09161204	-82.49775862
		1747	WE-S21-WC342718-CW2	Well	Twice Monthly	28.09159683	-82.49775862
		N/A	TR-S21-WC342718	Transect	Annually		
SOP	397	3054	SG-SOP-NE152618-CG	Surface Water	Twice Monthly	28.22806315	-82.49527801
		1749	WE-SOP-NE152618-CW2	Well	Twice Monthly	28.22810368	-82.49527056
		N/A	TR-SOP-NE152618	Transect	Annually		
SOP	398	1752	SG-SOP-PC282618-CG	Surface Water	Twice Monthly	28.18981564	-82.5104848
		1753	WE-SOP-PC282618-CW2	Well	Twice Monthly	28.18982466	-82.51048205
SOP	399	N/A	TR-SOP-PT322618	Transect	Annually		
SOP	400	855	SG-STK-PTC332618-CG	Surface Water	Twice Monthly	28.1797342	-82.5128043
		1768	WE-SOP-PTC332618-CW2	Well	Twice Monthly	28.17975685	-82.51278319
		1769	WE-SOP-PTC332618-UW	Well	Twice Monthly	28.17905952	-82.51280717
SOP	401	1757	SG-SOP-PSW282618-CG	Surface Water	Twice Monthly	28.18730939	-82.51627322
		1758	WE-SOP-PSW282618-CW2	Well	Twice Monthly	28.18735189	-82.51627396
		N/A	TR-SOP-PSW282618	Transect	Annually		
SOP	402	N/A	TR-SOP-PC332618	Transect	Annually		
SOP	403	N/A	TR-SOP-PSE282618	Transect	Annually		
SOP	404	1765	SG-SOP-PSW332618-CG	Surface Water	Twice Monthly	28.1764651	-82.51556823
		1766	WE-SOP-PSW332618-CW2	Well	Twice Monthly	28.17643724	-82.51554171
		1767	WE-SOP-PSW332618-UW	Well	Twice Monthly	28.17719935	-82.51566682
		N/A	TR-SOP-PSW282618	Transect	Annually		
SOP	406	1750	SG-SOP-SC162618-CG	Surface Water	Twice Monthly	28.2159098	-82.50640555
		1751	WE-SOP-SC162618-CW2	Well	Twice Monthly	28.21591048	-82.50641512
		N/A	TR-SOP-SC162618	Transect	Annually		
STK	411	N/A	TR-STK-S-5	Transect	Annually		
STK	412	884	SG-STK-S-6-CG	Surface Water	Twice Monthly	28.24868638	-82.6484059
		960	WE-STK-S-6-CW	Well	Twice Monthly	28.24859411	-82.64832744
		3084	SG-STK-S-6-EG	Surface Water	Twice Monthly	28.24861731	-82.64793566
		N/A	TR-STK-S-6	Transect	Annually		

Wellfield Code	Wetland ID	District ID	Permittee Name	Monitor Type	Frequency	Latitude	Longitude
STK	414	899	SG-STK-S-8-CG2	Surface Water	Twice Monthly	28.24444226	-82.64407762
		975	WE-STK-S-8-CW	Well	Twice Monthly	28.24449338	-82.64407119
		3028	SG-STK-S-8-EG	Surface Water	Twice Monthly	28.24454145	-82.64411229
		3029	WE-STK-S-8-UW	Well	Twice Monthly	28.24479565	-82.64416972
		N/A	TR-STK-S-6	Transect	Annually		
STK	415	3123	SG-STK-S-10-CG3	Surface Water	Twice Monthly	28.23921658	-82.64266961
		931	WE-STK-S-10-CW	Well	Twice Monthly	28.23922958	-82.642673
		3030	SG-STK-S-10-EG	Surface Water	Twice Monthly	28.23921723	-82.64267
		N/A	TR-STK-S-10	Transect	Annually		
STK	418	3050	SG-STK-S-16-CG2	Surface Water	Twice Monthly	28.2404004	-82.62529794
		938	WE-STK-S-16-CW	Well	Twice Monthly	28.24040624	-82.62530404
		3031	SG-STK-S-16-EG	Surface Water	Twice Monthly	28.24034392	-82.62526776
		N/A	TR-STK-S-16	Transect	Annually		
STK	421	N/A	TR-STK-S-23	Transect	Annually		
STK	422	N/A	TR-STK-23	Transect	Annually		
STK	424	869	SG-STK-S-31-CG	Surface Water	Twice Monthly	28.24733657	-82.61426028
		3119	SG-STK-S-31-EG	Surface Water	Twice Monthly	28.245528	-82.6141639
		944	WE-STK-S-31-CW	Well	Twice Monthly	28.24734009	-82.61426192
		1958	WE-STK-S-31-UW	Well	Twice Monthly	28.24734881	-82.61460711
		N/A	TR-STK-S-31	Transect	Annually		
STK	425	3051	SG-STK-S-35-CG3	Surface Water	Twice Monthly	28.23751836	-82.61320797
		945	WE-STK-S-35-CW	Well	Twice Monthly	28.23752467	-82.61319561
		3033	WE-STK-S-35-UW	Well	Twice Monthly	28.23758022	-82.61354665
		3032	SG-STK-S-35-EG	Surface Water	Twice Monthly	28.237525	-82.61335427
		N/A	TR-STK-S-35	Transect	Annually		
STK	428	873	SG-STK-S-39-CG	Surface Water	Twice Monthly	28.25415938	-82.60668071
		948	WE-STK-S-39-CW	Well	Twice Monthly	28.25416019	-82.60668408
		N/A	TR-STK-S-39	Transect	Annually		

Wellfield Code	Wetland ID	District ID	Permittee Name	Monitor Type	Frequency	Latitude	Longitude
STK	429	875	SG-STK-S-42-CG	Surface Water	Twice Monthly	28.25785584	-82.61515859
		950	WE-STK-S-42-CW	Well	Twice Monthly	28.25785587	-82.61516152
		N/A	TR-STK-S-42	Transect	Annually		
STK	430	N/A	TR-STK-S-44	Transect	Annually		
STK	431	876	SG-STK-S-46-CG	Surface Water	Twice Monthly	28.2454052	-82.60410955
		952	WE-STK-S-46-CW	Well	Twice Monthly	28.24540155	-82.60411034
		N/A	TR-STK-S-46	Transect	Annually		
STK	433	879	SG-STK-S-52-CG	Surface Water	Twice Monthly	28.25584945	-82.59515978
		955	WE-STK-S-52-CW	Well	Twice Monthly	28.25584921	-82.59515816
		3034	SG-STK-S-52-EG	Surface Water	Twice Monthly	28.25600439	-82.59552824
		N/A	TR-STK-S-52	Transect	Annually		
STK	434	880	SG-STK-S-53-CG	Surface Water	Twice Monthly	28.24714626	-82.59254543
		1973	WE-STK-S-53-CW	Well	Twice Monthly	28.24715063	-82.59252599
		1961	WE-STK-S-53-UW	Well	Twice Monthly	28.24715833	-82.59229412
		N/A	TR-STK-S-53	Transect	Annually		
STK	435	N/A	TR-STK-S-54	Transect	Annually		
STK	436	882	SG-STK-S-55-CG	Surface Water	Twice Monthly	28.25846019	-82.58740659
		958	WE-STK-S-55-CW	Well	Twice Monthly	28.25846179	-82.58741184
STK	438	885	SG-STK-S-62-CG	Surface Water	Twice Monthly	28.25123515	-82.58368348
		1963	WE-STK-S-62-CW2	Well	Twice Monthly	28.25123206	-82.58368864
		N/A	TR-STK-S-62	Transect	Annually		
STK	439	886	SG-STK-S-63-CG	Surface Water	Twice Monthly	28.24864714	-82.58335691
		962	WE-STK-S-63-CW	Well	Twice Monthly	28.24866874	-82.58335788
		N/A	TR-STK-S-63	Transect	Annually		
STK	440	887	SG-STK-S-64-CG	Surface Water	Twice Monthly	28.2413091	-82.58526081
		963	WE-STK-S-64-CW	Well	Twice Monthly	28.24130592	-82.58525721
		N/A	TR-STK-S-64	Transect	Annually		
STK	445	893	SG-STK-S-70-CG	Surface Water	Twice Monthly	28.25039225	-82.56923029
		969	WE-STK-S-70-CW	Well	Twice Monthly	28.25039743	-82.56923174
		N/A	TR-STK-S-70	Transect	Annually		
STK	447	N/A	TR-STK-S-73	Transect	Annually		

Wellfield Code	Wetland ID	District ID	Permittee Name	Monitor Type	Frequency	Latitude	Longitude
STK	448	896	SG-STK-S-74-CG	Surface Water	Twice Monthly	28.25703133	-82.56656873
		972	WE-STK-S-74-CW	Well	Twice Monthly	28.25702925	-82.56656692
		1969	WE-STK-S-74-UW	Well	Twice Monthly	28.25656565	-82.56670103
		N/A	TR-STK-S-74	Transect	Annually		
STK	449	N/A	TR-STK-S-75	Transect	Annually		
STK	451	1640	SG-STK-S-80-CG	Surface Water	Twice Monthly	28.23666119	-82.58292611
		1693	WE-STK-S-80-CW2	Well	Twice Monthly	28.23665715	-82.58292225
		N/A	TR-STK-S-80	Transect	Annually		
STK	454	902	SG-STK-S-84-CG3	Surface Water	Twice Monthly	28.23200936	-82.6045417
		3035	SG-STK-S-84-EG	Surface Water	Twice Monthly	28.2319971	-82.6045583
		978	WE-STK-S-84-CW	Well	Twice Monthly	28.23201124	-82.60454281
		3036	WE-STK-S-84-UW	Well	Twice Monthly	28.23241983	-82.60474461
		N/A	TR-STK-S-84	Transect	Annually		
STK	456	904	SG-STK-S-89-CG	Surface Water	Twice Monthly	28.23911274	-82.56605632
		3120	SG-STK-S-89-EG	Surface Water	Twice Monthly	28.23925147	-82.56646035
		980	WE-STK-S-89-CW	Well	Twice Monthly	28.23911382	-82.56605282
		1971	WE-STK-S-89-UW	Well	Twice Monthly	28.23944323	-82.56669813
		N/A	TR-STK-S-89	Transect	Annually		
STK	457	N/A	TR-STK-S-90	Transect	Annually		
STK	459	907	SG-STK-S-95-CG	Surface Water	Twice Monthly	28.24462698	-82.60264778
		983	WE-STK-S-95-CW	Well	Twice Monthly	28.24462665	-82.60264448
		3037	SG-STK-S-95-EG	Surface Water	Twice Monthly	28.24480203	-82.6028019
		N/A	TR-STK-S-95	Transect	Annually		
STK	461	909	SG-STK-S-97-CG	Surface Water	Twice Monthly	28.23941678	-82.59695856
		985	WE-STK-S-97-CW	Well	Twice Monthly	28.23941227	-82.59695649
		N/A	TR-STK-S-97	Transect	Annually		
STK	464	858	SG-STK-S-108-CG	Surface Water	Twice Monthly	28.23872977	-82.55878281
		933	WE-STK-S-108-CW	Well	Twice Monthly	28.23872772	-82.55878314
		1955	WE-STK-S-108-UW	Well	Twice Monthly	28.23892381	-82.55887169
		N/A	TR-STK-S-108	Transect	Annually		
STK	465	N/A	TR-STK-S-109	Transect	Annually		

Wellfield Code	Wetland ID	District ID	Permittee Name	Monitor Type	Frequency	Latitude	Longitude
STK	468	3052	SG-STK-S-113-CG	Surface Water	Twice Monthly	28.23342873	-82.58989626
		3053	WE-STK-S-113-CW	Well	Twice Monthly	28.23342359	-82.58989985
		N/A	TR-STK-S-113	Transect	Annually		
STK	471	912	SG-STK-SC-30-CG	Surface Water	Twice Monthly	28.30249632	-82.59614733
		988	WE-STK-SC-30-CW	Well	Twice Monthly	28.30243566	-82.59611403
		3038	SG-STK-SC-30-EG	Surface Water	Twice Monthly	28.30243492	-82.59611912
		N/A	TR-STK-SC-30	Transect	Annually		
STK	475	915	SG-STK-SC-58-CG	Surface Water	Twice Monthly	28.21135211	-82.60150583
		990	WE-STK-SC-58-CW	Well	Twice Monthly	28.21128499	-82.60136245
		N/A	TR-STK-SC-58	Transect	Annually		
STK	476	916	SG-STK-SC-59-CG	Surface Water	Twice Monthly	28.23722038	-82.67203077
		991	WE-STK-SC-59-CW	Well	Twice Monthly	28.23722222	-82.67203843
		N/A	TR-STK-SC-59	Transect	Annually		
STK	478	1053	SG-STK-SC-67-CG	Surface Water	Twice Monthly	28.20991062	-82.63498626
		1002	WE-STK-SC-67-CW	Well	Twice Monthly	28.20990908	-82.63498325
		3039	SG-STK-SC-67-EG	Surface Water	Twice Monthly	28.21015782	-82.63473065
		N/A	TR-STK-SC-67	Transect	Annually		
STK	483	918	WE-STK-SC-92-CW	Well	Twice Monthly	28.2185249	-82.60208735
		3042	SG-STK-SC-92-EG	Surface Water	Twice Monthly	28.21862942	-82.60199457
		N/A	TR-STK-SC-92	Transect	Annually		
STK	484	N/A	TR-STK-STWF-Central-01	Transect	Annually		
STK	485	N/A	TR-STK-STWF-N	Transect	Annually		
STK	486	N/A	TR-STK-STWF-D	Transect	Annually		
STK	487	N/A	TR-STK-Z	Transect	Annually		

Wellfield Code	Wetland ID	District ID	Permittee Name	Monitor Type	Frequency	Latitude	Longitude
STK	488	920	SG-STK-T-7-CG	Surface Water	Twice Monthly	28.25581994	-82.58241951
		998	WE-STK-T-7-CW	Well	Twice Monthly	28.25581095	-82.58240043
		N/A	TR-STK-T-7	Transect	Annually		
STK	489	921	SG-STK-T-9-CG	Surface Water	Twice Monthly	28.24435524	-82.5521213
	489	1679	WE-STK-T-9-CW	Well	Twice Monthly	28.24435619	-82.55211866
	489	N/A	TR-STK-T-9	Transect	Annually		
STK	490	919	SG-STK-T-10-CG	Surface Water	Twice Monthly	28.23718299	-82.55171673
NULL		3063	SG-MOD-MDSTAFF-A-CG	Surface Water	Twice Monthly	28.14085761	-82.2452608
NULL		3064	SG-MOD-MDSTAFF-I-CG	Surface Water	Twice Monthly	28.13633838	-82.23965933
NULL		3066	SG-MOD-MDSTAFF-K	Surface Water	Twice Monthly	28.13823758	-82.23939476
NULL		3076	SG-MOD-MDSTAFF-K-EG	Surface Water	Twice Monthly	28.13827051	-82.23949938
NULL		3065	SG-MOD-MDSTAFF-Z-CG	Surface Water	Twice Monthly	28.13765946	-82.23022909
CNR	52	3067	SG-CNR-C5-CG	Surface Water	Twice Monthly	28.11511789	-82.10770796
CNR	52	3069	WE-CNR-C5-CW	Well	Twice Monthly	28.11512045	-82.10771017
CNR	53	3068	SG-CNR-C6C-CG	Surface Water	Twice Monthly	28.12541324	-82.12022226
CNR	53	3070	WE-CNR-C6C-CW	Well	Twice Monthly	28.1254106	-82.12022701

Exhibit C.5
Augmentation Sites

Exhibit C.5
Augmentation Sites

Site Name
Goose Lake
Clear Lake
Spring Lake
Duck Pond
Round Pond
Lost Lake
Cross Bar-6
Cross Bar-8
Cypress Creek W-3
Cypress Creek W-5
Cypress Creek W-21
Cypress Creek W-36
Cypress Creek W-37
Lake Dan with Modifications

Augmentation Wells			
Permittee ID No.	**District ID No.**	**Latitude**	**Longitude**
CBR-CB1	820	282116.48	822741.91
CBR-CB2	821	282134.65	822754.66
CBR-CB3	822	282145.36	822838.36
CBR-CB4	823	282157.34	822802.00
CBR-CB5	824	282232.92	822732.74
CBR-CB7	825	282234.70	822841.08
CBR-CB8	826	282215.00	822852.55
CBR-CB9	827	282308.59	822806.67
CYC-W21	828	281642.45	822432.91
CYC-W3	829	281812.90	822239.85
CYC-W36	831	281742.19	822211.73
CYC-W37	832	281744.71	822213.99
CYC-W5	833	281819.24	822254.00
ELW-139	834	280947.54	823824.93
ELW-5B	835	280906.78	823940.57

Exhibit C.6
MFL Sites

Exhibit C.6
MFL Sites

Lake	County
Alice	Hillsborough
Allen/Harvey/Virginia	Hillsborough
Big Fish	Pasco
Bird	Hillsborough
Brant	Hillsborough
Calm	Hillsborough
Camp	Pasco
Charles	Hillsborough
Church/Echo	Hillsborough
Crenshaw	Hillsborough
Crescent	Hillsborough
Crews	Pasco
Crystal	Hillsborough
Cypress	Hillsborough
Dan	Hillsborough
Dosson/Sunshine	Hillsborough
Fairy (Maurine)	Hillsborough
Garden	Hillsborough
Halfmoon	Hillsborough
Helen/Barbara/Ellen	Hillsborough
Horse	Hillsborough
Jackson	Hillsborough
Juanita	Hillsborough
Linda	Pasco
Merrywater	Hillsborough
Mound	Hillsborough
Platt	Hillsborough
Pretty	Hillsborough
Rainbow/Little Moon	Hillsborough
Raleigh	Hillsborough
Reinheimer	Hillsborough
Rogers	Hillsborough
Round	Hillsborough
Saddleback	Hillsborough
Sapphire	Hillsborough
Starvation	Hillsborough
Strawberry (N. Crystal)	Hillsborough
Sunset	Hillsborough
Taylor	Hillsborough
Unnamed Lake #22 (Loyce)	Pasco

Wetlands
Cross Bar Q-1
Cross Bar T-3
Cypress Bridge 16
Cypress Bridge 25
Cypress Bridge 32
Cypress Bridge 4
Cypress Creek W-11
Cypress Creek W-12
Cypress Creek W-17
Cypress Creek W-56 (G)
Eldridge Wilde 11 (NW-44)
Eldridge Wilde 5
Morris Bridge Clay Gully Cypress (MBR-88)
Morris Bridge Entry Dome (MBR-35)
Morris Bridge Unnamed (MBR-16)
Morris Bridge X-4 (MBR-89)
North Pasco 21
North Pasco 3
South Pasco 2 (NW-49)
South Pasco 6 (NW-50)
South Pasco South Cypress
Starkey Central
Starkey Eastern (S-73)
Starkey M (S-69)
Starkey N
Starkey S-75
Starkey S-99
Starkey Z

Rivers
Pithlachascotee
Upper Hillsborough

Aquifers
Northern Tampa Bay SWIMAL

Exhibit D
Operations Plan

Operations Plan Update

Revised December 2014

Submitted to the Southwest Florida Water Management District

OPERATIONS PLAN
UPDATE

Revised December 2014

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December 2014

1. INTRODUCTION

In 1998, Tampa Bay Water developed an Operations Plan to govern the operations of the 11 Central System Facilities under the direction of (a) the Amended and Restated Interlocal Agreement between the Tampa Bay Water Member Governments, (b) the Partnership Agreement between Tampa Bay Water, its Member Governments, and the Southwest Florida Water Management District (SWFWMD), and (c) the Consolidated Permit for the Central System Facilities. This update to the 2010/2011 Updated Operational Plan includes all updates and modifications made to the OROP since that time. Changes to the Operations Plan will occur in accordance with conditions of the Interlocal Agreement, Recovery Plan (Chapter 40D-80, F.A.C), and Consolidated Permit. At a minimum, submittal of the Operations Plan bi-annual reports to the SWFWMD is required. Copies of the original OROP report (1998) and annual report updates (July 1999 – July 2009) are available in the Records Department of Tampa Bay Water.

This updated Operations Plan is comprised of Tampa Bay Water's operations protocol, the Optimized Regional Operations Plan, and supporting models and data used in the development of a weekly well rotation schedule for the Central System Facilities. The Operations Plan is considered a Primary Environmental Permit as defined in the Amended and Restated Interlocal Agreement.

The objectives of the Operations Plan are to improve Tampa Bay Water's ability to understand the water-level effects of water supply operations that affect environmental conditions, enhance water supply management programs to benefit the surrounding environment, and increase water levels in areas of interest while meeting Member Government water demands.

2. GENERAL OPERATIONS PROTOCOL

It is the policy of Tampa Bay Water to minimize constraints and maximize operational flexibility of its public water supply system, while giving priority to meeting the Member Governments' demand for Quality Water, complying with all permit conditions and limitations, and reducing the adverse environmental effects of excessive or improper withdrawals of water from concentrated areas.

<u>Regional System General Description</u>
Tampa Bay Water has constructed a regional water delivery system that is comprised of groundwater sources, surface water sources, an off-stream storage reservoir, a seawater desalination facility and pumping and piping to distribute Quality Water. The table below summarizes the regional system facilities in service as of December 2009. The location of these facilities is shown on Figure 1.

Distribution	Groundwater Facilities	Surface Water Facilities
• 8 pumping/booster stations	• 13 wellfields	• 3 river withdrawal points; 1 desalination withdrawal point
• 21 points of connection	• 178 wells	• 1 re-pump station
• ~100 miles of raw water pipeline	• 2 individual well facilities	• 1 15.5 billion gallon surface water storage reservoir
• ~100 miles of finished water pipeline	• 4 groundwater treatment facilities	• 1 surface water treatment plant
• 2 alkalinity adjustment facilities	• 1 hydrogen sulfide removal facility	• 1 seawater desalination plant

<u>General Operations Protocol</u>
Given the infrastructure, regulatory, and water quality constraints of the system, the uncertainty in climate, demands and sources, and the Board's policy, Tampa Bay Water plans to use the best mix of supplies to meet demand under all hydrologic conditions, including droughts.

Tampa Bay Water's operations protocol provides general guidance in the planning and scheduling of water supply sources to meet member demands. Annual planning of the allocation and use of water supplies starts with the agency's budget preparation. The agency budgeting process begins each January and concludes with Board for Directors approval the following June. The budget is implemented in October; start of the new fiscal and water year. Based on the expected annual delivery of water for the upcoming water year, an average annual supply allocation is determined that meets the agency's policy directive. As the upcoming water year approaches, the expected demand and supply quantities are re-evaluated and allocated monthly based on seasonal hydrologic factors and expected climate influences. Monthly allocations are then used to guide the weekly Optimized Regional Operations Plan well withdrawal scheduling based on weekly demand forecasting and weekly surface water availability. Table 1 summarizes the implementation of this general operations protocol.

3. OPTIMIZED REGIONAL OPERATIONS PLAN

<u>A. Introduction</u>

The Optimized Regional Operations Plan (OROP) is a key component of the Operations Plan. The OROP is a custom-built application which incorporates an optimization model and utilizes output from various models, current hydrologic and pumpage data, and a set of operating constraints to manage the 11 wellfields under the Consolidated Permit (also known as the Central System Facilities), the Brandon Urban Dispersed Wells (BUDW), and the Carrollwood wells (Figure 2) through the development of weekly production schedules. The models used to provide input to the optimization model include the Integrated Hydrologic Model (through the development of a unit response matrix (URM)), a group of artificial neural network models, surface water forecasting tools, and short-term demand forecasting models. Input to the optimization model includes demands, surface water availability and scheduled withdrawals from the Hillsborough River/Tampa Bypass Canal system, Alafia River and Regional Reservoir, and scheduled production from the seawater desalination facility. The optimization model schedules production from the Central System wellfields based on current hydrologic conditions, operational constraints, permit limits, forecasted treated surface water reliably available from the regional surface water treatment plant, and reliably available desalinated seawater, to meet forecasted Member Government demands, and seeks to optimize groundwater levels based on targets at a selected set of surficial aquifer and Upper Floridan Aquifer monitoring wells called control points. It also adheres to operating policies and infrastructure physical limits as well as complies with conditions of the Consolidated and other water use permits. Policy issues are addressed by using weights to assign preferences to maximize groundwater levels at the control point locations. The output of the optimization routine is a weekly schedule prioritizing pumpage from all active production wells of the Central System Facilities.

The optimization model is a linear/nonlinear programming (LP/NLP) package based on the primal simplex method. The model has an objective function and a system of constraints. Constraints that govern the optimization model generally fall into one of four categories – physical constraints (e.g., pump capacities, conveyance facilities), regulatory constraints (e.g., wellfield pumping limits, specified water levels), operational constraints (e.g., water quality, minimum production limits), and demand constraints. An additional set of constraints that represents the integrated surface/groundwater hydrologic system is required to complete the optimization formulation.

The hydrologic model, which is based on the physical characteristics of the surface and groundwater systems, simulates changes in water levels due to changes in pumpage and rainfall. The pumpage/water-level relationships are based on the Integrated Hydrologic Model (IHM) Northern Tampa Bay application providing a unit response for each production/monitor well combination which relates pumpage changes to water-level changes.

Water quality constraints are included in both the physical constraint and regulatory constraint categories. Tampa Bay Water produces a "finished" product that must meet standards and requirements against multiple metrics under our Master Water Supply Contract with the Member Governments, principally involving the defined term "Quality Water". Section 1.01 of the Amended and Restated Interlocal Agreement defines "Quality Water".

Firstly, Quality Water must meet state and federal drinking water regulations and standards as defined in Rule 62-550, Florida Administrative Code; see http://www.dep.state.fl.us/water/drinkingwater/rules.htm for a downloadable .pdf file which provides the details. These are broadly applicable requirements for public water supply utilities.

Secondly, Quality Water would not cause a particular Member Government utility to adopt new treatment techniques beyond modified chemical dosages and/or optimization of existing unit processes. This is a special requirement imposed on Tampa Bay Water by the six Member Governments, which largely concerns assignment of responsibilities and cost allocations between the wholesale and retail partners.

Thirdly, Quality Water shall meet the standards provided in Exhibit D of the Master Water Supply Contract (Table 2). This is a special requirement imposed on Tampa Bay Water by the six Member Governments and reflects the local community value of an expectation of consistently high quality drinking water that is in certain regards better than the state and federal requirements. The driving force behind Exhibit D is to highlight these community expectations, and to identify parameters of concern or potential concern. For those cases where numeric limits are not shown in Exhibit D, consensus has not been achieved among the parties and the constituent is under study for future consideration through amendment(s) to the Exhibit.

The original mathematical formulation for the optimization routine was described in the revised OROP report (October 30, 1998). Several revisions and improvements have been implemented since the October 30, 1998 report and are described in the series of OROP annual reports. Copies of the reports are available in the Records Department of Tampa Bay Water. The OROP in its latest updated form is presented in this report.

B. Description of Facilities under the OROP

The groundwater production facilities governed by the OROP include the 11 wellfields of the Consolidated Permit (Cross Bar Ranch, Cypress Creek, Cypress Bridge, North Pasco, Starkey, Northwest Hillsborough Regional, Eldridge-Wilde, Cosme-Odessa, Section 21, South Pasco, and Morris Bridge), the BUDW, and the Carrollwood Wells. The Enhanced Surface Water System, Tampa Bay Water's seawater desalination facility, and the interconnects with the City of Tampa provide input into the optimization routine. These facilities are shown in Figure 2.

(1) Cosme-Odessa Wellfield

The Cosme-Odessa Wellfield is comprised of 19 active wells and one standby well located in the northwest region of Hillsborough County. All of the wells except wells 1C and 2 are located on one-acre parcels purchased by Tampa Bay Water. These one-acre parcels are located within larger tracts of property owned by the City of St. Petersburg. Wells 1C and 2 are located on property owned by the City of St. Petersburg with easements provided to Tampa Bay Water. The wellfield feeds raw water to the Cosme Water Treatment Plant (WTP) which is owned and operated by the City of St. Petersburg. Public water supply is then transmitted to the City of St. Petersburg water service area via a distribution system owned and operated by the City of St. Petersburg. Tampa Bay Water owns and operates the wellfield facilities.

(2) Cross Bar Ranch Wellfield

The Cross Bar Ranch Wellfield is comprised of 17 wells and provides water to Tampa Bay Water's Regional System. The wellfield is located in north-central Pasco County. The production wells are on individual one-acre parcels located within an 8000-acre tract owned by Pinellas County. The raw water is piped through a 60-inch diameter transmission main to the Cypress Creek WTP. Tampa Bay Water owns and operates the Cross Bar Ranch Wellfield facilities and the Cypress Creek WTP.

(3) Cypress Bridge Wellfield

The Cypress Bridge Wellfield provides water to the Regional System through its connections to the Cypress Creek WTP and the Lake Bridge WTP. The Cypress Bridge System includes a total of ten wells, a water treatment plant (the Lake Bridge Water Treatment Plant), and ancillary transmission facilities. The wells are on dispersed one- to 40-acre properties located in south-central Pasco County and in north-central Hillsborough County. The treatment plant facilities include a 6.9 million gallons per day (mgd) pumping station with three high service pumps, and disinfection and pH control facilities. The Cypress Bridge wells, Lake Bridge WTP, and transmission mains are owned and operated by Tampa Bay Water.

(4) Cypress Creek Wellfield

The 13 wells of the Cypress Creek Wellfield provide water to the agency's Regional System. The wellfield is located in central Pasco County. The wellfield is located on 4900 acres of which SWFWMD owns 3628 acres and Tampa Bay Water owns the remainder. Water is pumped to the nearby Cypress Creek WTP which is equipped with two five-million-gallon above-ground storage reservoirs and six high service pumps. The WTP also receives raw water from the Cross Bar Ranch Wellfield. The water is chloraminated and treated with sodium hydroxide for pH control. The permitted treatment capacity is 110 mgd. Diesel generator power is available for operation of three high service pumps during power outages. The wellfield facilities and WTP are owned and operated by Tampa Bay Water.

(5) North Pasco Wellfield

The North Pasco Wellfield is located in west central Pasco County. The wellfield was permitted for six wells; four of the production wells have been constructed. Two wells are now operational, providing water through a 36-inch raw water transmission main connecting to the Starkey Wellfield raw water collection main. The wells are on dispersed one-acre tracts generally located within or adjacent to property purchased by the Florida Department of Transportation. During the reporting period, water from this facility served the West Pasco County and New Port Richey service areas. Tampa Bay Water owns and operates the wellfield facilities.

(6) Northwest Hillsborough Regional Wellfield

The Northwest Hillsborough Regional Wellfield (NWHRW) is comprised of seven regional production wells and two subdivision wells (Manors of Crystal Lakes wells 1 and 2) in northwestern Hillsborough County. The production wells are situated on dispersed one- to four-acre tracts. Six of the seven regional wells supply water primarily to Hillsborough County's Northwest Hillsborough Potable Water Facility (for distribution to the northwest Hillsborough Service Area). Infrastructure is in place to also provide water from these six wells to the City of St. Petersburg's Cosme WTP. A raw water transmission main connecting NWH well number 7 to the Section 21 Wellfield was completed in December 2009. The two subdivision wells (Manors of Crystal Lakes wells 1 and 2) provide potable water to an isolated service area within the northwest Hillsborough Service area and are not included in the optimization model, but these well production totals are included in calculating the 12-month running average for the Northwest Hillsborough Regional Wellfield. Production from both subdivision wells is included in the pump package of the integrated hydrologic model on a weekly basis. Tampa Bay Water owns and operates the Northwest Hillsborough Regional Wellfield and the two subdivision production wells.

(7) Section 21 Wellfield

The Section 21 Wellfield, which includes six active wells and two standby wells, is located in northwest Hillsborough County. The wells are located on one-acre parcels within a 583-acre tract owned by the City of St. Petersburg. This wellfield provides raw water exclusively to the Northwest Hillsborough Service Area via Hillsborough County's Lake Park WTP. Tampa Bay Water owns and operates the wellfield facilities.

(8) Starkey Wellfield

The Starkey Wellfield includes nine active production wells and five standby wells located in west-central Pasco County on 7980 acres of land owned by the SWFWMD. These facilities provide water supply to the New Port Richey and West Pasco County service areas. The West Pasco Transmission main was completed and placed into service in December 2007. Raw water from the Starkey Wellfield is now piped to the City of New Port Richey's Joseph Maytum WTP for treatment and distribution to New Port Richey and Pasco County. Tampa Bay Water and the City of New Port Richey entered into a water purchase agreement which guides the amount of groundwater treated at the Maytum WTP. Five Starkey Wellfield production wells (Well 14, well 13, well 11, well 1 and well 2) have been placed in standby due to very high hydrogen sulfide concentrations. Placing these wells on standby does not constrain Tampa Bay Water's ability to meet emergency demands for Pasco County or New Port Richey that may be caused by infrastructure failures. The wellfield facilities are owned and operated by Tampa Bay Water.

(9) Morris Bridge Wellfield

The Morris Bridge Wellfield is located on 3800 acres of land in north-central Hillsborough County acquired by the SWFWMD for flood control as part of the lower Hillsborough River Flood Detention area. The wellfield is comprised of 20 active wells. Treated groundwater is provided to Tampa Bay Water's Regional System. The wellfield facilities are owned and operated by Tampa Bay Water.

(10) Eldridge-Wilde Wellfield

The Eldridge-Wilde Wellfield is located on approximately 1800 acres in the northeast corner of Pinellas County and the northwest corner of Hillsborough County. The wellfield consists of 34 active wells. Raw water is piped to the S.K. Keller WTP, which is owned and operated by Pinellas County. Treated water is then transmitted to Pinellas County's service area. The wellfield facilities and hydrogen sulfide removal facility are owned and operated by Tampa Bay Water.

(11) South Pasco Wellfield

The South Pasco Wellfield is comprised of eight active wells located on one-acre parcels within a 590-acre tract owned by the City of St. Petersburg. This wellfield is located in southwest Pasco County near S.R. 54. This water is piped to the City of St. Petersburg's Cosme WTP and to Hillsborough County's Lake Park WTP. Tampa Bay Water owns and operates the wellfield facilities.

(12) Brandon Urban Dispersed Wells

The Brandon Urban Dispersed Wells facility (BUDW) consists of five widely-dispersed wells in the Brandon area. The original BUDW well number 5 was removed from service during Water Year 2006, and following District approval this well's permitted well quantities were re-distributed to the four remaining wells. Tampa Bay Water conducted tests to determine a suitable replacement well location for BUDW well number 5. Permitting of the replacement well occurred during renewal of the BUDW water use permit which was completed in Water Year 2009. The wells are connected to the Regional System via the Brandon/South-Central Connection, a 30-inch diameter pipeline interconnecting the Regional Facilities with the BUDW and the existing Lithia WTP. Treated water from the BUDW is provided to the regional system and to the Lithia WTP.

(13) Carrollwood Wells

The Carrollwood Wells facility consists of three dispersed wells in the Northwest Hillsborough service area. The Carrollwood wells have been in service for decades, located on residential lots within the Carrollwood neighborhood. Tampa Bay Water acquired the water use permit, production wells and land in 2004 and Hillsborough County acquired the service area from Florida Governmental Utilities Association (FGUA). The wells are connected to the Regional System via a newly constructed raw water main that connects these wells to the Northwest Hillsborough Regional Wellfield. The wells were placed into service during Water Year 2008. These wells have a combined permitted capacity of 820,000 gallons per day. Tampa Bay Water owns and operates the wells and transmission facilities.

(14) Enhanced Surface Water System Facilities

The Enhanced Surface Water System facilities consist of a pump station on the Tampa Bypass Canal (TBC), a pump station on the Alafia River, the regional surface water treatment plant (RWSTP), a re-pump station, the C.W. Bill Young Regional Reservoir and associated transmission mains. The pump station at the TBC delivers raw water to the RSWTP through an 84-inch diameter pipeline. The pump station at the Alafia River delivers raw water to the RSWTP through the 72-inch diameter South-Central Intertie or to the Regional Reservoir through its transmission main. Also located at the regional facility site is a re-pump station which delivers excess raw water supplies available from the Regional Facility to the Regional Reservoir. Raw water from the Regional Reservoir is gravity-fed back to the RSWTP via the South-Central Intertie.

(15) Seawater Desalination Facility

The Tampa Bay Seawater Desalination facility is located adjacent to the Tampa Electric Company's Big Bend Power station near Apollo Beach on Tampa Bay. This plant has a design nominal treatment capacity of 25 mgd.

(16) Tampa/Hillsborough Interconnect

The Tampa/Hillsborough Interconnect (THI) became operational in 1997 and supplies treated surplus water from the City of Tampa to the Hillsborough County Northwest Service Area. It has a peak firm capacity of 7.5 mgd. However, the surplus supply is limited by the City of Tampa's water treatment capacity, demands, and water use permit. During Water Year 2005, the THI was taken off-line in March 2005 for Hillsborough County to evaluate options to address distribution water quality issues. The THI was returned to service in December 2005 and has operated continuously since that time.

(17) U.S. 301 Interconnect

During 2002, the City of Tampa constructed a 36-inch diameter interconnect (U.S. 301 Interconnect) and this pipeline became operational in December 2003. This treated water interconnect from the City of Tampa to the Regional High Service Pump Station has a projected peak capacity of 20 mgd and will enable the supply of 2-5 mgd on an annual average basis. However, the surplus supply is limited by the City of Tampa's water treatment capacity, demands, and water use permit. In 2008, Tampa Bay Water made improvements at the U.S.301 interconnect which will allow Tampa Bay Water to provide up to 30 mgd of potable water to the City on an emergency basis, as requested by the City. Tampa Bay Water owns and operates the facilities.

C. Optimization Formulation and Implementation

a.) Optimization Formulation

The objective of this optimization problem is to maximize ground-water levels at specified locations in the surficial aquifer system (SAS) while satisfying the projected water demands and complying with regulatory requirements, given the system constraints. The primary decision variables for each time period are the pumping rates at each production well withdrawing from the Upper Floridan Aquifer system (UFAS). The secondary decision variables (also called state variables) are the ground-water levels in monitoring wells for both the SAS and UFAS. The problem is subjected to two general constraint sets and three specific constraint sets. The general constraint sets consist of a system of equations describing the surface and ground-water hydrology and the variable bounds. Tampa Bay Water's Integrated Hydrologic Model of the Northern Tampa Bay area is currently used to simulate the physical system hydrology. The specific constraint sets consist of the demand constraints, the regulatory constraints on water levels and pumpage specified in the water use permits (WUPs), and operation/maintenance and water quality constraints of the infrastructure system. The optimization routine determines the wellfield and well production schedule based on the water demands projected for each of the points of connection and reliably available treated surface water and desalinated seawater.

Before the problem is formulated mathematically, a set of notations must be defined. Let,

i = an index of an element in the set R^u or R,

t = an index for time period corresponding to the week number in the simulation model, ($t \leq 0$ refers to time index prior to the start of simulation)

$h^u_{i,t}$ = the SAS water level at location i at the end of time period t,

$h_{i,t}$ = the UFAS water level at location i at the end of time period t,

ω_i = the assigned weight to enable priority factors applied to reduce environmental stress preferentially at location i,

R^u = a set of monitoring wells in SAS where water levels are being maximized,

R = a set of regulatory monitoring wells specified in WUPs,

H_i = regulatory water level in the UFAS at the monitoring well i,

$q_{j,t}$ = average weekly pumping rate from the j^{th} well for time period t,

$d^r_{n,t}$ = pipe flow from the n^{th} source to the r^{th} point of connection during time period t,

D^r_t = water demand for the r^{th} point of connection for time period t,

w_n = a set of production wells for the n^{th} wellfield,

j = an index of an element in the set w_n,

P^y_n = regulatory 12-month average withdrawal for wellfield n,

P^m_n = regulatory peak month withdrawal for wellfield n,

P_j^m = regulatory peak month withdrawal for well *j*,

W_t = the week number in water year (commence on Oct 1 each year) for time period *t*,

C_j^{Fe} = level of measuring iron concentration (mg/l) in production well *j*,

C_j^{H2S} = level of measuring hydrogen sulfide concentration (mg/l) in production well *j*,

$\underline{Q}_j, \overline{Q}_j$ = the lower and upper production limits (by the maintenance requirement, or well capacities, or the peak shaving program) for the j^{th} well,

Q^{cc} = the Cypress Creek Pumping Station capacity,

$\underline{Q}_n^{wf}, \overline{Q}_n^{wf}$ = minimum and maximum limits (required to maintain line pressure or to stay in the venturi calibration ranges) for the n^{th} wellfield,

All pumping rates, production limits, demand requirements, and flow quantities are in mgd. All water levels are in ft NGVD. In addition to the above notation the following abbreviations are used to identify source and demand points:

cr = Cross Bar Ranch Wellfield,
cc = Cypress Creek Wellfield,
cb = Cypress Bridge Wellfield,
sp = South Pasco Wellfield,
mb = Morris Bridge Wellfield,
s21 = Section 21 Wellfield,
nwh = Northwest Hillsborough Wellfield,
cm = Cosme Odessa Wellfield,
ew = Eldridge Wilde Wellfield,
st = Starkey Wellfield,
np = North Pasco Wellfield,
bu = Brandon Urban Dispersed Wells,
sch = South-Central Hillsborough Wellfield,
crw = Carrollwood wells,
cot = Purchased water from City of Tampa
WF^c = {*cr,cc,cb,sp,mb,s21,nwh,cm,ew,st,np*} is a set of Consolidated Permit Wellfields,
CC = Cypress Creek Water Treatment Plant (WTP),
MB = Morris Bridge WTP,
LB = Lake Bridge WTP,
LP = Lake Park WTP,
NW = Northwest Hillsborough WTP,
CM = Cosme WTP,
LR = Little Road WTP,
MT = Maytum WTP,
PD = West Pasco Point of Connection – Pasco Distribution System,
OD = Odessa Water Treatment Plant– Pasco Distribution System,
CH = Central Hillsborough Regional Water Treatment Facility (replaced Highview)
MP = South Pasco Meter Pit,
PK = Pinellas County Distribution System (Keller WTP and Regional System),
LT = Lithia Water Treatment Plant,
RWTP = Regional Surface Water Treatment Plant,

SDP = Seawater Desalination Plant,
TBC = Hillsborough River/Tampa Bypass Canal pump station,
ALF = Alafia River pump station,
$TBRR$ = Tampa Bay Regional Reservoir,
$CBTM$ = Cypress Bridge Transmission Main,
$NCHI$ = North-Central Hillsborough Intertie,
$SCHI$ = South-Central Hillsborough Intertie.

The problem can be expressed mathematically as follows:

Objective function

$$Maximize \quad Z = \sum_{i \in R^u} \sum_{t=1}^{T} \omega_i h_{i,t}^u \tag{1}$$

Constraints

Demand constraints:

Some wellfields and Points of Connection (POC) are interconnected to the "Regional System" as shown in Figure 3. This constraint set must satisfy not only demands at Points of Connection but also the physical representation of the Regional System, namely, the quantity and direction of pipe flow. All demands used in this formulation are projected demands obtained from the Short-Term Water Demand Forecasting System Model (see Section 3D Summary of Models).

a) Morris Bridge WTP

$$d_{cc,t}^{MB} \geq D_t^{MB}, \quad \forall\, t = 1,\ldots,T \tag{2}$$

$$\sum_{j \in w_{mb}} q_{j,t} - d_{mb,t}^{CC} = 0, \quad \forall\, t = 1,\ldots,T \tag{3}$$

b) Lake Bridge WTP

$$d_{cc,t}^{LB} \geq D_t^{LB}, \quad \forall\, t = 1,\ldots,T \tag{4}$$

$$\sum_{j \in w_{cb}} q_{j,t} - d_{cb,t}^{CC} = 0, \quad \forall\, t = 1,\ldots,T \tag{5}$$

c) Lake Park WTP

$$d_{mp,t}^{LP} + d_{s21,t}^{LP} + d_{\mathrm{cot},t}^{THIC} \geq D_t^{LP}, \quad \forall\, t = 1,\ldots,T \tag{6}$$

$$\sum_{j \in w_{s21}} q_{j,t} - d_{s21,t}^{LP} + q_{nw7,t} = 0, \quad \forall\, t = 1,\ldots,T \tag{7}$$

d) Cosme WTP

$$d_{nwh,t}^{CM} + d_{mp,t}^{CM} + d_{cc,t}^{CM} + \sum_{j \in w_{cm}} q_{j,t} \geq D_t^{CM}, \quad \forall\, t = 1,\ldots,T \tag{8}$$

e) Northwest Hillsborough WTP

$$d^{NW}_{nwh,t} \ge D^{NW}_{t}\,, \quad \forall\ t = 1,\ldots,T \tag{9}$$

$$\sum_{j\in w_{nwh}} q_{j,t} - q_{nw7,t} + \sum_{j\in w_{crw}} q_{j,t} - d^{NW}_{nwh,t} - d^{CM}_{nwh,t} = 0, \quad \forall\ t = 1,\ldots,T \tag{10}$$

f) Keller WTP (has been combined with Pinellas County Distribution System)

g) Pinellas County Distribution System

$$d^{PK}_{cc,t} + \sum_{j\in w_{ew}} q_{j,t} \ge D^{PK}_{t}\,, \quad \forall\ t = 1,\ldots,T \tag{11}$$

h) Little & Maytum WTPs – Equations (12) and (13) reflect the new West Pasco Infrastructure

$$d^{LR}_{cc} + d^{LR}_{mt} \ge D^{LR}_{t}, \quad \forall\ t = 1,\ldots,T \tag{12}$$

$$\sum_{j\in\left\{w_{st}\cap w_{np}\right\}} q_{j,t} - d^{LR}_{mt} \ge D^{MT}_{t}\,, \quad \forall\ t = 1,\ldots,T \tag{13}$$

i) Pasco Interties

$$d^{PD}_{cc} \ge D^{PD}_{t}, \quad \forall\ t = 1,\ldots,T \tag{14}$$

$$d^{OD}_{cc} \ge D^{OD}_{t}, \quad \forall\ t = 1,\ldots,T \tag{15}$$

j) Regional (Cypress Creek WTP) and sub-regional pipe flow water balance

$$d^{PK}_{cc,t} + d^{MP}_{cc,t} + d^{CM}_{cc,t} + d^{PD}_{cc,t} + d^{OD}_{cc,t} + d^{LR}_{cc,t} = \sum_{j\in w_{cr}} q_{j,t} + \sum_{j\in w_{cc}} q_{j,t} + d_{CBTM,t}, \quad \forall\ t = 1,\ldots,T \tag{16}$$

$$d^{LB}_{cc,t} + d^{MB}_{cc,t} + d_{CBTM,t} - d^{CC}_{mb,t} - d^{CC}_{cb,t} - d_{NCHI,t} = 0, \quad \forall\ t = 1,\ldots,T \tag{17}$$

$$\sum_{j\in w_{sp}} q_{j,t} + d^{MP}_{cc,t} - d^{CM}_{mp,t} - d^{LP}_{mp,t} = 0, \quad \forall\ t = 1,\ldots,T \tag{18}$$

k) Finished water clear wells

$$d_{NCHI,t} = d_{SDP,t} + d_{RWTP,t} + d^{US301}_{COT,t} - d^{CH}_{cc,t}\,, \quad \forall\ t = 1,\ldots,T \tag{19}$$

l) Raw water tanks and high service pump station

$$d_{SCHI,t} = d_{RWTP,t} - d_{TBC,t}\,, \quad \forall\ t = 1,\ldots,T \tag{20}$$

m) Flow from Tampa Bay Regional Reservoir

$$d_{TBRR,t} = d_{SCHI,t} - d_{ALF,t}\,, \quad \forall\ t = 1,\ldots,T \tag{21}$$

n) Central Hillsborough Water Treatment Facility and Lithia WTP

$$d^{CH}_{cc,t} \ge D^{CH}_{t}\,, \quad \forall\ t = 1,\ldots,T \tag{22}$$

$$d_{cc,t}^{LT} + \sum_{j \in w_{bu}} q_{j,t} + \sum_{j \in w_{sch}} q_{j,t} \geq D_t^{LT}, \quad \forall\, t = 1,\ldots,T \tag{23}$$

In constraints (20) and (21), $d_{TBC,t}, d_{ALF,t}, d_{SDP,t}$, and $d_{TBRR,t}$ are the forecasted availability of surface water supply at Tampa Bypass Canal pump station, Alafia River pump station, Seawater Desalination Plant, and the C.W. Bill Young Regional Reservoir, respectively.

Regulatory and facility constraints:

a) WUP's regulatory levels for non-cumulative weekly average (swing level)

$$h_{i,t} \geq H_i - 3, \quad \forall\, i \in R;\ t = 1,\ldots,T \tag{24}$$

b) WUP's regulatory levels for cumulative weekly average (minimum level)

$$\left(\sum_{\tau = -W_{-1}}^{t} h_{i,\tau} \right) / W_t \geq H_i, \quad \forall i \in R;\ t \,|\, W_t > 8 \tag{25}$$

c) Weekly minimum and maximum production by wellfield (facility constraints, rulecurves, venturi limits)

$$\underline{Q}_n^{wf} \leq \sum_{j \in w_n} q_{j,t} \leq \overline{Q}_n^{wf}, \quad \forall n \in WF^c \bigcup \{bu\};\ t = 1,\ldots,T \tag{26}$$

d) 12-month running average total pumpage from the Consolidated Permit Wellfields
This permit constraint can be expressed as,

$$\sum_{n \in WF^c} \sum_{j \in w_n} \sum_{\tau = t-51}^{t} q_{j,\tau} \leq 52 P^y, \quad \forall\, t = 1,\ldots,T \tag{27}$$

e) Peak month for each wellfield (4-week basis)

$$\sum_{j \in w_n} \sum_{\tau = \max(1,t-3)}^{t} q_{j,\tau} \leq \min(4,t) P_n^m, \quad \forall n \in WF^c \bigcup \{bu\};\ t = 1,\ldots,T \tag{28}$$

f) Peak month for each well (4-week basis)

$$\sum_{\tau = \max(1,t-3)}^{t} q_{j,\tau} \leq \min(4,t) P_j^m, \quad \forall j \in w_n;\ n \in WF^c \bigcup \{bu\};\ t = 1,\ldots,T \tag{29}$$

g) Cypress Creek Pumping Station capacity

$$\sum_{j \in w_{cr}} q_{j,t} \sum_{j \in w_{cc}} q_{j,t} \leq Q^{cc}, \quad \forall\, t = 1,\ldots,T \tag{30}$$

h) Saltwater intrusion

Constraint equations to address saltwater intrusion are expressed in the same manner as regulatory wells. Equations (24) and (25) are applied at saltwater intrusion monitoring wells using the long-term mean values of water levels as the minimum levels.

i) South Central Hillsborough Wellfield permit condition

$$\sum_{j\in w_{sch}} \sum_{\tau=t-51}^{t} q_{j,\tau} \le 52 P_{sch}^{y}, \quad \forall t = 1,\ldots,T \tag{31}$$

$$\sum_{j\in w_{sch}} \sum_{\tau=\max(1,t-3)}^{t} q_{j,\tau} \le \min(4,t) P_{sch}^{m}, \quad \forall t = 1,\ldots,T \tag{32}$$

j) Carrollwood Wells peak month limitation based on Lake Carroll stage

$$\sum_{j\in w_{crw}} \sum_{\tau=\max(1,t-3)}^{t} q_{j,\tau} \le \min(4,t) P_{crw}^{m}, \quad \forall t = 1,\ldots,T \tag{33}$$

$$P_{crw}^{m} = \begin{cases} 0.820 \text{ mgd, if Lake Carroll monthly level } \ge \text{ 34.5 ft NGVD} \\ 0.707 \text{ mgd, otherwise.} \end{cases} \tag{34}$$

k) Water quality

One of Tampa Bay Water's obligations is to deliver Quality Water to its Member Governments. In order to meet this requirement, the Operations Department staff identified four wellfields in which certain wells exhibit a history of poor raw water quality with respect to iron and hydrogen sulfide concentrations. In order to address this raw water quality issue which is not addressed in the treatment of groundwater, Operations Department staff developed maximum concentrations of iron and hydrogen sulfide for the effluent from these wellfields. Constraint set 35 was formulated based on long-term observations of iron and sulfide concentrations (C_j^{Fe} and $C_j^{H_2S}$) from wells in Starkey Wellfield, Cross Bar Ranch Wellfield, Morris Bridge Wellfield and South Pasco Wellfield (see Figures 4 through 6). Beginning in Water Year 2009, Starkey Wellfield has been removed from the wellfield set in constraint 35, because five production wells with very high hydrogen sulfide concentrations placed on standby and removed from service. This removes the requirement to adjust the rotation schedule based on a water quality constraint at this wellfield.

$$\begin{aligned} &\sum_{j\in w_n} q_{j,t} C_j^{Fe} \le 0.3 \sum_{j\in w_n} q_{j,t}, \quad \forall\, n \in \{cr, mb\}; t = 1,\ldots,T \\ &\sum_{j\in w_n} q_{j,t} C_j^{H_2S} \le 2.5 \sum_{j\in w_n} q_{j,t}, \quad \forall\, n \in \{mb, sp\}; t = 1,\ldots,T \\ &\sum_{j\in w_{st}} q_{j,t} C_j^{H_2S} \le 1.0 \sum_{j\in w_{st}} q_{j,t}, \quad \forall\, t = 1,\ldots,T \end{aligned} \tag{35}$$

Other operating constraints: (requested by Operations Department)

a) Minimum flow from Eldridge-Wilde wellfield

$$\sum_{j\in w_{ew}} q_{j,t} \ge 3, \quad \forall\, t = 1,\ldots,T \tag{36}$$

b) Balance flows in pipelines for COSME cutoff

$$d_{cc,t}^{MP} = d_{cc}^{CM}\,, \quad \forall\, t = 1,\ldots,T \tag{37}$$

c) Lake Park venturi minimum

$$d_{mp,t}^{LP} \ge 4, \quad \forall\, t = 1,\ldots,T \tag{38}$$

d) Flow range for Maytum water treatment plant

$$2.5 \le \sum_{j \in \{w_{st} \cap w_{np}\}} q_{j,t} \le 10, \quad \forall\, t = 1,\ldots,T \tag{39}$$

Physical System: (derived from IHM model see Appendix A)

$$\mathbf{g(h^u, h, q) = 0} \tag{40}$$

Upper and lower bounds:

$$\underline{Q}_j \le q_{j,t} \le \overline{Q}_j, \quad \forall\, j \in w_n;\, n \in WF^c \cup \{bu, sch\};\, t = 1,\ldots,T \tag{41}$$

Non-negativity: (unidirectional flow pipes)

$$\begin{aligned}
&d_{cc,t}^{r} \ge 0, \quad \forall r \in \{PK, OD, PD, CM, MP, LB, MB, CH, LR, LT\}\ ;\ t = 1,\ldots,T \\
&d_{nwh,t}^{CM} \ge 0,\ d_{mp,t}^{CM} \ge 0,\ d_{nwh,t}^{NW} \ge 0,\ d_{mp,t}^{LP} \ge 0,\ d_{s21,t}^{LP} \ge 0,\ d_{mb,t}^{CC} \ge 0 \quad \forall\, t = 1,\ldots,T \\
&d_{mt,t}^{LR} \ge 0,\ d_{cb,t}^{CC} = 0,\ d_{COT,t}^{THIC} \ge 0,\ d_{COT,t}^{US301} \ge 0, \quad \forall\, t = 1,\ldots,T \\
&d_{ALF,t} \ge 0,\ d_{TBC,t} \ge 0,\ d_{RWTP,t} \ge 0,\ d_{SDP,t} \ge 0,\ d_{NCHI,t} \ge 0 \quad \forall\, t = 1,\ldots,T
\end{aligned} \tag{42}$$

b.) Implementation Details

Unit Response

Equation (40) represents the physical system constraint that consists of the set of equations describing the surface and ground-water hydrology. Theoretically, the Integrated Hydrologic Model could be embedded as a constraint function within the optimization routine. Due to the run times of the IHM, this is not practical since each optimization iteration requires as many functional evaluations as there are decision variables. In addition, the embedded approach would require a nonlinear optimizer to solve the optimization problem. An alternative, the *unit response* method, is used to represent the functional constraint with an equivalent linear response system of equations predetermined using IHM. The development of the unit response matrix is described in Appendix A.

Let,

$\varphi_{i,j}$ = a matrix element of the (SAS or UFAS) water level from the base scenario at location *i* at the end of time period *t*,

$\mathbf{u}_{i,j}$ = a (SAS or UFAS) unit response matrix as defined in Eq. (3) for the monitoring location *i* and production well *j*,

$\Delta q_{j,t}$ = a matrix element represents the increase in pumpage from the base scenario at the j^{th} well during the time period τ,

Using Eq. (4) in Appendix A the constraint (40) is replaced by two sets of system equations relating pumpage increments to water levels in each aquifer layer and is expressed as follows:

$$h_{i,t}^{u} = \varphi_{i,t}^{u} - \sum_{j} \sum_{k=1}^{t} u_{i,j,k}^{u} \Delta q_{j,t-k+1}, \quad \forall\, i \in R^{u}\,;\, t = 1,\ldots,T \tag{43}$$

$$h_{i,t} = \varphi_{i,t} - \sum_{j} \sum_{k=1}^{t} u_{i,j,k} \Delta q_{j,t-k+1}, \quad \forall\, i \in R\ \,;\, t = 1,\ldots,T \tag{44}$$

The incremental pumpage, $\Delta q_{j,t}$, is related to the decision variables $q_{j,t}$ as $\Delta q_{j,t} = q_{j,t} - v_{j,t}$ where $q_{j,t}$ is the pumpage from the base scenario or the initial projection of the pumpage schedule. The graphical representation of the above equation is depicted in Figure 8.

Note that the objective function can now be explicitly expressed in terms of pumpage decision variables by substituting the expression (43) into equation (1) to yield

$$Minimize \quad Z = \sum_{i \in R^{u}} \omega_i \sum_{t=1}^{T} \left(\sum_{j} \sum_{k=1}^{t} u_{i,j,k}^{u} \Delta q_{j,t-k+1} \right) \tag{45}$$

Investigation of the unit response time profiles found that SAS drawdowns at various monitoring wells recover from a pumpage pulse differently depending on the nearby hydrogeology and the distance between the pulsed and observation well pair. For a longer lag-time response, rainfall will play a major role in influencing water-level responses. Hence, the resting (e.g., non pumping) drawdown profile or the calculated responses from the pumpage no longer apply. To take advantage of differences in drawdown volumes at various monitoring sites, the time summation in (45) should be shortened to include the time profile up to the next expected effective rainfall (EERF) week. The expected number of weeks for effective dry-spell (T') will vary from week to week and can be predetermined from the twelve long-term rainfall gages in the region. This can be achieved by changing the terminal week number on the time summation, T, in the above equation to T'. In addition, the equation can be simplified if this time summation is predetermined such that:

$$\hat{u}_{i,j,\tau} = \sum_{k=\tau}^{T'} u_{i,j,k}^{u}, \ \text{for } \tau = 1..4 \tag{46}$$

and the objective function can be rewritten as:

$$Minimize \quad Z = \sum_{i \in R^{u}} \omega_i \sum_{\tau=1}^{4} \left(\sum_{j} \hat{u}_{i,j,\tau}^{u} \Delta q_{j,\tau} \right) \tag{47}$$

The effective rainfall can be estimated using output from the 18-year run of the INTB model by regressing the basin rainfall with the weekly water-level responses at each OROP monitor well. The results revealed that the effective rainfall varies from 0.126 inch at BUD-21fl to 0.191 inch at Cosme-20s. Using an effective rainfall of 0.2 inch, the probability of occurrence (see Figure 9) was computed using data from the 12 long-term rain gages located in the region. In Figure 9, weeks one through four correspond to January and weeks 48 through 52 correspond to December. To be conservative, the next EERF-week will occur when the probability of occurrence is above 0.8 (80%).

Solving the Optimization Problem

Each week OROP is run. The solution is optimized over the upcoming four-week period using the incremental analysis approach. With the incremental analysis, the prevailing hydrologic conditions are not used directly to derive the optimum solution. A set of preferential weights for control points is used to establish priority pumping sites. The current formulation provides for this preferential selection through a set of weighting factors, ω_i, which are assigned based on the surficial aquifer status at each control point at the start of the four-week period. A normalized weighting/ranking function was developed for this purpose as described in detail in Appendix D of the Revised OROP (October 30, 1998). A new approach to the weighting formulation was approved as part of the July 2003 OROP annual report. The function was modified to consider the natural range of wetland water-level fluctuations at all associated OROP control points.

Basically, the weight at each monitoring site is calculated by applying the current field measured water level to the functional relationship for that site (see Section 3E – Control Points). Since weights are predetermined and constant over the duration of the optimization routine, the optimum solution is limited to only a short-term (4-week) projection. Since the solution is optimized over a four-week period, a sequence of these short-term solutions may not yield the optimal operation in the long run. This is because the short-term solution lacks some knowledge of seasonal demand patterns. To overcome this constraint, the optimization model is run in two steps, a long-term (52-week) projection and the short-term (4-week) projection. The long-term projection is made without the weighting factors to first establish the upper and lower bounds of production at each wellfield, taking into account seasonal variations in demand. These bounds become the operational rulecurves for the short-term projection. All constraints for the short-term and long-term cases are the same with the following exceptions: (1) the time index and the summation for constraints with a time-averaged function must be adjusted (corresponding to time span of the stress period); that is, since the time span for a stress period of the short-term (one week) and long-term (4 week) model are different, the constraint function involving time-averages in the two models will have different running and terminal indices (e.g., the annual average for the one-week stress period will be averaged over 52 values compared with 13 values for the four-week stress period) and, (2) the upper and lower bounds for production values by well and wellfield are different (the short-term case being constrained by the rule-curve results determined in the long-term case).

c.) Current OROP Implementation Procedure

1. Inputs to OROP

A. Demand at 12 Points of Connection (POC)

Each Friday morning, weekly demands for each of the 12 delivery points are forecasted using the Short-term Demand Forecast application. Results are reviewed by Systems Decision Support or Operations Department staff and either accepted or changed. Factors for consideration to make a change to the demand forecast include recent weather trend or an infrastructure change at a POC that has not been captured by the model (e.g., increased hydraulic capacity, new connection, temporary connection, and temporary maintenance activity by member government such as free chlorine burn). The OROP data base automatically picks up the results and stores them for use in the weekly OROP production run. Staff can further revise the demand forecast prior to actually running OROP.

B. Alternative sources availability and use

a. On Thursdays Operations, Regulatory Compliance, and Systems Decision Support Managers discuss SWTP production options and any operating constraints for the upcoming week, decide the appropriate production quantity and use of reservoir (storage or withdrawal). On Fridays, Systems Decision Support staff enters this quantity into the OROP database for use in the weekly OROP production run. Factors for consideration include annual budget and current (year to date) production, near term (next week) and next month surface water availability, reservoir level, season, total system demand, infrastructure constraints (e.g., scheduled maintenance, source water quality, chemical deliveries).

b. Each Friday morning, weekly rates in mgd of surface water availability for the Alafia River, Lower Pool TBC, and Middle Pool TBC are forecasted for four weeks into the future by Systems Decision Support staff; the OROP database automatically picks up the results and stores them for use in the weekly OROP production run.

c. Each Friday morning, weekly rates in mgd for the desal facility are determined and entered into the OROP data base. Factors for consideration include water quality, intake water temperature, blending ratios with treated surface water, seasonal demands, scheduled maintenance and TECO activities which affect production.

d. Operations staff informs Systems Decision Support staff if Tampa Bay Water plans to purchase water from the City of Tampa and the quantity. Staff enters this data into the OROP data base. Factors for consideration include season, surface water availability, the City's ability to deliver, and budget.

C. Wellfield production constraints

When scheduling the weekly OROP production run, the Operations staff have the opportunity to consider additional constraints at the wellfield level, either turning a wellfield off, setting a production minimum or production maximum. These are not permanent constraints and are available to handle short term operational problems. If there are not additional specific constraints for the week, then this information is not used by OROP.

D. Wells on-line status

Within the OROP database are the well status tables. Data is stored regarding the status of all production wells, regarding on-line or off-line, permanent or temporary, and the reason for being off-line (e.g., bacteriological testing, water quality, mechanical problems, electrical problems). The Operations staff maintains the wells on-line/off-line status, which can be updated prior to the weekly OROP production run.

E. Water level data and predicted water levels at control points and 18 UFAS wells

a. Continuous water-level data are collected at all OROP control point monitor wells and sent to the Enterprise database through wireless transmission. The data are subjected to automated quality control/quality assurance procedures and stored. The OROP database retrieves the most current water-level data for all control point wells automatically through stored-procedures in the database.

b. Predictive water levels for the 18 UFAS wells and 42 control points are currently generated by the groundwater artificial neural network (ANN) models developed by staff. The OROP database retrieves these predicted water levels and stores them for use in the weekly OROP production run.

F. Current pumpage

a. Daily production for all active wells is collected and stored in Tampa Bay Water's SCADA database. This production data is processed through our automated quality control/quality assurance procedures and stored in the Enterprise database for use. The OROP database retrieves current pumpage data for all production wells in order to determine well peak month current quantities and the 12-month running average to compare against program constraints.

b. Initial value for well production is taken from the last seven days of actual production prior to the OROP weekly run.

2. OROP PROGRAMMED MODEL (see figure 10)

Internal to the OROP program are the numerous infrastructure, regulatory, and source water quality constraints which have been previously described.

Pipe flow constraints
Meter limitations both lows and highs
Constraints due to pump stations requirements (e.g., Morris Bridge pump station, when on, must be at least 6 mgd)
Delivery limitations
Well peak month limits
Well hydraulic limitations
Wellfield limitations consistent with permit (e.g., twelve-month running average and county production limits per partnership)
Unit Response Matrix
UFAS OROP minimum levels
Hydrogen sulfide constraints for South Pasco, Morris Bridge and Starkey wellfields, and Iron constraints for Cross Bar and Morris Bridge wellfields.

3. OROP FUNCTIONS

The weekly OROP production schedule must be generated by staff. Each Friday either Systems Decision Support or Operations staff performs the following steps:

a. Open the OROP application
b. Select "Production Run"
c. Check data availability; OROP will return a message if any data is missing. The program will use the most recent available data to replace missing data and automatic notification occurs to ensure missing data is collected and entered into the database.
d. Review short term demands, make adjustments as needed

e. Review well status, make adjustments as needed
f. Review Wellfield production constraints, make adjustments as needed
g. Review alternative sources to be used and make adjustments as needed
h. Run the program. The program automatically calculates control point weights and determines the optimal well rotation schedule.
i. Review the results; if model returns a feasible solution, and no further adjustment is needed; publish the results. OROP reports are emailed to distribution list.
j. If OROP determines that the solution is infeasible, the user is notified, a summary of problems is provided, and the user either makes adjustments in demand or supply options so that a feasible solution is generated or if a programming problem is encounter SREP staff are contacted to correct the problem.

4. OROP OUTPUT

A. OROP Detailed Report includes demand summary, surface water availability, wellfield pumpage rates, well priorities, control point weights, etc.

B. OROP Operators Report provides well priorities and pumpage rates, and wellfield rates for first two weeks of four week schedule; summarizes alternate sources availability for the upcoming two weeks.

C. OROP Schematic of Weekly Flows.

D. Summary of Models

The current OROP uses MINOS 5.5 (Systems Optimization Laboratory, Stanford University) as a solver. MINOS is the Primal Simplex Linear Programming software and is one of the most widely used commercial software packages. The optimization formulation is written in AMPL, a high level, comprehensive, and powerful algebraic modeling language for mathematical programming. AMPL is the software developed by AT&T Bell Laboratories that uses common notation and familiar concepts to formulate optimization models and examines solutions while the software manages communication with an appropriate solver and databases. The language acts as a shell script that allows efficient prototyping, change and/or experimentation with the model. AMPL supports most commercial solvers including MINOS. The optimization model application has been re-developed and deployed under a Microsoft Windows ™ application using Visual Basic.net programming language. This allows the application to conform to Tampa Bay Water's Information System technical requirements, facilitates use of the application by the Operations staff, and improves software maintenance and documentation. The OROP solution or the weekly pumping schedule is obtained via Tampa Bay Water's Decision Support System (DSS). The optimization model was approved by the District as part of the original OROP report (1998). Input data for the optimization model is available from Tampa Bay Water upon request.

OROP develops an optimized well production schedule for the upcoming four-week period. In addition to constraint parameter data and current well production rates, the optimization model requires weekly information for the forecasted inputs. These inputs include weekly demands forecasts at each of the points of connection, projected UFAS and SAS water levels, and weekly forecasted surface water availability. Since the original OROP was implemented, Tampa Bay Water has developed additional modeling tools which provide weekly input to OROP.

Weekly Demand Forecast Models

Demand delivered to the points of connection is one piece of input data that is required to be forecasted. In 2002, Tampa Bay Water developed a set of short-term forecasting models for eleven points of connection. These models were subsequently implemented as part of the OROP process beginning in 2003. In 2005, the performance of these models was evaluated. This evaluation concluded that reasonable weekly forecast could be generated from the models using the average of the six daily models. The study included a recommendation to evaluate alternate forecasting methods. Performance of these models was highly dependent upon obtaining reliable real-time rainfall data for three NOAA rainfall stations and rainfall forecasts. Not all of the NOAA stations used to develop the models provide real time rainfall data accessible to Tampa Bay Water. In some cases delays of up to three months were experienced. In addition, Tampa Bay Water explored several approaches for obtaining improved rainfall forecast for one-week, two-weeks and four-week periods, but to date have not found suitable rainfall products readily available. Documentation and evaluations of these models have been provided in previous OROP annual reports.

In 2006, Tampa Bay Water implemented a new set of short-term demand forecasting models. Seven autoregressive with exogenous variable (ARX) models for 11 points of connections were developed. Variables include recent demands, several rainfall measures (including rain amount, number of rainy days in a week, and number of consecutive dry days), and a temperature threshold. Model inputs are based on observed data; no forecasts of model inputs are currently conducted. For two points of connection (Central Hillsborough and Morris Bridge) there are insufficient data available to develop ARX models; the naïve forecast (previous week's demand) is used to forecast Central Hillsborough demands. The Morris Bridge POC demands are currently based on the City of Tampa's request for water. The agency continues to investigate short-term rainfall forecasting methods which could be incorporated into the new ARX models to improve the near-term demand forecast. These models will continue to be evaluated and revised, if necessary, based on additional period of record data. Appendix B provides additional detail on model development.

Groundwater Level Forecast Models

In 2004, Tampa Bay Water developed a set of artificial neural network models to predict water levels at the set of surficial aquifer control points and set of UFAS monitor wells. A complete description of the development and testing of these models is included in Appendix C. In 2005, Tampa Bay Water began implementing these models to replace the use of the ISGW model for predicted UFAS and SAS water levels used in the optimization model.

Surface Water Availability Models

Tampa Bay Water has two water use permits authorizing withdrawals from surface water sources. The Hillsborough River/Tampa Bypass Canal (HRTBC) water use permit was originally issued in 1999 and authorized diversions from the Hillsborough River during high flow times (Hillsborough Reservoir discharge > 100 cfs) and withdrawals from the Tampa Bypass Canal Lower and Middle Pools while requiring a minimum flow of 11 cfs over TBC structure S-160. In 2007, this water use permit was modified to remove the minimum flow over S-160 requirement, base withdrawals from the Tampa Bypass Lower Pool on pool stage, and increase the Hillsborough River diversion percentage while maintaining a minimum flow of 100 cfs over the dam. Tampa Bay Water placed the Tampa Bypass Canal withdrawal facilities and pump station into service in September 2002.

The Alafia River water use permit was issued in 1999 and authorized withdrawals of up to 10% of available flow to a maximum of 51.8 mgd when the river flow is above the permit threshold of 80 mgd. Tampa Bay Water acquired a renewal to permit with some modification. The new permit rule allows Tampa Bay Water to withdraw 10% of the calculated baseline flow above 143 cfs up to a maximum of 60mgd. Tampa Bay Water placed the Alafia River withdrawal facilities and pump station into service in February 2003.

In 2002, Tampa Bay Water began development of models to forecast surface water availability from the Hillsborough River/Tampa Bypass Canal system. The Hillsborough River/TBC watershed is a very complex hydrologic system including groundwater and surface water interactions, several major tributaries, spring discharges, and man-made routing and flow control structures. The purpose of the HRTBC models was to generate streamflow predictions for the major tributaries to the lower Hillsborough River basin and to route these flows through the lower Hillsborough River and Tampa Bypass Canal. The resulting predicted TBC flow rates and associated water surface elevations were used to predict the quantity of surface water supply available for withdrawal, treatment and distribution. Flow generation models for the Hillsborough River gauges were developed using artificial neural network (ANN) modeling techniques (see OROP Annual report for Water Year 2002 submitted July 2003). An assessment of these neural network models was performed for the July 2005 OROP annual report. Details of this assessment are available in Appendix M of the July 2005 OROP annual report. Results of this assessment showed that the models did not perform as well during Water Year 2004 as during the initial testing and validation of the models. A second evaluation of these ANN models was conducted in 2006. The results of this evaluation indicated that the surface water flow models demonstrated good performance based on known upcoming rainfall and the hydraulic models showed good performance based on known stream flow. However, once upcoming rainfall was considered unknown, stream flow model performance degraded considerably.

A weekly Markov flow model was first developed for the Alafia River at the Lithia gauge as described in the OROP Annual Report for Water Year 2001. The focus of the Alafia River water availability model was on prediction of flow for the Alafia River at the Lithia gauge. Since the flow component from Lithia Springs is both small and relatively invariant, when compared to Alafia River flow at the Lithia gauge, short term predictions for Lithia Springs flows are treated as a constant equal to the last weekly observation.

Each week the Markov model was used to forecast Alafia River flow at the Lithia gauge for the next four upcoming weeks. These results along with the last measurement made for Lithia Springs were entered into the equation to determine the forecasted flow at the Alafia River Pump Station. The last step of the weekly forecast was to apply the WUP withdrawal rules to the forecasted flow to obtain the projected surface water availability for the next four weeks. This procedure was followed every week, i.e. updating the last three weeks of the previous weekly forecast and projecting one more week into the future. Staff discontinued use of this model after new surface water forecasting models were developed.

In 2007, Tampa Bay Water developed new surface water artificial neural network models to forecast river flows for the Hillsborough River (Morris Bridge gauge), Trout Creek, Cypress Creek, and Alafia River. The current models used to provide input into OROP were developed using a GLUE-based (generalized likelihood uncertainty estimate) neural network approach and generate weekly forecast for up to four weeks. Inputs to the models include past stream flow, rainfall and water levels of shallow and deep aquifers. Documentation of this approach is provided in Appendix D. The models are developed using MATLAB®. Water use permit withdrawal rules are applied to the results of the forecasted flows to determine the amount of surface water expected to be available for the upcoming four-week OROP period. These models are currently used to provide surface water availability input data for OROP.

E. Control Points

Thirty-one surficial aquifer monitor wells were established as control points for the initial optimization model as described in Appendix C of the approved OROP (October 30, 1998). Historical data were used to perform correlation analyses and to develop regression relationships that formed the basis for the weighting function at each site. Discussions in Appendix D of the Revised OROP document (October 30, 1998) include the development of target aquifer levels from the correlation and regression analyses (based on mean groundwater level values and wetland/lake Minimum Levels) and application of the weighting function (based on actual recent data and the historical high/low range of data).

Since implementation of the OROP in January 1999, changes have been made to the original set of 31 control points. These changes are documented in previous OROP annual reports. Currently, there are 40 surficial aquifer system (SAS) and two Upper Floridan Aquifer system (UFAS) monitor wells which are used as control points in the optimization routine (see Figure 11). Since the 2011 Operations Plan update, there have been two control point changes implemented as approved by the District: 1) at Cypress Creek wellfield, TMR-2s was substituted by CYC-821-Synth, and 2) Carrollwood RMP-11s was replaced by CWD-Elem SAS.

In the Revised OROP (October 30, 1998), one of the tasks to be included in the annual update reports was a re-evaluation of the correlation and regression analyses that were performed in selecting the original control point locations. Those analyses describing the relationship between groundwater levels at the specific surficial aquifer monitoring wells and associated nearby wetlands and lakes (Appendix I, Revised OROP, October 30, 1998) were completed using data beginning in the early 1980s. For the July 2004 OROP annual report, an evaluation was conducted to determine if the wetland/control point regression analyses needed to be updated annually. The results indicated that conducting regression updates every other year is sufficient for control points that have been active for several years. The results of the bi-annual update to the control point target levels will be included in the bi-annual Operations Plan summary report. Proposed changes to target levels will be implemented following Tampa Bay Water Board approval.

Updates for Water Year 2014 are included in the Appendix L of the Operations Plan Biennial Report dated July 2014. This report was submitted to the District and subsequently approved in a letter dated September 4, 2014. The approved changes to the control point target levels from the report are included on Table 3, which lists control points by wellfield.

Target groundwater levels have been established for all of the control points in the vicinity of the 11 wellfields, the Brandon Urban Dispersed Wells and the Carrollwood Wells. Most target levels were based on regression analysis between historical groundwater levels and water levels in nearby wetland or lake systems. Exceptions are noted on Table 3. Target groundwater levels correspond through these relations to the Minimum Levels set by the SWFWMD.

Preferential Weights for Objective Function

The primary purpose of the optimization problem is to seek a pumpage scenario that given demands, operational and system constraints, and availability of alternative supplies will minimize water-level drawdown at specific locations (i.e., control points). An optimization routine has been setup with an objective function that will maximize the weighted sum of the water levels at all 42 OROP control points.

The preferential weights ω_i enable priority factors to be applied to enhance water levels preferentially at the wetland associated with the i^{th} SAS monitoring site or control point. This weighting factor is predetermined for each control point based on the most recent water-level reading, and remains constant throughout the optimization simulation period (four weeks). Actual water levels at the monitor wells (based on observed data) are compared to the target levels every week. Individual weighting factors for each site are updated every week based on observed water levels, and are used in revising the four-week short-term analysis for pumping distributions. The weights are based on relative measures of water levels compared to the target levels set at each monitor well and are applied to reflect the deviation between actual and target levels. The weights function as a ranking system for the optimization algorithm that causes the search for an optimal solution to preferentially reduce drawdown (in support of increased water levels) at locations with greater weight, thereby driving those water levels toward their target levels. Equal weights apply to all cases in which current water levels are equal to or above their respective targets. The weighting system is strongly non-linear. Sites with large water-level deficits receive considerably higher weight than those where current water levels are near their targets. In certain cases, actual water levels may be above their target levels, which would result in a preference for production in that vicinity as compared to other locations in the region where water levels are below target levels. The current weighting function is expressed in the functional form of a piecewise linear on semi-logarithmic scale as follows:

$$\log(\omega) = \begin{cases} \left[(H_{MAX} - h)/(H_{MAX} - H_T)\right], & \text{if } h \geq H_T \\ 1 + \left[(H_T - h)/(H_T - H_{NL})\right], & \text{if } \mathrm{H}_{\mathrm{NL}} \leq h \leq H_T \\ 2 + 2\left[(H_{NL} - h)/6\right], & \text{if } h < H_{NL} \end{cases} \tag{48}$$

where H_{MAX} is the period of record (POR) maximum water level and H_{NL} is the lowest elevation of the natural fluctuation range, which has been determined to be 8 ft below the H_{MAX}. This weighting function provides three different semi-logarithmic linear equations for three regimes of water-level fluctuations. The piecewise weighting function will bind the weighting factor at H_{MAX}, H_T, H_{NL}, and (H_{NL}-6) to 1, 10, 100, and 10000, respectively. The rate of change in weighting factor after the water level drops below H_{NL} will be the same for all wells. When H_T is lower than H_{NL}, the function reduces to two equations since the second piece of the linear equation is no longer applicable. The remaining third function is modified to maintain a constant slope and becomes:

$$\log(\omega) = 1 + 2\left[(H_T - h)/6\right], \text{ if } h < H_T \tag{49}$$

Figure 12 depicts the current functional relationship of the weighting factor and water level for the same OROP well and wetland pair. . Under this function, the weighting factor is unbounded or undefined when measured water level in the control well is above H_{MAX} or below H_{NL}. If the water level is above H_{MAX}, the weighting factor becomes insignificant which will rotate production to nearby wells. If the water level drops below H_{NL}, the weighting factor becomes very large and will force production away from nearby wells, even if the drawdown response is relatively small. Graphs of this function for several representative control points with relatively low and high control point monitor levels are illustrated in Figure 13.

Natural Range of Water Level Fluctuation

In order to compensate for the historical influence of pumpage on surficial aquifer system (SAS) levels, the natural range of surficial aquifer system (SAS) water level fluctuations is included in the weighting function as the H_{NL}. This issue was discussed in detail in the 2003 OROP Annual Report. In that report, the range of historic water-level fluctuations (POR maximum – POR minimum) for non-OROP control wells, and for a baseline period for some OROP control point monitor wells, was analyzed.. The baseline data represented the range of water-level fluctuations at the Cross Bar Ranch OROP control point monitor wells for data collected through 1987, and for data collected prior to 1996 for Cypress Bridge OROP control point monitor wells. (These baseline ranges were established in previous OROP annual reports and represent times of relatively little production impacts at these facilities.)

Because of low geographic variability, the average value (8 feet below POR high, or H_{MAX}) for the combination of the two methods (baseline and non-OROP control) was used in the calculation of H_{NL}. This recommendation was presented and accepted at the January 16, 2003 OROP TAC meeting.

F. Environmental Management Plan Wetland Referrals

As part of the Consolidated Permit for the 11 Central System wellfields, Tampa Bay Water implements an Environmental Management Plan (EMP). The EMP requires monitoring of wetland hydrology and ecology and periodic review of environmental conditions at wetlands that could potentially be affected by water production. Hydrologic parameters at monitored wetlands are statistically compared to reference and control sites semi-annually at the end of both the spring (dry) and fall (wet) seasons. Sites that fail this statistical test are called "outliers" and are tabulated and tracked during future semi-annual tests. In compliance with Special Condition 3 of the 2011 Consolidated Water Use Permit, Tampa Bay Water staff modified the protocol for the interaction between the EMP and OROP (Appendix E). Based on this protocol, no action is required for the first two consecutive failures of the outlier test. If a wetland site fails a third consecutive outlier test a site-specific analysis is performed to determine if there is an adverse environmental impact and if it is attributable to wellfield pumpage. If adverse impacts due to wellfield pumpage are confirmed, then the wetland site is referred to OROP to attempt to relieve the impact. Actions undertaken within OROP could include the adjustment of an OROP control point target level or the addition of a new control point. (If it is determined that a change in OROP will not have a "meaningful effect", a referred wetland may also go directly to the Phase 2 Mitigation program, with no recommended change in OROP.)

A tracking tabulation of the semi-annual outlier tests will be included in the wellfield annual reports. The results of site-specific wellfield impact analyses for referred wetlands will be summarized in wellfield annual reports and in an appendix to the bi-annual Operations Plan Summary. Any recommended changes to OROP resulting from site-specific studies will require approval of Tampa

Bay Water's Board of Directors and the District prior to implementation. Results which conclude that no action in OROP is needed will be discussed in the wellfield annual reports.

4. REPORTING REQUIREMENTS

Rule 40D-80 requires that an Operations Plan report be submitted to the District by July 10 for years 2012, 2014, 2016, 2018 for review. The report shall document updates to the Operations Plan (approved with the 2010 renewal of the Consolidated Permit), provide a work plan that encompasses the upcoming two years include activities approved in Tampa Bay Water's budget for the upcoming year and provide summary information and data on Operations Plan activities during the preceding reporting period. The Water Year 2010 Operations Plan Summary Report and Work Plan are provided in a separate report.

In compliance with special conditions of our Water Use Permits, wellfield annual reports are completed each year for all of Tampa Bay Water's potable water supply facilities. These reports are submitted to the District by July 1 of each year and contain an assessment of the water resources and environmental systems in the vicinity of Tampa Bay Water's production facilities. The annual reports contain statistical analysis and assessment of period-of-record hydrologic, water quality, and ecological data. Long-term trends in water production, aquifer levels, water quality, stream discharge, wetland hydrology, and other related parameters are presented. Modifications to wellfield monitoring programs are also discussed if any changes were made during the reporting period. Analysis of aquifer and wetland recovery is not a requirement of the OROP annual report. Hydrologic recovery of water levels for OROP control-point wells and non-OROP wells as well as lakes, streams, and wetlands are based on analyses of multi-year data. The ecosystem recovery will be assessed in other projects in association with monitoring activities conducted by Tampa Bay Water and the District; results will be included in the wellfield annual reports.

5. REFERENCES

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FIGURES

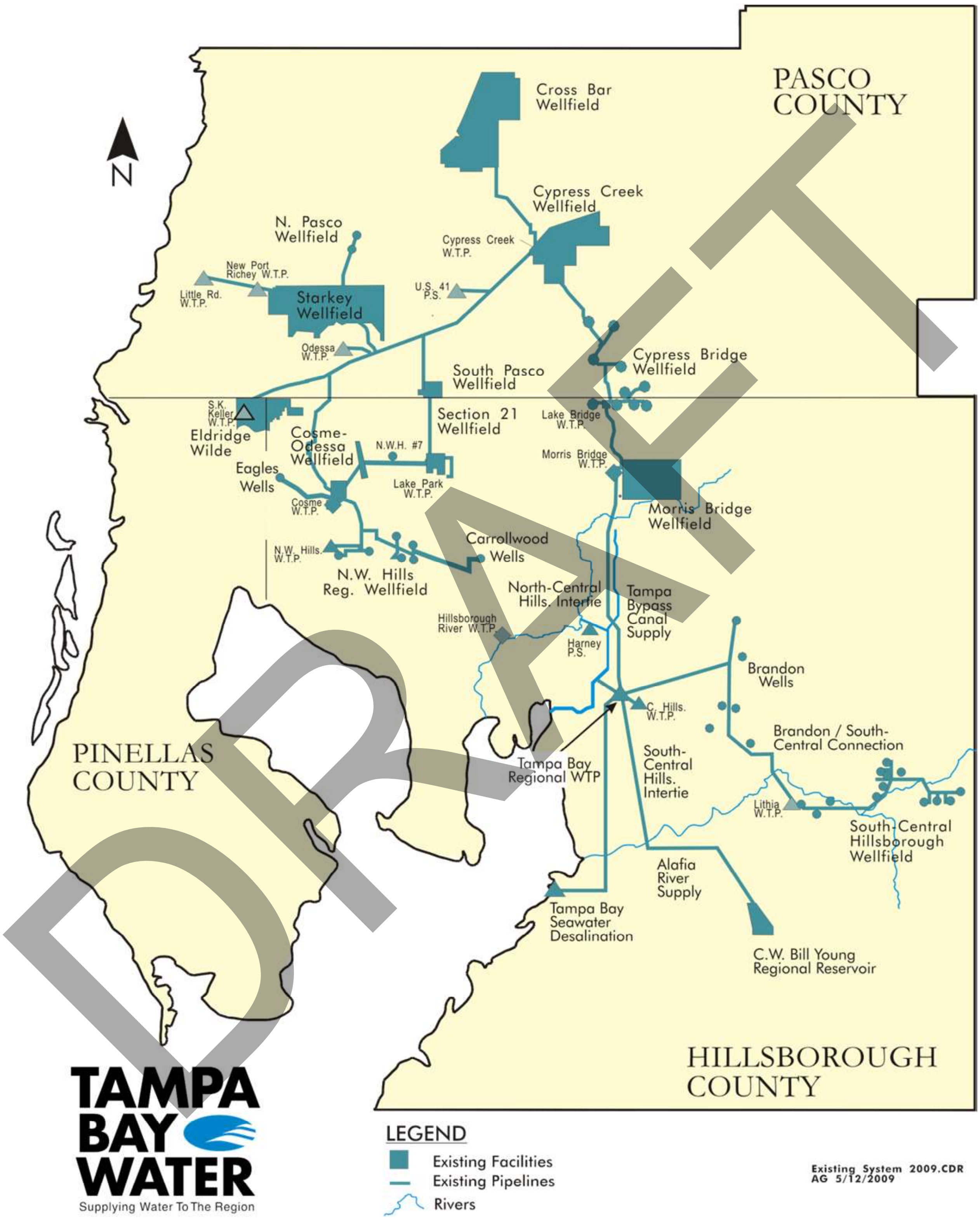
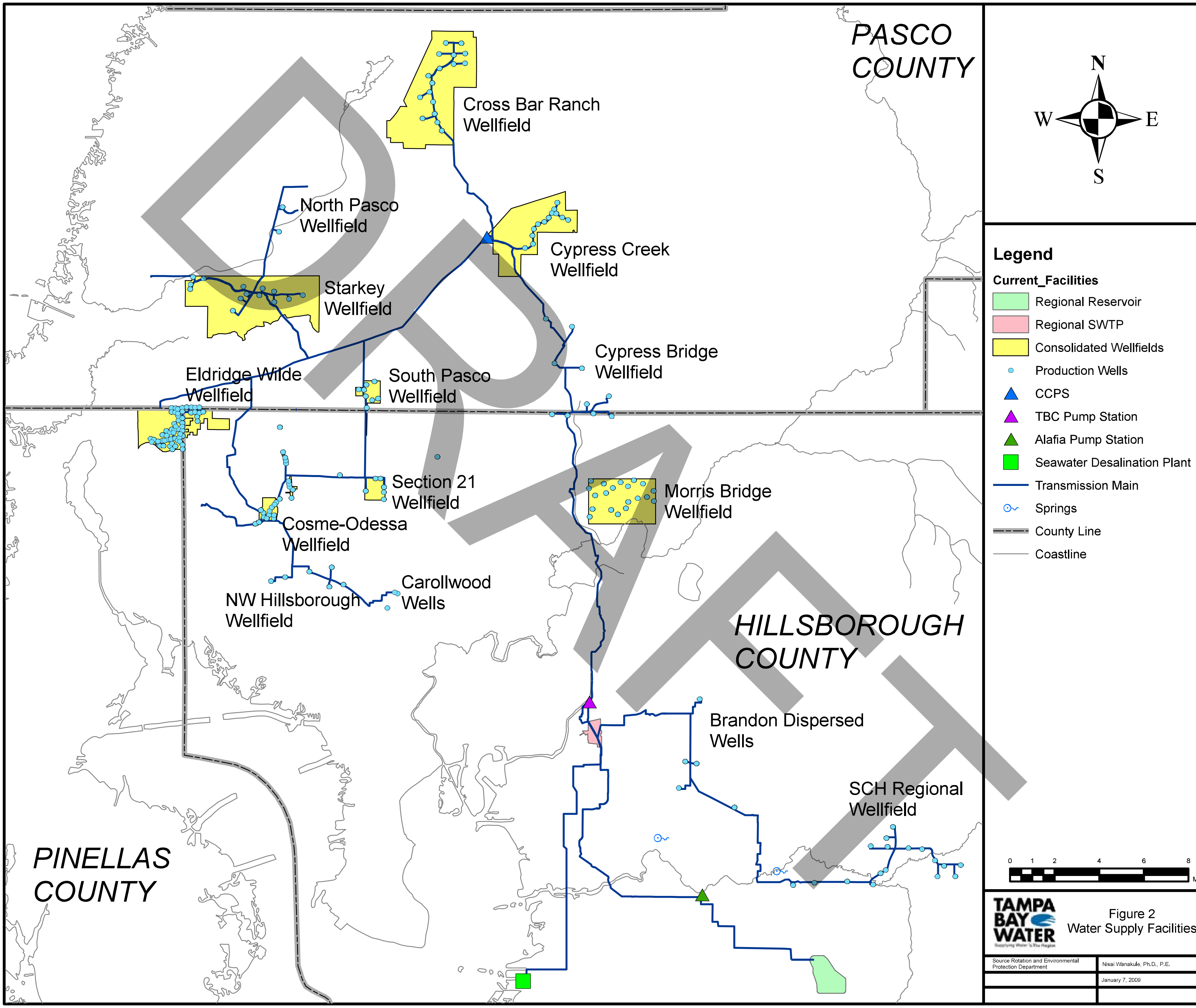


Figure 1: Tampa Bay Water Regional System


PASCO COUNTY
HILLSBOROUGH COUNTY
PINELLAS COUNTY
Cross Bar Ranch Wellfield
North Pasco Wellfield
Starkey Wellfield
Cypress Creek Wellfield
Cypress Bridge Wellfield
Eldridge Wilde Wellfield
South Pasco Wellfield
Section 21 Wellfield
Morris Bridge Wellfield
Cosme-Odessa Wellfield
Carollwood Wells
NW Hillsborough Wellfield
Brandon Dispersed Wells
SCH Regional Wellfield
DRAFT
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Legend
Current_Facilities
Regional Reservoir
Regional SWTP
Consolidated Wellfields
Production Wells
CCPS
TBC Pump Station
Alafia Pump Station
Seawater Desalination Plant
Transmission Main
Springs
County Line
Coastline
0 1 2 4 6 8
Miles
TAMPA BAY WATER
Figure 2
Water Supply Facilities
Source Rotation and Environmental Protection Department
Nisai Wanakule, Ph.D., P.E.
January 7, 2009

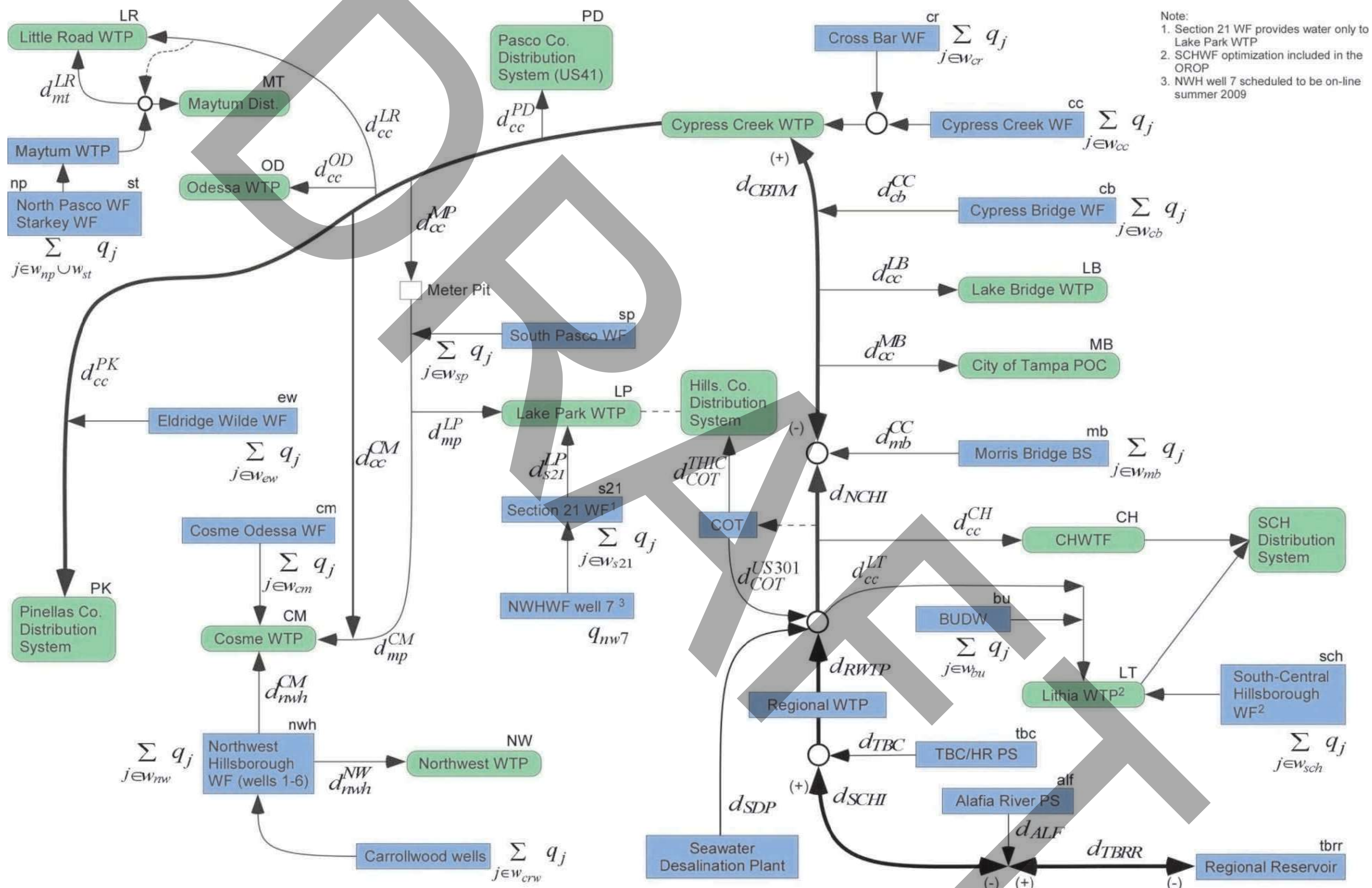


Figure B-3. Schematic Diagram of OROP Infrastructure

Figure 4. Starkey Wellfield H2S Concentrations by Well (2002 - 2007)

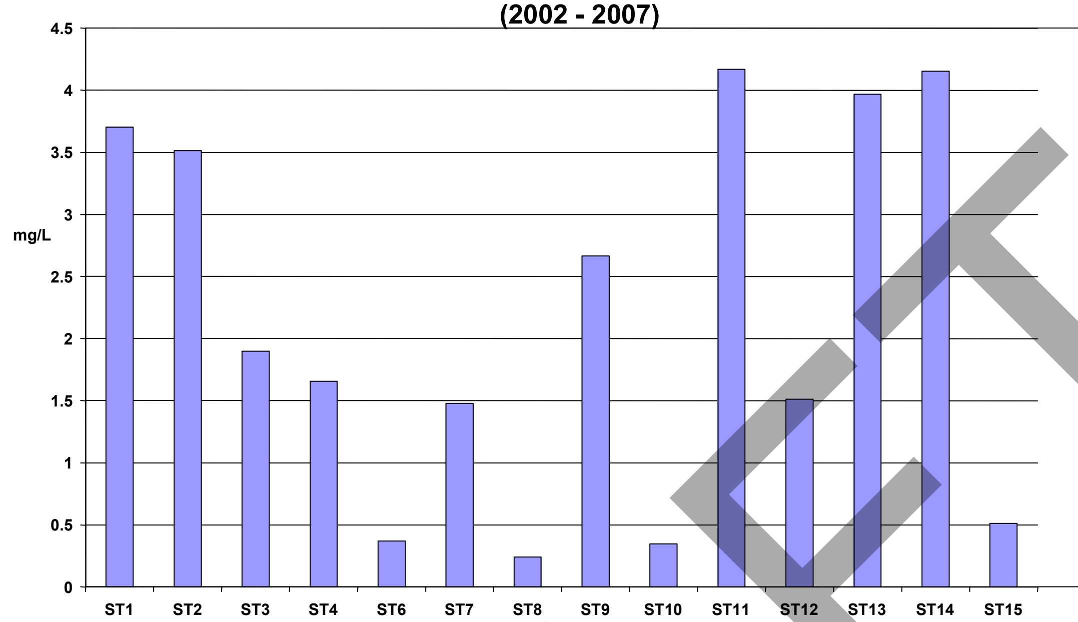


Figure 5. Cross Bar Ranch Wellfield Iron Concentrations by Well (2002 - 2007)

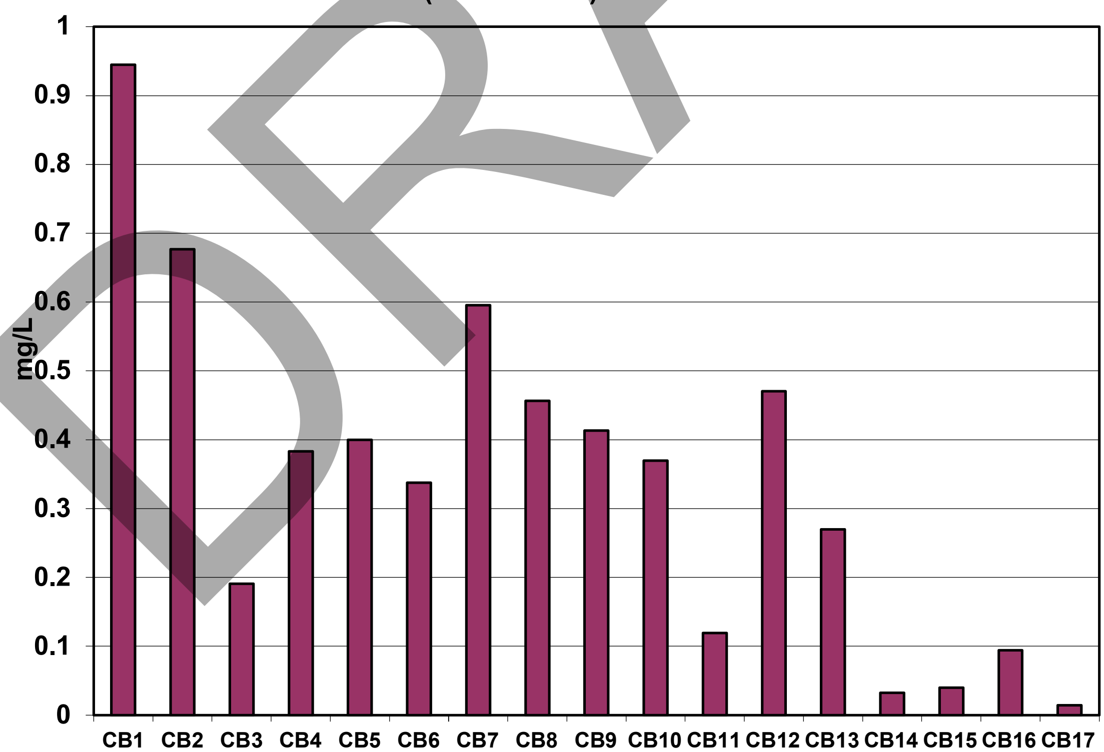


Figure 6. Morris Bridge Wellfield Concentrations by Well

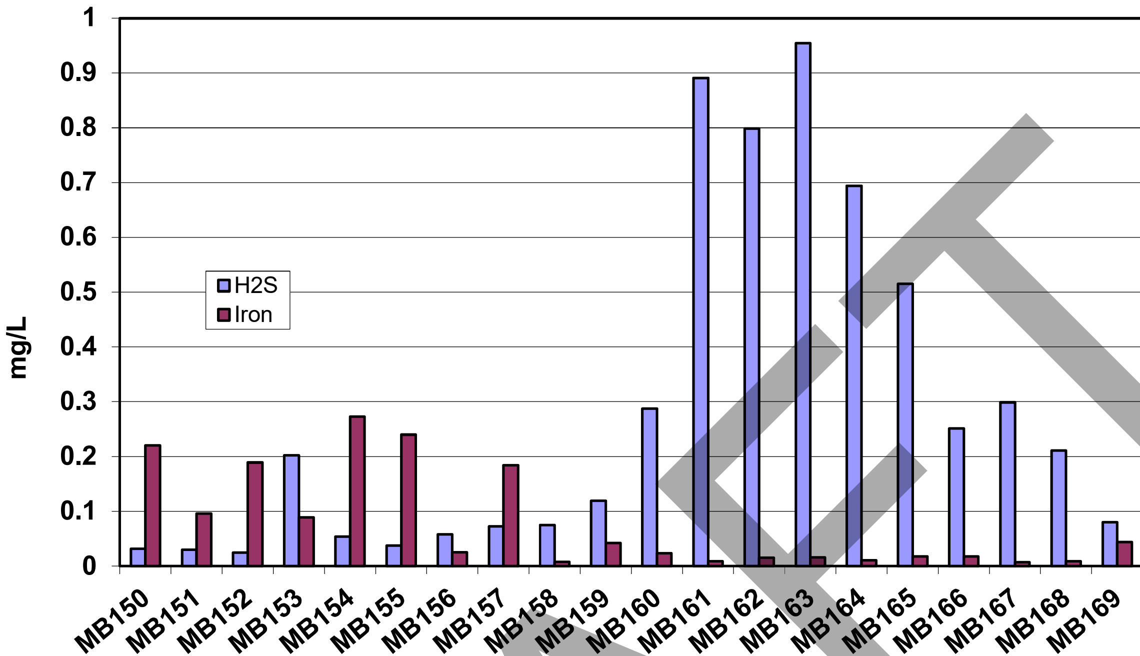


Figure 7. South Pasco Wellfield H2S Concentrations by Well (2002 - 2007)

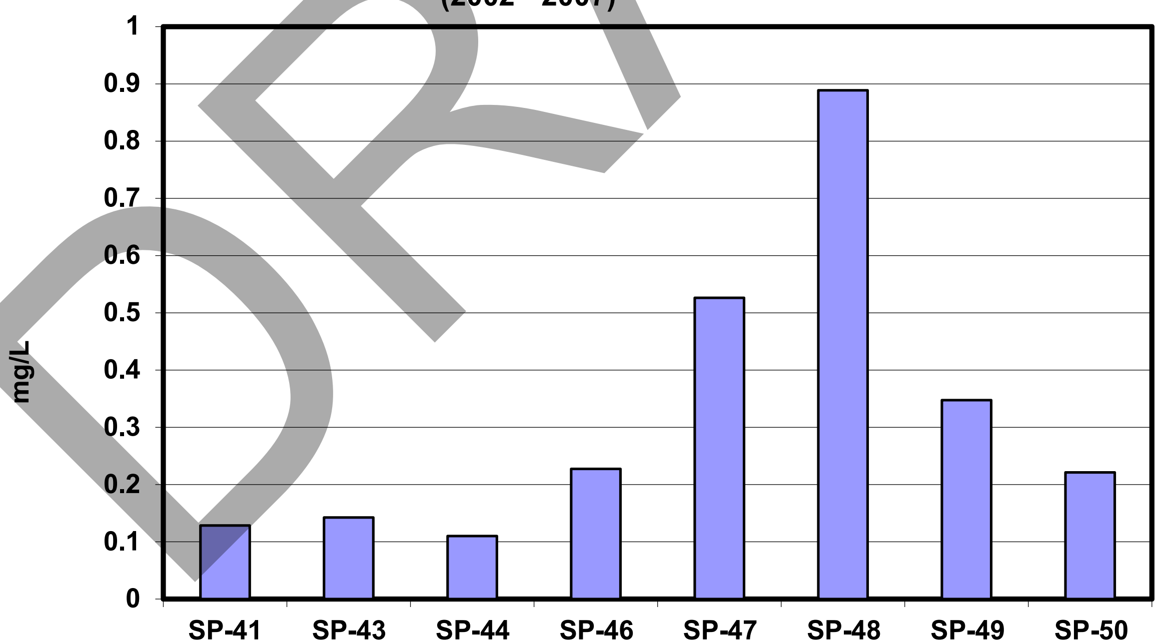
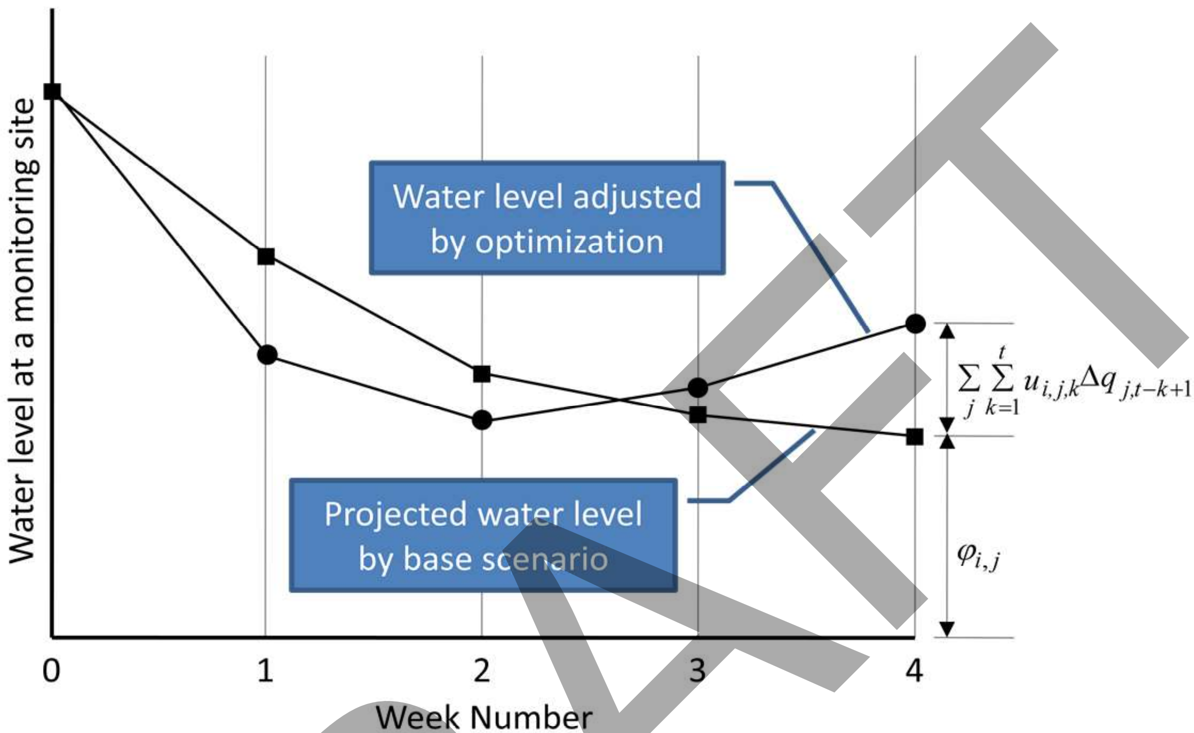


Figure 8. Adjustment of water level with incremental drawdown



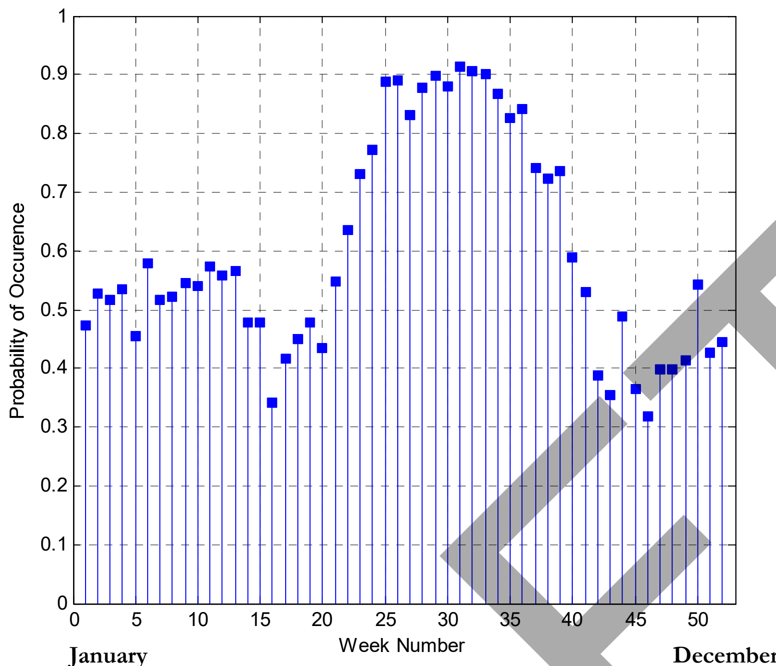


Figure 9. Probability of weekly average rainfall greater than 0.2 inch

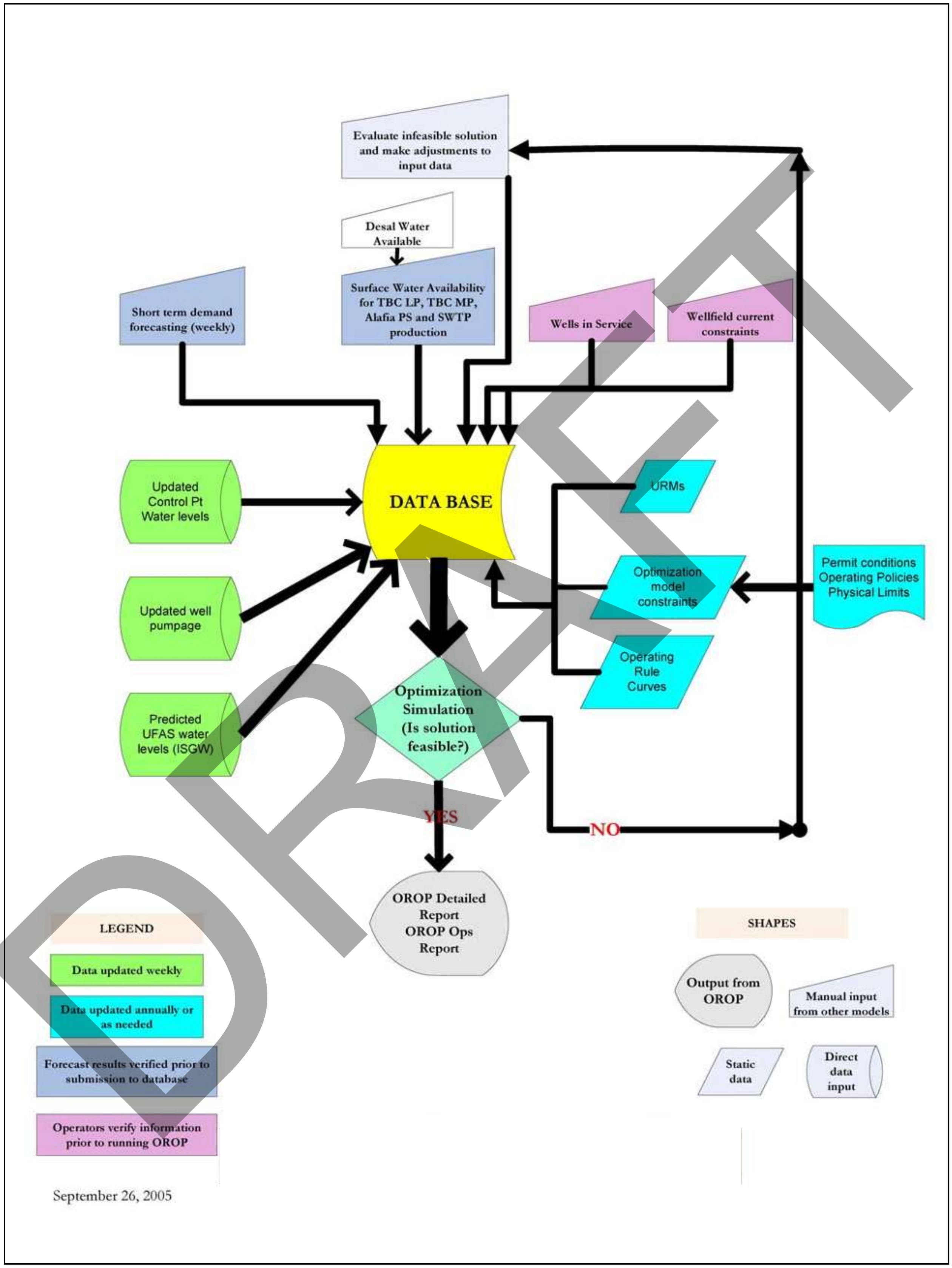
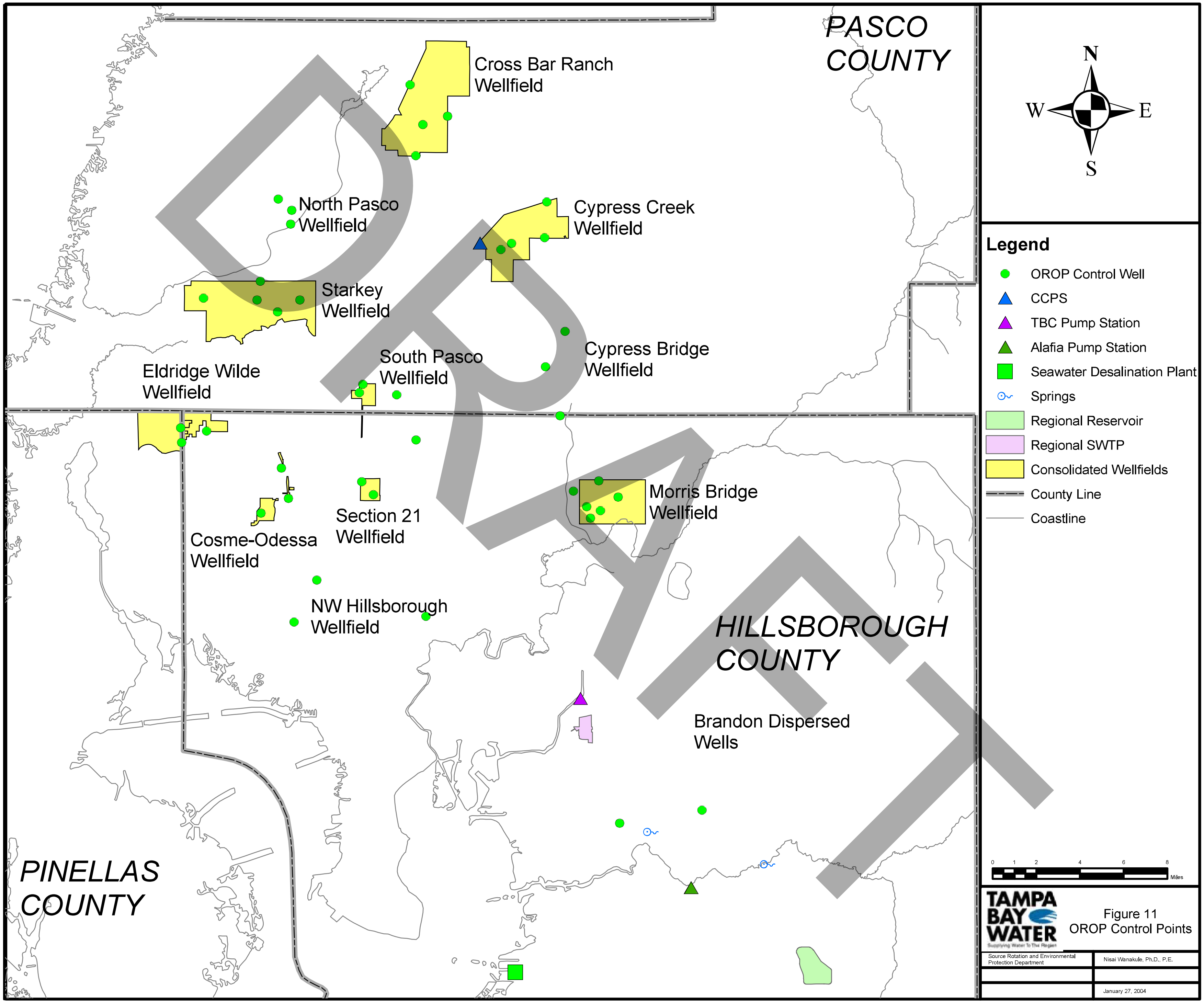


Figure 10. OROP Implementation Process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Cross Bar Ranch Wellfield
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Regional SWTP
Consolidated Wellfields
County Line
Coastline
0 1 2 4 6 8
Miles
TAMPA BAY WATER
Figure 11
OROP Control Points
Source Rotation and Environmental Protection Department
Nisai Wanakule, Ph.D., P.E.
January 27, 2004

Figure 12. The Piecewise Linear Weighting Function on Semi-Logarithmic Scale

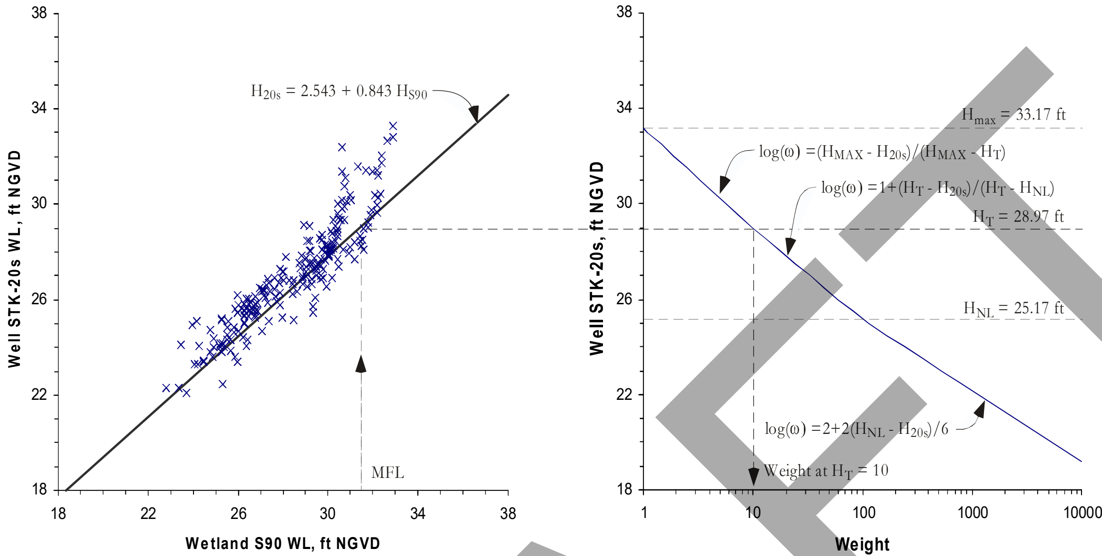
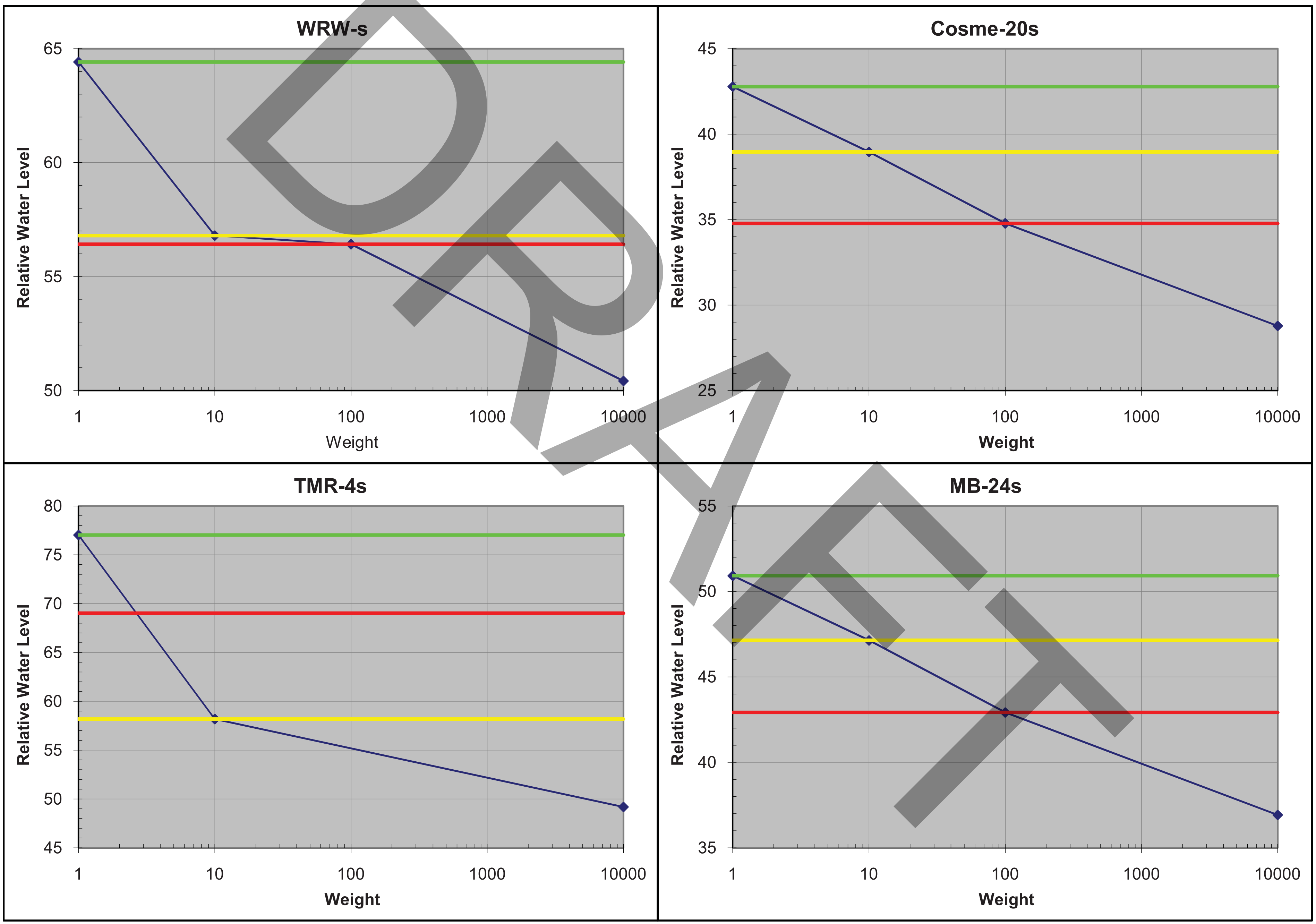


Figure 13. Comparison of piecewise semilog linear functions for OROP wells with relatively high and low target levels



TABLES

GENERAL OPERATIONS PROTOCOL

Objective: Given the infrastructure, regulatory, and water quality constraints of the system, the uncertainty in climate, demands and sources, and the Board's policy, Tampa Bay Water plans to use the best mix of supplies to meet demand under all hydrologic conditions, including droughts.

ANNUAL (18 month) LOOK AHEAD	ANNUALLY
Perform demand forecast for upcoming fiscal year and provide general assessment of supply constraints	Update annual demand forecast and source constraints
Run budget tools to obtain annual source allocation consequences given demand forecast	Prepare planned supply allocations of groundwater, surface water and desal components by month and reservoir operating schedule.
Establish Board policy as part of annual budgeting process; results in annual allocation of groundwater and surface water components	Review prior year annual performance and prepare OROP annual report

SEASONALLY	MONTHLY	OROP WEEKLY
Update surface water availability and desal operating schedule	Track actual demand and production against targeted monthly values; analyze deviations and make adjustments as needed	Maintain weekly constant SWTP and desal production rates
If reservoir is not full in July, plan to fill reservoir during wet season	Plan to use more surface water if demands are increasing; plan to use less groundwater if demands are decreasing	Implement weekly forecasting for OROP scheduling
Plan to operate the reservoir during dry periods to meet SWTP annual allocation		Balance Desal production with SWTP production to meet water quality criteria
Prioritize use of surface water consistent with prudent utility practices		Track actual demand/production against forecasted weekly

GENERAL GUIDANCE

A. Plan to operate at monthly targeted source allocations that are derived from evaluation of monthly forecasted demand, historical seasonality and annual goal (plan to match actual season-to-season, month-to-month source allocations). When conditions provide higher than expected river flows, plan to use more surface water and less groundwater to meet demand (compared to initial target allocations) and adjust targeted allocations accordingly. Plan to operate desal plant at or above its minimum production allocation with short-term adjustments based on maintenance and blending requirements and constraints. Plan to reduce the overall groundwater withdrawals from the South Central Hillsborough Regional Wellfield (SCHRWF) and the Brandon Urban Dispersed Wells (BUDW), located in part in the SWUCA, by at least 3 mgd as long as supply can be made up from other regional sources.

B. In the weekly planning schedule and based on surface water availability, plan to use more surface water when actual demands exceed expected demands and plan to use less ground water when actual demands are less than expected

C. Track actual demand/production against targeted monthly values. Analyze and assess short-term and cumulative deviation from annual plan, so that source allocations can be adjusted as the water year progresses if deemed reasonable to achieve policy and objectives.

D. Implement demand forecasting, weekly surface water forecasting, and weekly OROP scheduling (improve environmental stewardship) guided by targeted allocations (including adjustments as applicable due to operational constraints, source availability and demand variations). Improve environmental stewardship means the opportunity to incrementally improve environmental conditions, greater than the permit threshold requirements, when hydrologic conditions, operational constraints, and demand are favorable.

E. Fill the reservoir during wet periods and during low demand periods, while balancing capture of flows between Tampa Bypass Canal and Alafia River in an effort to maximize surface water use (ensure source reliability and meet water quality).

F. End the water year with reservoir full (ensure source reliability).

G. Expect to operate the reservoir as a source during water years with SWTP allocation greater than the historical long-term surface water flows (40 mgd).

H. Maintain nearly constant SWTP and desal production rates on a weekly timescale, and limit week-to-week incremental increase or decrease to controllable changes and use reservoir to store excess surface water flows (achieve consistent operation and meet water quality and blending requirements).

I. Balance desal production blended with SWTP production (meet water quality), consistent with efficiency analysis derived from desal baseline assessment (achieve cost effectiveness).

Table 2. Tampa Bay Water - Exhibit D Water Quality Parameters

Revised October 2004

Parameter	Units	Standards
pH	Std pH units	>= 7.0
Conductivity	umhos/cm	< 850
Temperature	oC	< 35
Total Sulfide	mg/l as H2S	< 0.1
Alkanlinity	mg/l as CaCO3	> 100
Total Hardness	mg/l as CaCO3	< 300
Calcium Hardness	mg/l as CaCO3	50 < x < 250
Turbidity	NTU	< 1
Color	p.c.u.	< 15
Ammonia	mg/l as N	< 1
Nitrate	mg/l as N	< 10.0
Nitrite	mg/l as N	< 1.0
Fluroide	mg/l as F	<= 0.8
Ortho P	mg/l as P	< 1.0
TDS	mg/l as TDS	< 500
Total Organic Carbon	mg/l as TOC	<= 4.6
Iron	mg/l as Fe	<= 0.3
Boron	mg/l as B	
Dissolved Oxygen	mg/l as O2	
Bromide	mg/l as Br	
Sulfate	mg/l	
Chloride	mg/l	
Bromate	mg/l as BrO3	
HAA5	ug/l	
TTHM	ug/l	

TABLE 3. OROP Control Points

WELLFIELD	Wetland or Lake	Control Well	Target level (H_T)	COMMENTS
Starkey	S90	STK-20S	28.96	
Starkey	S53	SM-2	46.33	
CCWF	**W41**	**CYC 821 sar/d**	**71.80**	**Replacement well for TMR-2s (2012)**
CCWF	W12A	TB-22a	58.78	
CCWF	W45A	TMR-1as	61.68	
CCWF	W23A	W-56B(Upland)	62.31	Replacement well for TMR-4s (2011)
Cross Bar Ranch	Q1	SRW	72.67	
Cross Bar Ranch	NA	A1S	*68.02*	*median level from baseline period*
Cross Bar Ranch	NA	SERW-s	*67.85*	*median level from baseline period*
Cosme-Odessa	NC262717	SP JAMES 10	45.28	
Cosme-Odessa	C142717	KEYSTONE 36	57.27	
Cosme-Odessa	L. Rogers	COS20S	37.91	
ELW	PMD11	SM28	34.82	
ELW	PMD5	SM15	27.08	
ELW	NW45	EW11	20.80	
NWH	EC072818	RMP8	34.95	
NWH	EC232817	RMP13	19.24	
S21	WC212718	HILL13	45.74	
S21	DOSSON	J26A	53.52	
S21	NE112718	LUTZ PARK 40	65.45	
SOP	CAMP	HARRY M	62.51	
SOP	PSE282618 QL02	NORTH	57.73	
SOP	PTE332618T2	SP47	56.33	
NOP	NP-3	NPMW-9	42.35	
NOP	NP-21	NPMW-8	44.76	
NOP	NP-31r	NPMW-7	46.40	
CYB	WET 4	WT-02-500	64.22	
CYB	NA	WT-09-500	*47.56*	*median level from baseline period*
MBR	MB-100	MB537	41.56	
MBR	MB-14	MB 4s	30.08	
MBR	MB-91	SGW1	36.04	
BUDWF	Lithia Springs (Major)	BD-14FL (5)	13.20	
BUDWF	Buckhorn Springs	BD-21FL (5)	15.19	
Starkey	S-62	EMW16s	40.61	
MBR	MB91	MB23s	33.06	
Starkey	S108	WT 15s	43.79	
CYB	NA	WT-05-200	*52.29*	*median level from baseline period*
MBR	MB30	MB24s	28.93	
Cross Bar Ranch	NA	WRW-s	*56.80*	*median level from baseline period*
Starkey	S-113	EMW8s	41.34	
Carrollwood	Lake Carroll	CWD-Elem-SAS	37.54	Replacement well for TMR-11s (2012)
MBR	MB30	MB25s	30.20	

APPENDIX A

UNIT RESPONSE MATRIX DOCUMENTATION

Development and Validation of the New Unit Response Matrix for the Optimized Regional Operations Plan (OROP) Model

TAMPA BAY WATER
Supplying Water To The Region

Source Rotation and Environmental Protection Department

Tampa Bay Water, Clearwater, Florida

August 2009

Development and Validation of the New Unit Response Matrix for the Optimized Regional Operations Plan (OROP) Model

Introduction

The Optimized Regional Operations Plan (OROP) is a set of protocols and procedures by which Tampa Bay Water schedules production from the 11 Consolidated Permit Wellfields. OROP was first developed in 1998. Since then OROP has been updated and revised as Tampa Bay Water's integrated regional system has changed. These changes are documented in annual reports. The most recent OROP model formulation can be found in WY 2008 OROP Annual Report (Tampa Bay Water, 2009).

Within OROP, optimization of well pumpage is performed by a linear programming model. The objective is to maximize the sum of the weighted water levels in selected Surficial Aquifer System (SAS) monitoring wells known as control points. The linear programming model comprises four major categories of constraints:

- Meeting expected demands at Points of Connection
- Compliance with regulatory requirements (e.g., Water Use Permit conditions including 12-month running average, peak month, regulatory water levels)
- Satisfying system physical limits (e.g., well capacities, transmission network and pipe capacities)
- Satisfying a functional relationship between pumpage and water level (e.g., the use of Unit Response Matrix) instead of implicitly embedding a groundwater simulation model as a constraint.

The objective function can be expressed mathematically as:

$$\text{Maximize} \quad Z = \sum_i \omega_i \sum_t h_{it} = \sum_i \omega_i \sum_t \left[H_{it} + \sum_j \sum_{k=1}^{t} u_{ijk} \Delta q_{j,t-k+1} \right] \tag{1}$$

where i, j, and t are, respectively, indices for a control point, a production well, and a time-step; ω is a vector of normalized weights; and h is the vector of SAS water levels at control points. Using Control System terminology, the state variable h is said to relate to the control variable (rate of pumpage, q) through a dynamic system represented by a simulation model where its first derivative ($\Delta h / \Delta q$) is the Unit Response Matrix (URM). Imposing this functional relationship as a constraint set, the decision variable becomes a vector of adjusted pumpage ($q = Q + \Delta q$) while h is replaced by the square bracket expression in (1). H is a vector of reference water levels determined from a groundwater simulation model with estimated pumpage, Q.

Definition and Assumptions

The URM is a two-dimensional matrix with its elements derived from pulsing a pumping well and simulating the response of groundwater levels. The concept is similar to the Unit Hydrograph in surface water hydrology where the hydrograph represents direct runoff produced by a unit of effective rainfall. By definition, a vector of unit response (UR) is the time-series of water level drawdown at a certain location, usually a monitoring well site, caused by a unit pulse at a production well. Two time scales for a unit pulse were used in developing the new unit responses, a week or a month of pumpage at the rate of one million gallons per day (mgd). Also in this report, the terms 'UR hydrograph' and 'UR (time) profile' are used interchangeably to refer to a graph of unit drawdown (negative response) over time for a monitoring well and a production well pair.

The development and use of the URM involve two assumptions as follows:

- The response is entirely effected by the pulse from the pumping well and is independent of boundary and initial conditions and other excitations
- The pulse-unit response model behaves approximately as a linear system such that proportion and super-position methods can be applied to determine a total response

The assumptions allow the use of convolution to obtain a drawdown time profile (s_t) from a time-series of changes in pumpage (Δq_t) at a production well. The drawdown can be expressed in discrete form as:

$$s_t = \sum_{k=1}^{t} u_k \Delta q_{t-k+1} \tag{2}$$

$$\begin{bmatrix} s_1 \\ s_2 \\ \vdots \\ s_T \end{bmatrix} = \begin{bmatrix} u_1 & & & \\ u_2 & u_1 & & \\ & \cdots & \cdots & \\ & & \cdots & u_1 \end{bmatrix} \begin{bmatrix} \Delta q_1 \\ \Delta q_2 \\ \vdots \\ \Delta q_T \end{bmatrix} \tag{3}$$

where u in (2) is the vector of Unit Response (time-profile) of a unit pulse at a location, and $[u]$ in (3) is the Unit Response Matrix, usually expressed as a monitoring well i and a production well j pair, $[u_{i,j}]$. The drawdown at a monitoring well i resulting from multiple pumping wells can be determined by super-positioning responses from all production wells, as in (4),

$$s_{it} = \sum_{j} \sum_{k=1}^{t} u_{ijk} \Delta q_{j,t-k+1} \tag{4}$$

URM Development

Tampa Bay Water and the Southwest Florida Water Management District (SWFWMD) have collaborated to develop an Integrated Hydrologic Model (IHM) which was calibrated using data from 1989 through 1998 with specific application to the Northern Tampa Bay area. This application,

Table 1. Matrix of INTB model scenarios for URM development

Pulsing Rate	Scenario Name (Scenario Number)	
	Dry season pulse (Jan 1-7, 2000)	**Wet season pulse (Jul 1-7, 2000)**
0.2 mgd for 1 week	dry0.2mgd_1week (15)	wet0.2mgd_1week (16)
2.0 mgd for 1 week	dry2mgd_1week (17)	wet2mgd_1week (18)
2.0 mgd for 4 weeks	dry2mgd_4week (19)	wet2mgd_4week (20)

referred to as the Integrated Northern Tampa Bay (INTB) model, was employed to generate the new sets of URM. The base run employed historical data for a two-year simulation period from January 1, 2000 through December 31, 2001.

Six INTB scenarios (see Table 1) were designed and investigated to assess and confirm the validity of the underlying assumptions. Each scenario has different pulsing rates, pulsing seasons, and pulsing intervals or time scales. For each production well, a pulse run was performed with the addition of a pulse to the historical pumpage at that well. Each drawdown time profile was obtained by computing the head differences between the pulse and the base runs. The UR vector was calculated by dividing the profile drawdown by the pulsing rate. The four-week pulse was included to accommodate the need of the current and the future enhanced OROP models that require a URM for both one- and four-week time steps. Tampa Bay Water owns a total of 210 production wells (including the active, inactive, and plugged wells); therefore each scenario required 210 INTB simulations.

The following discussion will focus on the UR time profile comparisons. A log-scale in the unit of days is used on the time axis (x-axis) to magnify the display of responses during the pulsing period. Also, UR hydrographs were plotted with a higher time resolution during the first six weeks, e.g., one-day instead of one-week interval.

Figure 1 compares the UR time profiles for different scenarios at STK-20s monitoring well with the unit pulse imposed on ST-01 production well. The figure shows insignificant differences in UR profiles from different pulsing rates as well as from different pulsing seasons. Inspecting similar graphs[1] from other well pairs shows similar results, except for those monitoring sites where the issue of variable specific yield exists. This issue of variable specific yield is addressed in some detail later in this report.

However, differences in UR profiles for one-week and four-week pulsing intervals are expected as shown in Figure 1. To have an appropriate comparison between the two pulsing time scales, one must compare the four-week time scale UR profile with the UR profile derived from convolving one-week UR profile over 4 time-steps. Figure 2 demonstrates this assertion by comparing the UR profiles from '*dry0.2mgd_4week*' and '*wet0.2mgd_4week*' with those from '*dry0.2mgd_conv*' and '*wet0.2mgd_conv*'. The latter two UR profiles were calculated by applying a time-series of four 1-mgd pumpage to the '*dry0.2mgd_1week*' and '*wet0.2mgd_1week*' profiles, respectively.

[1] accessible on-line at http://www.tampabaywater.org/nisai/presentations/URM_OROP_TAC/Scenario.pdf

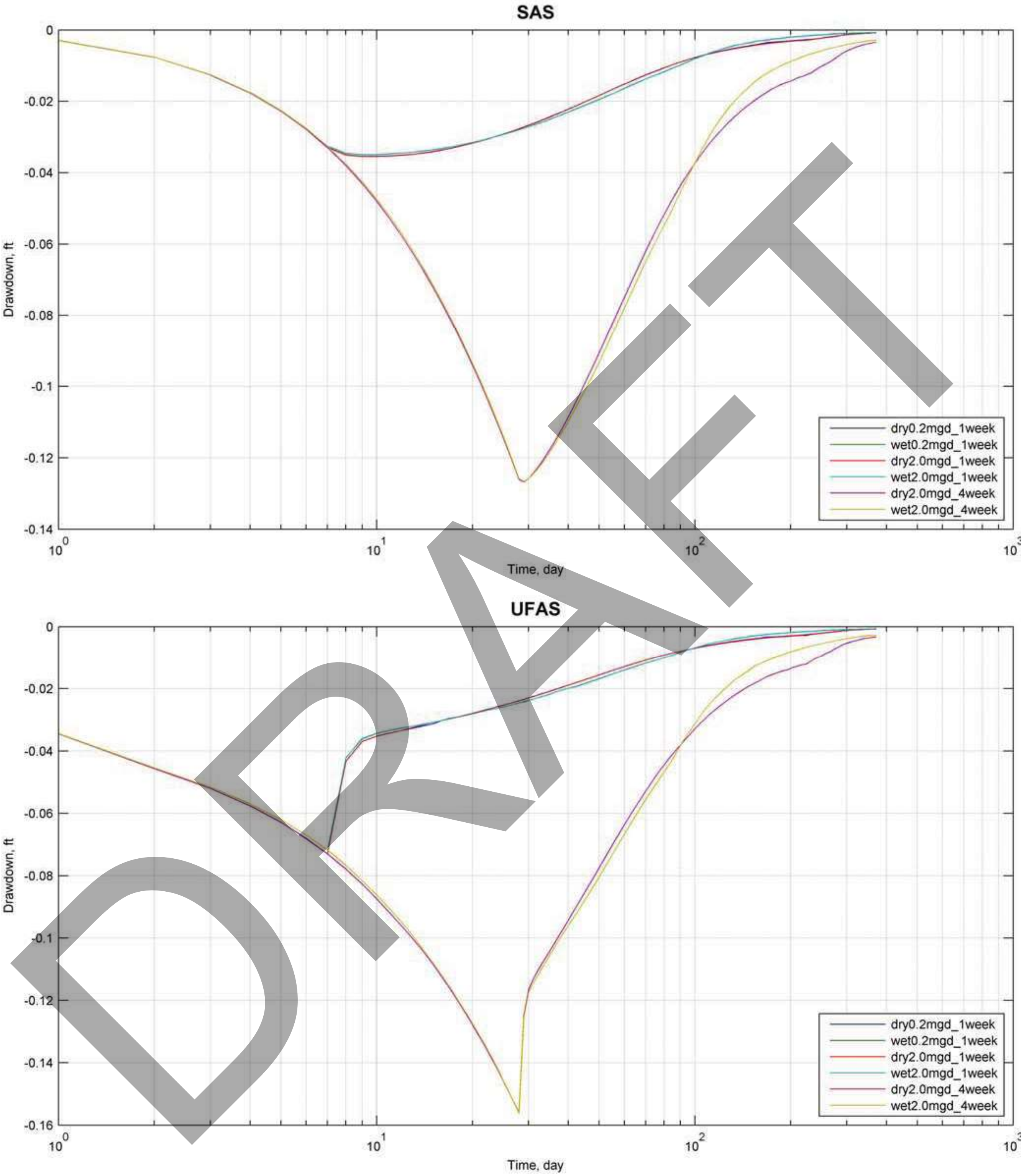


Figure 1. UR profiles of different scenarios at monitoring well STK-20s and pulsing well ST-01

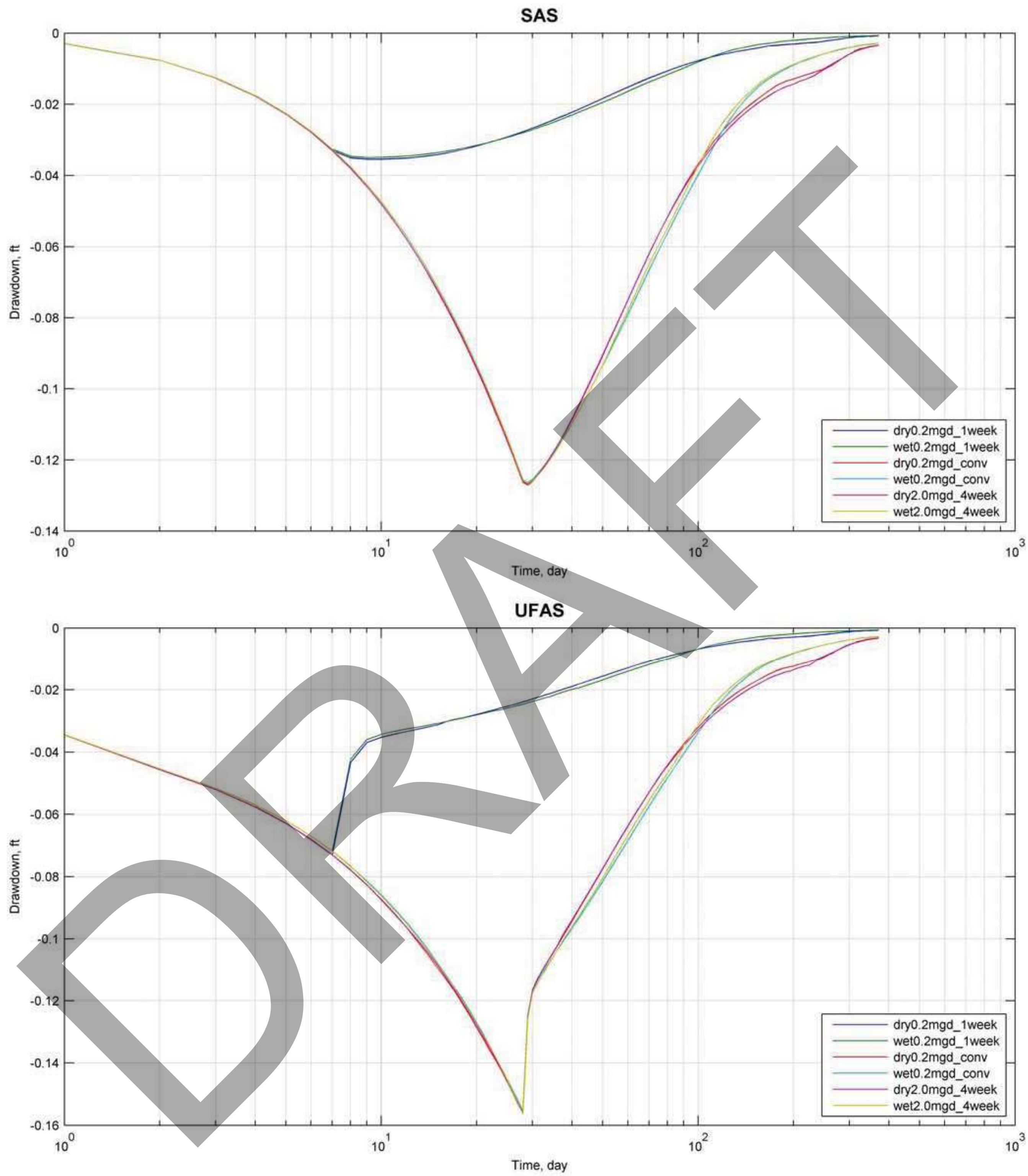


Figure 2. UR profiles of different time scale at monitoring well STK-20s and pulsing well ST-01

The magnitude and shape of the drawdown response hydrograph is dependent on the distance between the monitoring well and the production well pair and their surrounding hydrogeologic properties, primarily transmissivity, storativity, and leakance. For a homogeneous, isotropic system, the drawdown hydrograph can be determined from a theoretical 'Well Function', which is well established in the literature. In this regard, it may be of one's interest to compare the UR profiles from different production wells. Figure 3 compares magnitudes and shapes of responses from various production wells in Cypress Creek Wellfield at monitoring well CYC-TB-22s. Comparing similar graphs[2] (with a fixed scale) from all the wellfields shows that a maximum unit drawdown in the SAS of about 0.22 ft occurred at monitoring well CYC-TB-22s resulting from a unit pulse at production well CC-10. For UFAS, the maximum unit drawdown of 2.70 ft occurred at monitor well MBR-25s resulting from a unit pulse at production well MB-162.

During IHM-INTB model calibration, Parallel PEST (Doherty 2004) was used as a guide to the manual calibration process. The model used by PEST was setup with the simulation period from January 1, 1996 to December 31, 1997 which covered a low to high transition in the hydrologic regime. This same simulation period was used during the initial development of the new URM. The INTB was developed and calibrated using a variable specific yield for SAS. Under certain hydrologic conditions, it is difficult to obtain a consistent unit response where the underlying model includes a variable specific yield. This is due to changes in the water table level and storage properties that occur as the water table approaches land surface. This issue as it relates to the development of the URM was quickly discovered using the period January 1, 1996 through December 31, 1997. Spikes and steps appeared in some UR profiles during shallow depth to water level (DTW) and high intensity rainfall events. As the SAS head approached land surface, a small change in water level under shallow DTW caused the pulse run to behave relatively more or less different than the base run. The factors contributed to this change were the small values (< 5%) of specific yield for water table near land surface and the timing of rain event. The effect was very pronounced in some monitoring-production well pairs causing the UR profiles to be poorly defined. The following strategies were attempted to overcome these issues.

Developing URM during deep DTW

To avoid the aforementioned issue of variable specific yield, an alternate two-year simulation period with deeper DTW was sought. The hydrograph of median DTW among OROP control point wells indicated that DTW during 2000-2001 was the deepest two-year period since the implementation of OROP. The simulation period for URM development was moved to January 1, 2000 through December 31, 2001. This eliminated all ill-defined UR profiles and significantly improved most of the UR profiles.

Tightening closure criteria in MODFLOW

The smallest magnitude of unit drawdown can be in the order of 1e-4 ft. To eliminate the introduction of noise from the numerical solver in the UR determination, the MODFLOW head closure criteria was reduced from 1e-4 to 1e-5 ft. The maximum number of inner iterations was also increased accordingly from 100 to 200. Although the test result showed insignificant improvement in UR profiles, these criteria were retained in all simulation runs throughout the final URM development process.

[2] accessible on-line at http://www.tampabaywater.org/nisai/presentations/URM_OROP_TAC/Prodwell.pdf

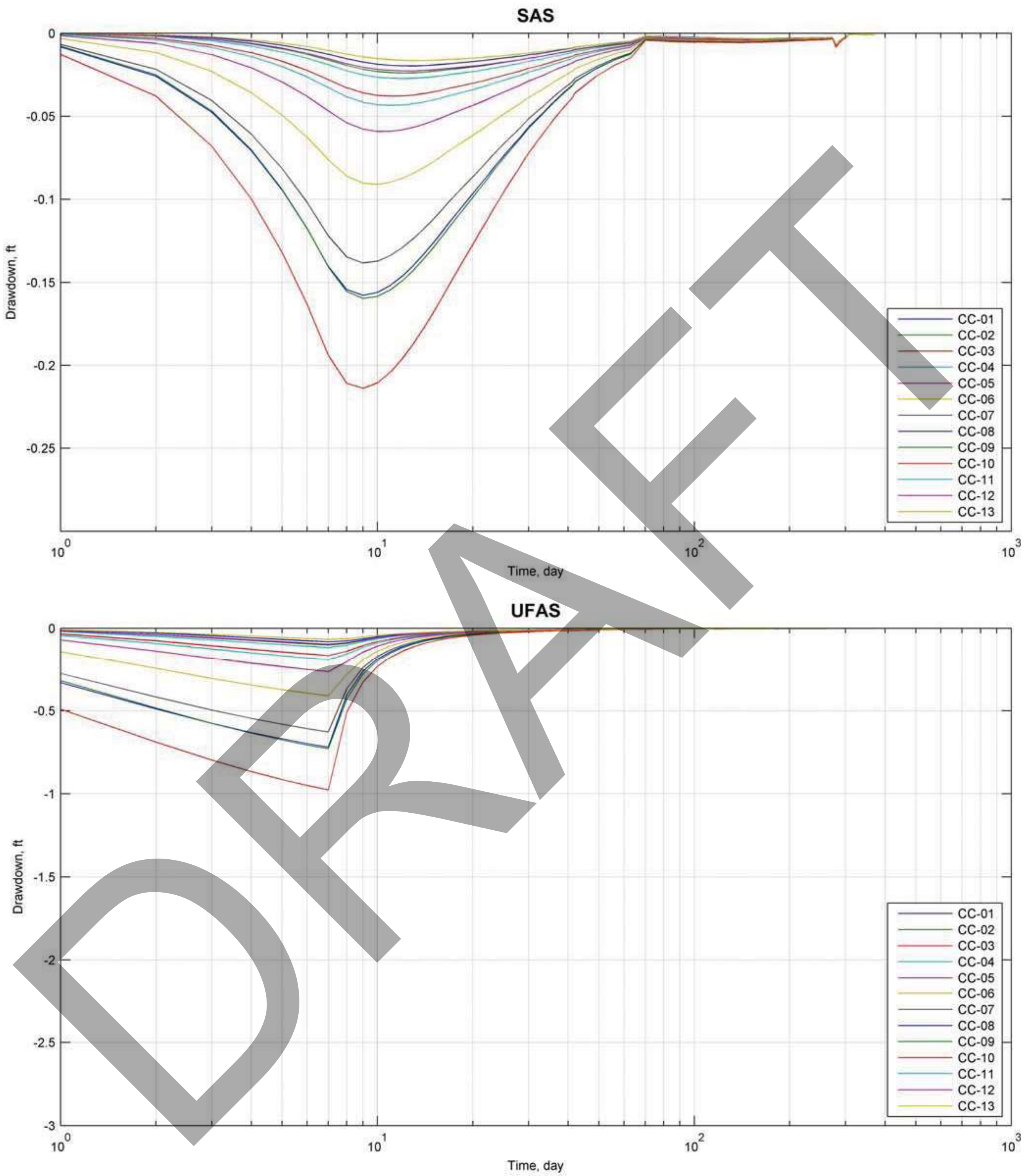


Figure 3. UR profiles at monitoring well CYC-TB-22s with pulses by different production wells

Reducing calibration ratios of capillary fringe and capillary zone thickness

IHM implements variable specific yield by shifting soil moisture content profile with the rise and fall of water level. Since variable specific yield is active within the capillary zone, reducing this zone thickness should alleviate the effect of variable specific yield on UR profile. Unfortunately, the test results showed that the reduction also significantly shifted the UR profiles. In some cases, the maximum drawdown was altered by as much as 20%. Hence, this strategy was removed from consideration for final development of the URM.

Using multiple rainfall realizations

All of the above strategies could not completely eliminate all spikes and small jumps in some UR profiles. Recognizing that the effects were predominately caused by local rainfall intensity, an approach to use median UR profiles from multiple rainfall realizations was introduced. A test performed using 50 random rainfall realizations yielded promising results as shown in Figure 4. The figure, which is based on '*dry0.2mgd_1week*' scenario, shows the ensemble median of UR profiles determined from 50 basin rainfall realizations. The UR profiles are smooth and all spikes and jumps were eliminated. As expected, no variation was detected in UFAS unit drawdown profiles derived from these basin rainfall realizations. Due to the demanding computer storage by this strategy, the head-file archiving interval in this test was increased from one day to seven days to correspond to the pulsing time scale. As a result, data used for plotting the UR profiles have a time resolution of one week, in contrast to one day from previous figures. Similar plots[3] for other well pairs are also available for examination from Tampa Bay Water website. The multiple rainfall realization approach was used in the final URM development.

Parallel to this study, a basin rainfall generating model has been developed for Monte Carlo (MC) analysis using the INTB model. One thousand realizations of basin rainfall were generated using an annual Auto-Regressive model based on annual long-term rainfall gage data which included an 8-year cycle (AR8 model). Spatial disaggregation was achieved by the inverse distance (gage to basin centroid) weighted average method. Temporal disaggregation to daily and 15-minute time scales was based on statistics derived from INTB historical basin rainfall. The daily disaggregation model was constructed using the second-order, two-state, Markov Chain process parameterized by basin and month. Gaussian Copula random generator[4] was used to maintain historical spatial and temporal correlations of the daily time-series. The 15-minute disaggregation process relied on sampling from historical rainfall distributions based on daily rain.

In the final stage of URM development, one hundred rainfall realizations were selected based on the grid computing system ability to finish the development task in a reasonable time without sacrificing the URM accuracy. To maintain the realization probability distribution, stratified sampling was employed to select 100 realizations from the population of one thousand MC basin rainfall realizations. Two scenarios, '*dry0.2mgd_1week*' and '*dry2.0mgd_4week*', were used for a total of 2x100x210 INTB simulation runs needed.

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[3] accessible on-line at http://www.tampabaywater.org/nisai/presentations/URM_OROP_TAC/Realization.pdf

[4] see description of 'copularnd' function in MATLAB's Statistical Toolbox™

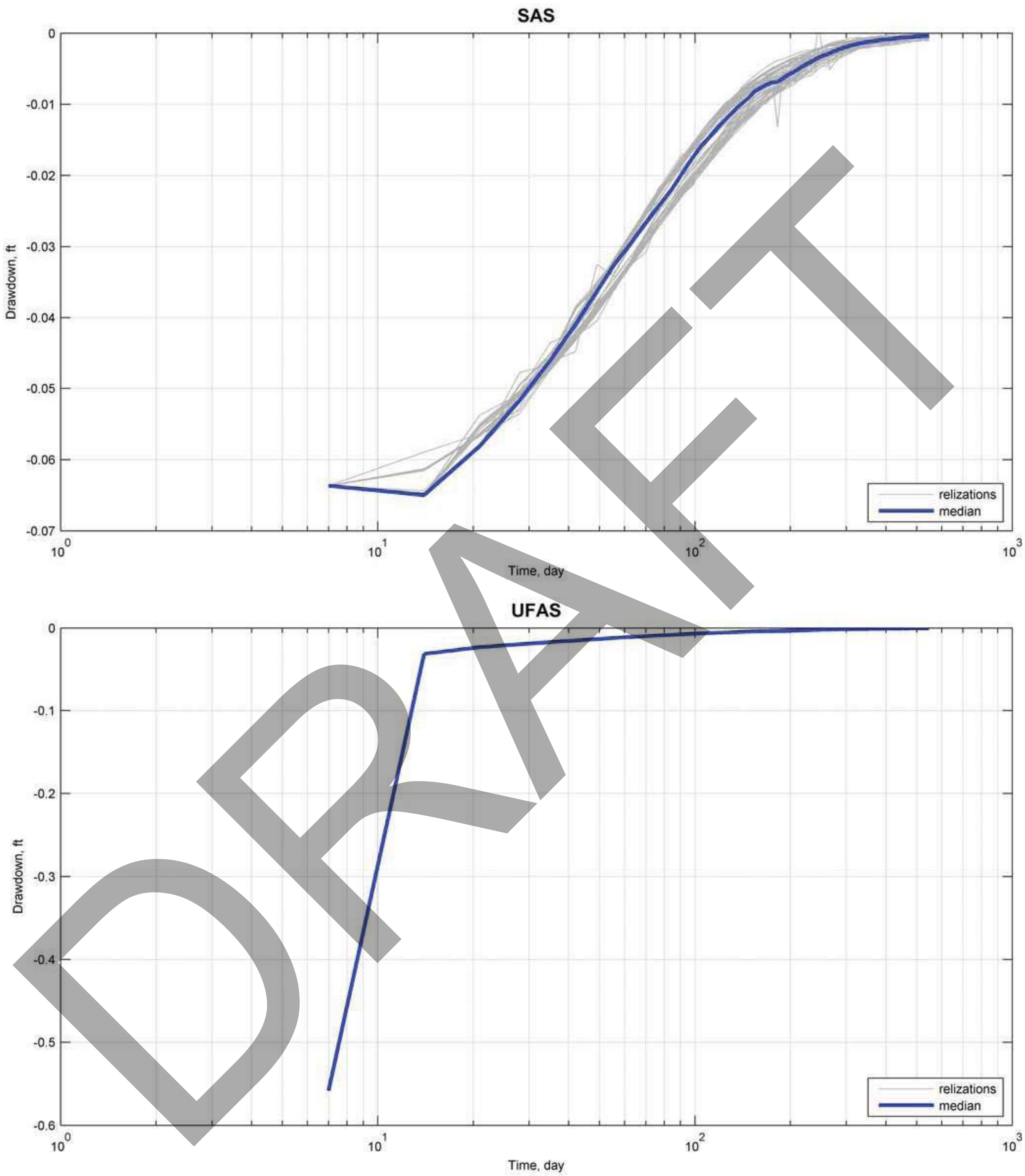


Figure 4. Ensemble median of UR profiles determined from 50 basin rainfall realizations at monitoring well STK-EMW-16s and the pulsing well ST-08

Figure 5 depicts the ensemble median and the 25-75 percentile range of SAS UR profile for '*dry0.2mgd_1week*' scenario at STK-20s with a pulse at ST-04. The plot uses a log-log scale so that the median profile can be differentiated from the two red lines of 25 and 75 percentiles establishing a band of profile uncertainty. The figure also provides a map inset displaying the well-pairs distance relative to the wellfield boundary. After examining the full set of results, the following conclusions were drawn:

- The uncertainty band of 25-75 percentile is tight, hence median UR profile is most likely independent of rainfall
- As distance between well-pair increases, the magnitude of unit drawdown decreases while the lag response increases
- Profiles of ensemble median for all well-pairs are smooth and appropriate for future applications of the URM.

A sub-set of graphs[5] similar to Figure 5 are available via the Tampa Bay Water website.

Validation

The purposes of this validation are to verify that

- The numerical values of URM's elements were determined accurately
- The underlining linear assumption is not violated and the following properties hold
    - Temporal super-position or time convolution
    - Spatial super-position and proportion
    - Independency of other excitations than the pulse
- The process of applying URM is correctly carried out and the errors are within the acceptable limit

The validation process involves comparing water-level responses determined from the IHM-INTB model and the URM. Two model runs, namely Run-A and Run-B, were performed with two different sets of pumpage randomly selected from the MC pumpage realizations which were randomly selected from the feasible solutions of the OROP constraint programming. The runs had the same setup as the URM development runs except that the first year pumpage was replaced by the corresponding MC pumpage realizations. The two-norm (square root of sum square), also known as Euclidean norm, is usually used to gage the magnitude of differences between two vectors. The norms of the realization pumpage differences are varied from week to week between 3.77 to 12.14 mgd with an average of 8.63 mgd. Figure 6 shows the distribution map of the pumpage differences in week 49 when the Euclidean norm is the highest. With a total of 151 wells, the root mean square of the difference for the week is about 0.99 mgd indicating that the two pumpage patterns are highly contrasted.

[5] accessible on-line at http://www.tampabaywater.org/nisai/presentations/URM_OROP_TAC/Median.pdf

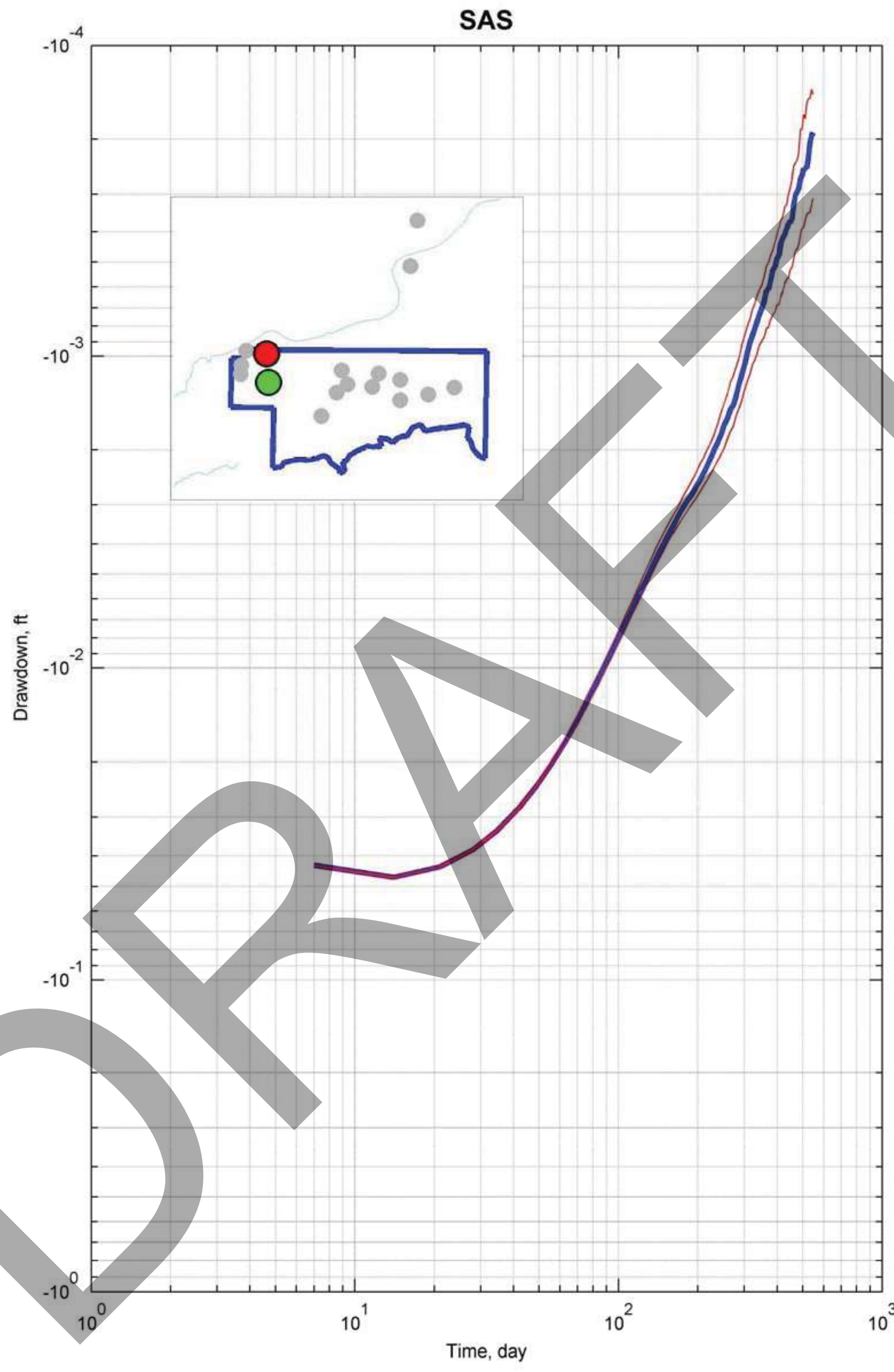


Figure 5. Ensemble median and a band of 25-75 percentiles of UR profiles determined from 100 basin rainfall realizations at monitoring well STK-20s (green circle) and the pulsing well ST-04 (red circle)

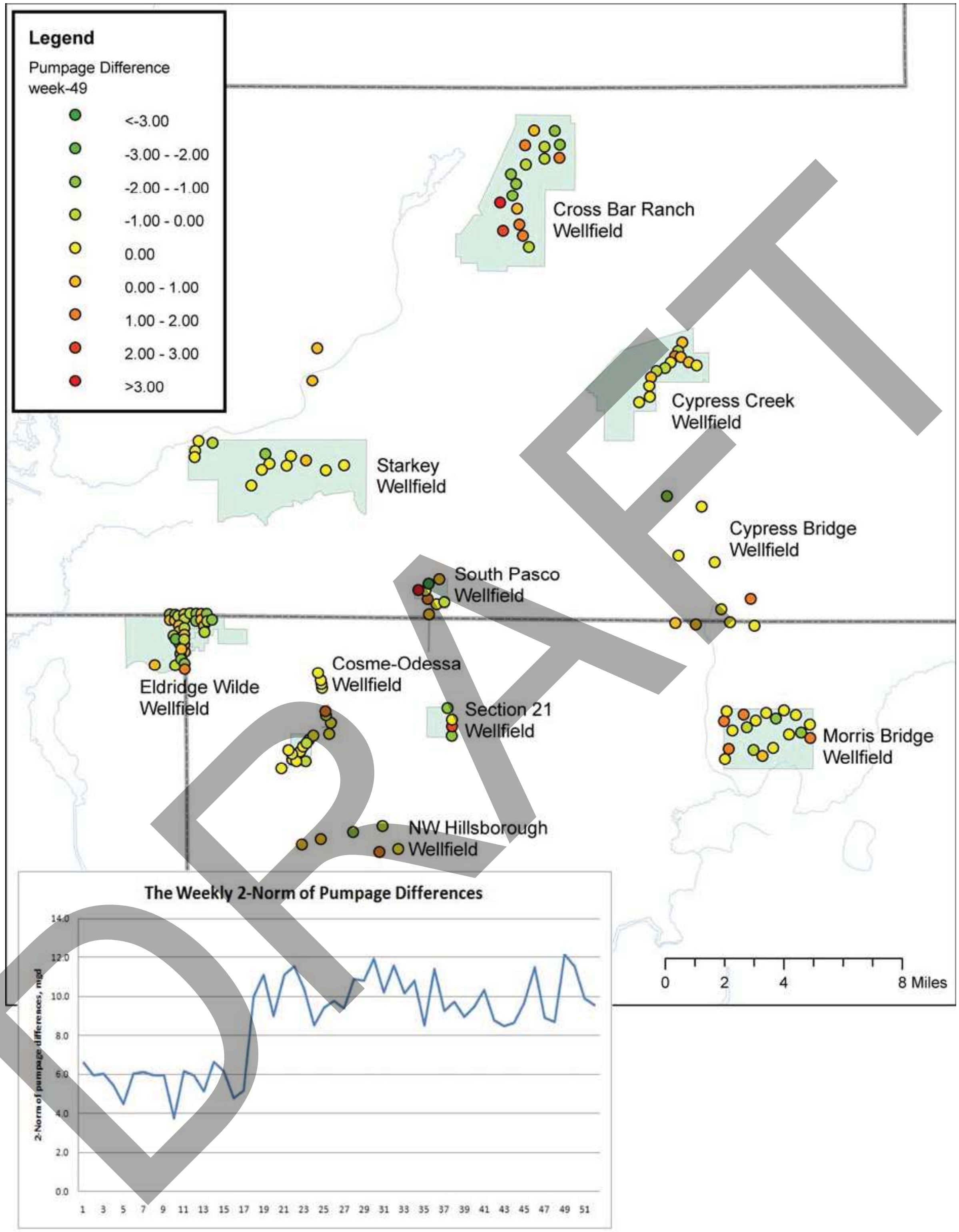


Figure 6. Pumpage differences between two realizations - The weekly two-norm and map of the distribution of week 49

IHM-INTB responses were determined from head differences between two runs while the URM responses were calculated by applying pumpage differences to URM and super-positioning the responses. Figure 7 compares the result at monitoring well CC-TB-22s in Cypress Creek Wellfield. Differences in total wellfield pumpage are overlain on the graphs with the scale in mgd shown on the right y-axis. The error statistics from a full set of graphs[6] for all OROP control wells indicated that URM approach was able to produce very accurate response estimations. Note that the relative errors in UFAS are much smaller than in SAS due to the response behavior of the UFAS being more nearly linear.

To estimate water levels using the URM, a reference model run is required. The calculation is performed using a similar expression to the one in the square bracket in equation (1). To demonstrate this process, Run-A is designated as the reference run such that adding the previously determined URM responses to Run-A water levels will yield the URM estimation of Run-B water levels. Figure 8 compares Run-B water levels determined from IHM and the URM estimation. Visually examining similar graphs[7] for all control wells affirms the validity of using the URM approach in OROP. Perhaps a more convincing evidence of validity robustness could come from Table 2 where ensemble statistics derived from 50 pairs of runs were compared. Among all OROP wells, Table 2 shows that the ensemble mean and standard deviation of the temporal averages in SAS water level estimation errors should be lower than 0.02 and 0.20 ft, respectively.

Summary and Conclusions

Two URM sets were developed using the IHM-INTB model to simulate the 2000-2001 responses from one- and four-week dry season pulses with 100 basin rainfall realizations. One realization in a set required 210 model runs, each with a 0.2 mgd pulse from a production well. The URM in each set was determined from the ensemble median of the UR profiles calculated from head differences resulting from a unit pulse applied to 100 simulations with different basin rainfall realizations. Selecting a deep DTW period and using multiple rainfall realizations to develop URM alleviated various issues, related to the variable specific yield implementation in IHM. Validation suggested that any errors in using URM to evaluate pumpage responses are insignificant relative to the range of water level fluctuations. The database tables for the new URM have been created and are ready to implement in OROP.

[6] accessible on-line at http://www.tampabaywater.org/nisai/presentations/URM_OROP_TAC/Response.pdf
[7] accessible on-line at http://www.tampabaywater.org/nisai/presentations/URM_OROP_TAC/Watlev.pdf

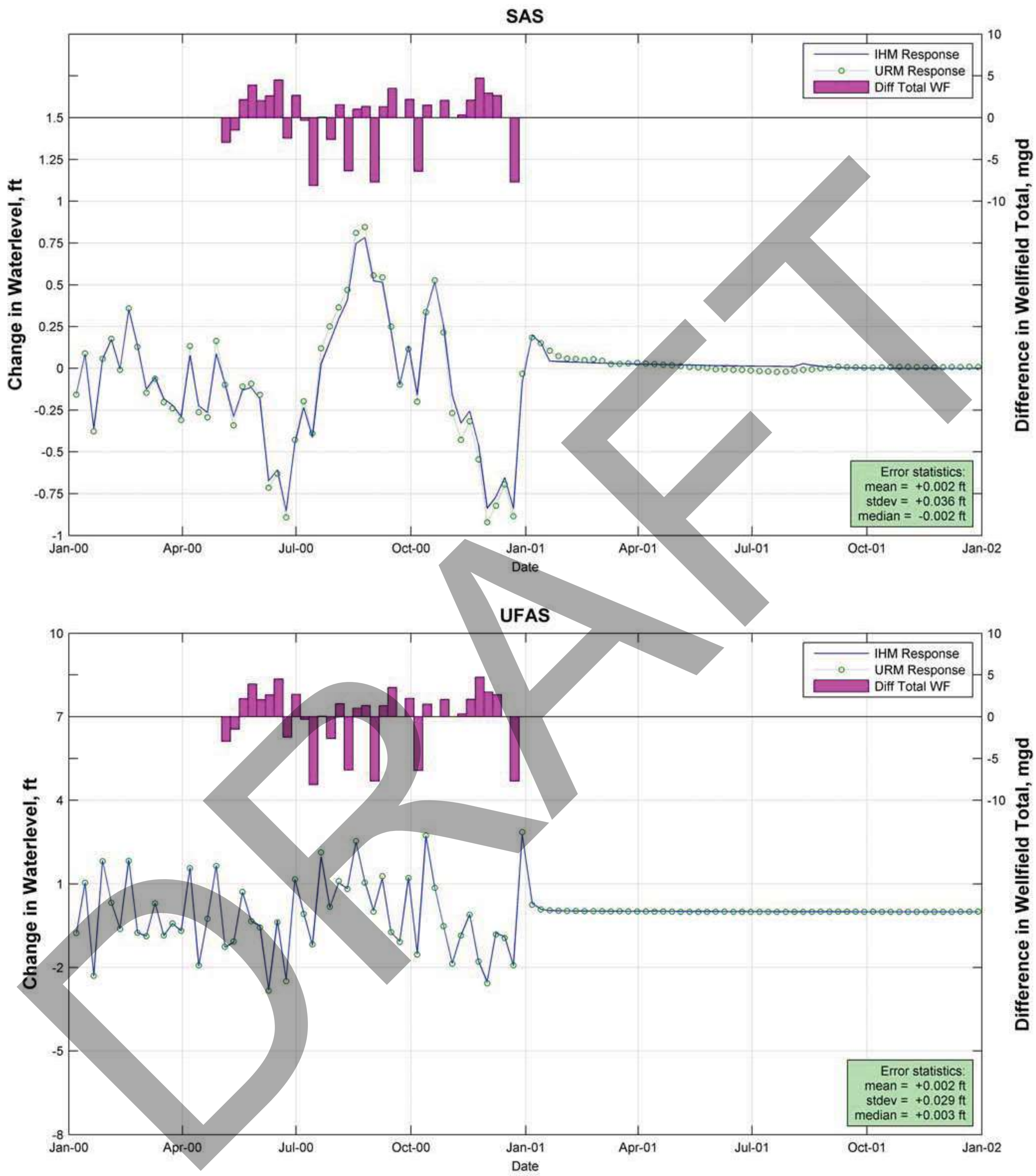
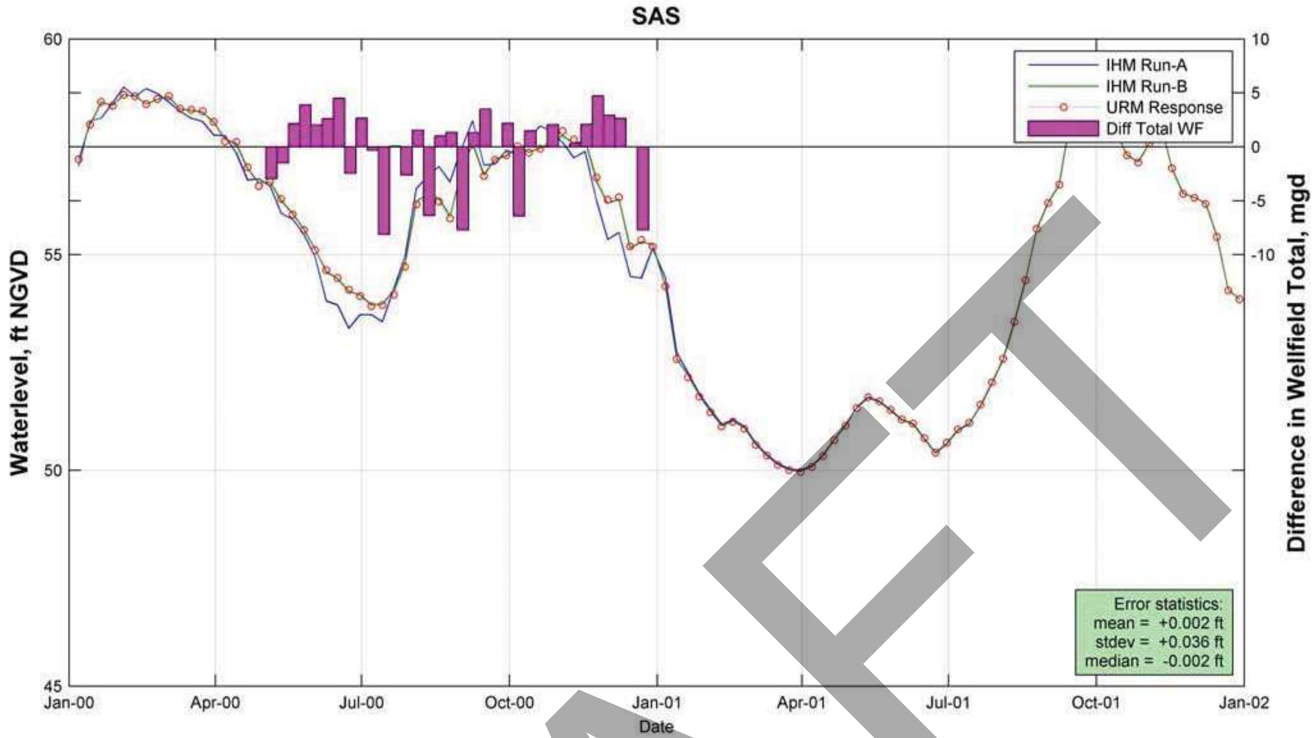


Figure 7. Comparison of IHM and URM responses



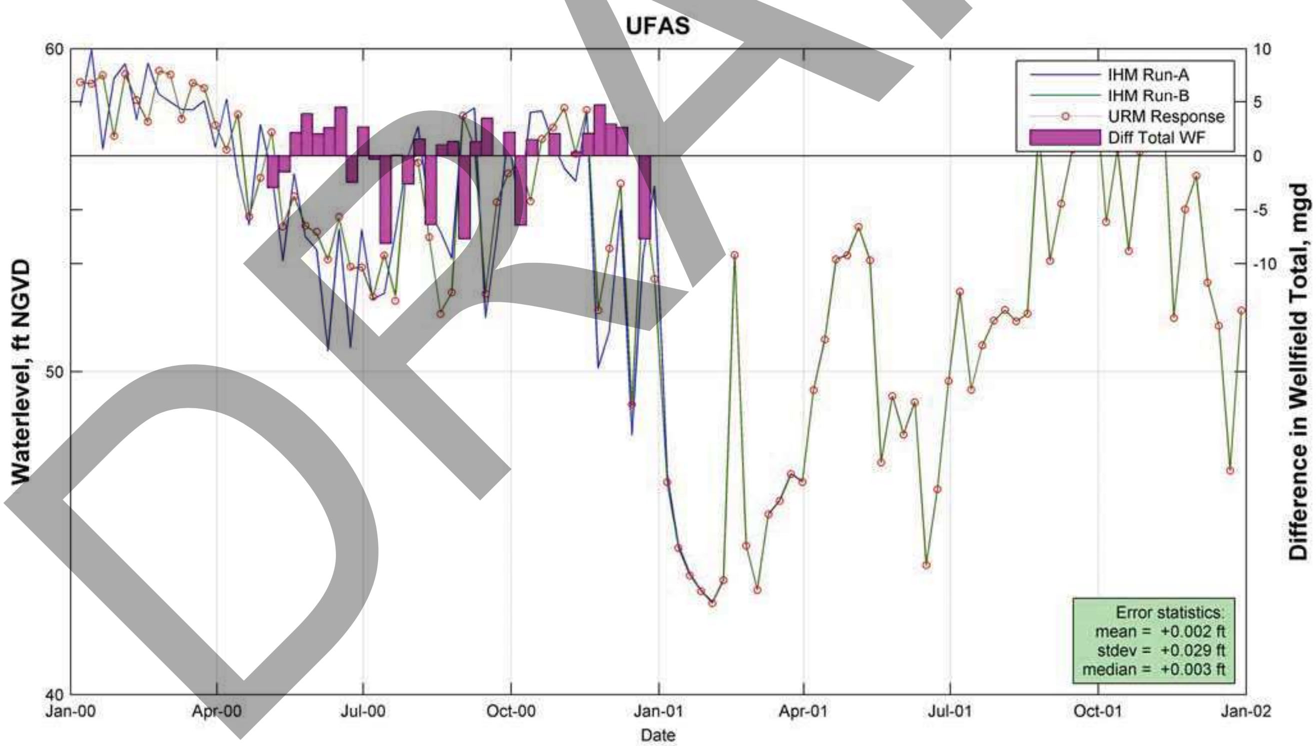


Figure 8. Comparison of water level from IHM Run-B and the estimation using URM

Table 2. Ensemble statistics of errors from 50 validations

Ensemble	Mean	Mean	STDEV	STDEV	Mean	Mean	STDEV	STDEV
Temporal*	Mean	STDEV	Mean	STDEV	Mean	STDEV	Mean	STDEV
Well Name	SAS				UFAS			
A-1s	-5.36E-04	3.68E-02	5.84E-03	2.77E-02	-3.56E-04	1.57E-02	3.95E-03	1.02E-02
Cosme-20s	6.24E-04	7.83E-03	6.50E-03	5.41E-03	3.50E-03	2.87E-02	3.63E-02	2.76E-02
CC-TB-22A	-1.09E-03	7.83E-02	2.11E-02	3.21E-02	-2.64E-04	4.19E-02	8.18E-03	1.36E-02
TMR-1As	-3.60E-03	7.72E-02	4.00E-02	3.35E-02	-2.46E-04	1.30E-01	1.26E-02	3.49E-02
WT-5-200	7.86E-04	2.23E-02	1.18E-02	1.12E-02	2.45E-04	1.93E-02	5.66E-03	5.00E-03
EW-11s	-8.10E-03	5.79E-02	9.66E-02	2.43E-02	-5.81E-03	9.38E-02	6.97E-02	3.25E-02
SGW-1	2.78E-04	3.89E-02	1.17E-02	2.40E-02	5.94E-04	3.77E-02	7.35E-03	7.80E-03
NPMW-7s	9.94E-03	4.49E-02	5.61E-02	4.35E-02	3.28E-02	1.31E-01	1.83E-01	1.34E-01
RMP-13s	-5.03E-04	4.93E-03	2.58E-03	3.17E-03	1.40E-03	1.22E-02	1.41E-02	1.03E-02
Hills-13s	1.82E-02	1.39E-01	1.98E-01	1.90E-01	3.06E-02	2.01E-01	3.25E-01	2.63E-01
Jacksn26As	6.29E-03	4.90E-02	6.67E-02	6.68E-02	3.63E-02	2.48E-01	4.03E-01	3.27E-01
StPt-47s	-9.46E-04	3.15E-02	1.95E-02	1.87E-02	5.44E-03	4.12E-02	6.40E-02	5.31E-02
WT-15s	1.76E-04	9.48E-03	8.03E-03	5.08E-03	1.85E-03	1.30E-02	1.34E-02	9.81E-03

* Note: Temporal statistics were evaluated from a time-series error of a validation pair.

Reference

Doherty, J. (2004). *PEST, Model-Independent Parameter Estimation*, User manual: 5th Edition, Watermark Numerical Computing.

Tampa Bay Water (2009). *Optimized Regional Operations Plan, WY 2008 Annual Report*, Submitted July 2009, Prepared for Southwest Florida Water Management District, Tampa Bay Water, Clearwater, Florida.

APPENDIX B

WEEKLY DEMAND FORECAST MODELS

Weekly Demand Forecast Models

In 2006, Tampa Bay Water completed the development of seven autoregressive with exogenous variable (ARX) models for 11 points of connection (POC) or combinations of POCs (see Figure 1). Inputs to these models are recent demands, different forms of rainfall (including rain amount, number of rainy days in a week, and number of consecutive rainy days), and a temperature threshold. Table 1 lists the POC's whose aggregate demand is being forecasted along with the "nearest" rainfall stations. Location of the "nearest" rainfall station to a water demand area can affect the quality of the demand prediction at that area and the POCs.

Table 1 Weekly Demand Model Structure

Model Number	Daily Demand for POCs	Rainfall Stations
1	Little Road, US41, Odessa	STK-west, STK-east, STK-14, NOP-NP, CYC-Plant, CBR-South
2	Cosme	NWH-NW-5-Rain, COS-COSME-Rain
3	Lake Bridge	CYC-PLANT, CYC-C3, CYC-TOT, CYB-CY-7
4	Lithia	SCHM2, SCH-SC-1, SCH-SC-4, SCH-SC-17
5	Maytum	STK-west, STK-east, STK-14
6	Pinellas, Keller	COS-COSME-Rain, NWH-NW-5-Rain
7	NWH, Lake Park	COS-COSME-Rain, NWH-NW-5-Rain

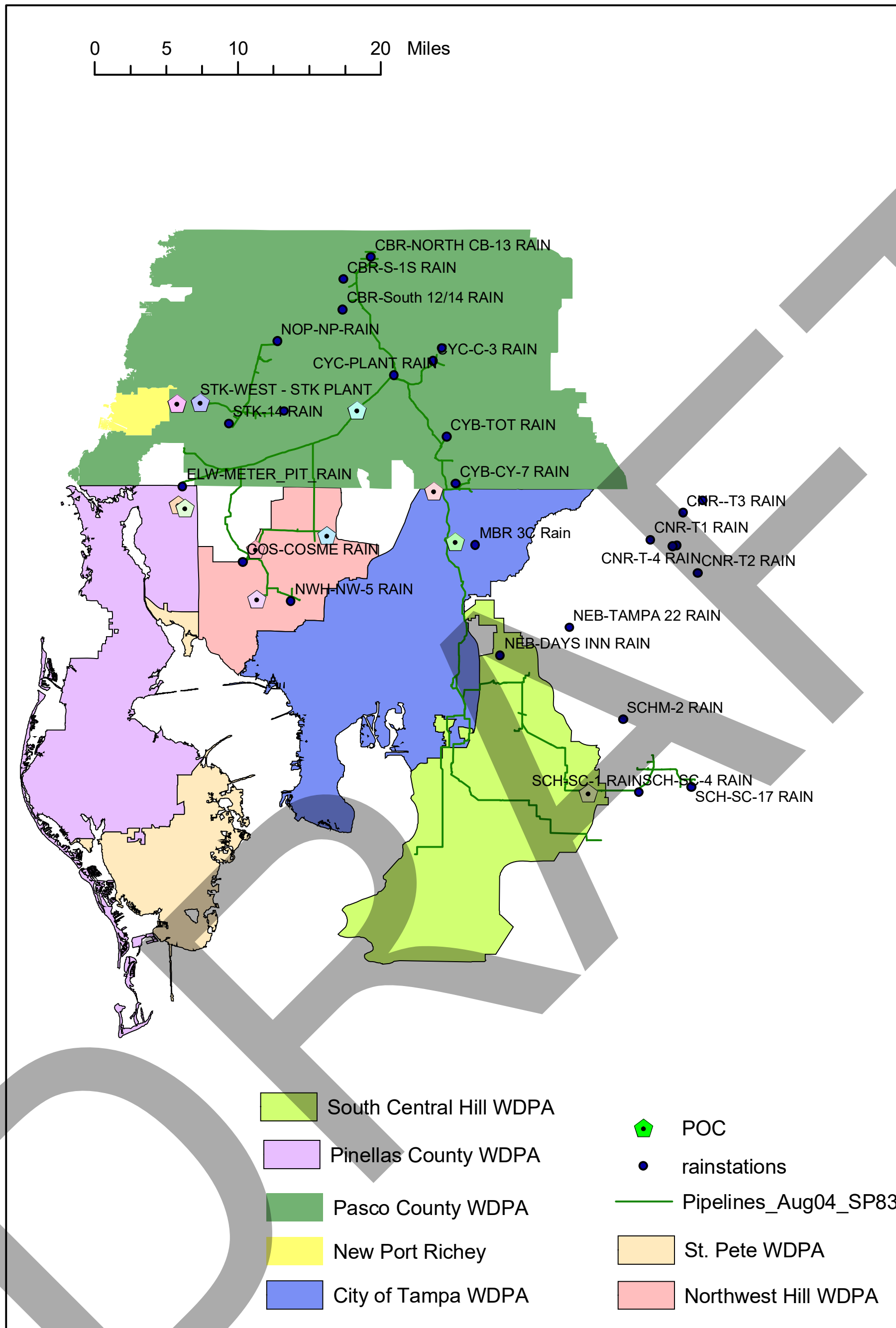


Figure 1. Weekly demand forecasting areas

Exploratory Data Analysis – Little Road Point to Connection Model Development

Exploratory data analysis was conducted for each point of connection; the steps are illustrated using the Little Road model development. Data analyzed included actual demands from October 1991 through May 2005, rainfall and temperature.

Rainfall Data gaps

Several gaps exist in rainfall data. These gaps were analyzed using different techniques (simple averaging, a nearest neighbor estimate, linear regression, and inverse distance square (IDS)). IDS and linear regressions were the two best techniques with IDS providing a slight improvement over linear regression. The IDS approach was used for this project. Table 2 shows results of different technique for the 22 Tampa Bay Water rain gauges.

Table 2. Performance of testing data set in filling missing data

	Regression		IDS		Nearest Neighbor		Simple Averaging	
Station	RMSE	MAD	RMSE	MAD	RMSE	MAD	RMSE	MAD
1	0.218	0.081	0.253	0.099	0.251	0.090	0.303	0.123
2	0.201	0.072	0.194	0.076	0.251	0.090	0.251	0.102
3	0.203	0.076	0.175	0.065	0.198	0.066	0.216	0.090
4	0.238	0.087	0.113	0.037	0.130	0.039	0.224	0.091
5	0.190	0.069	0.130	0.041	0.130	0.039	0.252	0.094
6	0.269	0.094	0.229	0.090	0.299	0.103	0.276	0.109
7	0.218	0.085	0.206	0.077	0.280	0.101	0.275	0.106
8	0.241	0.091	0.219	0.084	0.261	0.086	0.264	0.107
9	0.229	0.090	0.262	0.099	0.280	0.101	0.311	0.123
10	0.204	0.079	0.238	0.089	0.281	0.093	0.262	0.103
11	0.229	0.080	0.238	0.088	0.281	0.093	0.269	0.107
12	0.254	0.099	0.235	0.082	0.247	0.080	0.273	0.100
13	0.242	0.090	0.203	0.075	0.247	0.080	0.235	0.092
14	0.261	0.104	0.221	0.087	0.272	0.094	0.243	0.100
15	0.218	0.079	0.230	0.088	0.272	0.094	0.261	0.104
16	0.208	0.081	0.210	0.082	0.239	0.086	0.263	0.105
17	0.229	0.086	0.269	0.102	0.277	0.098	0.344	0.138
18	0.146	0.050	0.182	0.064	0.257	0.083	0.267	0.110
19	0.128	0.045	0.232	0.082	0.257	0.083	0.283	0.112
20	0.177	0.067	0.196	0.070	0.231	0.076	0.266	0.103
21	0.193	0.073	0.193	0.069	0.231	0.076	0.252	0.100
22	0.247	0.097	0.210	0.078	0.252	0.088	0.277	0.103

Performance Measures

Following four measures are used

Simulation error $\varepsilon = y_{obs} - y_{sim}$

Naïve error $\varepsilon' = y_{obs} - y'$

$$MAD = \frac{1}{N}\sum_{i=1}^{N} abs(\varepsilon_i)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\varepsilon_i^2}$$

$$TU = \sqrt{\frac{\frac{1}{N}\sum_{i=1}^{N}(\varepsilon_i / y_i^{'})^2}{\frac{1}{N}\sum_{i=1}^{N}(\varepsilon_i^{'} / y_i^{'})^2}}$$

Schwarz's Bayesian Information Criteria $SIC = n\ln\sigma_\varepsilon^2 + n + n_{par}\ln(n)$ where n is sample size and n_{par} is number of parameters.

The model underlying this naïve forecast is the random walk, which can be specified as

$y_t^{'} = y_{t-1} + \xi_t$ where ξ_t ~ i.i.d. N (0, σ^2) .

That is, each value in the time series is the previous value plus some noise. We may then compare a selected model to the random walk. Behind this notion is the belief that if a forecasting model cannot do better than a naïve forecast, then the model is not doing an adequate job. Theil's U is a statistic that uses the random walk as a benchmark for comparing the quality of forecast models.

Input data

Besides the historical demand data at point of connections (POC), rainfall and temperature were the two other parameters that were used. Figure 1 shows locations of rainfall stations, POC, water demand planning areas (WDPA), and transmission lines. For Little Road POC six neighboring rainfall stations were isolated: STK-west, STK-east, STK-14, NOP-NP, CYC-Plant, and CBR-South, representing part of Pasco county WDPA. Temperature readings from the Tampa International Airport station were used.

Explanatory Data Analysis (EDA)

Figure 2 shows the historical average (OROP schedule, Saturday to Friday) weekly demand. The 13 years average demand is 10.2mgd with standard deviation of 1.68mgd.

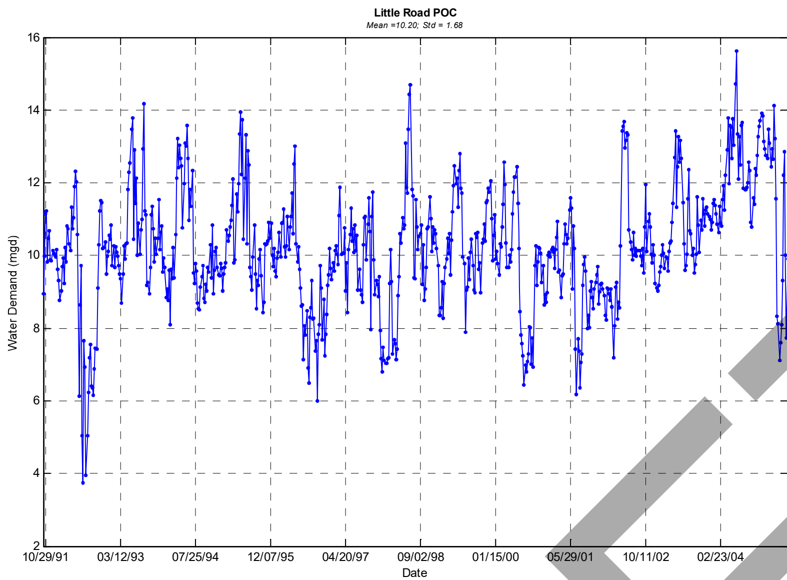


Figure 2. Average weekly demand using OROP schedule (Saturday to Friday)

The mean removed weekly demand shows a strong auto correlation as shown by the ACF and PACF plot.

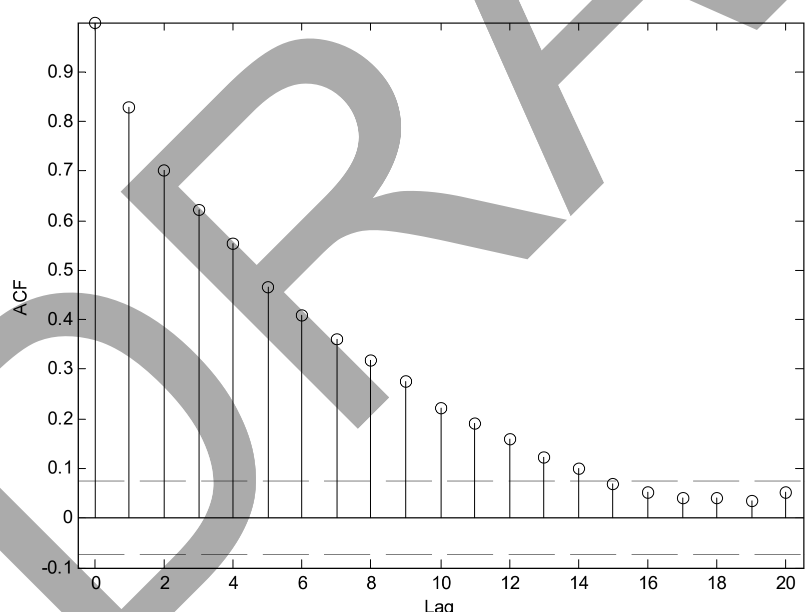


Figure 3. ACF

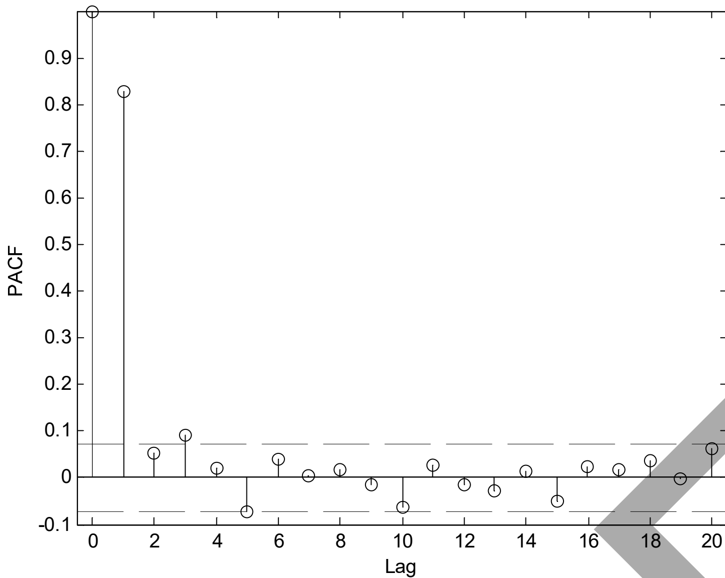


Figure 4. PACF

In addition to auto regression characteristics of demand, different forms of the exogenous variable were explored to see if they could explain the demand pattern. These selected explanatory parameters are:

1) Average rainfall of six stations that lies within the demand area
2) Number of rainy days in OROP in a week (Saturday to Friday). This is done by assigning a Boolean 1 or 0 for occurrence/non-occurrence using different thresholds for rainfall amount. These values range between 0 and 7.
3) Number of consecutive rainy days. This parameter is used to capture people behavior for not just a rainy day but wet days in a row.
4) Number of hot days. This is calculated by accounting days with a temperature exceeding a given threshold.

Table 3 summarizes performance of different ARX models developed using different time lags of the explanatory variables. Figure 5 shows one of the best results that used a lag 1 demand and lag 0 and 1, consecutive rainy days.

The following conclusion may be drawn from these analyses for the Little Road POC demand time series

1) Demand at this POC is highly correlated at lag 1. Using higher lag does not improve the model (see also PACF, Figure 4).
2) Consecutive rainy days and number of rainy days explain the water demand better than the actual rainfall itself suggesting that rainfall occurrence model is more important than a model that predicts rainfall amount. Also, note that lag 0 of these parameters explain a lot of the demand pattern compared to those that used only historical (lag 1 and higher).

3) Number of hot days (here days with temperature exceeding 80F is used) is a better indicator than the actual temperature itself.

Table 3. ARX models of Little Road POC

AR(X) Structure	Coefficients (se)	SIC (training)	RMSE (mgd)	MAD (mgd)	TU (-)
AR(1)	b1 = 0.8147 (0.02)	-53.002	0.8998	0.6496	0.9660
AR(2)	b1 = 0.7381 (0.04) b2 = 0.0936 (0.04)	-51.718	0.9099	0.6532	0.9783
ARX(1), lag 1 avg. rain frequency	b1 = 0.824 (0.03) r1 = 0.0207 (0.026)	-47.212	0.8984	0.6473	0.9654
ARX(1) lag 0 avg. rain frequency	b1 = 0.7793 (0.025) r0 = -0.2772 (0.021)	-182.425	0.7685	0.5608	0.8245
ARX lag0 and lag 1 avg.Rain Frequency	b1 = 0.817 (0.0236) r0 = -0.298 (0.021) r1 = 0.0936 (0.0231)	-188.9255	0.7345	0.5267	0.7940
ARX ,lag 0,1,2 avg. rain frequency	b1 = 0.833 (0.023) r0 = -0.3142 (0.021) r1 = 0.0895 (0.023) r2 = 0.056 (0.022)	-186.247	0.7085	0.4991	0.7671
ARX lag 0,1,2 avg. rain frequency lag 0 hot days (T >90)	b1 = 0.8201 (0.024) r0 = -0.3230 (0.021) r1 = 0.0725 (0.023) r2 = 0.0408 (0.022) h0 = 0.0327 (0.01)	-1.86.339	0.7181	0.5090	0.7756
ARX lag 1 # of rainy days	b1 = 0.7791 (0.028) r1 = -0.074 (0.026)	56.2986	0.9107	0.6648	0.9755
ARX lag 0 # of rainy days	b1 = 0.7619 (0.027) r0 = -0.2656 (0.023)	-175.054	0.8094	0.5939	0.8742
ARX lag 0,1 # of rainy days	b1 = 0.778 (0.0276) r0 = -0.278 (0.024) r1 = 0.0365 (0.027)	-169.803	0.7934	0.5783	0.8588
ARX lag 0,1,2 # of rainy days	b1 = 0.8223 (0.025) r0 = -0.315 (0.023) r1 = 0.01403 (0.021) r2 = 0.1295 (0.024)	-185.241	0.7296	0.5286	0.7987
ARX lag 0,1,2 # of rainy days, lag 0 hot days	b1 = 0.7896 (0.027) r0 = -0.3314 (0.023) r1 = -0.0132 (0.027) r2 = 0.1058 (0.0245) h1 = 0.0717 (0.017)	-195.511	0.7710	0.5446	0.8364
ARX lag 0 rainy days, lag 0 rain frequency, lag 0 hot days	b1 = 0.7583 (0.026) r0 = -0.2532 (0.029) rf0 = -0.1307 (0.037) h0 = 0.1217 (0.019)	-197.317	0.7889	0.5679	0.8517
ARX lag 0 and 1, rainy days, rain frequency and hot days	b1 = 0.7737 (0.026) r0 = -0.1646 (0.031) r1 = -0.0968 (0.032) rf0 = -0.2975 (0.044) rf1 = 0.2432 (0.044) h1 = 0.0934 (0.018)	-210.411	0.7730	0.5406	0.832
ARX lag 1 rainfall amount	b1 = 0.8102 (0.025) rn1 = -0.0282 (0.026)	-49.105	0.8102	0.6485	0.9596
ARX lag 0 rainfall	b1 = 0.825 (0.026)				

amount	rn0 = -0.1477 (0.037)	-108.519	0.8124	0.5893	0.8836
ARX lag 0 and lag 1 avg. rainfall amount	b1 = 0.8447 (0.027) rn0 = -0.2268 (0.036) rn1 = 0.1228 (0.041)	-105.132	0.8051	0.5871	0.8857
ARX lag 0,1,2 rain frequency, lag 0, 1 rainfall amount, lag 0 hot days (> 90F)	b1 = 0.8733 (0.021) rf0 = -0.3836 (0.047) rf1 = 0.2519 (0.048) rf2 = 0.1669 (0.035) rn0 = -0.1191 (0.0367) rn1 = -0.02605 (0.038) h1 = 0.0524 (0.017)	-162.731	0.6798	0.4787	0.7445

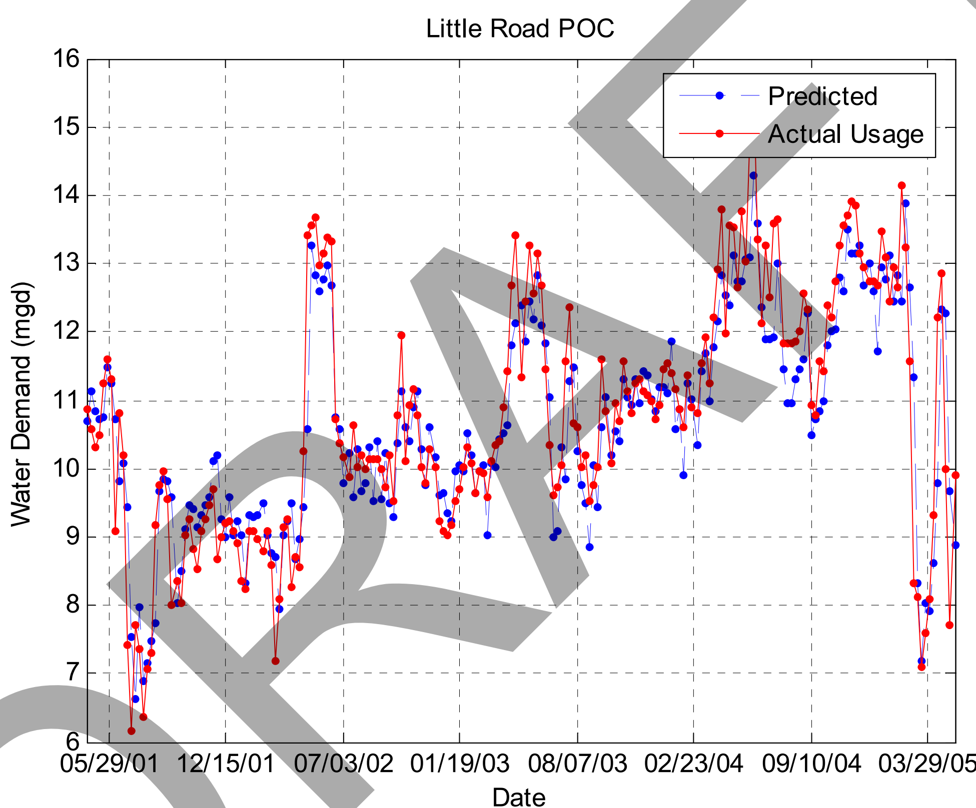


Figure 5. ARX model using lag 1 demand and lag 0 and 1, consecutive rainy days.

Disaggregation Model

Models one, three and seven (see Table 1) forecast an aggregate demand. During the initial model development it was shown that a model that forecasts an aggregate demand was better than single models for those POCs. In order to find the appropriate disaggregation methodology a simple autoregressive (naïve) disaggregation and a relatively complex k-nearest neighbor (K-NN) type were evaluated. The decision to use a specific type of disaggregation tool rests on the consistency of the previous demand pattern and data size. For example, if the recent demand ratios (the proportion of a given POC's demand to total forecasted demand) are completely different from the historical observation (in the sense of having enough data), methods like K-NN won't be effective. Figures 6 to 8 shows historical demand ratios for the three aggregated models.

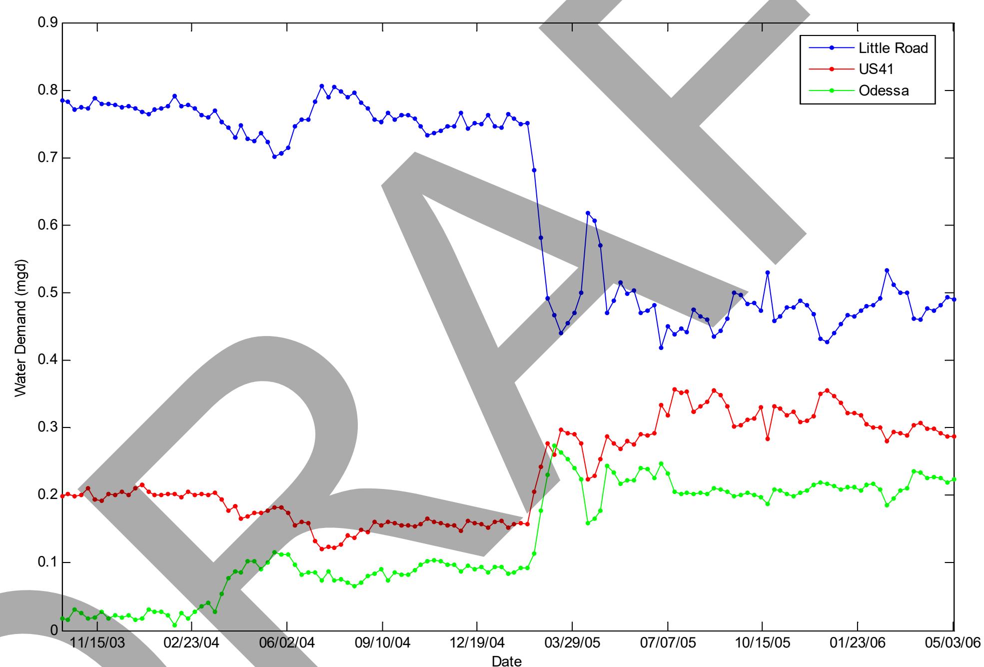


Figure 6: Demand fraction for Liitle Road, US41, and Odessas POC's

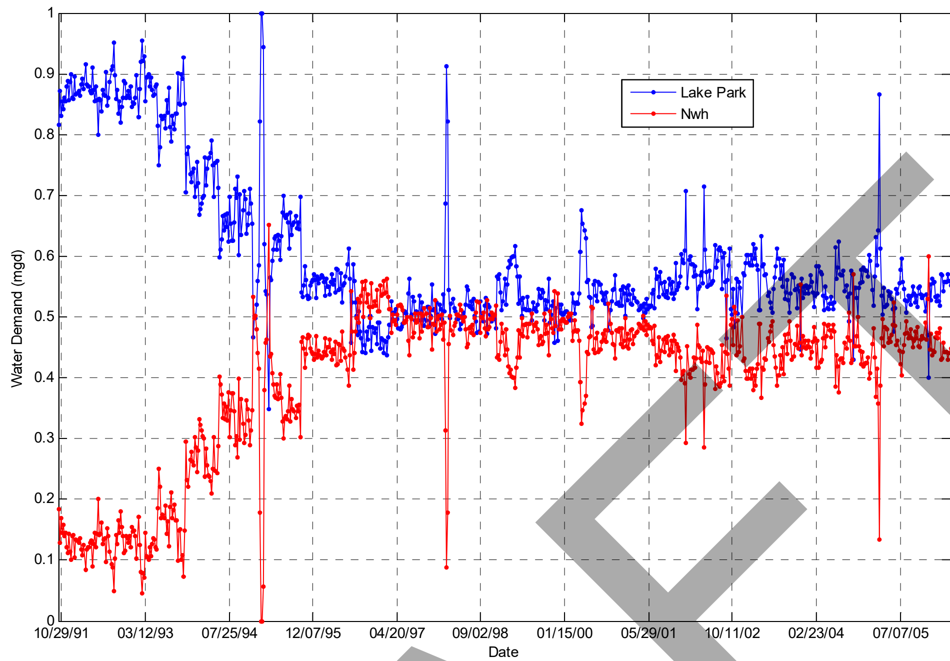


Figure 7: Demand fraction for Lake Park and NWH POC's

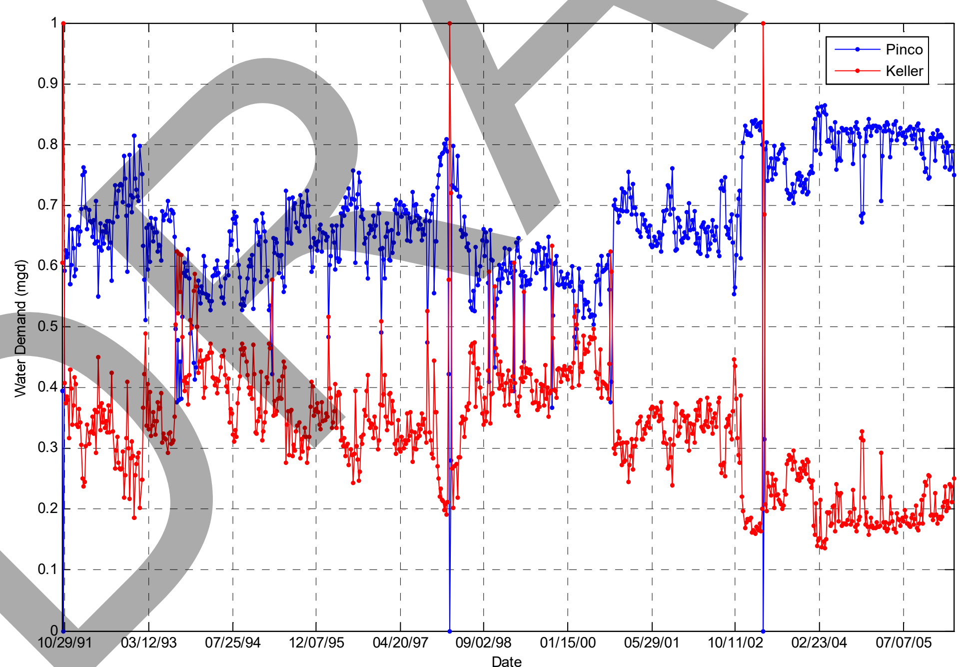


Figure8: Demand fraction for Pinco and Keller POC's

Each figure provides an illustration into the consistency of the relative proportions of the POC demand to the total demand. In Figure 6, the proportions of all the three POCs (in terms of mean) had a dramatic shift in recent measurements where as Figure 7 and 8 show a relatively longer stretch where the proportions of each POC remained close to constant (in terms of the mean). Therefore, in the present disaggregation implementation a naïve disaagregation algorithm is used for Little Road, US41 and Odessa split whereas a K-NN disaagregation methodology was used for Lake Park/NWH and Pinco/Keller split. A K-NN can still be used for Little Road/US41/Odessa split by explicitly taking account the shift in mean. A conditional K-NN algorithm is found to be better that the naïve dissagregation algorithm in the later cases. The K-NN method selected for this analysis uses the current and past week demand values as conditioning data and resample records that are close (in the sense of Euclidian distance) to these values. Conditioning to more than two weeks did not improve the result significantly. Then the first 5 (here K = 5) are selected in order to use the average ratios as the one to represent the forecast. An alternative approach would be to probabilistically select (weighted by distance or other measure) one value from these 5 (or more) observations and redo the process. This would again result in ensemble of forecast and that is not intended at this point. This procedure can be used to generate ensemble of demand forecasts within OROP framework. The current OROP framework is deterministic. Developing a probabilistic demand forecast would be required if the OROP framework becomes stochastic.

Evaluation of goodness of model fit

The new ARX models were compared with the regression models developed in 2002. Table 4 summarizes these result. The dark shaded cells represent better model performance by either models whereas light green represents a tie. As shown in the table both the root mean square error (RMSE) and mean absolute deviation (MAD) values favored the new model in all but one case. It is believed the slightly lower performance at Cosme POC might have been caused by the poor representation of rainfall in the demand area.

Table 4. Comparison between current and the new weekly demand model

	Current		New	
POC	RMSE(mgd)	MAD(mgd)	RMSE(mgd)	MAD(mgd)
Cosme	1.50	1.07	1.53	1.11
Keller	2.29	1.56	1.89	1.35
Lake Bridge	0.93	0.45	0.42	0.34
Lake Park	1.54	1.25	1.13	0.88
Little Road	1.50	1.25	1.16	0.91
Lithia	3.11	2.15	2.48	1.97
Maytum	0.33	0.26	0.23	0.19
NWH	1.27	0.84	0.95	0.73
Odessa	0.41	0.31	0.32	0.25
Pinco	3.90	2.85	3.55	2.85
US41	0.49	0.39	0.37	0.31

Implementation for OROP

A set of Matlab® scripts have been developed that implement the models, import the input data and provide model results back to the OROP database. The way the models are set up is that for a given POC, series of matlab scripts reads the model structure, conditioning data (recent observations) and make predictions for the coming week. As currently implemented all models use observed parameters including rainfall and temperature. There are no forecasted inputs. Because of this, similar to the current demand model there will be one week forecast and that would be assumed to be the prevailing demand for the coming four weeks.

References

Asefa, T. and Adams, A. 2007. Short-term urban water demand forecasting models in action: Challenges from model development to implementation to real-time operation, ASCE World Environmental & Water Resources Congress, May 15-19, Tampa, Florida.

APPENDIX C

GROUNDWATER ANN MODELS

APPENDIX C

ARTIFICIAL NEURAL NETWORK (ANN) MODELS FOR FORECASTING GROUNDWATER LEVELS

INTRODUCTION

ANN architecture and computation were inspired by the manner a human brain operates. The network of neurons learns from training (historical) data by adjusting weights of connections among neurons which is analogous to how synapses biologically transfer signals to neurons. ANN applications in hydrology and water resources have been focused on the feed-forward multi-layered perceptron networks with backpropagation learning algorithm. Detailed overview of ANN concepts and their applications in hydrology can be found in two separate articles by ASCE Committee of ANNs in Hydrology (ASCE, 2000a and ASCE, 2000b).

The OROP optimization routine requires a four-week water-level forecast at each SAS control well and UFAS monitor well. The Integrated Surface and Ground Water (ISGW) model has been used to predict end of the week water levels at these 57 monitoring wells. The ISGW model does provide accurate forecasts of water-levels for these short time steps. The deficiency in using this regional scale model is two folds. First, the model uses MODFLOW for groundwater simulation with a grid resolution of ¼ by ¼ square mile to represent a point forecast for a monitoring well. As with all numerical models, no mechanism or a feature is available to interpolate the cell spatial average to obtain the site specific well water-level. Secondly, the ISGW model requires a two-year simulation prior to the prediction weeks to overcome numerical instability brought about by unrelated changes in inputs. Restart mechanism was implemented to overcome this drawback with limited success.

In 2000, Tampa Bay Water staff started to investigate an alternate model that could provide more accurate predictions on short-term groundwater level fluctuations in monitoring wells. Limited data sets were provided to a graduate student at University of Arizona as part of his PhD thesis to develop ANN models for the Northwest Hillsborough Wellfield (Coppola, 2000, and Coppola, et. al. 2003). Recognizing the potential application of ANN in groundwater modeling, Tampa Bay Water staff put together a work-plan in the 2001 OROP Annual Report to initiate a preliminary study for ANN model development. In WY 2002, Tampa Bay Water hired a consultant to conduct a Phase I GWANN, a proof-of-concept study of ANN models for forecasting short-term groundwater levels. The scope of study included the design of multilayered network architecture for multiple neuron inputs that would closely represent a physical groundwater system. Considered inputs included: initial water levels; recent water levels (e.g., daily, weekly) both in the SAS and UFAS; recent water levels and flow rates at nearby streams, lakes, wetlands, and springs; local meteorological factors (e.g., rainfall, pan evaporation, temperature, relative humidity); and pumping schedules at nearby production wells. Results of the study were presented to the OROP/TAC in several occasions by the project consultants and Tampa Bay Water staff. The final report (Aly, 2002) was also made available to the TAC members. Results of the study clearly demonstrated that ANN models could effectively provide accurate short-term forecasts for groundwater levels. However, the accuracy dropped off rapidly for a forecast beyond the two-week period.

Methodology

Developing a machine learning or data-based model is generally known as the system identification process which involves four major steps; experimental design, selection of model structure, model parameter estimation, and model validation.

Experimental Design

Using a method similar to stepwise regression, Phase I study suggested that primary inputs should include recent SAS and UFAS water-levels, rainfall, pumpage, and wetland and lake water-levels. A data exploratory analysis (EDA) was performed to aid model conceptualization and to select specific input variables for the 39 SAS control wells and 18 UFAS monitor wells from the suggested list of inputs. One ANN model is required to represent each monitoring well and each week forecast. The preliminary model for each ANN UFAS monitor well model depended on stresses from pumpage and rainfall, initial conditions from recent water levels, and boundary conditions from lake or wetland water-levels. Twenty-four-week lag inputs were considered in the initial conceptual model as well as forecast inputs. Each ANN control well model was setup similarly except that a deep well was used for boundary condition. How to obtain a forecast input will be discussed later in the implementation plan.

A GIS spatial analysis was employed to assist in data and site selection processes. Depending on the density of available sites around the output well (i.e.,OROP control well or UFAS monitor well), all monitoring sites within 1 to 2 miles radius, including rain gauges, well recorders (production and water level), lake and wetland stages, were initially screened. Hyetographs and hydrographs of more than 500 sites were visually inspected to select candidate input sites. Most of the sites were selected based on the period of record, measurement frequency, data quality, type of instrument, correlation and serial cross-correlation. In a few cases where data were scarce or contained gaps in the period of record, filling missing records and record extension procedures were performed by Piecewise Cubic Hermite interpolation and Robust Regression with a nearby site. TABLE 1 (appeared at the end of this Appendix) listed sites selected for model input and output variables.

Model data were retrieved directly from Tampa Bay Water's enterprise database server and all data preparation steps, including general QA/QC and data aggregation, were done using Microsoft™ sequel stored procedures. Since OROP is operated in weekly time steps with a four-week projection, each ANN model to be developed to forecast in weekly time steps so that a total of 58 by 4 ANNs will be developed to forecast the water levels needed for the OROP program.

Figure 1 depicts the time horizon of the input data used to construct the model. A two-step ahead

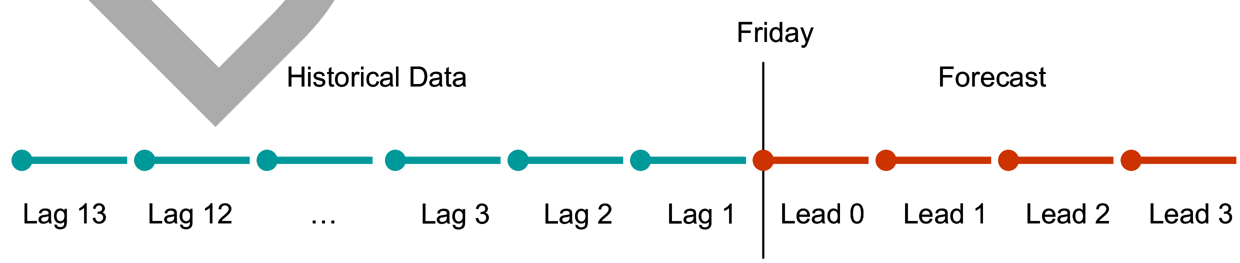


FIGURE 1 Time horizon of data used to construct an ANN model

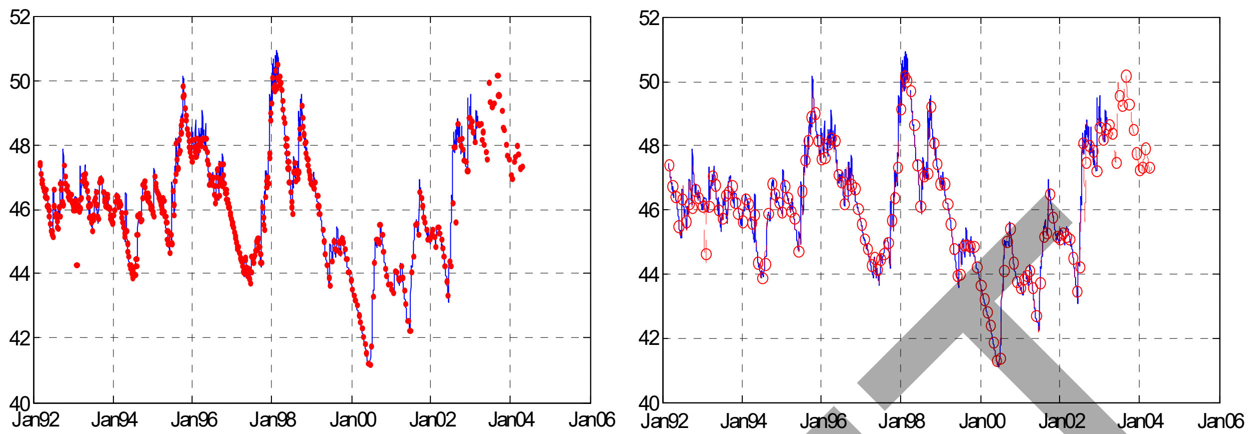


FIGURE 2 Comparison of interpolated weekending data (red open circle) from bi-monthly measurement (red dot) with daily average hydrograph from automatic recorder (blue line) for NPMW-7s

forecasting model will require lag-input of independent (exogenous) and dependent variables (endogenous) as well as two lead-forecast-inputs of the independent variables. Usually the OROP production schedules are generated every Fridays for the schedule to start on the following Saturday; therefore, an ANN model-week will span from Friday to Thursday. The conceptual model is based on the storage principle, thus pumpage and rainfall amounts used in the model will be a weekly total while water level will be the measured or calculated value at end of the week (i.e., on Friday). Water-level data with frequency other than daily will be interpolated using a Cubic Spline algorithm. FIGURE 2 shows a comparison of end-of-the-week time series interpolated from bi-monthly manual measurements with the daily hydrograph obtained from the automatic recorder at the same well. Evaluation of the results indicated that the interpolation method provides a good estimate of the week-ending value from the bi-monthly measurements.

Since water-level data at a monitoring location (site) maybe collected by more than one device (e.g., ADL, wireless, manual, outside sources), data are pooled together into one time series. Through the exploratory data analysis (EDA), quality of the water-level data was evaluated and a quality control procedure developed. Generally, there are two types of QC processes for hydrologic data. The first type involves site specific inspection of hydrographs, rigorous statistical tests, and requires insight knowledge of the local hydrology and human interactions. This can be a costly and time consuming QC process. The second type is a general procedure that involves preliminary statistical testing to automatically filter more obvious data errors. Data obtained from Tampa Bay Water's devices were subjected to second QC criteria to detect and correct data errors, such as a data point outside the minimum and maximum range of data series or a data point outside three standard deviations of the most recent measurements. Data obtained from other agencies were also screened using the second QC process to eliminate data points with duplicates and flag for missing value. However, a number of problem data points still remained after using the second QC type of process; therefore, a MATLAB script was written to implement the first QC type. The QC algorithms are based on the definitive outlier, Cubic Spline Interpolation, and Robust Regression comparing to a neighbor site. Brief descriptions of the algorithms are as follows:

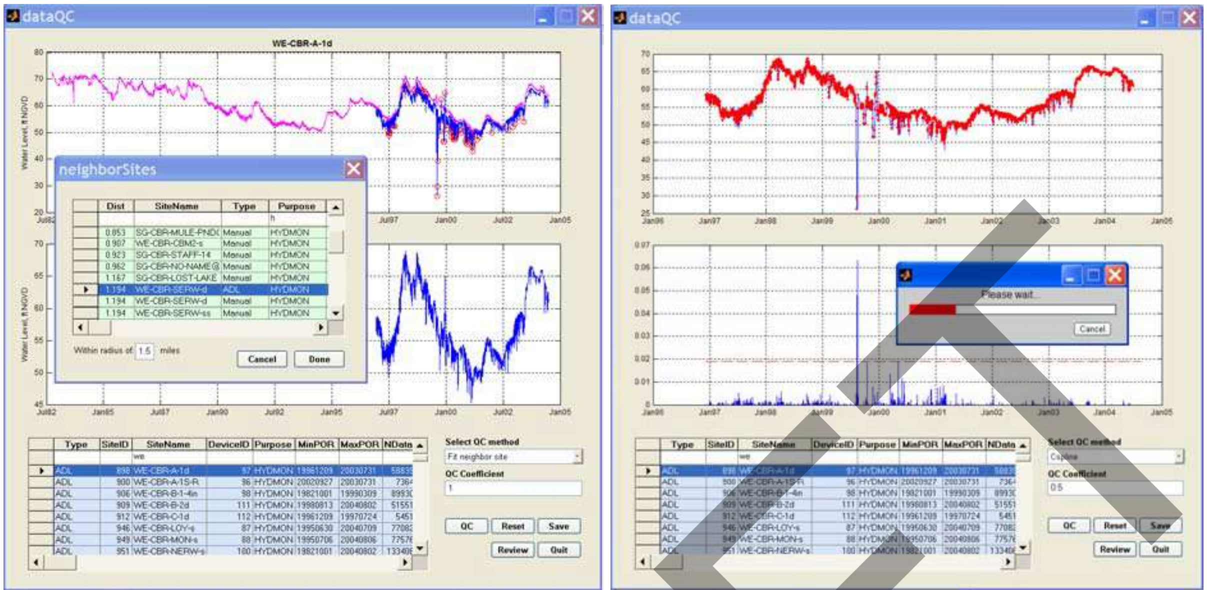


Figure 3 Data QC at A-1d site; (left) using the neighbor site SERW-d, and (right) display an intermediate iteration to identify regression outliers using Cook's Distance

- Data series outlier – the algorithm follows the box-plot definition in defining an outlier. If x_{lb} and x_{ub} are the lower (25th percentile) and upper (75th percentile) values of the box plot, and c is the adjustable outlier coefficient with a default value of 1.5, then, the lower bound (x_{lo}) and upper bound (x_{uo}) of the non-outlier range can be defined as

$$x_{lo} \le x_i \le x_{uo}, \quad \forall i$$
$$x_{lo} = x_{lb} - c\left(x_{ub} - x_{lb}\right)$$
$$x_{uo} = x_{ub} + c\left(x_{ub} - x_{lb}\right)$$

- Limit change – the algorithm is designed to detect data spikes by limiting the subsequent data change within $c\left(x_{ub} - x_{lb}\right)$, where c is the adjustable coefficient.
- Regression outlier – the algorithm uses Cubic Spline to construct an interpolated data series and uses robust regression to compare between the interpolated and the actual data series. An iterative procedure is devised such that a set of outliers will be eliminated each iteration. An outlier is determined by comparing the Cook's distance for a pair of regression points to the limit, $2c/\sqrt{n}$, where c is the adjustable outlier coefficient and n is the number of data points.
- Neighbor site outlier – the algorithm is similar to the regression outlier except that the neighbor site data series is used instead of the series constructed by Cubic Spline Interpolation

FIGURE 3 illustrated the graphic user interface implementation of the first type of QC process. This site specific QC was attempted during the course of model development and proved to be very time consuming; hence, not all of the sites used in modeling went through this rigorous process.

Unqualified data will affect the training and testing statistics. Handling for bad localized data will be built into the data partitioning under the network training process. Details of this process will be discussed later. The site specific data QC will be revisited during the implementation phase of the ANN models.

Model Structure

In dynamic system and control theory, there are some similarities in expressing model structures between linear and nonlinear systems. A discussion of linear model structures and their simplification is followed by a description of nonlinear model structures used to develop ANN model.

Let *u* and *y* be stochastic input (independent or exogenous) and output (dependent or endogenous) variables, respectively, and assume both time series are made stationary with zero means. A general discrete stochastic linear system that describes the functional relationship between input, output, and system noise can be expressed as (Ljung, 2004):

$$A(q)\,y_t = \frac{B(q)}{F(q)}u_t + \frac{C(q)}{D(q)}\varepsilon_t = q^{-n_k}\,\frac{B'(q)}{F(q)}u_t + \frac{C(q)}{D(q)}\varepsilon_t \qquad \text{(L-1)}$$

where ε_t is the system noise, q^{-1} is the backshift operator, n_k is the delay, and $A(q)$, $B(q)$, $C(q)$, $D(q)$ and $F(q)$ are polynomial functions of q and are defined as follows:

$$\begin{aligned} A(q) &= 1 + a_1 q^{-1} + a_2 q^{-2} + \ldots + a_{n_a} q^{-n_a} \\ B(q) &= b_1 q^{-1} + b_2 q^{-2} + \ldots + b_{n_b} q^{-n_b} \\ C(q) &= 1 + c_1 q^{-1} + c_2 q^{-2} + \ldots + c_{n_c} q^{-n_c} \\ D(q) &= 1 + d_1 q^{-1} + d_2 q^{-2} + \ldots + d_{n_d} q^{-n_d} \\ F(q) &= 1 + f_1 q^{-1} + f_2 q^{-2} + \ldots + f_{n_f} q^{-n_f} \end{aligned} \qquad \text{(L-2)}$$

Equation (L-1) can be easily expanded to include multiple inputs by using a summation term instead of a single term for input with corresponding coefficients. The notations used are defined slightly different than those found in econometrics literature (e.g., Box and Jenkins' transfer function noise model). The polynomial parameters, n_a, n_b, n_c, n_d, and n_f represent the order of the underline time-series processes. The following discussion uses the terms; system, model structure, and model, literally followed definitions provided by Ljung (2004). Equation L-1 can be generalized to represent linear and nonlinear systems as,

$$\text{True System } S: \quad y_t = G_o(B)x_t + H_o(B)\varepsilon_t \qquad \text{(L-3)}$$

where *G* and *H* are the complex time-series processes describing the true system *S*. A model to represent this true system will be determined by estimating process parameters from observed data. The model structure is a result of parameterizing equation (L-3) to allow for such estimation.

$$\text{Model Structure } M: \quad \left\{ G(B,\Theta), H(B,\Theta) \mid \Theta \in D_m \subset \Re^p \right\}$$
$$y_t(\Theta) = G(B,\Theta)u_t + H(B,\Theta)\varepsilon_t \tag{L-4}$$

The vector Θ comprised of *p* process parameters estimated or drawn from a set of parameters D_m constituted candidate models that generate observed data. D_m itself is a subset of the real system parameters R^p because observed data are only a fraction of the all realizations generated by a true system. For nonlinear system models, particularly ANN models, these parameters are neuron biases and neuron connection weights. Once the model parameters are determined, the estimated model is defined and its one-step prediction for future forecast can be carried out, i.e.

$$\text{Model } \hat{S}: \quad \hat{y}_t = G(B,\hat{\Theta})x_t + H(B,\hat{\Theta})\varepsilon_t$$
$$y_{t|t-1} = H^{-1}(B,\hat{\Theta})G(B,\hat{\Theta})x_t + \left[1 - H^{-1}(B,\hat{\Theta})\right]y_t \tag{L-5}$$

Certain assumptions can be made on time-series processes to simplify the general system representation and model structure. For example, if the underline time series process of the linear system is determined to be autoregressive with exogenous variable (ARX), i.e. $n_c = n_d = n_f = 0$, then equation (L-1) is reduced to, should define what nc, nd and nf are

$$A(q)y_t = B(q)u_t + \varepsilon_t = q^{-n_k}B'(q)u_t + \varepsilon_t$$
$$B(q) = b_{n_k}q^{-n_k} + b_{n_k+1}q^{-n_k-1} + \ldots + b_{n_k+n_b-1}q^{-n_k-n_b+1} = q^{-n_k}B'(q) \tag{L-6}$$

The corresponding ARX estimated model can be determined by parameterization of the above equation and rearranging into the following expressions:

$$\hat{y}_t(\Theta) = q^{-n_k}B'(q)u_t + \left[1 - A(q)\right]y_t = \varphi_t^T\Theta$$
$$\varphi_t = \left[-y_{t-1} \ldots - y_{t-n_a}, u_{t-n_k} \ldots u_{t-n_k-n_b+1}\right]^T \tag{L-7}$$
$$\Theta = \left[a_1 \ldots a_{n_a}, b_{n_k} \ldots b_{n_k+n_b-1}\right]^T$$

For nonlinear system model of any model structure, the real system and the estimated model are simply:

$$y_t = g(\varphi_t, \Theta) + \varepsilon_t$$
$$\hat{y}_t = g(\varphi_t, \hat{\Theta}) \tag{L-8}$$

If ANN is used to construct the nonlinear model system with ARX structure, then the resulting NNARX model structure can be represented as shown in FIGURE L-4.

ANN Architecture

This section will discuss the architecture of the neuron network that is represented by the green box in FIGURE 4. Note that all notations in this section may have different meanings from the same

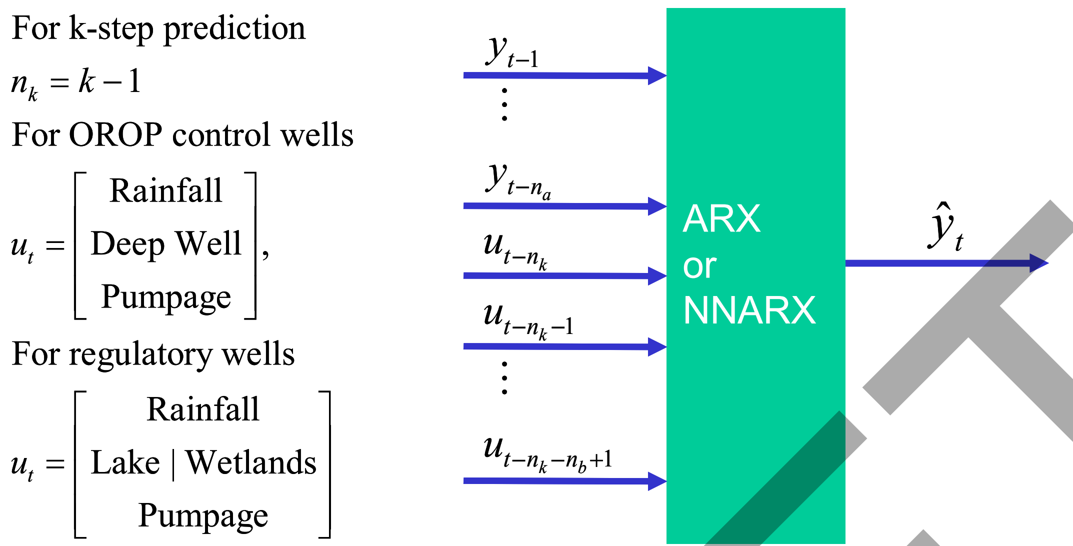


FIGURE 4 Schematic of NNARX model structure

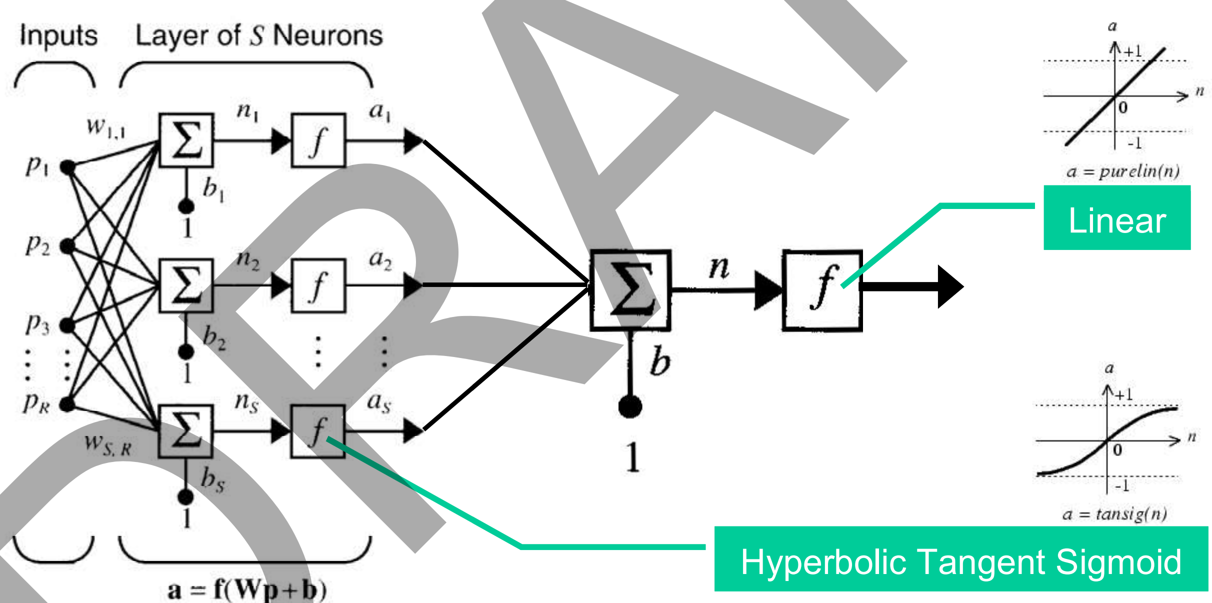


FIGURE 5 Architecture of the general feedforward neural network used in this study

notations in the last section. Most of notations and graphic representations of the neural networks are consistent with the MATLAB's Neural Network Toolbox User's Guide (Demuth and Beale, 2004).

Most functional relationships represented by an ANN model are generally of the feedforward network type with backpropagation learning algorithm. Designing a network involves making the following choices of the network architecture; number of hidden layers, number of perceptrons in each hidden layer, types of activation (transfer) functions for perceptrons in each layer. The

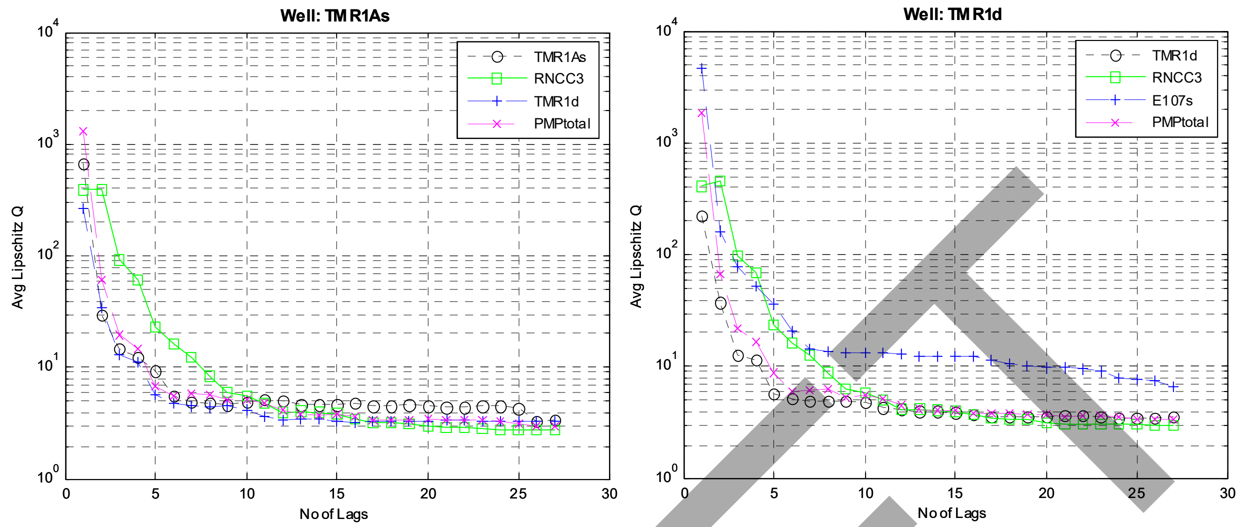


FIGURE 6 Lag-space analysis for TMR-1 paired wells

literature suggests that a network of one input layer, one output layer, and a single hidden layer with an adequate number of perceptrons could represent any functional relationship. For feedforward network, the hyperbolic tangent sigmoid activation function is often selected for the hidden layer perceptrons while the linear function is usually used for the perceptrons in the output layer. As a rule of thumb, the number of neurons in the hidden layer should be more than a third of the number of the input and output nodes combined. FIGURE 5 depicts the general feedforward neural network used in this modeling study; where the number of hidden layer neurons (*S*) is chosen to be a half the number of input nodes (*R*); and *p*, *W, b,* and *a* are input, connection weight, bias, and neuron output, respectively.

For NNARX model, the numbers of lags that determine the effects of the past inputs and past output on the future output are required in addition to the normal network architecture parameters. These numbers of lags must be chosen carefully from a priori knowledge of the physical system. Including a large number of lags will enlarge the network size and will consume processing time during training. The optimum number of lags can be approximated from the inflection point of a curve resulting from fitting a plot between number of lags and geometric means of Lipschitz's quotients on the semi-logarithmic scale as shown in FIGURE 6. The quotient is defined as:

$$q_{ij} = \left\| \frac{y_{t-i} - y_{t-j}}{\varphi_{t-i} - \varphi_{t-j}} \right\|, \quad i \neq j \qquad \text{(L-9)}$$

Unfortunately, this lag-space analysis is a time consuming iterative algorithm and results are site specific which makes it very difficult to implement when developing models for a large network. The lag-space analysis will be revisited in the next model revision. For simplicity, all networks in this study will have the same lag structure. Based on results from the EDA as well as experience the numbers of lags for water level, rainfall, and pumpage were determined to be 4, 8, and 13 weeks, respectively. This means that water-level time series in deep wells, lakes, and wetlands are assume to possess a fourth-order autoregressive process with external influences (cross-correlated) limited to the past four weeks for water-levels; the past eight weeks for rainfall; and the past 13 weeks for pumpage. These numbers of lags will be employed to construct all NNARX models for training. It is also assumed that there is no more than a week delay in the system responses.

Model Parameter Estimation (Training)

The candidate models structured as an NNARX feedforward network were trained using Levenberg-Marquardt backpropagation algorithm. This optimization algorithm was suggested in most literature specifically because it can achieve second-order training speed without having to evaluate the Hessian matrix. Regardless of the training algorithm selected, a loss function to evaluate the performance during training is also required. The most popular loss function is the mean square error (mse) of the predicted values. The function can be expressed in terms of error vector ε of N elements as,

$$\begin{aligned} \varepsilon &= y_{obs} - y_{pred} \\ mse &= \frac{1}{N}\left[\varepsilon^T \varepsilon\right] = \frac{1}{N}\sum_{i=1}^{N}\varepsilon_i^2 \end{aligned} \tag{L-10}$$

Neural networks are well-known to possess an ability to memorize training data, especially when the network is over parameterized or contains more neurons than necessary. When over-fitting occurred, the network losses its generalization (i.e., predictability power for unseen data). One of the methodologies to overcome this drawback is called regularization. The method penalizes the performance when more parameters are used in the network representation. The penalty is achieved by modified the loss function to include the mean square weight (msw) term as follows:

$$\begin{aligned} msereg &= \gamma\left(mse\right) + \left(1-\gamma\right)\left(msw\right) \\ &= \gamma\left(\frac{1}{N}\sum_{i=1}^{N}\varepsilon_i^2\right) + \left(1-\gamma\right)\left(\frac{1}{M}\sum_{j=1}^{M}\omega_j^2\right) \end{aligned} \tag{L-11}$$

where M is the number of network parameters, ω is the network parameters, (e.g., connection weights and biases), and γ is the adjustable performance ratio. The version called Bayesian regularization is available in the MATLAB's Neural Network Toolbox and was used in all network trainings.

Neural network inputs and outputs usually have different physical units. Connecting these variables to a neuron without scaling their magnitudes may cause unbalanced weights that favor larger numerical value inputs. In this model development, all input and output time-series are normalized such that they will have zero mean and variance of one.

Backpropagation is a nonlinear optimization problem where global solution is not guaranteed. To overcome multiple traps at local optima, a number of initial guesses are required by reinitializing the initial weights. In this study, it was found that an iterative procedure using random partitioning of the dataset was more effective for improving final solution. The method also provided a mechanism to prevent the network from learning localized bad data points.

$$\begin{bmatrix} Year1 \\ Year2 \\ \vdots \\ Year11 \\ Year12 \end{bmatrix} \begin{bmatrix} \left\{ \left(p_{1,t-1} \; p_{1,t-2} \; \cdots \middle| \; p_{2,t-1} \; p_{2,t-2} \; \cdots \middle| \; p_{3,t-1} \; p_{3,t-2} \; \cdots \right) \cdots \left(p_{1,t-1} \; p_{1,t-2} \; \cdots \middle| \; p_{2,t-1} \; p_{2,t-2} \; \cdots \middle| \; p_{3,t-1} \; p_{3,t-2} \; \cdots \right) \right\} \\ \left\{ \left(p_{1,t-1} \; p_{1,t-2} \; \cdots \middle| \; p_{2,t-1} \; p_{2,t-2} \; \cdots \middle| \; p_{3,t-1} \; p_{3,t-2} \; \cdots \right) \cdots \left(p_{1,t-1} \; p_{1,t-2} \; \cdots \middle| \; p_{2,t-1} \; p_{2,t-2} \; \cdots \middle| \; p_{3,t-1} \; p_{3,t-2} \; \cdots \right) \right\} \\ \vdots \qquad\qquad \vdots \qquad\qquad \vdots \\ \left\{ \left(p_{1,t-1} \; p_{1,t-2} \; \cdots \middle| \; p_{2,t-1} \; p_{2,t-2} \; \cdots \middle| \; p_{3,t-1} \; p_{3,t-2} \; \cdots \right) \cdots \left(p_{1,t-1} \; p_{1,t-2} \; \cdots \middle| \; p_{2,t-1} \; p_{2,t-2} \; \cdots \middle| \; p_{3,t-1} \; p_{3,t-2} \; \cdots \right) \right\} \\ \left\{ \left(p_{1,t-1} \; p_{1,t-2} \; \cdots \middle| \; p_{2,t-1} \; p_{2,t-2} \; \cdots \middle| \; p_{3,t-1} \; p_{3,t-2} \; \cdots \right) \cdots \left(p_{1,t-1} \; p_{1,t-2} \; \cdots \middle| \; p_{2,t-1} \; p_{2,t-2} \; \cdots \middle| \; p_{3,t-1} \; p_{3,t-2} \; \cdots \right) \right\} \end{bmatrix}$$

FIGURE 7 Arrangement of dataset for random partitioning by year

The dataset for developing a neural network model was partitioned to use in training and testing. Depending on the available dataset size, the training and testing partition ratio chosen was 70:30 for a small dataset (<15 years of data) to 80:20 for a larger dataset. Partitioning of dataset was done randomly by year to maintain the annual hydrologic cycle. For example, a twelve-year dataset was partitioned into eight years of data for training and four years of data for testing to obtain an approximate 70:30 partition ratio. Each of the eight-year training data sets was chosen randomly from the 12-year dataset. In order to achieve this random selection, the dataset was prepared so that the lag-structure were strung together to create one week of the dataset. This arrangement required truncating annual data such that a uniform 52 weeks per year dataset was attained. FIGURE 7 illustrates how a dataset is rearranged in a matrix form to achieve this yearly random partitioning. A row of the matrix contains 52 weeks of data with each week enclosed in a pair of parentheses. The vertical bars separate different sets of input variables, each contains lag structure as described above. Random partitioning is then achieved by random permutation of the matrix rows where the top 70-80 percent rows (i.e., eight rows in the above example) were used for training.

An iterative process is devised to overcome bad data points. For 12 years of data, choosing eight out of the 12 years with replacement has a combination of ${}_{12}C_{8}$ = 495. For a larger dataset, the number of combinations will increase and the exhaustive iteration will not be possible. A limit of 100 iterations was imposed and a weighted random partitioning was used instead. A different performance criterion known as Theil's U statistic was used to update the partitioning weights. This U statistic is defined as,

$$\varepsilon' = y_{obs} - y'$$

$$U = \sqrt{\frac{\frac{1}{N}\sum_{i=1}^{N}\left(\varepsilon_i / y_i'\right)^2}{\frac{1}{N}\sum_{i=1}^{N}\left(\varepsilon_i' / y_i'\right)^2}} \qquad \text{(L-12)}$$

where ε' and y' is the error and the output estimate from a naïve model which usually is represented by a lag-one output. The partitioning weight for a specific year is the data quality rating determined from the geometric mean of the U statistics from prior iterations.

<u>Model Validation (Testing)</u>

Once the network parameters were trained, the simulation was performed using the testing data. Residual diagnostics were conducted on the simulation errors to ensure that the errors were well-behaved. Results were evaluated by visual inspection of a series of standard residual diagnostic plots. The testing performance were evaluated based on the following statistics,

$$\varepsilon = y_{obs} - y_{sim}$$

$$me = \frac{1}{N}\sum_{i=1}^{N}\varepsilon_i; \qquad mae = \frac{1}{N}\sum_{i=1}^{N}|\varepsilon_i|; \qquad mse = \frac{1}{N}\sum_{i=1}^{N}\varepsilon_i^2 \tag{L-13}$$

These error statistics, as well as the Theil's U statistics defined in equation(L-12), will be reported and summarized in the next section.

Sensitivity analyses were also conducted to quantify the influence of each input on the simulated output. A number of simulations were performed with each input and its corresponding lags being perturbed by ±30%. For each simulation, the sensitivity was assessed by comparing results from the sensitivity simulation with the base case simulation. Resulting statistics were calculated based on output differences using similar expressions shown in equation(L-13). However, the U statistics was defined differently for sensitivity and are given as follows:

$$\varepsilon = y_{senc} - y_{base}$$

$$\varepsilon' = y_{obs} - y_{base}$$

$$U = \sqrt{\frac{\frac{1}{N}\sum_{i=1}^{N}\left(\varepsilon_i / y_{obs}\right)^2}{\frac{1}{N}\sum_{i=1}^{N}\left(\varepsilon_i' / y_{obs}\right)^2}}$$

Sensitivity results and findings will be discussed in the next section.

RESULTS AND DISCUSSION

As previously mentioned the models predict groundwater levels at OROP and regulatory wells for four-time steps ahead (OROP schedule week 1 to 4) using appropriate inputs. Inputs to the model are rainfall, pumpage, and groundwater levels at other monitoring wells in the vicinity of the prediction. These inputs consist of lagged inputs (values that are already observed) and future values (values that are not yet observed but must be supplied to the model in order to make a prediction). We call these future values "forecasted" inputs because their values have to be generated before the GWANN model is run. For example, forecasted input value of pumpage could come from demand analysis. Different model run results are discussed below.

Model Calibration and Validation

The model calibration and validation steps for this study (also known as training and testing) included an investigation of whether the underlying physical or other process can be represented by the GWANN model. Available data were split into two groups (70/30 or 80/20 depending on the sample size) one used for model training and the other used for testing. It is important to note that the GWANN model set up requires forecasted inputs of pumpage, rainfall, and water levels. Since at this stage the available data was split into training and testing, both lagged inputs and forecasted inputs came from the historical data. This would enable one to see the applicability of GWANN to

TABLE 2 Summary of Testing and Forecast ANN prediction results

Statistics		Test				Forecast			
		Step 0	Step 1	Step 2	Step 4	Step 0	Step 1	Step 2	Step 4
ME (ft)	Min	-0.14	-0.18	-0.20	-0.13	-0.15	-0.15	-0.14	-0.20
	Max	0.23	0.32	0.45	0.30	0.35	0.39	0.96	0.45
	Mean	0.02	0.02	0.03	0.02	0.05	0.07	0.10	0.07
MAE (ft)	Min	0.05	0.08	0.10	0.06	0.08	0.17	0.30	0.29
	Max	1.50	1.63	1.93	1.75	1.84	2.22	2.57	2.86
	Mean	0.56	0.62	0.68	0.71	0.74	1.00	1.19	1.38
RMSE (ft)	Min	0.09	0.14	0.15	0.10	0.12	0.28	0.59	0.61
	Max	1.97	2.29	2.87	2.68	2.54	3.11	3.31	3.76
	Mean	0.80	0.86	0.95	0.98	1.09	1.40	1.67	1.88
TheilsU	Min	0.19	0.05	0.03	0.04	0.45	0.51	0.42	0.72
	Max	1.00	0.96	0.82	0.76	1.15	1.27	1.27	1.26
	Mean	0.65	0.55	0.50	0.45	0.93	0.96	0.98	0.99

represent the underlying process without the interference of uncertainties introduced through the use of estimated forecasted inputs. The use of estimated forecasted inputs is discussed in the next section. The first half of TABLE 2 shows the results of the test runs. Performance was measured using four criteria: Mean error (ME), Mean absolute error (MAE), Root mean square error (RMSE), and Theil's U statistics. The table shows minimum, maximum, and mean values of these four performance measures for all sites. Each time steps (starting with step 0, see FIGURE 1) are based on GWANN predictions for week 1, week 2, week 3, and week 4 results. Complete listing of the performance summary of individual wells is available from Tampa Bay Water upon request.

Mean of the mean-errors varied between 0.02 to 0.03 foot for the four time steps; where as, mean of the mean-absolute-error varied between 0.56 to 0.71 foot. Mean of the root-mean-square-error was between 0.8 to 0.98 foot. The dimensionless Theil's U statistics measures the ratio between the root-mean-square-error and that of the naïve forecast. The naïve forecast used in this analysis is simply a lag-one forecast. All four criteria show excellent performance of the ANN models. Theil's U statistics for testing case increased as the prediction time-step increased. This is due to the fact that the naïve forecast (which is the denominator in Theil's U statistics) gets the further into the future the prediction. The opposite is true for the forecast run.

Prediction with Forecasted inputs

The second half of TABLE 2 presents results obtained using forecasted inputs. As mentioned before inputs to the ANN model is composed of both lagged and forecasted inputs (value of inputs in the week where prediction is being made). Forecasted input must come from an appropriate input forecast model. How to obtain forecasted inputs for rainfall will be discussed later. For OROP implementation where pumpage rates are one of decision variables, forecasted pumpage used in the ANN models are the same of the initial guess for the weekly optimization model. Pumpage rates for the optimization model are normally lag-one values. Results shown in TABLE 2 are obtained by using lag-one values as forecasted inputs. In other words, while predicting groundwater level at a given week, the forecasted inputs are set to their most recent observed values of input parameters. All mean statistics of the four performance measures have shown good results but with slightly higher values than the test case as expected. This is because now the lag-one forecasted inputs are used instead of the actual (historical) values.

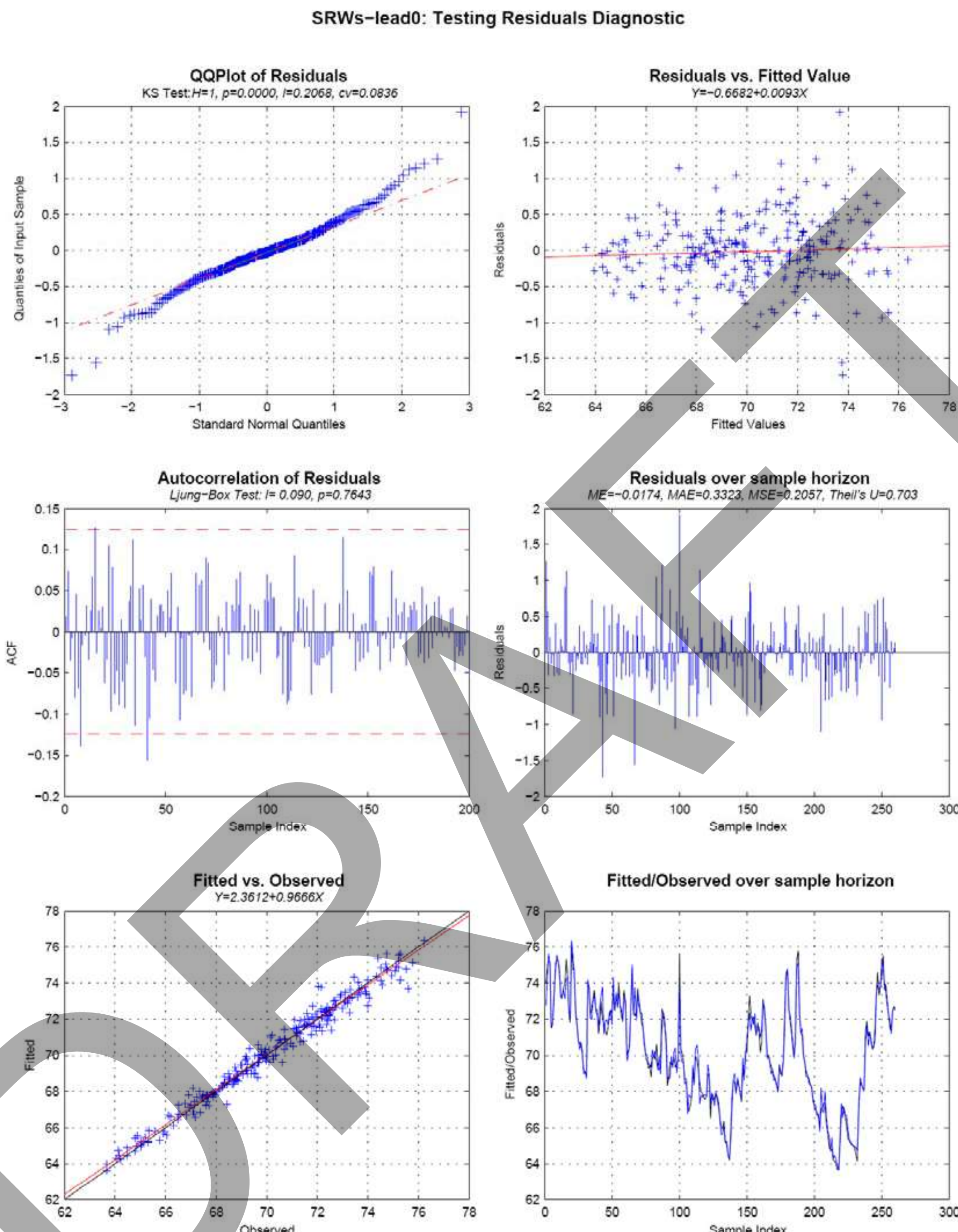


FIGURE 8 Sample of residuals diagnostic plots

Error Diagnostics

For each output well, a standard diagnostic of residuals was performed which included a Q-Q plot, a plot of residuals vs. fitted values, an autocorrelation plot of residuals, a plot of residuals over sample horizon, a one-to-one plot of fitted vs. observed values, a comparison plot of hydrographs of fitted and observed values. FIGURE 8 depicted a sample of the residual diagnostic plots for lead-0 model testing results of SRW-s well. Note that lead-0 (or step-0) is the one-step forecasting model for OROP week-1 prediction. The Q-Q plot as well as Kolmogorov-Smirnov test (KS test) is provided to aid the normal distribution inspection. The statistics for KS test are; H={0,1} for accepting or rejecting null hypothesis that the residual is normal distributed, p for the observed p-value, I for the observed KS statistic, and cv for the cutoff value to determine if KS statistic is significant at 95% confidence level. Q-Q plots from all output wells reveal that residuals are mostly well behaved and normally distributed even though the KS tests for normality failed. The failure was due to data outliers which could be observed from the departure from normal distribution line on both tails. The plot between residuals and fitted values is included to help detecting bias against the fitted value. A linear regression was fitted and the regression equation was shown on the top of the plot. Residuals from all output wells showed no bias since all regression slopes were close to zero. The autocorrelation plot and the plot of residuals against time are intended to assist in detecting residual temporal bias. Since the complete time series of data was disrupted by random sampling, interpreting autocorrelation plots may not yield meaningful results. The one-to-one plot and hydrograph plot between the fitted and the observed values are included to help visual inspection of the model performance. A linear regression was fitted on the one-to-one plot and the resulting equation is shown. For the best performance, the intercept and slope of the regression line should be close to zero and one, respectively. As expected, model performance (based on residual analysis) deteriorates as one goes from training to testing to forecasting.

TABLE L-3 Results of sensitivity analysis

Variable	Sensitivity Index	Statistics	Sensitivity (+20%)				Sensitivity (-20%)			
			Step 0	Step 1	Step 2	Step 3	Step 0	Step 1	Step 2	Step 3
Rainfall	ME	Min	-0.025	-0.016	-0.041	-0.030	-0.038	-0.037	-0.036	-0.020
		Max	0.041	0.041	0.041	0.025	0.027	0.016	0.042	0.029
		Mean	0.001	0.002	0.0004	-0.0003	0.000	-0.002	0.000	0.000
	MAE	Min	0.005	0.007	0.009	0.007	0.005	0.006	0.009	0.007
		Max	0.098	0.093	0.138	0.103	0.099	0.094	0.139	0.102
		Mean	0.046	0.047	0.048	0.046	0.046	0.047	0.048	0.046
	RMSE	Min	0.010	0.018	0.016	0.013	0.009	0.015	0.017	0.013
		Max	0.173	0.124	0.269	0.222	0.172	0.130	0.269	0.215
		Mean	0.073	0.075	0.079	0.075	0.075	0.075	0.079	0.075
	TheilsU	Min	0.023	0.021	0.019	0.033	0.023	0.022	0.019	0.033
		Max	0.304	0.230	0.238	0.229	0.307	0.234	0.229	0.232
		Mean	0.114	0.103	0.095	0.091	0.116	0.104	0.094	0.091
Water Level	ME	Min	-0.348	-0.320	-0.269	-0.230	-0.050	-0.066	-0.119	-0.121
		Max	0.055	0.082	0.100	0.160	0.324	0.297	0.243	0.206
		Mean	-0.031	-0.038	-0.028	-0.026	0.019	0.027	0.021	0.019
	MAE	Min	0.009	0.044	0.039	0.038	0.007	0.035	0.032	0.031
		Max	0.899	0.827	1.153	1.323	0.765	0.686	0.956	1.115
		Mean	0.212	0.246	0.294	0.301	0.185	0.215	0.250	0.258
	RMSE	Min	0.014	0.072	0.066	0.064	0.012	0.061	0.052	0.052
		Max	1.034	0.963	1.316	1.531	0.889	0.804	1.097	1.298
		Mean	0.276	0.314	0.371	0.383	0.242	0.276	0.317	0.329
	TheilsU	Min	0.035	0.038	0.039	0.023	0.031	0.030	0.032	0.019
		Max	3.313	2.474	2.482	2.184	2.685	2.262	2.105	1.749
		Mean	0.484	0.475	0.507	0.523	0.428	0.425	0.436	0.452
Pumpage	ME	Min	-0.099	-0.116	-0.142	-0.162	-0.110	-0.103	-0.084	-0.144
		Max	0.185	0.269	0.241	0.202	0.074	0.081	0.072	0.124
		Mean	0.016	0.020	0.010	0.015	-0.005	-0.011	-0.001	-0.006
	MAE	Min	0.011	0.020	0.014	0.028	0.007	0.011	0.009	0.020
		Max	1.240	1.348	1.317	1.410	0.902	0.979	0.976	0.998
		Mean	0.294	0.344	0.333	0.336	0.211	0.242	0.240	0.241
	RMSE	Min	0.018	0.043	0.025	0.039	0.011	0.019	0.016	0.031
		Max	1.537	1.688	1.821	1.755	1.196	1.306	1.291	1.294
		Mean	0.392	0.466	0.448	0.450	0.288	0.331	0.329	0.332
	TheilsU	Min	0.108	0.091	0.103	0.135	0.063	0.059	0.063	0.090
		Max	1.836	1.940	1.107	3.399	1.574	1.804	1.150	3.829
		Mean	0.458	0.501	0.430	0.474	0.336	0.357	0.318	0.369

Sensitivity Analyses

Sensitivity analyses study the response of a dependent variable (in this case the groundwater level) to input variable perturbation. This is done by varying the input values by some percentages and noting the change in predicted responses. Results of sensitivity analyses may be used in many ways: (1) to determine the level of input uncertainties that can be tolerated without unacceptably degrading predictions; (2) identify the most sensitive input parameter in order to improve quality of input

Table 4 Results of forecasted input sensitivity analyses

Variable	Sensitivity Index	Statistics	Sensitivity (+20%)				Sensitivity (-20%)			
			Step 0	Step 1	Step 2	Step 3	Step 0	Step 1	Step 2	Step 3
Rain	ME	Min	-0.135	-0.189	-0.197	-0.129	-0.172	-0.174	-0.200	-0.133
		Max	0.234	0.334	0.405	0.303	0.234	0.308	0.488	0.304
		Mean	0.023	0.023	0.031	0.024	0.022	0.020	0.030	0.025
	MAE	Min	0.056	0.088	0.098	0.068	0.058	0.085	0.100	0.066
		Max	1.508	1.621	1.968	1.803	1.495	1.652	1.971	1.763
		Mean	0.561	0.629	0.687	0.721	0.557	0.627	0.680	0.712
	RMSE	Min	0.090	0.140	0.151	0.100	0.093	0.134	0.152	0.098
		Max	1.979	2.286	2.882	2.700	1.965	2.308	2.847	2.678
		Mean	0.807	0.865	0.955	0.987	0.802	0.862	0.947	0.976
	TheilsU	Min	0.171	0.043	0.038	0.036	0.211	0.090	0.039	0.051
		Max	1.030	0.975	0.824	0.767	0.993	0.941	0.812	0.762
		Mean	0.664	0.553	0.510	0.459	0.657	0.549	0.505	0.452
Water Level	ME	Min	-0.337	-0.335	-0.253	-0.247	-0.172	-0.248	-0.226	-0.221
		Max	0.288	0.300	0.433	0.366	0.335	0.337	0.461	0.355
		Mean	-0.009	-0.017	0.003	-0.001	0.042	0.049	0.052	0.044
	MAE	Min	0.076	0.131	0.161	0.095	0.074	0.125	0.144	0.110
		Max	1.483	1.617	1.894	2.084	1.529	1.655	1.998	1.851
		Mean	0.615	0.692	0.766	0.803	0.614	0.692	0.763	0.789
	RMSE	Min	0.117	0.175	0.211	0.132	0.116	0.181	0.201	0.164
		Max	1.957	2.313	2.798	3.030	1.989	2.288	2.960	2.622
		Mean	0.857	0.927	1.031	1.070	0.872	0.936	1.037	1.062
	TheilsU	Min	0.192	0.121	0.107	0.117	0.181	0.060	0.094	0.051
		Max	1.072	0.988	0.940	0.817	1.029	0.991	1.029	0.897
		Mean	0.725	0.609	0.568	0.515	0.742	0.611	0.566	0.511
Pumpage	ME	Min	-0.144	-0.246	-0.265	-0.217	-0.203	-0.270	-0.213	-0.175
		Max	0.268	0.283	0.328	0.331	0.233	0.337	0.509	0.285
		Mean	0.038	0.042	0.040	0.039	0.017	0.011	0.029	0.018
	MAE	Min	0.059	0.092	0.124	0.077	0.056	0.087	0.101	0.076
		Max	1.856	2.106	2.217	2.335	1.711	1.772	2.172	1.846
		Mean	0.652	0.733	0.783	0.816	0.609	0.690	0.745	0.775
	RMSE	Min	0.095	0.141	0.188	0.109	0.091	0.139	0.153	0.108
		Max	2.415	2.761	3.054	3.202	2.213	2.434	3.088	2.613
		Mean	0.907	0.987	1.056	1.096	0.861	0.939	1.026	1.047
	TheilsU	Min	0.339	0.262	0.211	0.175	0.277	0.246	0.216	0.160
		Max	1.304	2.677	1.087	1.487	1.273	2.633	1.278	1.342
		Mean	0.748	0.668	0.579	0.534	0.705	0.634	0.558	0.505

parameter acquisition and/or estimation; and (3) identify the degree of acceptable input forecast models.

This analysis was done by changing the values of both lagged and forecasted inputs and comparing the resulting prediction with the base scenario, a prediction obtained using unchanged input variables. Both 10% and 20% input changes were analyzed. Summary of this analysis for ±20% is depicted in TABLE 3. The result of the sensitivity analysis shows that the ANN model performed well with a ±20% corruption in input values.

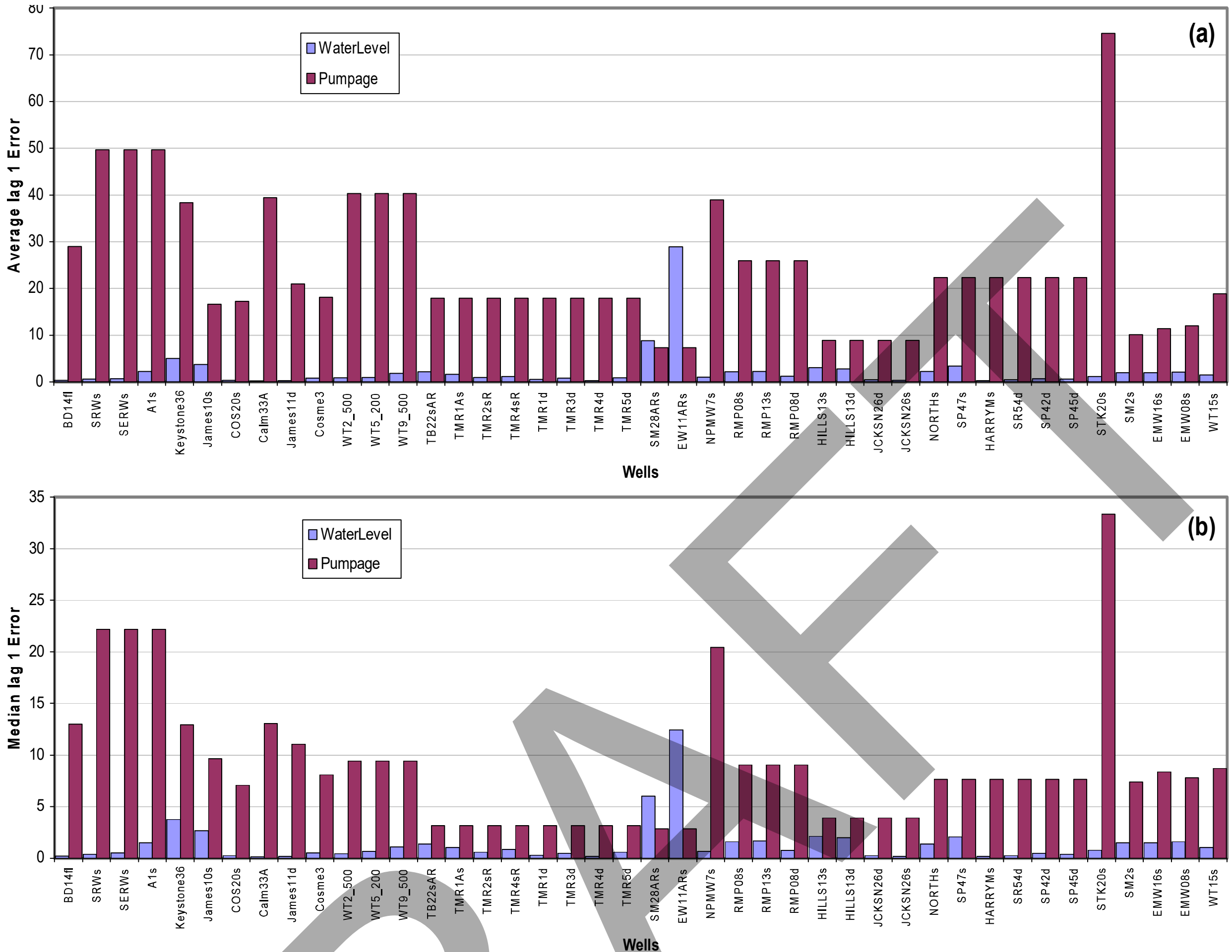


FIGURE 9 (a) Mean error for lag-one forecasting model. (b) Median error for lag-one forecasting model

Implementation Plan

To use the GWANN models with OROP, forecasted inputs for rainfall and water levels need to be obtained elsewhere. A simple rainfall model is proposed for this use in this study and will be discussed later. Tampa Bay Water continues to investigate methods for short-term rainfall forecasting. Lag-one inputs are proposed as the forecasted inputs for pumpage and water levels. It is more appropriate to perform an analysis to compare the uncertainty of lag-one forecast and their sensitivity when they are used as forecasted inputs.

Sensitivity of forecasted inputs

This sensitivity analysis was performed by varying the values of forecasted inputs and noting the change in predicted values of groundwater levels. The difference between this and the case presented above is that in this analysis values of lagged inputs were left unchanged. Then the performance criteria were evaluated by comparing these predictions with the base case scenario (predictions obtained by using unchanged forecasted input). Such an analysis coupled with lagged error analysis (explained below) helps in determining the acceptable level of input forecast models.

Table 5 Rainfall predictions using a sliding six-year window

	Median		Mean	
Group	**RMSE**	**MAE**	**RMSE**	**MAE**
1	1.320	0.916	1.273	0.878
2	1.344	0.904	1.258	0.852
3	1.316	0.866	1.254	0.843
4	1.290	0.852	**1.191**	**0.811**
5	1.227	**0.840**	1.208	0.834
6	1.258	0.869	1.237	0.862
7	1.416	0.940	1.334	0.924
8	1.217	0.850	1.244	0.883
9	1.224	0.873	1.245	0.891
10	**1.207**	0.856	1.227	0.886
11	1.255	0.870	1.233	0.885
12	1.282	0.902	1.268	0.915
13	1.262	0.880	1.234	0.893
14	1.322	0.915	1.287	0.914
15	1.304	0.916	1.286	0.906
16	1.331	0.939	1.292	0.894
17	1.382	0.987	1.333	0.961
18	1.325	0.943	1.311	0.946
19	1.431	1.012	1.306	0.944

Both 10% and 20% input changes were analyzed. Results of ±20% changes are summarized in Table 4.

Lagged input analysis

It was shown that the forecasted inputs were estimated using the lag-one values and the results of sensitivity analysis show that the GWANN model is able to perform well within a ±20% range for input inaccuracies. Here, we show the percentage of input inaccuracies that would be incurred by using lag-one forecasting model. To do that we used lag-one values to represent the naïve model and calculate the percentage of lag one error as compared to actual observations. FIGURE 9 shows these results with the output variable (wells) listed on the x-axis. One needs to refer to TABLE 1 for the water-level and pumpage variables used in the graphics. Not all output variables are necessary listed in this figure since some models use the same variables (sites) for water-level and pumpage.

As shown in FIGURES 9(a) and 9(b), most of lag-one mean errors for the pumpage variable are below 20% and the lag-one median error below 10%. Differences between the mean and median measures show the existence of outliers. Both mean and median errors are well below 5% for the water-level case. These results show that a model as good as or better than the naïve model may be used to estimate the forecasted input. It is not possible to present such analysis for rainfall since rainfall varies weekly from no-rainfall to rainfall and back to no-rainfall events making such lag-one percentage error calculations meaningless. Instead rainfall is handled differently as explained in the next section. Higher lag-one error for well Stk20s (a Starkey well) is because of the fact that this well is close to production well where differences in water-levels from week to week are higher.

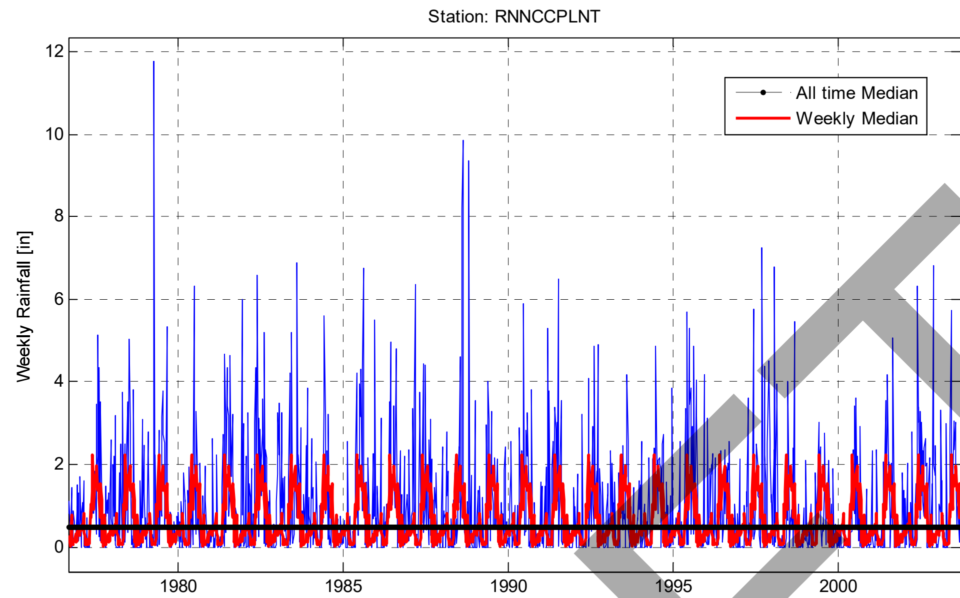


FIGURE 10 Weekly rainfall for the period of record along with weekly and all-time median

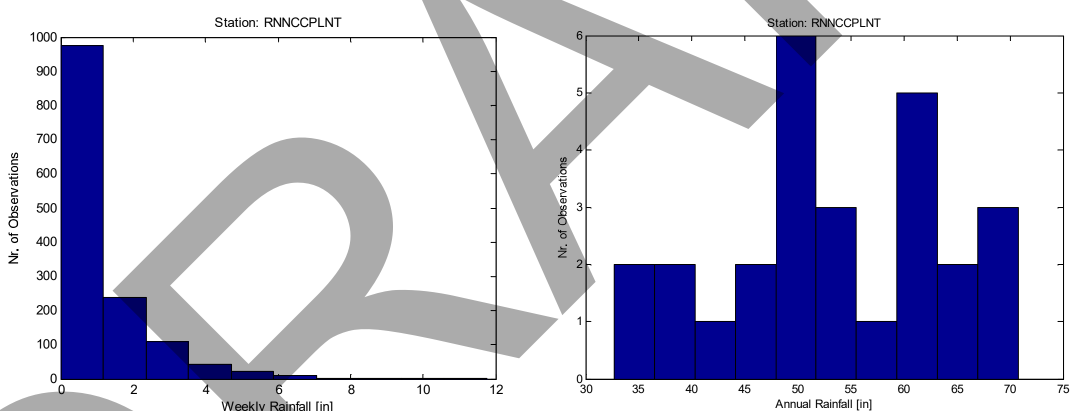


FIGURE 11 Weekly and annual rainfall histograms

Rainfall Model

We present an example of a rainfall analysis at Cypress Creek well fields. This station has 27 years of data spanning from water year 1977 to 2003. FIGUREs 10 and 11, respectively, shows weekly plots of the period of record, weekly and annual histograms. As shown in the figure the weekly rainfall is exponential and the annual is bimodal. Three types of rainfall estimation technique are presented below.

a) A Six-year sliding window predictor

A six-year sliding window was use to predict the last three water-years (WY 2001, WY2002 and WY2003). The six-year sliding window starts in WY 1977. For example, the first predictor based on statistics of observations of WY 1977 to WY 1982, the second that of WY 1978 to WY 1983, and so on. This results in 19 six-years sliding window estimators. Table L-5 summarizes the results. The best predictors are as follows: Using Median RMSE: WY1986 – WY 1991, Median MAE: WY1981 – WY 1986; using both RMSE and MAE Mean predictors: WY 1980 – WY 1985

b) Using the most frequently observed annual rainfall
Now referring to FIGURE 11, one could use the most frequent observed annual rainfall values as predictor. These frequently observed yearly rainfalls occurred in WY 1977, WY 1985, WY1989, WY 1990, WY1996, and WY 2002. Note that even though WY 2002 is one of the most frequently observed years it was not used as predictor as it is part of the testing set. Instead, the second most frequent data was used to replace WY 2002. Since there are five years within the second most frequently observed data range (see Figure 11) the one that give the best result was selected as part of the six years rainfall generator model. These data came from WY 1986.

Using these most frequent observed data as a future predictor results are Median RMSE = 1.173, Median MAE = 0.8297; and Mean RMSE = 1.142, Mean MAE = 0.816. These results are better than any of the six-year moving average.

c) Using a resampling methodology
In the approach presented above, if one changes the testing set (the last three years in this case) one would obtain a different predictor performance. To avoid this situation the following methodology is adopted:

- Randomly draw three years as testing set
- Using annual histogram select the six most frequent data from the remaining data set as rainfall simulator
- Predict the three years rainfall series using the most frequent data set
- Repeat above steps until some criterion is met.

Using the above algorithm the following performance is obtained:

Mean RMSE = 0.9273, Mean MAE = 0.6622, Median RMSE = 0.8921, and Median MAE = 0.6147. These results are better than any of the cases presented above. The selected best performing years are WY 1977, 1985, 1989, 1990, and 1994 and 1999, for the four performance measures.

Even though the rainfall simulator presented above provides acceptable model results given the small influence of inaccurate forecasted inputs as shown by the sensitivity analysis, staff is currently working on Markov type of rainfall generator to be used with the GWANN model. If a better result is obtained, it will replace the current proposed rainfall model in the implementation phase.

Comparison of GWANN and ISGW models

In the original implementation of OROP, the ISGW model was used to predict the next 4-week water level at control wells and at regulatory wells. TABLE 6 compares the values of performance measures based on GWANN and that of ISGW. It is obvious from the table that GWANN model results provide exceptional improvements in predictions over ISGW model for all wells that are available for comparison.

TABLE 6 Comparison between GWANN and ISGW models at some control points

Wellfield	Well ID	GWANN		ISGW		Wellfield	Well ID	GWANN		ISGW	
		MAE	ME	MAE	ME			MAE	ME	MAE	ME
CBR	SERWs	0.56	-0.05	1.64	-0.6	EDW	SM28ARs	0.24	-0.08	8.48	8.48
	A1s	0.28	0.04	1.75	0.65		SM15ARs	0.47	0.07	0.85	0.34
	WT9_500	0.4	0.05	0	0		EW11ARs	0.62	-0.08	1.33	-0.27
	WT2_500	0.37	-0.05	3.23	3.22	NOP	NPMW8s	0.19	0.01	1.02	0.89
	SRWs	0.56	-0.02	1.69	0.88		NPMW9s	0.32	-0.02	1.39	1.34
CYC	TMR-2sR	0.4	0.01	5.71	5.71	NWH	RMP13s	0.31	0.1	0.84	-0.01
	TB22sAR	0.27	0.05	1.95	0.7		RMP08s	0.2	0.02	1.18	0.96
	TMR2d	0.64	-0.03	4.45	3.03	S21	HILL13s	0.22	-0.0005	1.67	0.86
	TMR3d	1.27	0.11	3.05	0.36		HILL13d	0.92	0.07	1.88	1.45
	TMR1As	1.01	0.08	3.92	3.04		JCKSN26s	0.35	-0.0008	1.48	0.58
	TMR1d	1.06	-0.03	3.46	-0.04	SOP	SR54d	0.98	-0.1	2.34	2.21
	TMR4sAR	0.23	0.01	2.1	-1.85		HARRYMs	0.05	0.01	2.84	2.81
	TMR4d	0.52	-0.02	2.29	-1.68		SP47s	0.37	0.01	1.54	0.5
	TMR5d	0.37	0.05	1.92	-1.53		NORTHs	0.4	0.7	1.71	1.23
COS	CALM33A	1.05	-0.14	2.76	2.1	STK	EMW16s	0.34	-0.03	1.73	-0.85
	Keystone36	0.074	0.0038	1.29	0.75		STK20s	0.12	0.02	1.67	1.51
	COSME3	0.85	-0.08	1.51	1.88		SM2s	0.33	0.01	1.6	1.01

CONCLUSION

GWANN models were developed using NNARX structure based on a priori knowledge of the physical system components and interactions, namely the system stress and boundary and initial conditions. In order to provide what-if scenarios analysis capability, NNARX is extended to include forecasted inputs, a common practice in physical-based simulation models. An ANN is constructed for each output well (57 monitor wells) and each of four-time steps ahead prediction resulting in 57x4 networks. These networks were trained and test using weekly data. Since limited data QC was performed, some outliers may have affected the testing performance statistics. Sensitivity analyses revealed that satisfactory results could be achieved, if forecasted input prediction errors were within 20%.

It has been demonstrated that GWANN models provide more accurate forecast of groundwater fluctuations than a physically-based regional groundwater simulation model such as ISGW, especially for short-term prediction with small time step. Like other AR-based and data learning models, the model accuracy degrades as the number of prediction time steps increases. The model error will eventually converge to the long-term variance. Hence, while GWANN models are appropriate for short-term operations type application like OROP, they may not be appropriate for a planning model which requires a longer look ahead for prediction.

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Table 1 List of model input and output variables

Wellfield Code	Output Variable	Input Variable	Device Type	Site ID	Site Name/Code	Comment
BUD	BD14fl	BD14fl	Wireless ADL	829	WE-BUD-BD-14FL	Extended POR using Oakmont3
		RNNEBDINN	ADL	32	RN-NEB-DINN	
		HickoryLk	STA	173	HICKORY HAMMOCK LAKE	
		PMPtotal			Total Wellfield Pumpage	
	BD21fl	BD21fl	Wireless ADL	840	WE-BUD-BD-21FL	
		RNNEBDINN	ADL	32	RN-NEB-DINN	
		HickoryLk	STA	173	HICKORY HAMMOCK LAKE	
		PMPtotal			Total Wellfield Pumpage	
CBR	SRWs	SRWs	ADL	1043	WE-CBR-SRW-s	
		RNCB01	ADL	11	RN-CBR-CB01	
		SRWd	ADL	1042	WE-CBR-SRW-d	
		PMPsouth			Total production from southern wells (CB-01 to CB-08)	
	SERWs	SERWs	ADL	1040	WE-CBR-SERW-s	
		RNCB01	ADL	11	RN-CBR-CB01	
		SERWd	ADL	1039	WE-CBR-SERW-d	
		PMPsouth			Total production from southern wells (CB-01 to CB-08)	
	A1s	A1s	ADL	900	WE-CBR-A-1S-R	
		RNCB01	ADL	11	RN-CBR-CB01	
		A1d	ADL	898	WE-CBR-A-1d	
		PMPsouth			Total production from southern wells (CB-01 to CB-08)	
COS	Keystone36	Keystone36	WEL	74200	KEYSTONE PARK 36 SUR	
		RNCOS	ADL	35	RN-NWH-COS	Filled a gap between 4/18/2003 and 5/23/2003 with RNCOS20
		Calm33A	WEL	33900	ST PETE CALM 33A FLD	
		PMPkeystone36			Pumpage from production wells within 1 mile radius of monitoring well Keystone-36	
	James10s	James10s	WEL Wireless ADL	50000 1974	ST PETE JAMES 10 SHA	
		RNCOS	ADL	35	RN-NWH-COS	Filled a gap between 4/18/2003 and 5/23/2003 with RNCOS20
		James11d	WEL	65500	ST PETE JAMES 11 FLD	
		PMPjames10			Pumpage from production wells within 1 mile radius of monitoring well James-10	
	COS20s	COS20s	Manual Wireless ADL	1981	WE-NWH-COS-CO-20s	
		RNCOS	ADL	35	RN-NWH-COS	Filled a gap between 4/18/2003 and 5/23/2003 with RNCOS20
		ChurchLk	STA	477	CHURCH LAKE	
		PMPcosme20			Pumpage from production wells within 1 mile radius of monitoring well Cosme-20s	
	Calm33A	Calm33A	WEL	33900	ST PETE CALM 33A FLD	
		RNCOS	ADL	35	RN-NWH-COS	Filled a gap between 4/18/2003 and 5/23/2003 with RNCOS20
		CalmLk	STA	460	CALM LAKE	
		PMPcalm33			Pumpage from production wells within 1 mile radius of monitoring well Calm-33A	

Table 1 List of model input and output variables (cont'd)

Wellfield Code	Output Variable	Input Variable	Device Type	Site ID	Site Name/Code	Comment
COS	James11d	James11d	WEL	65500	ST PETE JAMES 11 FLD	
		RNCOS	ADL	35	RN-NWH-COS	Filled a gap between 4/18/2003 and 5/23/2003 with RNCOS20
		PMPjames11			Pumpage from production wells within 1 mile radius of monitoring well James-11	
	Cosme3	Cosme3	WEL	66500	COSME 3 FLDN	
		RNCOS	ADL	35	RN-NWH-COS	Filled a gap between 4/18/2003 and 5/23/2003 with RNCOS20
		SP1C6s	WEL	74700	ST PETE IC-6 SHALLOW	
		PMPcosme3			Pumpage from production wells within 1 mile radius of monitoring well Cosme-3	
CYB	WT2_500	WT2_500	Manual Wireless ADL	1271	WE-CYB-WT-2-500	
		RNTOT	Wireless ADL	24	RN-CYB-TOT	
		FL2_1000	Wireless ADL	1222	WE-CYB-FL-2-1000	
		PMPtotal			Total Wellfield Pumpage	
	WT5_200	WT5_200	Manual Wireless	1277	WE-CYB-WT-5-200	
		RNTOT	Wireless ADL	24	RN-CYB-TOT	
		FL5_1950	ADL	1224	WE-CYB-FL-5-1950	
		PMPtotal			Total Wellfield Pumpage	
	WT9_500	WT9_500	Wireless ADL	1285	WE-CYB-WT-9-500	
		RNTOT	Wireless ADL	24	RN-CYB-TOT	
		FL7_2000	ADL	1228	WE-CYB-FL-7-2000	
		PMPtotal			Total Wellfield Pumpage	
	WT2_1000	WT2_1000	Manual Wireless ADL	1266	WE-CYB-WT-2-1000	
		RNCYB7	Wireless ADL	23	RN-CYB-CYB7	
		FL2_1000	ADL	1222	WE-CYB-FL-2-1000	
		PMPtotal			Total Wellfield Pumpage	
CYC	TB22sAR	TB22sAR	Manual Wireless	1424	WE-CYC-TB-22SAR	
		RNCCPLNT	Wireless ADL	27	RN-CYC-CCPLNT	
		CC826d	Manual	1302	WE-CYC-826-d	
		PMPtotal			Total Wellfield Pumpage	
	TMR1As	TMR1As	Manual Manual	1428 1430	WE-CYC-TMR-1AS	Extended POR using E107s
		RNCC3	Wireless ADL	25	RN-CYC-CC3	
		TMR1d	Manual WEL	1429 21400	WE-CYC-TMR-1d	
		PMPtotal			Total Wellfield Pumpage	

Table 1 List of model input and output variables (cont'd)

Wellfield Code	Output Variable	Input Variable	Device Type	Site ID	Site Name/Code	Comment
CYC	TMR2sR	TMR2sR	WEL Wireless	68500 1433	CYPRESS CRK TMR-2 SH	Extended POR using BIO1
		RNCC3	Wireless ADL	25	RN-CYC-CC3	
		TMR2d	Manual WEL	1431 68400	WE-CYC-TMR-2d	
		PMPtotal			Total Wellfield Pumpage	
	TMR4sAR	TMR4sAR	Manual WEL	2995 33500	WE-CYC-TMR-4sar	
		RNCCPLNT	Wireless ADL	27	RN-CYC-CCPLNT	
		TMR4d	Manual WEL	1436 1075600	WE-CYC-TMR-4d	
		PMPtotal			Total Wellfield Pumpage	
	TMR1d	TMR1d	Manual WEL	1429 21400	WE-CYC-TMR-1d	
		RNCC3	Wireless ADL	25	RN-CYC-CC3	
		E107s	Manual	1393	WE-CYC-E-107s	
		PMPtotal			Total Wellfield Pumpage	
	TMR2d	TMR2d	Manual WEL	1431 68400	WE-CYC-TMR-2d	
		RNCC3	Wireless ADL	25	RN-CYC-CC3	
		E107s	Manual	1393	WE-CYC-E-107s	
		PMPtotal			Total Wellfield Pumpage	
	TMR3d	TMR3d	Manual WEL	1434 1075500	WE-CYC-TMR-3d	
		RNCC3	Wireless ADL	25	RN-CYC-CC3	
		CC826s	Manual	1303	WE-CYC-826-s	
		PMPtotal			Total Wellfield Pumpage	
	TMR4d	TMR4d	Manual WEL	1436 1075600	WE-CYC-TMR-4d	
		RNCCPLNT	Wireless ADL	27	RN-CYC-CCPLNT	
		CCS4	FLO	133	CYPRESS CREEK CCS-4	
		PMPtotal			Total Wellfield Pumpage	
	TMR5d	TMR5d	Manual WEL	1438 1075700	WE-CYC-TMR-5d	
		RNCCPLNT	Wireless ADL	27	RN-CYC-CCPLNT	
		TMR5s	Manual WEL	1439 9900	WE-CYC-TMR-5s	
		PMPtotal			Total Wellfield Pumpage	
EDW	SM28ARs	SM28ARs	Manual Wireless	1683	WE-ELW-SM-28SAR	
		RNEDW	ADL	28	RN-ELW-METER_ PIT	
		EW139G	Manual WEL	1570 65200	WE-ELW-139G	
		PMPtotal			Total Wellfield Pumpage	

Table 1 List of model input and output variables (cont'd)

Wellfield Code	Output Variable	Input Variable	Device Type	Site ID	Site Name/Code	Comment
EDW	EW11ARs	EW11ARs	Manual WEL	1556 52300	WE-ELW-11S	
		RNEDW	ADL	28	RN-ELW-METER_ PIT	
		EW113B	Manual WEL	1548 15900	WE-ELW-113B	
		PMPtotal			Total Wellfield Pumpage	
	SM15ARs	SM15ARs	Manual Wireless	1676 1677	WE-ELW-SM-15	
		RNEDW	ADL	28	RN-ELW-METER_ PIT	
		EW113B	Manual WEL	1548 15900	WE-ELW-113B	
		PMPtotal			Total Wellfield Pumpage	
	EW2S_dp	EW2S_dp	Manual WEL	1581 62200	ELDRIDGE-WILDE 2S DE	
		RNEDW	ADL	28	RN-ELW-METER_ PIT	
		EW3AW	WEL	1080700	ELDRIDGE-WILDE 3A W	
		PMPtotal			Total Wellfield Pumpage	
	EW139G	EW139G	Manual WEL	1570 65200	WE-ELW-139G	
		RNEDW	ADL	28	RN-ELW-METER_ PIT	
		LkDan	STA	297	LAKE DAN	
		PMPtotal			Total Wellfield Pumpage	
	EW113B	EW113B	Manual WEL	1548 15900	WE-ELW-113B	
		RNEDW	ADL	28	RN-ELW-METER_ PIT	
		LkDan	STA	297	LAKE DAN	
		PMPtotal			Total Wellfield Pumpage	
	EW2N	EW2N	Manual WEL	1580 37500	WE-ELW-2N	
		RNEDW	ADL	28	RN-ELW-METER_ PIT	
		LkDan	STA	297	LAKE DAN	
		PMPtotal			Total Wellfield Pumpage	
NOP	NPMW7s	NPMW7s	Wireless ADL	1949	WE-NOP-NPMW-7s	
		RNNOP	Wireless ADL	34	RN-NOP-NOP	
		NPMW7d	Wireless ADL	1948	WE-NOP-NPMW-7d	
		PMPtotal			Total Wellfield Pumpage	
	NPMW8s	NPMW8s	Wireless ADL	1950	WE-NOP-NPMW-8s	
		RNNOP	Wireless ADL	34	RN-NOP-NOP	
		NPMW7d	Wireless ADL	1948	WE-NOP-NPMW-7d	
		PMPtotal			Total Wellfield Pumpage	

Table 1 List of model input and output variables (cont'd)

Wellfield Code	Output Variable	Input Variable	Device Type	Site ID	Site Name/Code	Comment
NOP	NPMW9s	NPMW9s	Wireless ADL	1951	WE-NOP-NPMW-9s	
		RNNOP	Wireless ADL	34	RN-NOP-NOP	
		NPMW7d	Wireless ADL	1948	WE-NOP-NPMW-7d	
		PMPtotal			Total Wellfield Pumpage	
NWH	RMP08s	RMP08s	Wireless ADL	2060	WE-NWH-RMP-08s	
		RNNWH	Wireless ADL	37	RN-NWH-NWH5	
		RMP08d	ADL Manual	2058	WE-NWH-RMP-08d	
		PMPtotal			Total Wellfield Pumpage	
	RMP13s	RMP13s	Wireless ADL Manual	2071	WE-NWH-RMP-13s	
		RNNWH	Wireless ADL	37	RN-NWH-NWH5	
		RMP13d	Wireless ADL Manual	2069	WE-NWH-RMP-13d	
		PMPtotal			Total Wellfield Pumpage	
	RMP08d	RMP08d	ADL Manual	2058	WE-NWH-RMP-08d	
		RNNWH	Wireless ADL	37	RN-NWH-NWH5	
		NWH05s	Manual	2035	WE-NWH-NW-5s	
		PMPtotal			Total Wellfield Pumpage	
S21	HILLS13s	HILLS13s	WEL	17900	ST PETE HILLSBORO 13	
		RNS21	Wireless ADL	39	RN-NWH-S21	
		HILLS13d	WEL	17800	ST PETE HILLSBORO 13	
		PMPtotal			Total Wellfield Pumpage	
	JCKSN26s	JCKSN26s	WEL	53100	ST PETE JACKSON 26A S	
		RNS21	Wireless ADL	39	RN-NWH-S21	
		JCKSN26d	WEL	52900	ST PETE JACKSON 26A D	
		PMPtotal			Total Wellfield Pumpage	
	HILLS13d	HILLS13d	WEL	17800	ST PETE HILLSBORO 13	
		RNS21	Wireless ADL	39	RN-NWH-S21	
		LkCrnShaw	STA	415	LAKE CRENSHAW	
		PMPtotal			Total Wellfield Pumpage	
	JCKSN26d	JCKSN26d	WEL	52900	ST PETE JACKSON 26A D	
		RNS21	Wireless ADL	39	RN-NWH-S21	
		DossonLk	STA	488	DOSSON LAKE	
		PMPtotal			Total Wellfield Pumpage	

Table 1 List of model input and output variables (cont'd)

Wellfield Code	Output Variable	Input Variable	Device Type	Site ID	Site Name/Code	Comment
SOP	NORTHs	NORTHs	WEL	9600	NORTH SHALLOW	
		RNSOP	Wireless ADL	305640	RN-NWH-SOP	
		SR54d	WEL	9700	SR 54 DEEP	
		PMPtotal			Total Wellfield Pumpage	
	SP47s	SP47s	WEL	12600	ST PETE 47 SHALLOW	
		RNSOP	Wireless ADL	305640	RN-NWH-SOP	
		SP42d	WEL	42200	ST PETE 42 DP	
		PMPtotal			Total Wellfield Pumpage	
	HARRYMs	HARRYMs	WEL	35900	HARRY MATTS SHALLOW	
		RNSOP	Wireless ADL	305640	RN-NWH-SOP	
		CampLk	STA	182	CAMP LAKE	
		PMPtotal			Total Wellfield Pumpage	
	SR54d	SR54d	WEL	9700	SR 54 DEEP	
		RNSOP	Wireless ADL	305640	RN-NWH-SOP	
		SR54s	WEL	10100	SR 54 SHALLOW	
		PMPtotal			Total Wellfield Pumpage	
	SP42d	SP42d	WEL	42200	ST PETE 42 DP	
		RNSOP	Wireless ADL	305640	RN-NWH-SOP	
		SP42s	WEL	42300	ST PETE 42 SHALLOW	
		PMPtotal			Total Wellfield Pumpage	
	SP45d	SP45d	WEL	45100	ST PETE 45 DEEP	
		RNSOP	Wireless ADL	305640	RN-NWH-SOP	
		SP45s	WEL	45200	ST PETE 45 SHALLOW	
		PMPtotal			Total Wellfield Pumpage	
STK	STK20s	STK20s	Wireless ADL	2656	WE-STK-STARKEY-20s	
		RNSTKW	Wireless ADL	51	RN-STK-STKW	
		STK10d	Wireless ADL	2655	WE-STK-STARKEY-10D	
		PMP20s			Pumpage from production wells within 1 mile radius of monitoring well STK-20s	
	SM2s	SM2s	WEL	1075900	STARKEY SM-2 SHALLOW	
		RNSTKW	Wireless ADL	51	RN-STK-STKW	
		PZ4d	Wireless ADL	2528	WE-STK-PZ-4d	
		PMP2s			Pumpage from production wells within 1 mile radius of monitoring well STK-2s	
	EMW16s	EMW16s	Wireless ADL	2501	WE-STK-EMW-16s	
		RNSTKW	Wireless ADL	51	RN-STK-STKW	
		PZ4d	Wireless ADL	2528	WE-STK-PZ-4d	
		PMP16s			Pumpage from production wells within 1 mile radius of monitoring well STK-16s	

Table 1 List of model input and output variables (cont'd)

Wellfield Code	Output Variable	Input Variable	Device Type	Site ID	Site Name/Code	Comment
STK	EMW08s	EMW08s	Wireless ADL	2493	WE-STK-EMW-08s	
		RNSTKW	Wireless ADL	51	RN-STK-STKW	
		PZ1d	Wireless ADL	2525	WE-STK-PZ-1d	
		PMP08s			Pumpage from production wells within 1 mile radius of monitoring well STK-8s	
	WT15s	WT15s	Wireless ADL	2665	WE-STK-WT-15s	
		RNSTKW	Wireless ADL	51	RN-STK-STKW	
		PZ3d	ADL	2527	WE-STK-PZ-3d	
		PMP15s			Pumpage from production wells within 1 mile radius of monitoring well STK-15s	
MRB	SGW1sAR	SGW1sAR	Wireless Manual	1858	WE-MBR-SGW-1	Extended POR using MB1s
		RNCYB7	Wireless ADL	23	RN-CYB-CYB7	
		MB1d	Manual WEL	1724 50400	WE-MBR-01D	
		PMPtotal			Total Wellfield Pumpage	
	MB4s	MB4s	Manual Wireless Manual	1735	WE-MBR-04S	Extended POR using MB3As
		RNCYB7	Wireless ADL	23	RN-CYB-CYB7	
		MB3Ad	ADL Manual WEL	1730 55000	WE-MBR-03AD	
		PMPtotal			Total Wellfield Pumpage	
	MB23s	MB23s	Wireless ADL	1813	WE-MBR-23S	
		RNCYB7	Wireless ADL	23	RN-CYB-CYB7	
		MB6d	Manual WEL	1740 38800	WE-MBR-06D	
		PMPtotal			Total Wellfield Pumpage	
	MB24s	MB24s	Wireless ADL	1814	WE-MBR-24S	
		RNCYB7	Wireless ADL	23	RN-CYB-CYB7	
		MB6d	Manual WEL	1740 38800	WE-MBR-06D	
		PMPtotal			Total Wellfield Pumpage	
	MB537s	MB537s	Wireless ADL Manual WEL	1832 8800	WE-MBR-537S	Extended POR using P153s
		RNCYB7	Wireless ADL	23	RN-CYB-CYB7	
		MB537d	Wireless ADL Manual WEL	1831 8500	WE-MBR-537D	Extended POR using MB1d
		PMPtotal			Total Wellfield Pumpage	

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FIELD-SCALE APPLICATION OF THREE TYPES OF NEURAL NETWORKS TO PREDICT GROUND-WATER LEVELS[1]

Tirusew Asefa, Nisai Wanakule, and Alison Adams[2]

ABSTRACT: In this paper, a field-scale applicability of three forms of artificial neural network algorithms in forecasting short-term ground-water levels at specific control points is presented. These algorithms are the feed-forward back propagation (FFBP), radial basis networks (RBN), and generalized regression networks (GRN). Ground-water level predictions from these algorithms are in turn to be used in an Optimized Regional Operations Plan that prescribes scheduled wellfield production for the coming four weeks. These models are up against each other for their accuracy of ground-water level predictions on lead times ranging from a week to four weeks, ease of implementation, and execution times (mainly training time). In total, 208 networks of each of the three algorithms were developed for the study. It is shown that although learning algorithms have emerged as a viable solution at field scale much larger than previously studied, no single algorithm performs consistently better than others on all the criteria. On average, FFBP networks are 20 and 26%, respectively, more accurate than RBN and GRN in forecasting one week ahead water levels and this advantage drops to 5 and 9% accuracy in forecasting four weeks ahead water levels, whereas GRN posted a training time that is only 5% of the training time taken by that of FFBP networks. This may suggest that in field-scale applications one may have to trade between the type of algorithm to be used and the degree to which a given objective is honored.

(KEY TERMS: artificial neural networks; radial basis networks; generalized regression network; ground-water level prediction; Tampa Bay Water.)

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INTRODUCTION

Tampa Bay Water (http://www.tampabaywater.org), the largest wholesale water provider in Florida, is a special district created by inter-local agreement between Hillsborough, Pasco, and Pinellas counties, and the cities of St. Petersburg, New Port Richey, and Tampa who in turn provide water for more than 2 million customers. Tampa Bay Water supplies millions of gallons per day (mgd) to the region using a variety of sources including ground water, surface water, and a desalination plant. For example, during water year 2004, it supplied an average of 162.7 mgd. Of this, nearly 90 mgd came from ground-water production of 11 consolidated wellfields and urban-dispersed wells. Source-water allocations are made using a suite of tools including near real-time data

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analysis and forecasting of demands and surface-water availability. Ground-water well production is scheduled using a complex mathematical tool called Optimized Regional Operations Plan (OROP). The OROP is a customized computer tool that uses information on forecasted surface-water availability, water-level conditions, operating constraints, and current weather condition to determine how to rotate production among available wellfield supplies to meet demands in an environmentally sound manner. Details of this optimization tool are given in Tampa Bay Water's Annual Report (2005, Appendix B, accessible online).

The OROP rotates ground-water production among wellfields based on maximization of projected ground-water levels at specific locations known as control points that are comprised of surficial and deeper aquifer monitoring wells while satisfying the projected demand. Surficial aquifer target water levels are correlated to wetland water levels so that observed water levels at the control points serve as surrogates for wetland and lake water-level conditions. The current optimization routine requires a four-week water-level forecast at each of the 57 control points. Prior to the development of artificial neural network models, these four-week forecasts were generated using an Integrated Surface and Ground Water (ISGW) model that couples hydrological simulation program – FORTRAN (HSPF) (Bicknell *et al.*, 2001) and MODFLOW (Harbaugh and McDonald, 1996). The ISGW model, in addition to providing other inputs to OROP, forecasts ground-water levels for these short time steps. There are two deficiencies in using this regional-scale model for this specific task. First, the model simulates ground-water levels with a grid resolution of ¼ by ¼ miles square (about 400 meters by 400 meters), the result is intended to represent point forecasts for a monitoring well. To accurately represent ground-water levels at a control point, one would either be required to use a smaller grid cell, which in this case is prohibitively computationally expensive, or to create a mechanism that would interpolate the spatially averaged model forecast for a model cell to a site specific monitoring well water-level estimate. Second, the ISGW model requires a two-year start-up simulation prior to the prediction simulation to overcome numerical instability. A restart mechanism was implemented to overcome this drawback with limited success. Every Friday, the ISGW as well as other models (e.g., surface-water availability and demand forecasting tools) are run followed by OROP to schedule ground-water production for the coming weeks. Given the *repetitive* nature of the ground-water level forecasts, and the requirement to obtain forecasts at *only* control points, it is logical to use learning algorithms that can replace this physically based numerical model in a more efficient way. Previous pilot studies on a limited dataset showed that neural networks did better than the corresponding physically based model in predicting short-term water levels (Coppola *et al.*, 2003). We note that the learning algorithms are actually complementary to physically based models in that both modeling types are needed for OROP.

Learning algorithms are a set of equations and rules that are trained to do a specific task based on underlying physical and/or other processes and that allows the data to "speak." Once trained, these algorithms provide accurate predictions of ground-water levels in less time than that required to run physically based models. In the past, the focus of using learning algorithms has primarily been from a research or academic point of view. However, now many of these algorithms are being tested using field-scale applications.

Artificial neural networks (ANNs) are the most widely used learning algorithms in hydrology (see for example, ASCE, 2000). While the use of ANN applications is widely reported in the hydrology literatures, use of ANNs in subsurface hydrology in lieu of physically based models is very limited. Rogers and Dowla (1994) and Johnson and Rogers (2000) used ANNs to substitute time-consuming flow and transport models in an hypothetical case study on optimizing remediation in ground water. Coulibaly *et al.* (2001) used four types of ANN models to predict monthly shallow ground-water table fluctuations of four observation wells in the Gondo aquifer located in Sahel region and reported that ANNs provided accurate prediction when data are too scarce to run a physically based model. Coppola *et al.* (2003) developed ANN models to predict transient ground-water levels at 12 monitoring locations and concluded that the ANN-predicted ground-water levels were better than predictions from the calibrated numerical model. All of these studies are based on smaller scale applications than the field-scale application presented in this study. When developing hundreds of learning algorithms to replace a regional integrated numerical model, one of the first tasks is to study the practical limitations of these algorithms in terms of ease of implementation, accuracy of predictions, as well as training times required by these algorithms. Training time is especially important in this study, as these models are used as part of a decision support tool that oversees near real-time operations of wellfield productions. Consequently, as more data become available, it is important to know the frequency of re-training.

The objective of this study was to test the applicability of three learning algorithms, namely feed-forward back propagation (FFBP) networks, radial basis networks (RBN), and generalized regression networks (GRN) in predicting ground-water levels. Specifically, the algorithms were compared using three criteria: (1) accuracy of predictions at both surficial and deeper aquifer monitoring wells for different lead-time scales, (2) training time, and (3) ease of implementation.

DESCRIPTION OF DATA

Tampa Bay Water maintains a dense hydro-meteorological monitoring network that collects data at different time scales and organizes this data into an Enterprise Database. Continuous data are collected for rainfall, ground-water levels, wellfield productions, and water quality at numerous locations, processed through quality control/quality assurance (QC/QA) procedures and uploaded to the database daily.

Inputs to the weekly OROP runs include weekly forecasted water levels for ground-water control points for four weeks into the future. Currently, there are 57 control points that guide ground-water production rotations. Of these, 52 are the subject of this study (Figure 1). As OROP operates at weekly time steps with a four-week outlook, a total of 52×4 forecasting models need to be developed.

A GIS spatial analysis was employed to assist in the data and site selection process. Depending on the density of available monitoring sites around a control point where ground-water level predictions are to be made, all sites within a 1-2 miles radius, were initially screened. Monitoring sites that were screened included rain gauges, well recorders (production and water level), lake, and wetland stages. Hyetographs and hydrographs of more than 500 sites were visually inspected. Selection of data input sites was based on the period of record length, measurement frequency, data quality, type of instrument, serial and cross-correlations. In a few cases where data were scarce or contained gaps in the period of record, filling missing records and record extension procedures were performed by piecewise cubic hermite interpolation and robust regression with nearby sites. Model data were retrieved directly from Tampa Bay Water's Enterprise database. All data preparation steps, including general QA/QC and data aggregation, were performed using Microsoft™ sequel stored procedures and model/data integration was executed using Matlab's Database Toolbox™.

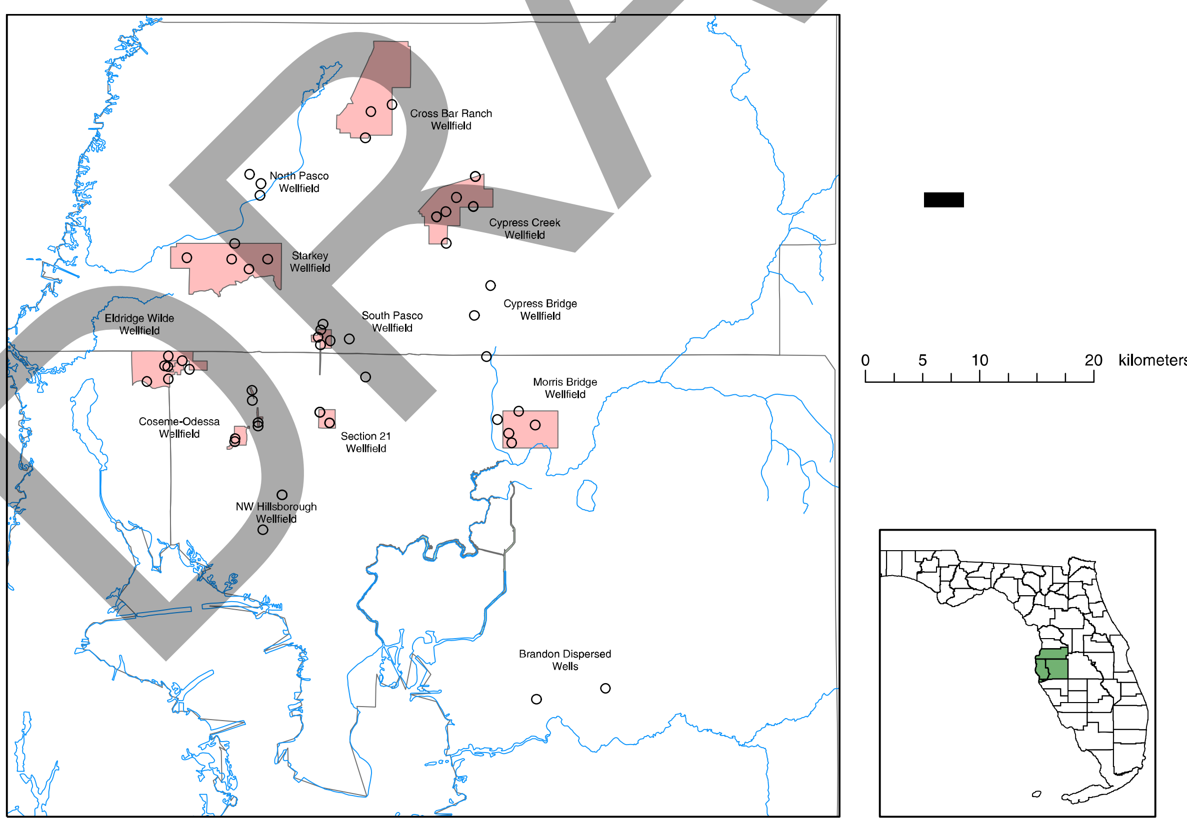

FIGURE 1. Tampa Bay Water Operating Zone. Circles represent locations of control points whereas polygons are wellfields that have a number of production wells (not shown). Sometimes production wells are in dispersed areas where there are no associated wellfields.

Using a method similar to stepwise regression, it was determined that primary inputs to the forecast models should include recent surficial and deeper aquifer water levels, rainfall, pumpage, and wetland and lake water levels (Tampa Bay Water, 2005, Appendix L). A data exploratory analysis was performed to aid model conceptualization and to select specific input variables for 52 control points from the suggested list of inputs. It was also found that one learning algorithm model is required to represent each monitoring well for each week forecast. There are two main reasons to adopt such approach. First, building single output network models for each monitoring wells rather than a multi-output network model makes it easier to add and/or delete control points as changes in environmental conditions may dictate and avoid the need to rigorously train/validate networks and modify corresponding databases every time a change occurs. Second, the use of multi-output networks results in less data for training and validation because now data are sought that are common for all the monitoring wells. In addition, we have found that such an approach while saving training times is inferior in terms of overall prediction accuracy.

The preliminary model for each control point depends on stresses from pumpage and rainfall, initial conditions from recent water levels, and boundary conditions from lake or wetland water levels. The conceptual model is based on the storage principle; thus, pumpage and rainfall amounts used in the model are weekly totals while water levels are the measured or calculated value at the end of the week (i.e., every Friday). Water-level data with a collection frequency other than daily will be interpolated using a cubic spline algorithm.

METHODOLOGY

Given a set of independently identically distributed (i.i.d) training samples $(h_1, \mathbf{x}_1)\cdots(h_L, \mathbf{x}_L)$, learning from data amounts to finding a function $f = h(\mathbf{x})$ that would look at new $\mathbf{x}$ value ($\mathbf{x}_{new}$) and give a "correct" prediction of $\hat{h}$, where h is the dependent variable (ground-water level in this case), $\mathbf{x}$ is the vector of independent variable represented by stresses and boundary conditions, and L is the training size. One then measures the correctness using the so-called loss functions in the form of least square, least modules (Huber, 1964), or ϵ-insensitive loss functions (Vapnik, 1998).

Loss functions measure how far estimates from observations are. Two problems arise: first, how do we know estimations are close enough to observations or in other words, how do we know that we pick the right function f from possibly an infinite number of functions that can go through the observed data? Second, how do we incorporate nonlinearity into the process as most real-life problems have nonlinear relationships?

To overcome the nonuniqueness problem, one usually restricts the functional space of f through regularization function. The regularization function is usually obtained from first-order or second-order derivatives of f to control its complexity. Therefore, instead of finding f by only minimizing a loss function, the objective function will include a regularization component that enforces simplicity on f. To accommodate nonlinearity, one usually transforms the independent variables into some other space referred as feature space and the optimization would be done on transformed values of $(h, \Phi(\mathbf{x}))$. This would allow one to learn a nonlinear relationship in the original (untransformed) space. This is known as the "kernel trick" as the transformation is done through kernels that are subject to certain optimization restrictions. Differences in the form of the loss functions and regularization function, hence the resulting objective function as well as the type of transformation function employed, are perhaps the two major factors separating different learning algorithm that are being used today. Below we highlight the algorithms used in this study.

Feed-Forward Back Propagation

A common architecture of FFBP is one that consists of layers of neurons in a network with a number of neurons in each layer. The size of the input layer corresponds to the number of independent variables, whereas the size of output layer is equivalent to the number of dependent variables. Layers in between (known as "hidden" layers) can have any number of neurons according to the complexity of the problem one tries to solve. Input layer nodes are directly connected to hidden layer nodes through a weight ("connection strength") that modifies the signal before it reaches the receiving neuron. The output of a node in the hidden layer is determined by applying a nonlinear transformation (activation function) to the sum of the weighted inputs it received from neurons in the previous layer. Mathematically, this is written in matrix form for a single hidden layer FFBP as

$$y = F(\mathbf{LW} \times G(\mathbf{IW} \times \mathbf{x} + \mathbf{Ib}) + \mathrm{Lb}), \tag{1}$$

where $F(\ )$ is a linear activation function of the output neuron, Lb is bias for this layer. **IW** and **Ib** are matrix of input layer weight and bias whose dimension is defined by the sizes of input, hidden layer, and the connection between them. **LW** is matrix of synoptic weights connecting the hidden unit to the output layer. $G(\ )$ is the transfer function (in this case tan sigmoid). Training the network amounts to finding connection weights and biases in each layer by minimizing an objective function. Here we used a Bayesian regularization back propagation algorithm to train the networks. This algorithm minimizes an objective function comprising of a least square loss function (that measures goodness of fit), and regularization component using the sum of network weights (controlling complexity). The tradeoff parameter between these two components of the objective function is automatically estimated within the Bayesian framework of MacKay (1992).

Radial Basis Networks

Radial basis networks consist of three layers. The neurons in the first layer just simply pass the input to the single hidden layer where a nonlinear transformation is made using a radial basis (Gaussian) kernel that has a form of $\exp(\|\mathbf{x}-\mathbf{w}\|^2/r^2)$, where r is a smoothing parameter (also called spread). $\|\ \|$ represents the Euclidean distance between input $\mathbf{x}$ and network weight $\mathbf{w}$. The output layer of RBN is linear and produces a weighted sum of the hidden layer. The neurons in RBN have localized receptive fields that respond to inputs that are close to their centers. This is in contrast to ANNs discussed above, where the tan-sigmoid function creates a global response. In the Gaussian kernel, larger values of r result in a smoothed function approximation. Very large and very small smoothing parameters result in having to fit a lot of neurons for both fast changing and slowly changing functions and the network may not generalize well. Radial basis kernel measures "similarity" in input space through the Euclidean distance measures. For example, neurons with weight vector quite different from input vector will output near zero values. These small outputs will then have negligible effect on the linear neuron in the output layer. Similarity in the output space is measured through a loss function.

Generalized Regression Networks

The theory of GRN was first developed in the early 1960s (Nadaraya, 1964; Watson, 1964) (as referenced in Rutkowski, 2004); recent literature on GRN may be found in Specht (1991). In a typical implementation of GRN, this method does not require an iterative procedure to find weights of the network; this is similar to RBN. The hidden unit uses a radial basis transfer function to process the incoming signal but once it reaches the output layer (which has a linear function), the signals are weighted by their sum for each training case. This effectively centers each hidden unit to every training case. As with RBN, the parameter that needs to be estimated during training is the smoothing parameter. GRN are universal approximators with asymptotic convergence where use of longer training data is expected to improve model predictions (Rutkowski, 2004). Cigizoglu (2005) reported a superior performance of GRN over FFBP for predicting steam flow mainly because of the fact that FFBP are prone to effects of sensitivity to initial weight as well as the problem of convergence to local minima. In the next section, we explain how to handle such problems.

APPLICATION

Implementation

As mentioned in the literature cited above, one of the weaknesses of FFBP networks is the fact that they may not be stable and consequently may not converge to the same point every time the networks are initialized (Vapnik, 1998, p. 399; Hastie *et al.*, 2001, p. 359). One of the remedies that has been proposed to overcome this problem is manipulating the random initial weights. Here one trains a number of networks using different initial weights for the same topology and training set. The final network will be selected using either ensemble average (e.g., where the ensemble size has to be small, say 10) (Shu and Burn, 2004) or the "best" network based on certain performance measure (in this case the size of the networks could be in the order of hundreds) (Asefa *et al.*, 2005). Another approach is to manipulate the training by a combination of resampling with replacement (bootstrapping) and aggregating the resulting networks, hence the name "bootstrap aggregations" or in short bagging. There are a number of ways to aggregate ranging from simple averaging to building another learning machine. A third approach (boosting) is where resampling is conditional rather than random, which is not the case in bagging. Once a network is trained using an initial training set, subsequent training samples are manipulated in such a way that training data points whose predicted values are far from observations are preferentially selected to be part of the training data in the next iteration cycle.

In this research, we employed a combination of the above approaches using sampling without replacement coupled with random initialization of network weights. Sufficient numbers of random samples were drawn without replacement from the complete set and each set loops through a number of random initialization of network weights. These networks are then ranked according to the performance on testing set and the best network is selected. Such an approach avoids the need for an additional aggregating algorithm. Table 1 presents model input/outputs. In the table, the wellfield column indicates the scale at which stresses may be aggregated (wellfield names correspond to Figure 1). Outputs are ground-water level prediction at control points that are surrogates to wetland states and representative of deeper aquifer regulatory compliance locations. The input column lists stresses and boundary conditions. The stresses are rainfall and pumpage whereas boundary conditions are water levels of lakes and other open water bodies. For example, for the first well field BUD; BD14 fl and BD21 fl are monitoring locations where ground-water levels are to be predicted; and RNNEBDINN, HickoryLk, and PMPTotal, respectively, represent rainfall, lake water level, and total wellfield pumpage.

Performance Measures of Prediction Accuracy

Three types of performance measures are used in this study. If $\varepsilon = y_{\mathrm{obs}} - y_{\mathrm{sim}}$ is the simulation error and $\varepsilon' = y_{\mathrm{obs}} - y'$, where $y' = y_{\mathrm{obs}}(t-1)$, then the persistence or naïve error

$$\mathrm{MAD} = \frac{1}{N}\sum_{i=1}^{N} \mathrm{abs}(\varepsilon_i) \tag{2}$$

$$\mathrm{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} \varepsilon_i^2} \tag{3}$$

$$\mathrm{TU} = \sqrt{\frac{\frac{1}{N}\sum_{i=1}^{N} (\varepsilon_i/y'_i)^2}{\frac{1}{N}\sum_{i=1}^{N} (\varepsilon'_i/y'_i)^2}} \tag{4}$$

give the mean absolute deviation (MAD), root mean square error (RMSE), and Theil's U (TU) statistics, respectively. The model underlying the naïve forecast is a random walk, which can be specified as

$$y'_t = y_{t-1} + \xi_t, \quad \text{where } \xi_t \sim \text{i.i.d. } N(0,\sigma^2). \tag{5}$$

That is, each value in the time series is the previous value plus a random shock. Behind this notion is the belief that if a forecasting model cannot do better than a naïve forecast, then the model is not doing an adequate job.

RESULTS AND DISCUSSION

All three learning algorithms were constructed using Matlab Neural Network Toolbox (Demuth and Beale, 2004). For all the cases, the ratio of training to testing data was 70/30. For the case of FFBP, the best network in terms of prediction accuracy was found to be the one with a single hidden layer with half the number of neurons as in the input layer. Note that the three-layer neural network has been shown to approximate any function. In addition, the following parameters were used: training parameter goal, 1.0e-3; training parameter minimum gradient, 1.0e-5; and epoch = 150. For both RBN and GRN, as they have three layers by design, the only parameter that was optimized during training was the smoothing parameter. Figure 2 shows an example of a smoothing parameter search result for monitoring well TMR4d in Cypress Creek wellfield during model identification phase. Lead 0 indicates RBN trained to predict one week ahead, Lead 1 indicate that of two weeks ahead, and so forth. As shown in the figure, even though the actual values of TU are different for different lead-time networks, the location of the spread that results in minimum TU values are consistent for a majority of the wells. The same optimum

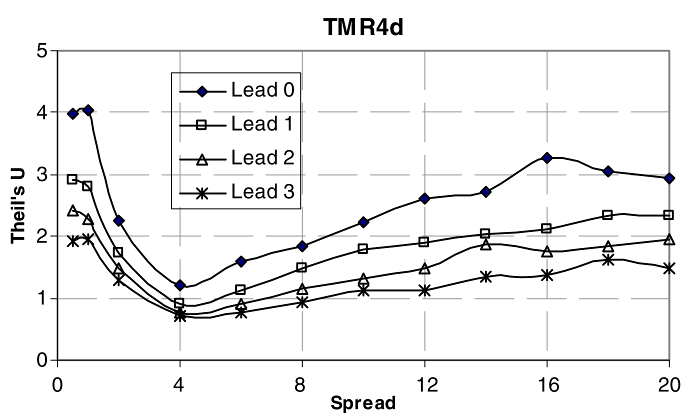

FIGURE 2. Parameter Search for RBN. Lead 0 is a network that is trained to forecast ground-water level 1 week ahead, Lead 1 that of 2 weeks ahead, and so on.

TABLE 1. Input and Outputs of the Learning Models.

Wellfield	Output*	Input**	Wellfield	Output	Input	Wellfield	Output	Input
BUD	BD14 fl	RNNEBDINN	COS	James11d	RNCOS	EDW	TMR4sAR	RNEDW
		HickoryLk			LkPretty			EW3AW
		PMPtotal			PMPjames11			PMPtotal
	BD21 fl	RNNEBDINN		Cosme3	RNCOS		TMR1d	RNEDW
		HickoryLk			SP1C6s			LkDan
		PMPtotal			PMPcosme3			PMPtotal
CBR	SRWs	RNCB01	CYB	WT2_500	RNTOT		EW113B	RNEDW
		SRWd			FL2_1000			LkDan
		PMPsouth			PMPtotal			PMPtotal
	SERWs	RNCB01		WT5_200	RNTOT		EW2 N	RNEDW
		SERWd			FL5_1950			LkDan
		PMPsouth			PMPtotal			PMPtotal
	A1s	RNCB01		WT9_500	RNTOT	S21	HILLS13s	RNS21
		A1d			FL7_2000			HILLS13d
		PMPsouth			PMPtotal			PMPtotal
COS	Keystone36	RNCOS		WT2_1000	RNCYB7		JCKSN26s	RNS21
		Calm33A			FL2_1000			JCKSN26d
		PMPkeystone36			PMPtotal			PMPtotal
	James10s	RNCOS	EDW	SM28ARs	RNEDW		HILLS13d	RNS21
		James11d			EW139 G			LkCrnShaw
		PMPjames10			PMPtotal			PMPtotal
	COS20s	RNCOS		EW11ARs	RNEDW		JCKSN26d	RNS21
		ChurchLk			EW113B			
		PMPcosme20			PMPtotal			DossonLk
	Calm33A	RNCOS		SM15ARs	RNEDW			
		CalmLk			EW113B			PMPtotal
		PMPcalm33			PMPtotal			
CYC	TB22sAR	RNCCPLNT	NOP	NPMW7s	RNNOP	SOP	SR54d	RNSOP
		CC826d			NPMW7d			SR54s
		PMPtotal			PMPtotal			PMPtotal
	TMR1As	RNCC3		NPMW8s	RNNOP		SP42d	RNSOP
		TMR1d			NPMW7d			SP42s
		PMPtotal			PMPtotal			PMPtotal
	TMR2sR	RNCC3		NPMW9s	RNNOP		SP45d	RNSOP
		TMR2d			NPMW7d			SP45s
		PMPtotal			PMPtotal			PMPtotal
	TMR4sAR	RNCCPLNT	NWH	RMP08s	RNNWH	STK	STK20s	RNSTKW
		TMR4d			RMP08d			STK10d
		PMPtotal			PMPtotal			PMP20s
	TMR1d	RNCC3		RMP13s	RNNWH		SM2s	RNSTKW
		E107s			RMP13d			PZ4d
		PMPtotal			PMPtotal			PMP2s
	TMR2d	RNCC3		RMP08d	RNNWH		EMW16s	RNSTKW
		E107s			NWH05s			PZ4d
		PMPtotal			PMPtotal			PMP16s
	TMR3d	RNCC3	SOP	NORTHs	RNSOP		EMW08s	RNSTKW
		CC826s			SR54d			PZ1d
		PMPtotal			PMPtotal			PMP08s
	TMR4d	RNCCPLNT		SP47s	RNSOP		WT15s	RNSTKW
		CCS4			SP42d			
		PMPtotal			PMPtotal			PZ3d
	TMR5d	RNCCPLNT		HARRYMs	RNSOP			
		TMR5s			CampLk			PMP15s
		PMPtotal			PMPtotal			

Notes: *Ground-water level prediction control points.
**Dependent variables in the form of stresses (e.g., rainfall, pumpage) and boundary conditions (e.g., water levels of lakes, surficial aquifer).

parameter search was also made for GRN. Such analysis was then repeated for 52 control points and the final ground-water-level forecasting algorithms used the best smoothing parameter. The relationships between inputs and outputs of the learning algorithms may be expressed as follows:

$$h_{\{i=1,\ldots,4\}} = \Gamma(\mathbf{I}), \tag{6}$$

where h is the ground-water level predictions at control points for weeks $i = 1,\ldots,4$. $\mathbf{I}$ is the input vectors, and Γ is the nonlinear transformation of the learning algorithms. Inputs to the models are further characterized as

$$\mathbf{I} = \left[\bigcup_{i=1}^{4} h_{t-i}, \bigcup_{i=1}^{8} P_{t-i+1}, \bigcup_{i=1}^{4} \mathrm{WL}_{t-i+1}, \bigcup_{i=1}^{13} Q_{t-i+1} \right]^{\mathrm{T}}, \tag{7}$$

where P, WL, and Q represent precipitation, water levels (of boundary conditions, e.g., lakes), and pumpage, respectively. The subscript i now indicates the extent to which past values of these parameters are included.

Our initial assessment showed that 100 samplings without replacement were found to be adequate for FFBP models whereas 500 resamplings were enough to make the outcomes of RBN and GRN independent of sample size; hence sampling sizes were kept constant at these values for all three algorithms. For the case of FFBPs, improvements in predictions accuracy were very small beyond 100 resamplings whereas the increase in training time was substantial (see discussion in the section "Training Time").

Comparison Based on Accuracy of Prediction

Figure 3 summarizes results of FFBP, RBN, and GRN models performance in predicting ground-water levels at 52 control points for lead-time one to four weeks using MADs. The figure shows that FFBP consistently performed better than that of RBN and GRN. Differences in these models are larger for shorter lead times. As lead time increases, differences between predictions of these models become smaller. Table 2 summarizes these results in term of minimum, maximum,

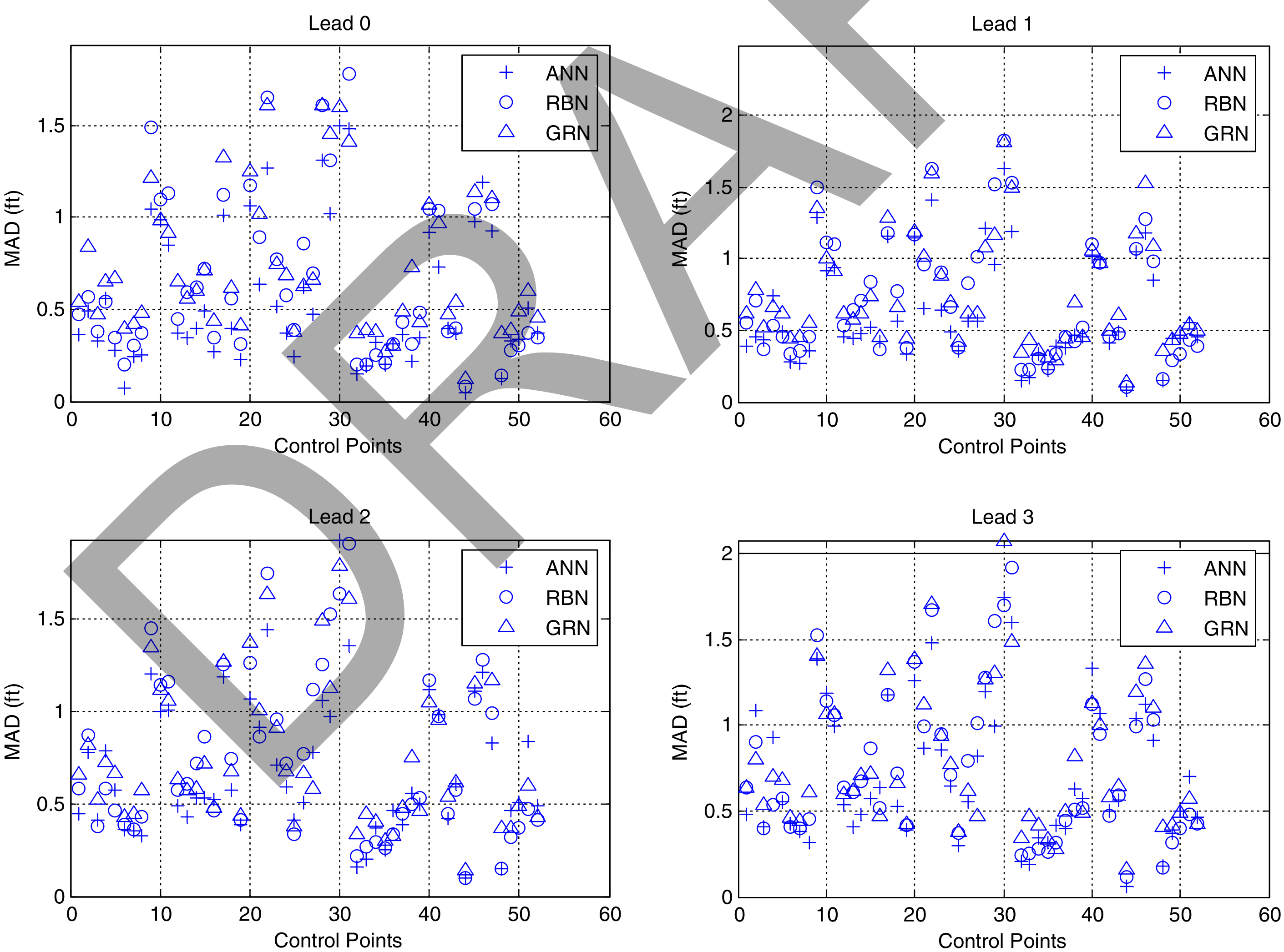

FIGURE 3. Mean Absolute Deviations (ft) of the Three Learning Algorithms.

TABLE 2. Summary of Performances of Learning Algorithms.

	Lead	MAD (ft)				RMSE (ft)				Theil's U			
		Min	Max	Mean	Std	Min	Max	Mean	Std	Min	Max	Mean	Std
ANN	0	0.05	1.50	0.55	0.38	0.10	1.97	0.80	0.52	0.19	1.00	0.65	0.16
	1	0.08	1.63	0.62	0.36	0.14	2.29	0.86	0.48	0.05	0.96	0.55	0.16
	2	0.10	1.93	0.68	0.38	0.14	2.87	0.95	0.52	0.03	0.82	0.50	0.16
	3	0.06	1.75	0.71	0.40	0.10	2.68	0.98	0.55	0.04	0.76	0.45	0.15
RBN	0	0.08	1.93	0.69	0.47	0.14	2.72	0.96	0.62	0.11	1.13	0.82	0.23
	1	0.10	2.48	0.74	0.49	0.14	3.69	1.03	0.69	0.08	1.00	0.65	0.19
	2	0.10	1.91	0.74	0.44	0.14	2.55	1.01	0.59	0.04	0.86	0.55	0.17
	3	0.11	1.92	0.75	0.44	0.17	2.48	1.02	0.58	0.04	0.78	0.49	0.15
GRN	0	0.12	1.61	0.74	0.39	0.24	2.30	1.04	0.54	0.10	1.70	0.84	0.29
	1	0.14	1.82	0.74	0.38	0.28	2.52	1.05	0.51	0.14	0.99	0.63	0.16
	2	0.14	1.79	0.77	0.40	0.26	2.63	1.09	0.56	0.08	0.87	0.54	0.14
	3	0.16	2.08	0.78	0.41	0.32	3.16	1.09	0.56	0.08	0.78	0.48	0.12

mean, and standard deviations of predictions for all 52×4 models. Again FFBP gave consistently better predictions than that of RBN and GRN.

As shown in the table, if one looks at the MADs, on average, FFBP networks are 20 and 26%, respectively, more accurate than RBN and GRN in forecasting one week ahead water levels and this advantage drops to 5 and 9% accuracy in forecasting four weeks ahead water levels. RBN has a 7% advantage over GRN in forecasting Week 1 water levels but this advantage drops to 3% for Week 4 predictions. When looking at the TU statistics, FFBP networks again have 21 and 23% higher accuracy than RBN and GRN for Week 1 forecast and these differences lower to 6 and 8% for Week 4. RBN also maintains a 6-8% accuracy advantage over GRN. It is interesting to note that the TU statistics for all algorithms becomes smaller and smaller as the forecasting horizon increases from Week 1 to Week 4. This is not because Week 4 models are better than Week 1 model (this is correctly shown by the other two performance measures) but the persistence model (naïve prediction) continues to degrade as the forecasting horizon increases, giving a smaller TU.

Sensitivity of Neural Networks to Sample Size. Data used in this study have relatively longer periods of record compared with previously reported studies and this allows an assessment of the performance of neural networks *vs.* sample size to some extent. Generally speaking, for learning algorithms, empirical risk (defined by loss function that measures deviation of prediction from observation) and expected risk (based on the underlying input/output probability distribution) will converge to the same level as sample size goes to infinity (Vapnik, 1998). However, in practice, most studies have limited sample sizes; therefore, appropriate training size for neural networks will depend on such factors as required level of accuracy, complexity of the system being modeled as well as the level of noise in the system.

We select four control points at Cypress Creek wellfield, with over 28 years of data for some of the wells, to study FFBP networks performance *vs.* different levels of training sample size. Table 3 summarizes this result. In all cases, six different levels of sample sizes are used to assess their effect on network accuracy. Wells 1 and 3 show what is called

TABLE 3. Sensitivity of FFBP Network Prediction Accuracy to Sample Size.

Train Size	MAD (ft)	Test Size	MAD (ft)
Well 1			
317	0.000	161	0.500
420	0.041	208	0.545
525	0.044	260	0.504
629	0.066	312	0.463
733	0.089	364	0.437
873	0.102	416	0.367
Well 3			
364	0.110	208	0.414
468	0.145	239	0.413
572	0.143	293	0.393
707	0.148	343	0.317
816	0.132	364	0.376
936	0.126	438	0.367
Well 5			
42	0.447	52	0.769
145	0.243	104	0.724
250	0.243	156	0.688
364	0.426	208	0.661
468	0.356	250	0.689
598	0.374	312	0.687
Well 9			
359	0.177	203	0.312
462	0.226	208	0.460
567	0.223	260	0.438
671	0.215	312	0.452
775	0.230	364	0.417
917	0.220	416	0.416

"well-behaved" characteristics in the sense that training errors consistently increase as sample size increases but testing errors consistently decrease as sample size increases. The increase in error with sample size during training can be explained by the fact that more data introduce more variability to be learnt by the network and lead to an increase in training error. But these networks will generalize well as they "have seen it all" and hence provide a smaller testing error as sample size increases.

The results for Well 5 show somewhat different characteristics than Wells 1 and 3 in that even though the generalization error (during testing) decreased as sample size increased, the training error continued to decrease with increasing sample size. The explanation of this could be there may be no more new patterns to learn, or the training size may not be sufficiently large to provide different patterns to learn (observe that this well has smaller total sample size than the others). The results for Well 9 show different characteristics than the three previous discussed wells with both training and testing error increasing as sample size increased. This might be an indication of the network not being able to see a sufficient number of different ground-water level patterns during training. In general, the increased sample size resulted in better network performances.

The above analysis looks at network performances as a function of sample size at a given location. Can one expect the same conclusion looking at networks at different locations? In other words, can one expect similar performances of structurally similar networks that use equivalent sample size at different locations? To answer this question, we analyzed prediction accuracies of all networks for a given time step (Week 1 forecasts) and their corresponding sample sizes. Using a clustering algorithm, the sample dataset is divided into three categories: (1) small sample size (six to eight years of data, represented by Cluster 1), (2) medium (11-18 years, represented by Cluster 2), and (3) large (20-28 years, represented by Cluster 3). Figure 4 shows this result. As shown in the figure, MADs for small and large sample cases are spread over a large range whereas the medium sample size networks produced less spread. This means that a large training/testing sample does not necessarily result in smaller prediction errors at all locations even though this may be true if one looks at only one location. Conversely, small sample size may still produce acceptable results at some locations.

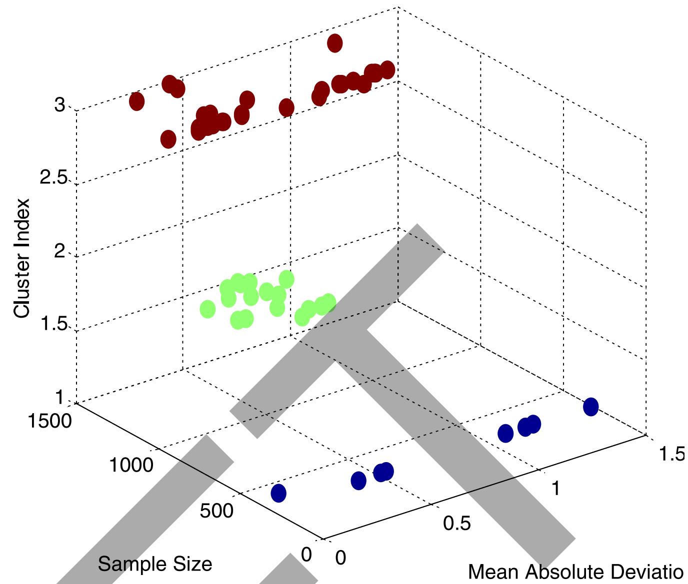

FIGURE 4. Cluster of Sample Size *vs.* Feed-Forward Back Propagation (FFBP) Network Performance. Cluster 1 corresponds to small sample size (blue), Cluster 2 denotes medium sample size (light green), and Cluster 3 represent large sample size (brown).

Training Time

Training of learning algorithms has two parts. The first part consists of establishing model structure, estimating kernel parameters, and analyzing lag space of the input vectors. Once this is completed finding the synoptic weights for the final model follows. In the case of FFBP, finding a suitable model structure means deciding the number of hidden layers and the number of neurons for those layers, whereas in the case of RBN and GRN, the first step amounts to finding appropriate smoothing parameters. As this step is subjective (e.g., the number of hidden layer and neurons, and the space within which kernel parameters are searched), we based our comparison of the algorithms on the time taken for estimating the synoptic weight once the best structure and/or optimal kernel parameters are obtained. Therefore, our reference of training time is limited to this part of the model building process. In addition, as more data become available, retraining of the network every six months to year time is planned and dramatic changes to the model structures are not expected. All the algorithms used a Pentium 4 desktop computer with 3.06 GHz Central Processing Unit and 1 GB of Random Access Memory. Table 4 compares the training time for the three algorithms. The Matlab tic/toc function was used to estimate the training time.

As shown in the table, the most time-consuming training was done by FFBP while the fastest training time belongs to GRN. In total 992 hours (over 41 days!) were required by FFBPs, compared with 85 hours by RBN and 46 hours by that of GRN to build 208 ground-water level forecasting models. The

TABLE 4. Training Times Used by Learning Algorithms (500 resampling without replacement).

	ANN*		RBN		GRN	
Wellfields (wells)	**Total Hours**	**Hours per Well****	**Total Hours**	**Hours per Well****	**Total Hours**	**Hours per Well****
BUD (2)	38.05	19.02	2.37	1.19	1.32	0.66
CBR (3)	60.80	20.27	6.03	2.01	3.43	1.14
CYB (4)	71.80	17.95	3.19	0.80	1.82	0.46
COS (6)	112.71	18.79	10.07	1.68	5.73	0.95
EDW (7)	110.02	15.72	0.85	0.12	0.64	0.09
CYC (9)	190.36	21.15	26.39	2.93	13.40	1.49
NOP (3)	54.19	18.06	2.29	0.76	1.40	0.47
NWH (3)	58.17	19.39	4.19	1.40	2.38	0.79
S21 (4)	79.54	19.88	8.70	2.18	4.62	1.16
SOP (6)	116.55	19.42	10.30	1.72	5.57	0.93
STK (5)	100.29	20.06	10.50	1.75	5.71	1.14

*Based on 100 resampling without replacements runs.
**There are four models for a given well corresponding to different lead-time predictions.

reduction in training time of FFBP to GRN is huge (95.4%). This significant difference is mainly because of the iterative nature of FFBP training and the use of back propagation algorithms to find the optimal synoptic weights. We note that these training times were for specific type of implementation (in this case with Matlab) and also include a resampling methodology that requires several runs.

Ease of Implementation

While implementing FFBP, one needs to select the best structure in terms of the number of hidden layers and neurons on those layers. As more and more hidden layers are used, the problem could become complex and identifying the right structure could be cumbersome, if not impossible.

Radial basis networks and GRN will always have one hidden layer whose size would be dictated by the size of the input vector and one needs to estimate only the smoothing parameter. Note that there are variants of RBN and GRN implementations where the number of hidden layer neurons could be less than or equal to input layer size depending on a predefined goal. In such implementation, the algorithms will iteratively create one neuron at a time and check to see if the prespecified goal is met. This procedure continues until the goal is met or the maximum number of neurons is reached. More explanation on this is given in Demuth and Beale (2004).

Feed-forward back propagations also require an iterative scheme to back propagate differences between predictions and observations, because of this there are several parameters (e.g., number of iterations, learning, and momentum rate together with their increments) that need attention during training of these networks depending on the type of algorithms implemented. Overall, the implementation FFBP was found to be more difficult and time consuming (additional time that is not accounted in the section Training Time) than either RBN or GRN.

IS REAL TIME OPERATION POSSIBLE?

Currently, Tampa Bay Water has implemented the FFBP models as part of OROP where every week initial ground-water levels are estimated using these models. Once preprocessing of the data (this includes real time input data inventory and data filling/extension tasks) is performed, simulation times for these trained networks are in the orders of minutes, making real time operation feasible. As part of this and other modeling efforts, Tampa Bay Water also acquired a grid of machines that enables one to run 88 instances of FFBP networks (on 21 machines) at the same time. This approach will use standalone Matlab Compiler™ and/or Matlab Distributed Computing Toolbox™ to substantially cut the training times reported in the section Training Time.

CONCLUSION

In the past, use of learning algorithms has mainly been from research or academic exercise point of view. Now these algorithms have passed the “testing” phase and are being considered for field-scale applications. We have demonstrated the applicability of three learning algorithms that could be implemented in lieu of complex numerical integrated physically based model in order to forecast ground-water levels within an OROP of Tampa Bay Water. Tampa Bay Water maintains a dense monitoring network that collects variety of data and organizes in one central database from which these learning algorithms were built for near real-time ground-water-level forecasts. These forecasts are inputs to the OROP that prescribes weekly ground-water production schedule in an environmentally sound manner. The fact that weekly ground-water-level forecasts are required at specific control points to ensure that well and well-field production meets certain environmental objectives and these forecasts are needed in a repetitive manner makes the use of learning algorithms an ideal choice. However, learning algorithms may not be the best choice over physically based models. There are instances where the use of an integrated surface/ground-water model is more appropriate.

We have shown the applicability of three learning algorithms, namely FFBP networks, RBN, and GRN in forecasting ground-water levels at specific control points that are used as surrogates for wetland water levels. We used three criteria to compare and contrast the performances of these models: lead-time forecasting accuracy, training time, and ease of implementation. For lead-time predictive accuracy the FFBP network was the best; however, this comes at the expense of longer training time and greater difficulty in implementation. On average, FFBP networks are 20 and 26%, respectively, more accurate than RBN and GRN in forecasting one week ahead water levels but this advantage drops to 5 and 9% accuracy in forecasting four weeks ahead water levels. RBN holds a 7% advantage over GRN in forecasting Week 1 water levels but this advantage drops to 3% for Week 4 predictions. The GRN models required the least amount of training time. The reduction in training time from FFBP to GRN is huge (over 95%). GRN also have a commanding lead over RBN in training time (45% reduction). This obviously indicates that "no one-size-fits all approach" is available when selecting learning algorithms and one may need to make tradeoffs between objectives and evaluation criteria. The huge training time saving by GRN opens up important implications for doing certain analyses that might otherwise be prohibitively time consuming. For example, formal lag-space analysis and rigorous uncertainty analysis on model structure, and data uncertainties may be done using this faster model. These issues have taken our immediate attention.

ACKNOWLEDGMENTS

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APPENDIX D

SURFACE WATER AVAILABILIY MODELS

JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION

AMERICAN WATER RESOURCES ASSOCIATION

ENSEMBLE STREAMFLOW FORECAST: A GLUE-BASED NEURAL NETWORK APPROACH[1]

Tirusew Asefa[2]

ABSTRACT: While training a Neural Network to model a rainfall-runoff process, generally two aspects are considered: its capability to be able to describe the complex nature of the processes being modeled and the ability to generalize so that novel samples could be mapped correctly. The general conclusion is that, the smallest size network capable of representing the sample distribution is the best choice, as far as generalization is concerned. Oftentimes input variables are selected *a priori* in what is called an explanatory data analysis stage and are not part of the actual network training and testing procedures. When they are, the final model will have only a "fixed" type of inputs, lag-space, and/or network structure. If one of these constituents was to change, one would obtain another equally "optimal" Neural Network. Following Beven and others' generalized likelihood uncertainty estimate approach, a methodology is introduced here that accounts for uncertainties in network structures, types of inputs, and their lag-space relationships by looking at a population of Neural Networks rather than target in getting a single "optimal" network. It is shown that there is a wide array of networks that provide "similar" results, as seen by a likelihood measure, for different types of inputs, lag-space, and network size combinations. These equally optimal networks expose the range of uncertainty in streamflow predictions and their expected value results in a better performance than any of the single network predictions.

(KEY TERMS: rainfall-runoff; neural networks; generalized likelihood; uncertainty; water resources.)

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INTRODUCTION

Artificial Neural Networks (ANNs) are the most widely used rainfall-runoff modeling learning tools in hydrology in the past couple of decades (ASCE, 2000a,b). In the past few years, most of the "Future of ANNs in Hydrology" recommendations outlined by the ASCE (2000b) review paper have been addressed by a the number of researchers (e.g., Bowden *et al.*, 2002; Aires, 2004; Shu and Burn, 2004).

An ANN modeling exercise may be categorized into three steps: (1) explanatory data analysis that prescribes the form of the input/output relationships to be modeled and define the input variables to be used at the onset; (2) a form of mutual information analysis that decides the lag-space relationships to be explored; and finally (3) network training and testing. This last part includes the specification of the size of hidden layers and associated nodes thereby estimating ANNs synoptic weights (weights that connect network nodes at different layers and embed the information of the underlying process being modeled). This is usually performed by trial and error. It is done by progressively increasing the number of hidden nodes and assessing the prediction accuracy on

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testing set. When the generalization error can not be further improved by increasing the size of hidden nodes, training stops (Zhang and Govindaraju, 2000; Shu and Burn, 2004; Sudheer, 2004). Even though such an approach results in the "best" network for given input types, known lag-space configurations, and fixed hidden node size, if one of these constituents was to change, one could easily obtain another equally "optimal" ANN. One can show that similar or better generalization ability can be obtained with a different set of inputs, lag-space, and node size configurations. Even holding all these variables constant and just changing the training sample through a resampling procedure, or changing the characteristics of the training/testing data split (Bowden *et al.*, 2002), or re-initialization of the networks could result in different optimal ANN synoptic weights (Shu and Burn, 2004; Asefa *et al.*, 2007). One of the few efforts that have been used to avoid these uncertainties in Neural Network applications is using ensemble forecasts instead of relying on a single optimal network. Shu and Burn (2004) present ensemble based ANN prediction aimed at improving the generalization of network predictions and decreasing their uncertainties to network weight initialization and training samples. The ensembles were generated by manipulating either the training dataset through random sampling or by re-initialization of network weights. They showed the resulting ensemble predictions to be superior compared to that of a single optimal network. Even though such an approach provides reliable networks in field applications, it accounts for uncertainties in only the training dataset sampling and network initializations. It does not account for uncertainties because of variations in input types, lag-space, and network structures (different hidden layer and different hidden nodes).

A more direct parametric accounting of the network uncertainties is presented by Aires (2004) and Aires *et al.* (2004). These studies provide analysis of uncertainty of ANN synoptic weights using the inversion of the Hessian matrix (**H**) of an optimally trained network. They showed that by using the optimal training weight together with the inverted **H** as covariance one can define probabilistic distribution functions (PDFs) that can then be used to find a range of network outputs accounting for uncertainty in neural network weights. The authors caution that while the method provides excellent results, inversion of **H** could be susceptible to instability as network size and complexity increases and/or the size of training data sample decreases. In addition, inversion of **H** depends critically on linearity assumption that may not always be justified. While the above approach provides prediction uncertainties, it accepts the notion of the existence of a unique optimal network weight to begin with, and the uncertainties are defined around this optimal network weight. Our analysis shows that there is not a unique set of input variables, or any single lag-space and/or hidden node size combination that provides the "best" ANN model. Instead, there are suites of models that perform in a similar manner. These equally optimal networks expose the range of uncertainty in streamflow predictions coming out of a variety of sources. To this end, the current study tries to add to the body of knowledge we have by systematically presenting an approach that accounts for uncertainties associated with different constituents of the ANN modeling. Extensive coverage of the theory of ANNs has been reported in many sources (e.g., Hagan *et al.*, 1996) and hence will not be repeated here.

The objective of this study is to demonstrate the applicability of an ensemble Neural Network forecast that accounts for (1) uncertainties in input variables, (2) uncertainties in their lag-space relationships, and (3) uncertainties in network structures.

METHODOLOGY

Beven and others' generalized likelihood uncertainty estimate (GLUE) approach has achieved a lot of success in conceptual as well as physically based rainfall-runoff modeling (e.g., see Beven and Binley, 1992; Freer *et al.*, 1996) mainly because of the method's systematically straightforward nonparametric form of handling a variety of uncertainties without explicitly assuming a form for the structure of the residuals. It is based on a large number of Monte Carlo runs by randomly sampling model parameters from their PDFs and testing the plausibility of the resulting model. The acceptability of each randomly generated model is assessed by analyzing differences between model outputs and observation through a likelihood measure (Franks *et al.*, 1998). This idea is explored in ANN modeling. The basic concept of the methodology proposed here follows the core principle of GLUE in that it rejects the idea of the existence of unique parameter/structure and/or input types, and hence, network synoptic weights to get an optimal prediction of streamflows. Rather it recognizes the existence of equally likely optimal Neural Networks. The procedure may be summarized by the following four steps:

(a) Selection of input parameters. Here, the conceptual knowledge of the rainfall-runoff relationships is used to specify the input variables. This includes rainfall observations at different locations within a watershed, groundwater levels at various locations at both surficial and deeper aquifers, as well as past streamflows. As the GLUE procedure discriminates nonbehavioral input variables and/or parameters combinations based on their acceptance on performance (discussed below) there was no attempt to disregard some of these observations at the onset as it has commonly been done in ANN applications of rainfall-runoff modeling.

(b) Constraining the boundary of the lag-space relationships for each input variable described in (a). This is done by using the method of He and Asada (1993) that uses a criterion based on Lipschitz Quotient defined as

$$q_{ij} = \left\| \frac{y(t_i) - y(t_j)}{\varphi(t_i) - \varphi(t_j)} \right\| i \neq j, \tag{1}$$

where q_{ij} is the Lipschitz Quotient and $y(t)$ and $\varphi(t)$ are, respectively, the dependent and independent variables at time t. One then selects the p largest quotients and calculates the criterion as

$$\begin{gathered}\overline{q}^{(l)} = \left(\prod_{k=1}^{p} \sqrt{n} q_k^{(l)} \right)^{1/p}, p \approx 0.01N - 0.02N \\ q_k^{(l)} \in \left\{ p \text{ largest quotient of } q_{ij}^{(l)} \right\}\end{gathered}, \tag{2}$$

where n is the data sample size.
Repeating this process for different lags and plotting of this index as a function lag will provide a "knee-point" on the curve that corresponds to the lag-space of input variable $\phi(t)$ that should be selected in order to explain the dependence between $y(t)$ and $\phi(t)$ (Nørgaard *et al.*, 2000, pp. 34-37).

(c) Generating Monte Carlo samples. This is done using *a priori* prescribed PDFs and by randomly generating realization of input variables, their corresponding lag-space, and network structures. Network structure refers to the size of hidden layer and the size of their associated hidden nodes. Size of input layer nodes is a direct result of the number of input variables and their associated lags. Once those two are randomly generated, the size of the input node is just a resultant. Output node is set as one, weekly streamflow.

(d) Assessing the plausibility of a randomly generated ANN model. This is done by defining a likelihood measure. The effect of a different likelihood measure on prediction uncertainty has been debated recently. Earlier studies have indicated that the sensitivity of streamflow prediction error bound to likelihood type in rainfall-runoff modeling to be very limited (Freer *et al.*, 1996; Franks *et al.*, 1998). On the other hand, recent studies have questioned such generalizations (e.g., Stedinger *et al.*, 2008). Given below is one of the most popular likelihood measures (Franks *et al.*, 1998):

$$L(\Theta_i|Y) = (1 - \frac{\sigma_i^2}{\sigma_{\text{obs}}^2})^n, \tag{3}$$

where $L(\Theta_i | Y)$, is the likelihood and σ_i^2, the variance of the error for parameter set Θ_i, and σ_{obs}^2 is the observed variance. Using a value of $n = 1$ amounts to that of the Nash and Sutcliffe efficiency measure. Higher values of n give more weight for better performing simulations. In this study both $n = 1$ and $n = 2$ are used.

CASE STUDY

Site Description

Figure 1 depicts the case study area. The watershed is located in the west-central coast of Florida. There are five rainfall stations, four groundwater level monitoring points, and two surface water flow gauges that are selected for this particular study. One week ahead, streamflow forecasts are needed as part of a conjunctive surface-ground-desalination water supply operation of Tampa Bay Water (http://www.tampabaywater.org) to meet demands of over two million customers in the Bay Area. An optimized regional operation plan selects the mix of water sources to be used for the coming four weeks (updated every week) based on a balance of supply and demand in an environmentally sound manner. Water withdrawals from the Hillsborough River follow specific regulatory rules that account for the available water in the river and downstream requirements. When more surface water is available than can be processed through a treatment plant, the excess water is stored in an offsite reservoir and used during a dry season in order to offset the groundwater production. Therefore, the ability to accurately forecast weekly streamflows and take advantage of the regulatory withdrawal rule is of paramount importance for the agency.

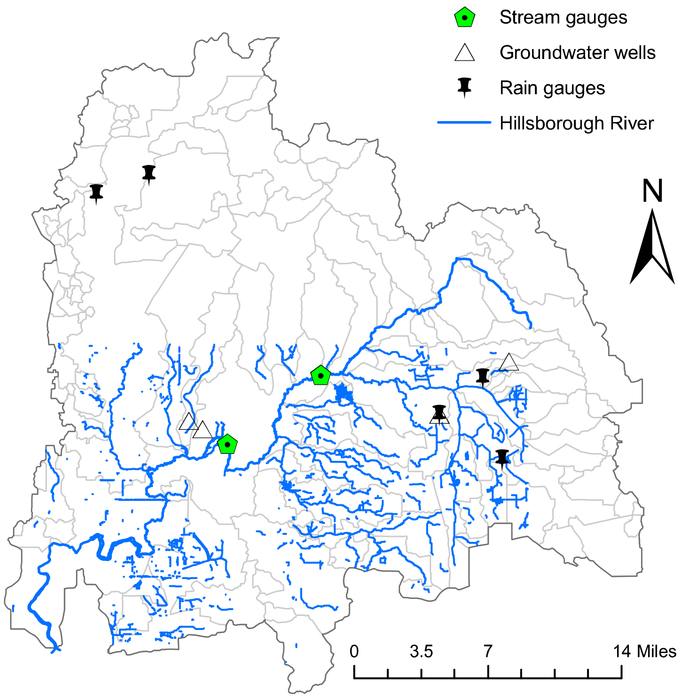

FIGURE 1. Case Study Area.

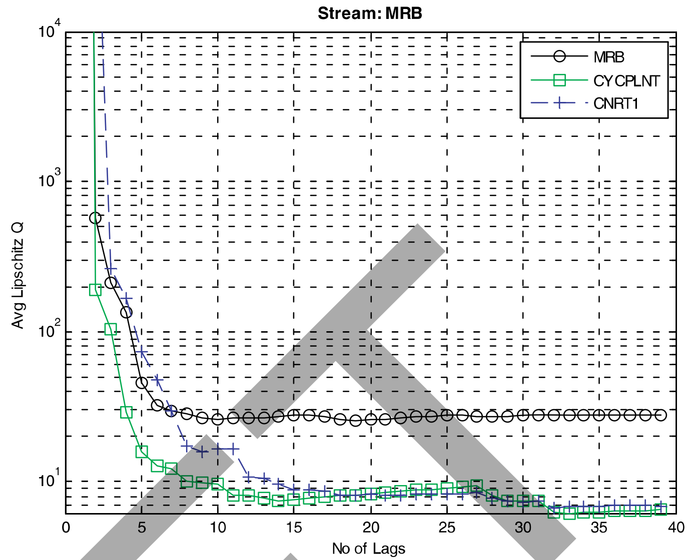

FIGURE 2. Lag-Space Plot: The "Knee-Point" Where the Slope of the Average Lipschitz Quotient Breaks Indicates the Number of Lags to Be Included.

Ensemble Neural Network Training

Generating Input Types and Their Lag-Space. Once the "universe" input variables are identified (five rainfall stations, four groundwater monitoring locations, and one streamflow location), the next step is finding the "universe" of their lag-space relationships as outlined in the Methodology section (b). This is done for each input variable. Figure 2, for example, provides such a plot for two rainfall stations as well as the Hillsborough River. As shown in the figure, the "knee-point" of the average Lipschitz Quotients where the slope breaks are, respectively, at 10, 10, and 13 weeks of lag for MRB (Hillsborough River), and rainfall stations CYCPLNT and CNRT1. The lag-space for all input variables were found similarly (the complete lag-space of the input variables is reported in the Result section). The input variables and their lag-space are then selected by randomly generating from a uniform distribution.

Generating Network Structures. A three layer Neural Network that is demonstrated to approximate any function has been employed here. The methodology described here can easily accommodate more than one hidden layer but is restricted to just one here. The size of input layer is a direct result of Section Generating Input Types and Their Lag-Space. The number of hidden nodes was obtained by sampling the ratio of input layer to hidden node size from a uniform distribution that varies between (0.05 and 3). This means that the number of hidden nodes was allowed to be as much as three times that of the input nodes (note that $2n + 1$, where n is input layer size, is the theoretical size of hidden nodes required due to Kolmogorov Theorem for three layer network to approximate any function). The lower boundary was not set to zero because that would not be a multilayer perceptron. The output layer node was set to one, corresponding to the weekly streamflow.

Monte Carlo Sampling of Neural Networks. Five thousand Neural Networks were randomly generated that account for differences in input variables, their lag-space relationships, and network structure (mainly the size of hidden node). Each of these 5,000 networks has different training and testing data size because inputs and lag-spaces are variable in each. Then the networks were trained and tested by random resampling without replacement of the common dataset. A 70/30 training/testing dataset random split was used. The importance of using statistically "similar" data split has been demonstrated in the literature. Here, a simplified form of the one proposed by Bowden *et al.* (2002) was followed and maintained a maximum of 5% dissimilarity between mean and standard deviation of the two samples. In other words, if the mean and standard deviation of the training and testing samples differed by more than 5%, the resampling procedure continued. One can also force the resampling to honor other statistics, such as min, max, and skewness of the two samples. Hundred resampling without replacement of "similar" data was then used for each network to select the best synoptic weights. Note that this last resampling of data accounts for network re-initialization and error in training data that is not being explicitly accounted for by the 5,000 Neural Networks (more information on the specifics of this procedure is given in Asefa *et al.*, 2007). A Matlab Distributing Computing Toolbox™ program (The MathWorks, Inc., Natick, Massachusetts, USA) that runs over a cluster of 24 computers with the ability to run four instances at a time was used to implement this population of Neural Networks. Details of the implementation including the algorithm used and associated parameters are reported elsewhere (Asefa *et al.*, 2007).

RESULTS AND DISCUSSIONS

Ensemble Performance

Figure 3 displays, for each weekly model, the likelihood as a function of network complexity ignoring those nonbehavioral networks (in this case negative likelihoods). Complexity of networks here is represented by the relative sizes of the input layer and that of hidden nodes. It is interesting to note in this case that most of the better performing networks have their hidden nodes of 25-50% less than that of the input layer size. Clearly, there are not many better performing networks whose hidden node sizes are more than twice that of the input layer. Complex networks produce high performance only when the underlying relationship to be represented itself is complex (Nørgaard *et al.*, 2000, p. 9) and/or there is enough data to learn different patterns. According to the principle of GLUE a streamflow prediction at a future time, *t*, comes from the ensemble of Neural Networks shown in Figure 3. But each model contributes differently according to its performance as measured by the likelihood function. Therefore, predicted values are likelihood averaged estimates. In fact, as explained below, one does not need to use all these models but only a fraction of them that are high performing. Figure 4 presents the likelihood as a function of input variable lag explored for all the 10 input variables. As in Figure 3, this figure also shows the existence of a wide range of input lags for a given likelihood even for just one input variable. These two plots highlight the fact that not only different combination of input variables but their lag-space combination as well as the network structure may also give similar results.

Figure 5 shows the performance of the ensemble as the number of Neural Networks in the ensemble increases. The overall likelihood averaged performance increases by using more and more of the top performing networks. But beyond 15 models, there is not much improvement to be gained by including more Neural Networks. Therefore, only the 15 top performing Networks were retained. It is also clear from the figure that the single best "optimal" model

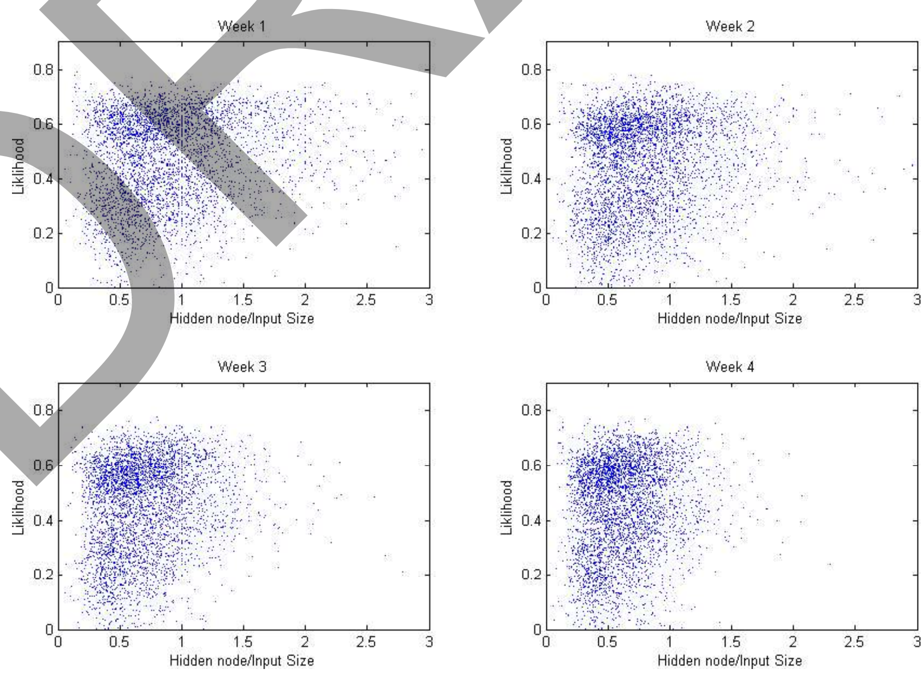

FIGURE 3. Likelihood *vs.* Complexity of Networks as Measured by the Relative Size of Input Layers and Number of Hidden Nodes.

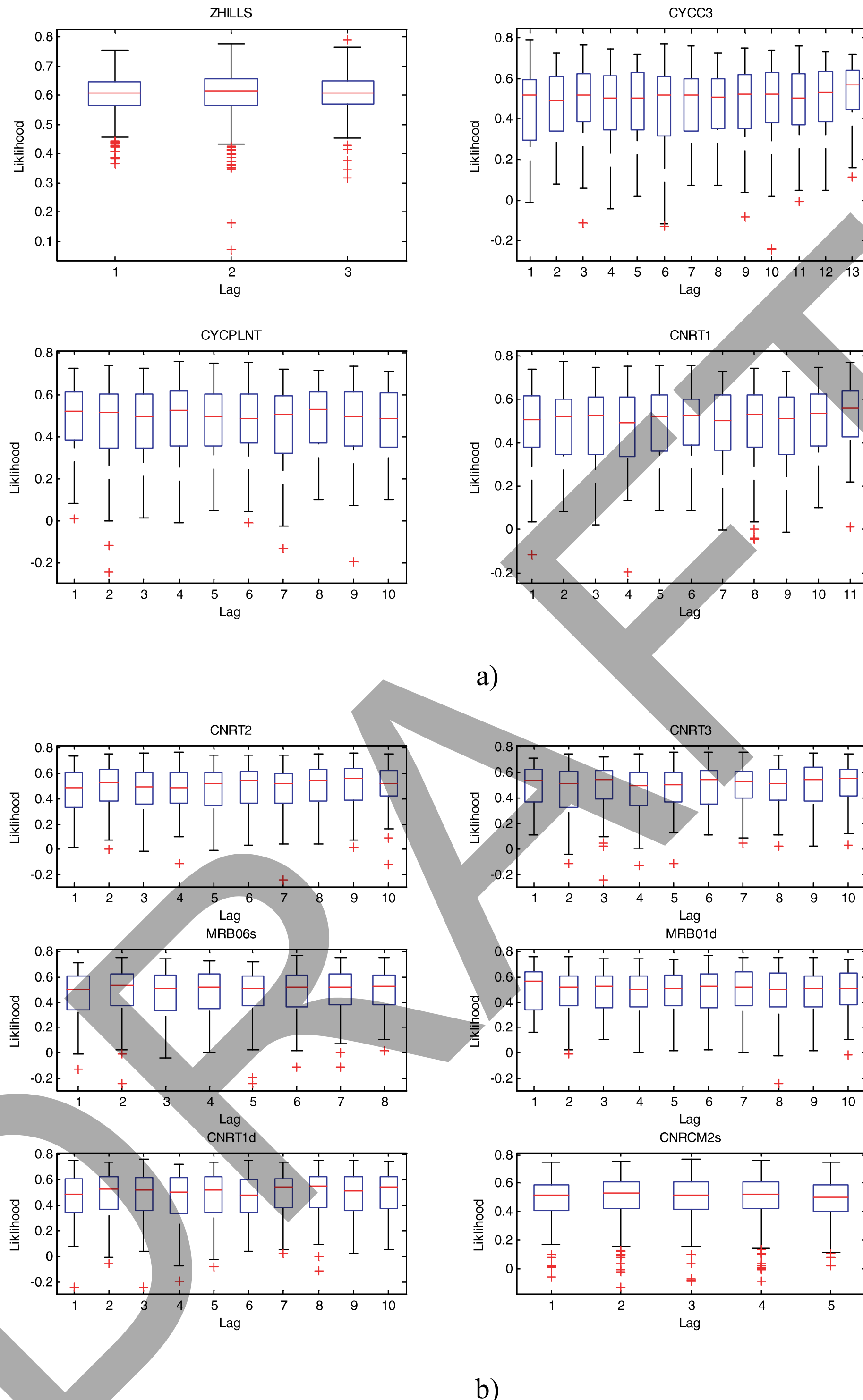

FIGURE 4. Likelihood as Function of Input Variable Lags.

(Ensemble Size 1) is outperformed by the combination of Neural Networks. The range of predictions of these models exposes the combined uncertainties from a variety of sources as shown in Figures 6a and 6b for cases where the likelihood parameter (Equation 3) is, respectively, n = 1 and 2.

Implications for Practical Applications

Oftentimes ANN applications in hydrology assume one or more input variables to be available at a forecasting time step (e.g., Zhang and Govindaraju, 2000; Garbrecht, 2006; Toth and Brath, 2007) whereas

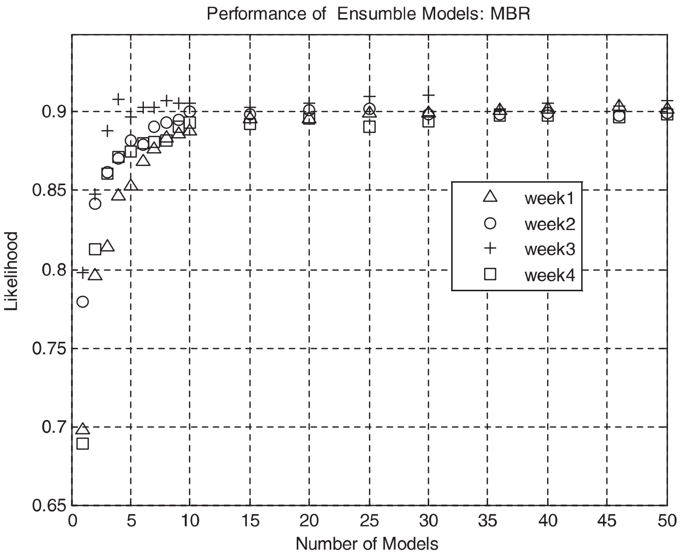

FIGURE 5. Performance of Ensemble Neural Networks.

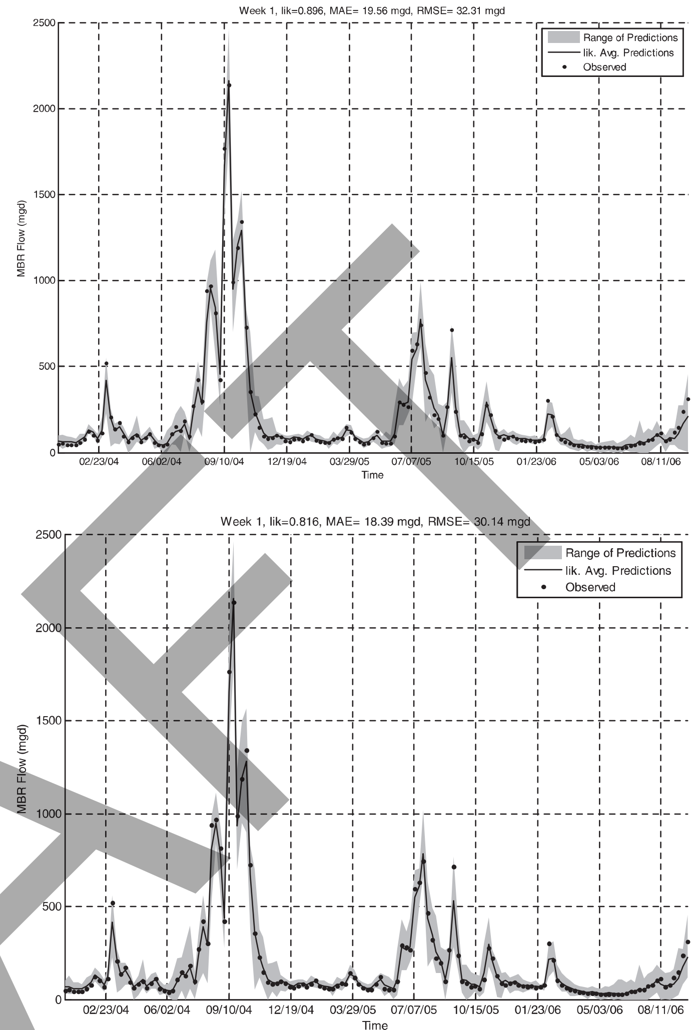

FIGURE 6. (a) Ensemble Neural Network Forecast for the Testing Period Using Likelihood With $n = 1$ (see Equation 3) and (b) Ensemble Neural Network Forecast for the Testing Period Using Likelihood With $n = 2$.

in practice those inputs are forecasted using another model or are set to some statistical or mean climatological values. In rainfall-runoff modeling this in effect means ANNs are used to understand the underlying hydrological process: given rainfall, find the runoff. Here to demonstrate the utility of the current approach in a practical setting, a simple K-Nearest Neighbor (K-NN) algorithm (e.g., Lall and Sharma, 1996) is used to forecast future inputs such as rainfall. A K-NN algorithm uses the current or recent observations of input and output variables as conditioning parameters and searches historical records for some similar values as starting points in time. Similarity may be defined in a number of ways including Euclidean distance. There may also be more than one similar (closer) neighbor in the historical data of which K of them may be selected. Figure 7 depicts results of GLUE ANN using recent data (September 2007 to November 2008) that have not been used for either model training or testing. The simple K-NN algorithm used Euclidean distance in a vector space of the input variables and estimated input quantities as the average of the top two neighbors. One can also use a more sophisticated selection criterion by using a distance-weighted probability function. From the figure, it can be seen that the GLUE ANN does a pretty good job of capturing the weekly streamflow. Notice that now there is a wider prediction range than the one shown in Figure 6. This is because the uncertainties of future input variables that were a result of another model (in this case a K-NN algorithm) are now accounted.

There are interesting consequences of the current approach worth emphasizing. (1) Unlike an approach based on a single optimal network, if one or more members of the ensemble of models were to be removed (which in practice is an occurrence that is very much likely to happen, for example, an agency may stop monitoring a given site that may be needed by a Neural Network), one need not have to go through this exercise again but use only the remaining ensemble models or add the next best performing network(s) from the remaining Neural Networks population that did not use this specific input. This may slightly change the overall performance but will not force one to redo the whole process. Theoretically, this may mean a slight change in the joint probability distribution that GLUE implicitly uses through the resampling process but in practice this may not be that big of a problem. (2) Perhaps the biggest advantage may be the fact that the current approach, since it uses different input types and associated lag-space

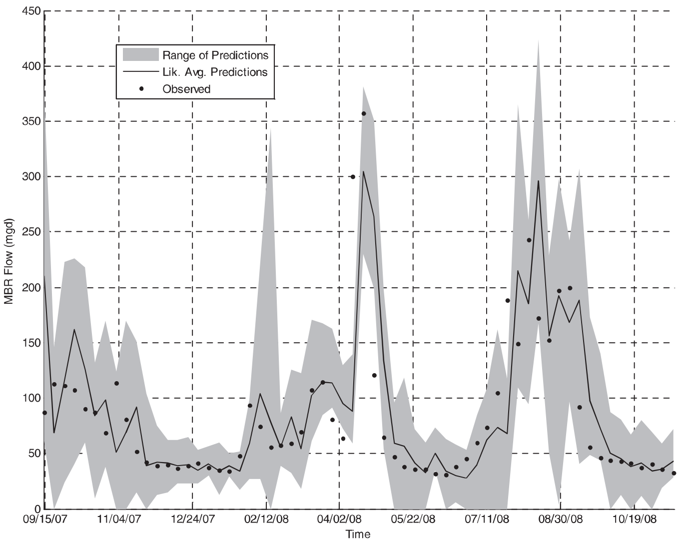

FIGURE 7. Ensemble Neural Network Forecast for Recent Data Using a K-Nearest Neighbor Future Input Forecast Algorithm.

between ensemble members, allows for the possibility of having different data sizes (for both training and testing) across networks. Whereas traditionally one has to trim data in search of commonality between all inputs and outputs.

CONCLUSION

An ensemble Neural Network forecasting approach based on the spirit of Beven and others' GLUE methodology has been presented. The core idea of the methodology is the recognition of the fact that there is not a single "optimal" Neural Network model but rather a collection of them that provide "similar" results. As shown, there is a wide range of input variables, their lag-space relationships, and network structure that results in similar likelihood measure. The ability to look at a population of Neural Networks rather than single optimal ones opens up the possibility of accounting for a variety of uncertainties, which have not been addressed explicitly before. These are (1) uncertainties in the input variables as demonstrated by using different types of variables at different sites, (2) uncertainties in their lag-space relationships, and (3) uncertainty in network structures. The methodology presented here makes a straightforward approach to handling all these in some objective manner that rewards models based on their performance as seen by a likelihood measure. Uncertainty bounds on predictions are a natural consequence of the procedure. Analyzing the overall likelihood performance as a function of ensemble sizes gives one an objective way of selecting ensemble size.

The approach also makes it easy to add new information through new ANN models or delete a Network (say, data feeding a specific network is not available anymore) without disrupting the overall effort and at the expense of minor deviation from the underlying theoretical assumption. This may change the aggregated performance of the remaining networks but will not force one to go through the whole training exercise all over again as is the case with a single optimal Neural Network approach. One aspect of GLUE that has not been looked at in this study is when more and more data are available what to do with the networks. Retrain all of them? The GLUE methodology allows one to update just the likelihood measure based on new information without going through the model building process again. Within the ANN framework, updating the likelihood to improve the overall prediction without going into the training process is an interesting research idea that is open for exploration.

ACKNOWLEDGMENTS

The author thanks the Associate Editor and two reviewers whose valuable comments are reflected in the current presentation.

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APPENDIX E

OROP/EMP REFERRAL PROTOCOL

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TAMPA BAY WATER
Supplying Water To The Region

Memorandum

TO: Alison Adams, Resource Optimization Manager

FROM: R. Warren Hogg, Evaluation and Permitting Manager

DATE: August 3, 2000

SUBJECT: Optimized Regional Operations Plan
Interaction between the Environmental Management Plan and the Optimized Regional Operations Plan

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The recent approval of the Environmental Management Plan (EMP) by the Tampa Bay Water Board of Directors and the imminent implementation of this plan have necessitated this memo that defines the procedure by which information will be transferred between the EMP and the Optimized Regional Operations Plan (OROP). The final EMP for the 11 wellfields covered by the Consolidated Water Use Permit (including changes and clarifications requested by the SWFWMD) was approved by the Tampa Bay Water Board on March 20, 2000. Following Board approval, the final EMP was forwarded to the SWFWMD for final approval on April 20, 2000 after the required holding period for arbitration requests had passed. SWFWMD approval to implement the Consolidated WUP EMP was received on June 7, 2000.

The scopes of work for all of the environmental monitoring and assessment consultants for these 11 wellfields will be modified as necessary to bring each of the monitoring programs into compliance with the final approved EMP. Full-scale monitoring as required by the EMP will commence in Fall 2000 and the Water Year 2000 annual environmental assessment reports for these 11 wellfields will contain all of the EMP-required data and analyses. The following section summarizes the monitoring and analytical requirements of the EMP and the impact determination assessment procedure as it relates to the OROP.

1) Monitoring Requirements of the Consolidated WUP EMP:

- Identify monitoring area(s) and individual stations for each of the 11 Consolidated WUP wellfields (include control and reference stations). **Complete within first year.**
- Map land use and natural communities in FLUCFCS Level 4 format. **Complete within first year.**

- Develop topographic transects including a deep zone and a transitional zone piezometer/staff gage. **Complete within first year.**
- Record water level information at staff gages and piezometers semi-monthly.
- Conduct Wetland Assessment Procedure (WAP) semi-quantitative monitoring twice each year (May/June and September).
- Evaluate control stations twice each year against reference stations to determine if controls are representative of wetlands in the area. **Complete for semi-annual report.**
- Determine normal pool elevations for all monitored wetlands and survey the geographic location and elevation of each monitoring point. **Complete within first year.**
- Conduct quantitative vegetation monitoring in the Northwest Hillsborough Region and at the Morris Bridge Wellfield every two years in the spring and fall of those years.

2) Analytical requirements of the Consolidated WUP EMP:

- Review and analyze all data collected under the EMP. Develop normal pool offset maps using the May and September water level data.
- Review aerial photography and ground-truth stressed areas if needed.
- Review information submitted by SWFWMD, member governments, the Hillsborough County EPC, USGS, etc.; review information collected from environmental complaint investigations.

As stated in the EMP, any direct impacts associated with ground water withdrawals are hydrological in nature. Indirect impacts, such as changes in vegetation, may occur as a result of hydrologic impacts, usually after a sustained period of hydrologic impact. Water level data collection and analyses are prioritized in the EMP because the hydrologic system reacts more quickly to potential wellfield impacts, and because a clearer relationship between water levels and wellfield production may be determined. The analysis of surficial aquifer and wetland water level data collected through the implementation of the EMP will be used as the primary indicator of current or potential future environmental stress in wetland systems.

The consultant for each environmental monitoring and assessment contract (covering all of the 11 Consolidated WUP wellfields) will assess period of record water level and WAP data on a semi-annual basis. These assessments will be performed after each semi-annual WAP monitoring event has been completed (May/June and September of each year). Each consultant will submit a letter report to Tampa Bay Water after the appropriate analyses have been completed (in accordance with the guidelines in the EMP) that identifies wetland sites that are considered to be stressed due to wellfield production. The analyses that lead to the identification of these sites shall be included in the letter report. Sites that were documented as stressed on or before January 1, 1999 (date of issuance for the Consolidated WUP) and were included in the Phase I Wetland Mitigation Program will not be included on these lists. The stressed sites that were previously identified and not included on these lists will be mitigated by the mandated reduction in production from the 11 wellfields and/or by action taken through the Phase 1 Wetland Mitigation Program. The intent of this identification program is to monitor for changes to previously unstressed wetland systems that could become stressed due to changes in production schedules as dictated by the OROP.

The OROP uses surficial aquifer water levels as surrogates for wetland water levels. Target levels are established in a set of surficial aquifer control points (monitor wells) based on correlation analyses with adjacent wetlands and normal pool data from those wetlands. Once a wetland system has been identified as stressed, a surficial aquifer monitoring well must be available in order for a new control point to be established for the optimization routine. If a surficial aquifer monitoring well is not available, a well must be established and data collected for an adequate period of time to correlate the wetland and surficial aquifer water levels and determine the weighting coefficients for that control point.

- Assess period of record water level and WAP data on a semi-annual basis (for the semi-annual reports) to determine if short and/or long-term hydrologic conditions at stations have identified or are currently indicating hydrological differences in comparison to the appropriate control stations or regional reference sites.
- If hydrological differences in surficial aquifer, lake, or wetland water levels are determined to be caused by wellfield production, the location of these monitoring sites and the degree of hydrological differences will be referred to the OROP. The location of the site will be examined to determine if it lies within the effective area of an existing OROP control point. If the site lies within the effective area of an OROP control point, water level data and target water levels for the site will be evaluated relative to the control point water level data to determine if the target level set at the control point is appropriate. Changes to OROP control point target water levels will be tested and implemented as appropriate. If the site is not located within the effective area of an existing OROP control point, the need for an additional OROP control point will be evaluated. Factors to be considered in this determination may include: the degree of hydrologic difference at the site in question, the number of times the site has been referred to the OROP, and the condition of nearby sites. Where it is determined that an additional OROP control point is needed, the well location will be proposed and will be subsequently constructed, tested, and added to the OROP as applicable.
- If a site has been referred to the OROP based on two consecutive semi-annual data review events and the site still exhibits hydrological stress, the extent of the stress will be measured against criteria to determine the potential relative degree of stress. If degree of stress is less than threshold criteria, the location of these monitoring sites and degree of hydrological differences will again be referred to the OROP (see procedure outlined in the previous step). If the degree of stress is greater than the threshold criteria, mitigation options will be explored for the site. The site-specific information is to be considered in determining the need for additional or replacement control points for the OROP. It is understood that the installation and monitoring of wetland and surficial aquifer water level data for a new or replacement control point for the OROP is a process that cannot be completed in less than twelve months. If new or replacement control points are deemed necessary, approximately 6 to 12 months of bi-monthly water level monitoring will be required before this new control point can be utilized.

Implementation

The first environmental monitoring event to be completed under the approved Consolidated WUP EMP will be in September 2000. This semi-annual monitoring event will identify stressed wetlands according to the flow chart contained in the approved EMP. The final semi-annual report is due to Tampa Bay Water in December 2000. If the semi-annual report identifies stressed wetlands that are not addressed under the Phase I Candidate Sites Evaluation Study, then in January 2001 staff will determine what changes can be tested/implemented in the OROP to address the stressed wetland systems.

The second monitoring event will occur in Spring 2001 (April/May). This monitoring report will be completed by August 2001 and will identify stressed wetlands according to the flow chart contained in the approved EMP. If the semi-annual report identifies stressed wetlands that are not addressed under the Phase I Candidate Sites Evaluation Study, then in September 2001 staff will determine what changes can be tested/implemented in the OROP to address the stressed wetland systems.

The third (September 2001) and subsequent monitoring events will identify newly stressed systems as well as chronically stressed systems that remain stressed even though changes were made to the OROP to address these stressed wetlands. This semi-annual monitoring report will be completed by December 2001. In January 2002, staff will identify and implement measures to address newly identified stressed wetlands and define new or different measures to address the stressed wetlands which did not improve as a result of the previous changes made to the OROP.

Monitoring/Evaluation Step in EMP	**OROP IMPLEMENTATION**
IV.A.2	Site information sent to OROP staff. OROP staff will determine if site is near an existing control point, if near an existing monitoring station, or if a new monitoring point should be established.
IV.A.3	First six-month monitoring event, no action in OROP
IV.A.4	Second six-month monitoring event, if site exhibits chronic stress, then changes in the OROP will be implemented to address the chronic stress condition in the wetland.
IV.A.5	Site continued to be referred to OROP for corrective action.
IV.A.6	OROP ineffective in correcting hydrologic stress conditions, site sent back to program for continued monitoring, and referred to step IV.D.1 for additional recovery analysis.
IV.D.2	Site referred back to OROP due to recovery analysis (wellfield reduction) results for corrective action.

Exhibit E
Environmental Monitoring Plan

EXHIBIT C

Environmental Management Plan

for the Tampa Bay Water Central System Wellfields

TABLE OF CONTENTS

ATTACHMENTS

1. INTRODUCTION

This document presents information regarding the history and development, specific monitoring and reporting requirements, and impact determination and assessment procedures and methodologies of the Environmental Management Plan (EMP). The EMP has been prepared to meet specific regulatory requirements of the Consolidated Water Use Permit (WUP) conditions as issued by the Southwest Florida Water Management District (District). The plan is designed to allow flexibility in its implementation while meeting the intent of both regulatory criteria and best management practices for regional water production facilities.

2. BACKGROUND

Chapter 40D-2, Florida Administrative Code (F.A.C.) contains the regulatory framework for the issuance of this Permit by the District. Among the conditions for issuance of Water Use Permits are requirements which state that the water use: "Will not cause harmful hydrologic alterations to natural systems, including wetlands or other surface water features" (Rule 40D-2.301(2)(g)4, F.A.C.); and "Will not otherwise cause harmful hydrologic alterations to the water resources of the area" (Rule 40D-2.301(2)(g)5, F.A.C.). The rules also require that "The Permittee shall mitigate any adverse impact to environmental features or offsite land uses as a result of withdrawals. When adverse impacts occur or are imminent, the District shall require the Permittee to mitigate the impacts." (Rule 40D-2.381(3)(l), F.A.C.).

This Consolidated Permit is the second renewal of WUP 2011771.00 that was originally issued to Tampa Bay Water on December 15, 1998, with an effective date of January 1, 1999, and was renewed with an effective date of January 25, 2011, expiring on January 25, 2021. The second renewal of the Consolidated Permit is for the ten wellfields comprising Tampa Bay Water's Central System. The Central System wellfields are of: Cosme-Odessa (COS), Cross Bar Ranch (CBR), Cypress Bridge (CYB), Cypress Creek (CYC), Eldridge-Wilde (ELW), Morris Bridge (MBR), Northwest Hillsborough Regional (NWH), Section 21 (S21), South Pasco (SOP), and Starkey (STK). The North Pasco Wellfield was originally part of the Central System but has been permanently removed from service and is no longer producing water, although the remaining monitoring sites at this former wellfield are still active and considered to be part of this permit.

The EMP has been developed to assist in the management of the Central System wellfields to reduce or minimize withdrawal-related impacts on ecological resources such as wetlands and lakes. In particular, the EMP defines:

- how environmental conditions in the vicinity of the Central System wellfields will be monitored, how adverse environmental impacts in the vicinity of the Central System wellfields will be identified,
- how identified adverse impacts are referred to the Optimized Regional Operations Plan and,
- how persistent adverse impacts caused by water production will be mitigated by Tampa Bay Water.

The EMP employs a decision-making process, summarized as the EMP Decision Flow Chart (Figure 1) as a framework to accomplish these goals.

A Special Condition of the Consolidated Permit allows Tampa Bay Water to propose revisions to the EMP during its implementation. It is foreseen that some components may require revision during the life of the EMP such as revisions to the monitoring site list, or revisions to the EMP that are required to remain consistent with the latest approved wetland health indices and hydrological or ecological monitoring and analytical methodologies. Such changes will not be considered by Tampa Bay Water to be a modification to a Primary Environmental Permit, as described in Tampa Bay Water's Amended and Restated Interlocal Agreement. Any proposed revisions must be approved by the District before becoming effective.

3. SPECIFIC MONITORING AND REPORTING REQUIREMENTS

A. Monitoring Requirements

The monitoring site network of the EMP has been established for the collection of hydrological and ecological data that can be analyzed to evaluate the potential impacts of wellfield operations. Direct impacts from water withdrawals are hydrological. Water level data collection and analyses are prioritized in the EMP because the hydrologic system reacts more quickly to potential wellfield impacts, and because a clearer relationship between water levels and wellfield operations can be determined.

Indirect wellfield impacts such as changes in vegetation, habitat value for wildlife, or aesthetic and recreational values can result from changes in hydrology. They are difficult to detect because they exhibit a time lag from the hydrological change and because they often are influenced by a variety of other factors. The Wetland Assessment Procedure (WAP, Attachment A) specifies the data collection and analyses for vegetation, wildlife, and aesthetic and recreational values. The Wetland Evaluation Method for Xeric-associated Wetlands (Attachment C) provides a similar function for the subset of geographically isolated wetlands in xeric landscapes (e.g. sandhill).

During the previous permit duration (No. 20011771.001) of the Consolidated WUP, the Recovery Assessment Plan was developed to assess the degree of recovery throughout the Consolidated WUP area that had occurred since the reduction in groundwater production to 90 million gallons per day (MGD). During this process, the area wetlands were categorized into three categories for the assessment of long-term hydrologic condition: isolated wetlands in a mesic soils setting, isolated wetlands in a xeric soils setting, and connected wetlands.

Isolated wetlands in a mesic soils setting (isolated mesic sites) are preferred for EMP monitoring. This wetland category has a better-understood relationship between wetland water levels, wetland health metrics, and the surrounding groundwater system. This is the type of system compatible with the District's Minimum Flows and Levels (MFL) wetland assessment methods, using a Normal Pool elevation minus 1.8 feet as the threshold for adverse impacts to long-term water levels.

Isolated wetlands in a xeric soils setting (isolated xeric sites) were found during the Recovery Assessment Plan analyses to exhibit different hydrologic responses than isolated mesic sites. This category typically has greater water level fluctuation and are highly variable in the vegetation species assemblages and zonation they support. The proposed method defines isolated xeric sites as having more than 27% of the upland soils within a 500-foot buffer around the wetland perimeter classified as xeric soils. The reference elevation is the period of record water level 3% exceedance level (i.e. "P03") or 97th percentile, and the threshold (offset) is 3.7 feet below this reference elevation.

Connected wetlands are those associated with surface water conveyances, such as flowing (streams, floodplain) and flow-through (sloughs, interconnected wetlands) systems. In some cases, water only flows during periods of higher water levels. For the purposes of this EMP, connected wetlands have a defined and visible connection upstream or downstream, either consisting of wetland vegetation or a channel or swale. The hydrologic behavior of these sites is highly variable and typically quite different from the isolated sites. The current assessment method for long-term wetland health of connected wetlands uses a reference elevation based on the period of record 10% exceedance value (i.e. "P10") or 90th percentile, and a threshold (offset) of 2.5 feet below this reference elevation.

The above recovery metrics are for assessment of long-term wetland hydrologic condition. Although they have a role in assessments under the EMP, the routine semi-annual analyses (see Section 4 below) is designed to detect shorter term stress and respond by adjusting pumpage using the OROP.

The District and Tampa Bay Water maintain networks of rainfall gages. These data and Doppler based rainfall estimates can be used to characterize the variability in rainfall amounts and patterns throughout the area potentially affected by the Central System wellfields. Consideration of rainfall data is essential to interpreting vegetative monitoring data and hydrologic data.

This following section outlines specific monitoring requirements of the EMP. This is meant to provide a basis for implementing and conducting the hydrological and biological monitoring requirements of the EMP.

1) The Consolidated Permit specifies that the monitoring program must include all water supply facilities encompassed in the Consolidated Permit and affected areas outside the boundaries of the facilities. Monitoring sites must be established so as to provide ecological and hydrological data that accurately and comprehensively represent wetlands and surface waters. Wetlands and surface waters that are distant from permitted withdrawals

(control sites and reference sites) must be included in the monitoring program in addition to those potentially affected by permitted withdrawals.

For the purposes of this EMP, Treatment sites are monitored lakes or wetlands that are located within the potential drawdown influence of wellfields and have not been shown to meet the assigned recovery metric for wetlands of their type, as evaluated on a long-term median basis. Reference sites are monitored wetlands or lakes that are located a significant distance from any major water withdrawal and also are not impacted by drainage changes associated with land management and development. Control wetlands are monitored wetlands or lakes usually located within the same general area as the wellfields, and subject to similar atmospheric, geologic, and land use conditions, but are not adversely impacted by water production. The reference sites are used to evaluate whether the individual control sites have been impacted by wellfield production or regional development to the degree that they are not valid controls. The control, reference and treatment sites are included as Attachments D, E and F of this document.

The current WAP methodology is best suited to hydrologically-isolated mesic systems. WAP monitoring will be discontinued at isolated xeric-associated wetlands. They will be monitored according to the Wetland Evaluation Method for Xeric-Associated Wetlands (Attachment C). This method may be reassessed by Tampa Bay Water and the District after sufficient data have been collected. District-approved revisions to the method will be implemented during the permit term, and in accordance with permit conditions.

WAP monitoring has already been discontinued for connected wetlands. No vegetative monitoring will be required for connected wetlands, they will be assessed on the basis of the hydrologic data.

A list of the monitoring sites included in the current monitoring program is presented in Exhibit A.5 of the Consolidated Permit. New sites to be added to the network should be chosen where long-term access is expected to be allowed and where monitoring activities are not anticipated to interfere with landowner activities. For any proposed change to the EMP or associated monitoring sites, the Permittee shall submit a request in writing to the District. Approval by the District must be obtained prior to implementation of any changes by the Permittee. Any District approved change to elements of the EMP or monitoring sites shall be documented in the subsequent Annual Report for the next reporting period.

2) Isolated Wetland – Mesic sites will be set up for water level monitoring and vegetation monitoring in accordance with Section 3.2 of the current WAP Manual (Attachment A of this EMP). Isolated Wetland – Xeric sites have similar water level monitoring devices as mesic sites. Vegetation monitoring

at xeric sites will be performed in accordance with the Wetland Evaluation Method for Xeric-Associated Wetlands (Attachment C). If, however, the transect for the xeric-associated wetland method has not yet been set up by the WAP monitoring period (May and June of every year) WAP monitoring will continue until such time as the xeric-associated wetland evaluation method can be implemented.

3) Water level data will be collected at appropriate staff gages and wells at each monitored wetland, regardless of category, twice per month with each reading separated by approximately 2 weeks.

4) Vegetation and ecological monitoring will be performed at all Isolated Wetland – Mesic sites once each year between May 1 and June 30 using the most current WAP Manual (Attachment A) and WAP Field Form (Attachment B).

5) Vegetation and ecological monitoring will be performed at all Isolated Wetland – Xeric sites once each year using the Wetland Evaluation Method for Xeric-Associated Wetlands (Attachment C).

B. **Wellfield Annual Reports**

The primary reporting mechanism associated with this EMP is the wellfield annual reports
submitted to the District. Each year a wellfield annual report will be prepared in accordance with the applicable Special Condition of the Consolidated Permit. The wellfield annual reports will primarily contain summary data presented as graphs or tables as opposed to presenting large volumes of raw data. Some summary statistics and results of statistical analyses may be included in the tables and graphs. EMP-related information that will be presented in the wellfield annual reports includes:

- Wetland water levels
- Wetland hydroperiod
- Wetland normal pool offset
- Wetland Assessment Procedure (WAP) scores
- Wetland Evaluation Method for Xeric-Associated Wetlands scores
- Wildlife opportunistic sightings of protected and wetland-dependent species
- Aerial photography interpretation as specified in the Consolidated Permit
- Results of semi-annual EMP analyses.
- History of EMP outlier analysis

Note that there is additional content for these reports as outlined in the Consolidated Permit. The manner in which the above data is presented within each year's Annual Report shall be determined by Tampa Bay Water using the latest guidance from the District.

4. IMPACT DETERMINATION AND ASSESSMENT PROCEDURES AND METHODOLOGIES

Overview of Impact Determination Procedures

The impact determination procedures outlined in the following sections are designed to detect change in a surface water system's hydrology, and to proceed with successively more in-depth efforts to characterize and correct the observed change. At critical points in these investigations, the system is evaluated with respect to applicable regulatory criteria.

Initially, the investigations focus on water level changes since that is where potential impacts are more quickly and more easily detected, and determination of contributing causes may be more accurate. If it is found that wellfield operations have caused a measurable and adverse hydrologic change in a surface water system, then water withdrawals should be rotated away from the impacted area to correct the impact to the greatest extent possible. If impacts persist, mitigation or more comprehensive production rotation is pursued.

Indirect impacts to vegetation, wildlife, recreation, and/or aesthetics can result from long-term alteration of a system's hydrology. For systems exhibiting long-term hydrologic change, WAP data, or the equivalent data for the xeric-associated wetlands method, are analyzed for comparison to applicable regulatory criteria found in Section 3 of the District's Water Use Permit Applicant's Handbook, Part B.

The primary method for correcting impacts detected under the EMP is through OROP. If OROP fails to improve conditions and a site is identified to be adversely impacted by wellfield operations, then that site may be mitigated in accordance with Section 4.A.6 of this EMP.

Availability of Numeric Impact Criteria and Thresholds

Impact determination for the resources monitored by the EMP is subject to the narrative standards for wetlands, lakes, and streams/springs found in Section 3.3.1 of the Water Use Permit Applicant's Handbook, Part B referenced in Chapter 40D-2, F.A.C. The criteria found in Rule 40D-2.301(2)(g)4 and 5, F.A.C. are narrative and have requirements that withdrawals will not cause harmful hydrologic alterations to water resources. The performance standards found in Section 3.3.1 of the Water Use Permit Applicant's Handbook, Part B provide additional guidance that the water levels and/or flow rates in wetlands, lakes, and streams do not deviate from their normal ranges to the degree where adverse impacts occur. The degree of alteration of water levels or flow that constitutes an adverse impact is not specified. The determination of an adverse impact relies on professional experience, reasonable scientific judgement and expertise to choose the most appropriate analyses for the data, to properly apply the criteria, and to understand how the numerical data and analytical results reflect conditions of the system. For purposes of this EMP, a wetland health metric based on the Minimum Level criteria found in Chapter 40D-8, F.A.C. shall be used for applicable wetland and lake systems (isolated mesic) as the metric for determinations of hydrologic health.

Quantifiable long-term hydrologic impact criteria/thresholds applicable to connected systems and isolated systems in xeric soils were developed under the Recovery Assessment Plan during the prior term of the Consolidated Permit. These metrics are calculated from the site's water level data as opposed to being set by biological indicators, but testing of water levels against the metric is performed similarly to that done for isolated mesic systems. Although these methods will be periodically reviewed, they are the best available as of date of this permit.

The EMP only specifies the objectives or purposes of the tests that need to be performed. It does not specify the exact procedures, tests, or confidence limits to be used because it is not possible to specify a single set of details that will be appropriate for all cases. It is anticipated that impact determination criteria and methods will be updated throughout the life of the EMP in response to changes in applicable regulatory criteria and to new findings based on analysis of environmental data. With respect to the semi-annual outlier analyses performed, guidance and reference wetland water level data are provided, but analysts are expected to apply their professional judgment with respect to the datasets they are analyzing.

The Optimized Regional Operations Plan

There are points in the impact determination and mitigation procedures where the information resulting from the environmental monitoring and analyses are referred to the Optimized Regional Operations Plan (OROP). This plan minimizes environmental stresses resulting from wellfield operations by rotating production away from areas with depressed water levels. Prevailing hydrologic conditions are input into the plan from a network of surficial aquifer wells (i.e., control points) that have been paired with nearby wetlands or lakes such that a statistically significant relationship between water levels in the lake/wetland and water levels in the monitoring well is established. The statistical relationship between the control point well and its associated lake or wetland is used to determine a target level in the well that will maintain the health of the lake/wetland. The OROP monitors water levels in the control point surficial aquifer wells and provides production schedules for wellfields according to the relative stress levels.

Target levels in the OROP control point monitoring wells are based on their correlation with representative wetlands and do not reflect variability in wetland response to drawdown. It is possible, however, to provide additional data to the OROP if a specific wetland or lake system is suspected of being impacted by production, to see if a change in the production schedule will relieve the hydrologic stress. The site is then referred back to the ongoing environmental monitoring program to see if recovery occurs.

Standard Procedures for Wetlands, Lakes, and Streams

The following sections are designed to standardize implementation of the hydrological and vegetation data analyses, interpretation of results, and determination of wellfield-related impacts at all monitored sites for the EMP.

The decision flow chart in Figure 1 provides the conceptual framework for the sections and tasks in Chapter 4 of this EMP. The tasks below correspond to boxes and diamonds in Figure 1. For example, the flow chart box that describes the WAP and water level monitoring is discussed in Chapter 4, Section A, Task 1, and is enumerated within the flow chart box as 4.A.1.

A. Wetland and Lake Impact Determination Assessment Procedure

The following Tasks (4.A. 1 - 6) correspond to boxes and diamonds in the wetland impact determination decision flow chart (Figure 1).

1) **Routine Monitoring** - Semi-monthly hydrological and yearly vegetative monitoring at wetland sites is conducted. For lakes analyzed within the EMP, water level data is compiled semi-annually from the District or other sources.

2) **Semi-annual Outlier Test** - Statistical tests are performed on recent water level data for each wetland/lake site (including sites designated as "controls") semi-annually. Reference sites are used to test that sites designated as "control" are valid controls, and not impacted hydrologically, regardless of cause. Treatment and control sites are then tested, using category-specific outlier thresholds, to determine if short- or long-term hydrologic conditions are statistically different in comparison to either the reference sites or a control/reference site pool. If no significant difference has occurred, routine monitoring is resumed. Statistically different sites (outliers) are added to the Consecutive Test Group, and the results of subsequent semi-annual analyses are tracked to see if these sites will be evaluated further with Task 4.A.3. Sites with anomalously high water levels are not tracked.

   Analyses for both lakes and wetlands are performed. For wetlands, a standard deviate test or similar outlier test procedure is performed on hydrologic parameters. Monitored wetlands are compared to statistics derived from a population of reference wetlands (or pooled reference and control wetlands). Lakes are not designated as control, reference or treatment. The target level is the lake's Minimum Lake Level or Low Level, depending on whether the lake has adopted levels under the MFL program. It is possible that other tests may be performed such as an outlier test of longer-term water level means, or that trends in long-term water levels will be tested.

   The results from this task shall be tracked for each wetland or lake and reported in the Wellfield Annual Reports under the EMP Analysis section.

3) **Three–Consecutive Test** - Sites that were identified as outliers (Consecutive Test Group) are tracked with respect to the outcomes of subsequent outlier tests. If the site passes one of the next two semi-annual

outlier tests, then it is removed from the group. The site may once again be identified as an outlier in future tests. If, while in the Consecutive Test Group, a site is identified as a statistical outlier in three consecutive semi-annual tests, then this site will be added to the Wellfield Test Group and await further evaluation with Task 4.A.4. The reason three consecutive outlier failures are required is to prevent additional study and analysis on a site that may be experiencing a transient water level anomaly that may correct itself. Also, statistical tests have a probability (the 5% or p=0.05 level is often applied) that a site will fail the test by random chance alone. The probability that a site will fail three consecutive tests merely by chance alone should be negligible.

4) **Wellfield Influence Test** - Sites identified as outliers in three consecutive tests undergo evaluation to determine if wellfield operations are the cause of the anomalously low water level conditions. An assessment will also be performed to determine if the hydrologic characteristic identified as a statistical outlier results in an adverse environmental impact to the site. The evaluation will likely include statistical analyses and application of the appropriate long-term recovery metric. Additional supporting work may include aerial photographic interpretation, review of drainage studies, field investigations, and inspection of other data types. The evaluation should be complete enough to conclude whether wellfield operations do or do not affect the site. If the site-specific study does not conclude that wellfield operations affect the site, then the site is added to the Previously Tested Group and Routine Monitoring and Semi-Annual Testing are continued. Where it is concluded that a site's low water conditions are attributable to wellfield operations and an unacceptable adverse impact results, those sites are added to the OROP Referral Group. A plan to make OROP-related adjustments, along with proposed success criteria and timelines, will be developed. Monitoring is continued and conditions tracked while additional analysis is performed to determine what changes to wellfield operations can be taken to correct the identified adverse water level anomaly. Different actions or combinations of actions may be tried, and the response of the site observed until the water level anomaly is corrected or all practical alternatives are exhausted.

5) **OROP Success Test** - If the OROP was able to restore water levels within the impacted site to a condition that no longer fails the outlier test, then those corrective actions will be maintained in order to keep the site from failing the three-consecutive test in the future. Routine monitoring and Semi-Annual Outlier Testing will continue. If none of the OROP corrective actions were able to achieve the success criteria, then it is assumed that the site will remain impacted as long as the permitted wellfield operations continue, and the site is addressed under EMP Mitigation (Task 4.A.6).

6) **EMP Mitigation**

This task determines the effectiveness and feasibility of various forms of mitigation for the impacted wetland or lake. Successful completion of this task will involve coordination between Tampa Bay Water and the District and potentially the affected local government(s), and the landowner(s). The process begins with the identification and quantification of the ecological functions and values that have been impacted and require mitigation. The methods used for this analysis will be mutually agreed up by Tampa Bay Water and the District on a case by case basis. Tampa Bay Water, affected local government(s), and the landowner(s) will evaluate mitigation alternatives. The preferred alternative is then selected and presented to the District for approval. Tampa Bay Water and the District will meet to review those water bodies identified as needing mitigation, the selection of options, status of implementation, and success of the measures implemented.

There are various types of potential mitigation alternatives available through the EMP which include but may not be limited to:

1) further use of the OROP
2) modification of drainage characteristics
3) environmental augmentation
4) construction of offsite wetland mitigation
5) use of existing Tampa Bay Water offsite mitigation credits
6) purchase of mitigation credits from a wetland mitigation bank.

When the plan has gained all regulatory approvals and is shown to fulfill Performance Standards contained in Section 3.3.1 of Part B of the Water Use Permit Applicant's Handbook, the alternative(s) will be implemented. The impact will be determined to be corrected if the mitigated system meets the success criteria developed for the project (pending District approval). If the mitigated wetland or lake is not currently monitored under the EMP, a monitoring plan will be established to track recovery at that site. In the case of mitigation by purchase of mitigation bank credits, use of existing Tampa Bay Water mitigation credits, or wetland construction, the site(s) for which this mitigation has been taken will be removed from the wellfield environmental monitoring program and will be ineligible for further analysis or mitigation actions.

5. DEFINITIONS

This section defines the terms and words used in the EMP. Note that additional definitions are included to assist with interpretation of the Wetland Assessment Procedure (WAP) Instruction Manual as part of Attachment A.

A. **Control Sites** - monitored wetlands or lakes sites that are usually located within the same general area as the wellfields, and subject to similar atmospheric and geologic conditions, but are generally outside the influence of water production and drainage changes associated with land management and development. Such sites are compared to treatment sites to determine if wellfield-induced hydrologic impacts are occurring. Control sites are compared to reference sites yearly to verify that they represent valid control conditions.

B. **Hydroperiod -** the period of time during a year in which there is measurable standing water in a wetland's basin at a designated elevation or position, most often reported for the deepest or central portion of a wetland in scientific literature or reports.

C. **Reference Sites** - monitored wetland or lake sites that are located a significant distance from any major water withdrawal and do not exhibit signs of impacts from drainage changes associated with land management and development. These sites are used to evaluate the quality of control sites and to establish hydrologic statistics used in outlier detection.

D. **Regional Control Sites** - control sites that can be used to evaluate treatment sites at more than one wellfield.

E. **Treatment Site** - those environmental monitoring sites that are located within the influence of potential wellfield-induced hydrologic impacts. Such sites are compared to control/reference sites to determine if wellfield-induced hydrologic impacts are occurring.

F. **Wetland** - those areas that are inundated or saturated by surface water or groundwater at a frequency and duration sufficient to support, and under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soils. Soils present in wetlands generally are classified as hydric or alluvial or possess characteristics that are associated with reducing soil conditions. The prevalent vegetation in wetlands generally consists of facultative wetland or obligate hydrophytic macrophytes that are typically adapted to areas having soil conditions described above. These species, due to morphological, physiological, or reproductive adaptations, have the ability to grow, reproduce or persist in aquatic environments or anaerobic soil conditions. Florida wetlands generally include swamps, marshes, bayheads, bogs, cypress domes and strands, sloughs, wet prairies, riverine swamps, and marshes, hydric seepage slopes, tidal marshes, mangrove swamps, and other similar areas. Florida wetlands generally do not include longleaf or slash pine flatwoods with an understory dominated by saw palmetto.

G. **Wetland type** – a class of wetlands commonly recognized by biologists as sharing similar characteristics of hydrology, geomorphology and plant species, such as cypress domes, marshes, etc. For purposes of the EMP, wetland types are defined according to the classification system employed in the WAP Manual (Attachment A) and the Recovery Assessment Plan.

Permit No.: 20011771.002
Permittee: Tampa Bay Water
Exhibit C Environmental Management Plan
Figure 1
Figure 1. Decision Flow Chart for Wetland and Lake Impact Determination and Corrective Action (Note: Pertinent EMP Text is Referenced)

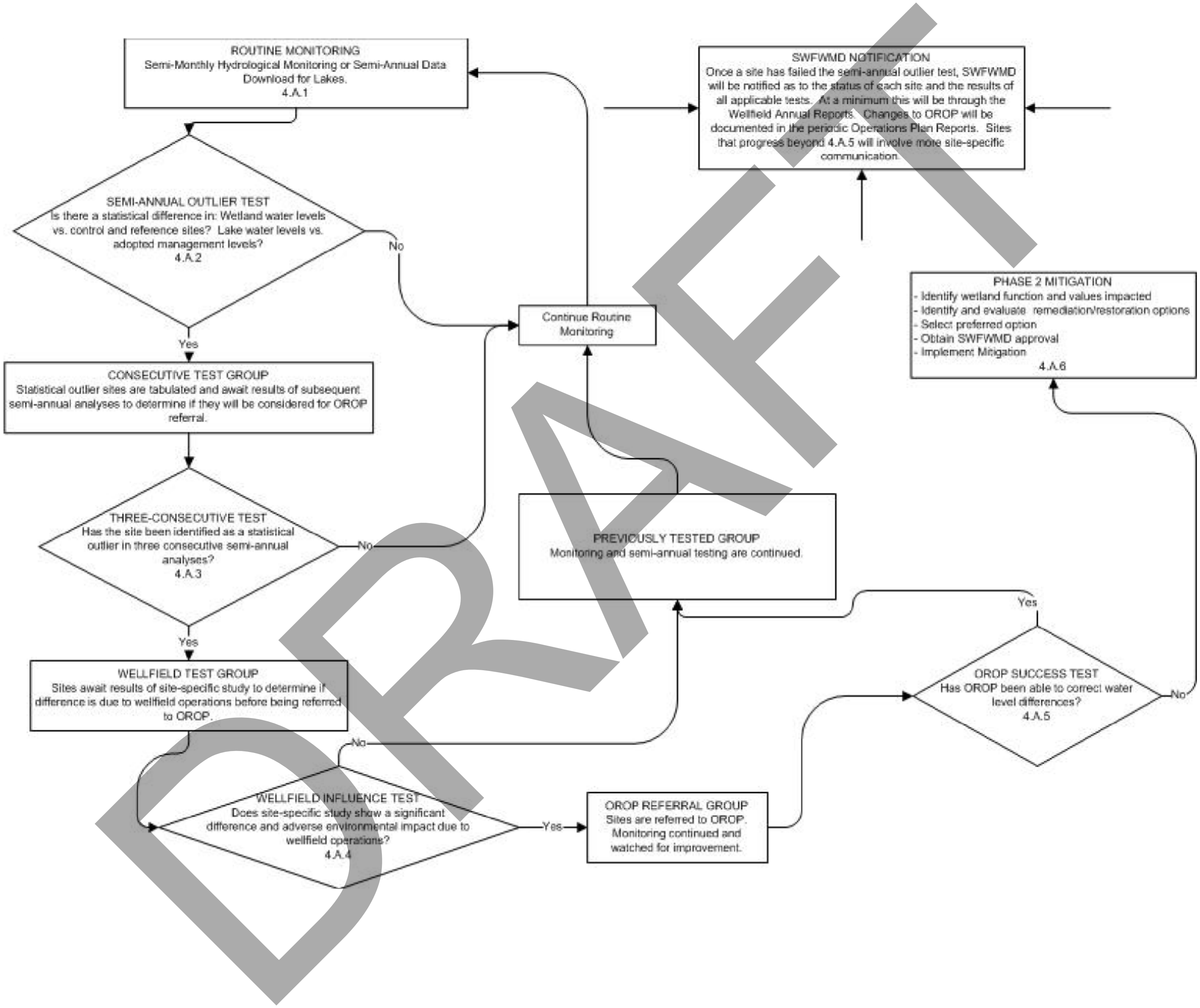
ROUTINE MONITORING
Semi-Monthly Hydrological Monitoring or Semi-Annual Data Download for Lakes.
4.A.1
SEMI-ANNUAL OUTLIER TEST
Is there a statistical difference in: Wetland water levels vs. control and reference sites? Lake water levels vs. adopted management levels?
4.A.2
No
Yes
Continue Routine Monitoring
CONSECUTIVE TEST GROUP
Statistical outlier sites are tabulated and await results of subsequent semi-annual analyses to determine if they will be considered for OROP referral.
THREE-CONSECUTIVE TEST
Has the site been identified as a statistical outlier in three consecutive semi-annual analyses?
4.A.3
No
Yes
WELLFIELD TEST GROUP
Sites await results of site-specific study to determine if difference is due to wellfield operations before being referred to OROP.
No
WELLFIELD INFLUENCE TEST
Does site-specific study show a significant difference and adverse environmental impact due to wellfield operations?
4.A.4
Yes
OROP REFERRAL GROUP
Sites are referred to OROP. Monitoring continued and watched for improvement.
PREVIOUSLY TESTED GROUP
Monitoring and semi-annual testing are continued.
SWFWMD NOTIFICATION
Once a site has failed the semi-annual outlier test, SWFWMD will be notified as to the status of each site and the results of all applicable tests. At a minimum this will be through the Wellfield Annual Reports. Changes to OROP will be documented in the periodic Operations Plan Reports. Sites that progress beyond 4.A.5 will involve more site-specific communication.
PHASE 2 MITIGATION
- Identify wetland function and values impacted
- Identify and evaluate remediation/restoration options
- Select preferred option
- Obtain SWFWMD approval
- Implement Mitigation
4.A.6
OROP SUCCESS TEST
Has OROP been able to correct water level differences?
4.A.5
Yes
No
DRAFT

Exhibit C

Environmental Management Plan

Attachment A

Wetland Assessment Procedure (WAP)
Instruction Manual for Isolated Wetlands

WETLAND ASSESSMENT PROCEDURE (WAP)

INSTRUCTION MANUAL FOR ISOLATED WETLANDS

March 2005

Prepared by:

Southwest Florida Water Management District

and

Tampa Bay Water, a Regional Water Supply Authority

Table of Contents

WETLAND ASSESSMENT PROCEDURE (WAP) INSTRUCTION MANUAL FOR ISOLATED WETLANDS (2005 REVISION)

1.0. INTRODUCTION

This instruction manual is designed to guide the user through the steps necessary to apply the Wetland Assessment Procedure (WAP), including the installation of wetland transects and the performance of the periodic evaluations. The WAP was originally developed in 2000 as part of the Environmental Management Plan (EMP – March 4, 2000) – a plan used to collect data to be used in the management of the Central System wellfields included in Tampa Bay Water's Consolidated Water Use Permit. This instruction manual constitutes the first revision of the original WAP, and replaces Attachments C through F of the EMP.

Note that certain words and phrases used throughout this manual (presented in bold type) are defined in Appendix B. Abbreviated definitions are sometimes included within the text of this instruction manual, but the user should review the more detailed definition of terms in Appendix B. Please be aware that some definitions have been modified for the WAP and may deviate from generic definitions.

The objective of the WAP is to collect information on vegetation, **hydrology**, soils, and other pertinent variables in monitored wetlands to accurately characterize the ongoing biological condition and health of each wetland. This information will be used for a variety of water management purposes, including wellfield management considerations, the development of minimum flows and levels, and the assessment of recovery in areas that have experienced historic hydrologic and biologic impacts due to ground-water withdrawals. It is important to understand that although the WAP seeks to document and monitor many aspects of wetland health, many of these aspects are not the procedure's focus. Many wetlands are also subject to negative health impacts caused by surrounding land management and drainage practices, encroaching development, cattle operations, **exotic plant** species introduction, disease, and other variables, but the WAP attempts to focus on the collection of data that will be used to assess biologic changes caused by the hydrologic effects of ground-water withdrawals.

Note that as of 2005, this WAP methodology is appropriate for isolated wetlands only. The Southwest Florida Water Management District (SWFWMD) suggests that evaluators continue assessing flow systems as appropriate, but evaluators should not apply this revised method to flow systems. An assessment methodology for flow systems will be addressed at a later date.

The results of the WAP include health assessment scores, data collection, observations, and other general information. One critical aspect of the procedure is the written documentation requested to explain various decisions made by the evaluator, as well as a written, ongoing history of each site. The written explanations and comments are intended to document the evaluators logic in deriving scores, provide a basis for ongoing quality control (as well as future correction of errors), and provide the evaluator the ability to document potentially important wetland health-related observations that may not be fully included in the current procedure. Therefore, it is important to realize that the written explanations, comments, and history are essential products of the WAP, and should not be considered optional.

An attempt has been made to make the following instructions as comprehensive as possible. However, if an evaluator finds a situation that is apparently not included in these instructions, the situation should be documented, and the documentation forwarded as soon as possible to Tampa Bay Water and/or the SWFWMD for clarification or resolution before long-term decisions are made.

2.0. DATA REPORTING AND FORMATS

The type and format of data to be submitted to Tampa Bay Water and/or the SWFWMD will be dependent on the current databases and data processing tools. Therefore, the details of data reporting and formatting will be addressed in a separate document, based on procedures agreed upon by both the SWFWMD and Tampa Bay Water. Data to be submitted will include:

a. Wetland history information (see Appendix E)
b. Documentation of transect, well, and **staff gage** installations (see Appendix F)
c. Soils information (see Section 4.1 below)
d. Annual WAP data (see Section 5.0 below)

3.0. ACTIVITIES TO BE PERFORMED FOR INITIAL WETLAND SETUP

3.1. <u>Historical Assessment</u>

A history of the wetland should be established (referred to as the "wetland history" throughout this document). The wetland history should include an initial evaluation of the status of the wetland condition based on several factors, which may include: 1) study of **historical** aerial photography, 2) interviews with previous evaluators, 3) review of previous studies in the area, and 4) initial field visits to the wetland (including documentation of long-term biologic indicators of past hydrologic conditions). The purpose of the **historical** assessment is to provide information on the wetland condition, **historical stresses**, and potential existing **stresses** in the area. See Appendix E for a more detailed discussion of information that should be included in the wetland history.

3.2. <u>WAP Transect Selection and Setup</u>

Once a wetland is chosen for monitoring, the following steps are necessary to establish the **WAP Transect**. Unless the **WAP Transect** needs to be moved or reestablished, this process should only need to be performed once. See Appendix F for a detailed list of information that should be included in the documentation of the transect setup.

WAP Transect selection. All vegetation assessments will be conducted along a **WAP Transect**. The **WAP Transect** is a straight line from the **historic wetland edge** to the **wetland interior**, and should be chosen such that it provides the best opportunity to fully assess all aspects of the wetland, including the **transition zone** (see below). Practical considerations, such as access issues, existing disturbance, minimizing vegetation disturbances while monitoring, and lines of sight, should also be taken into account when choosing a **WAP Transect**. If a **wetland well**, **upland well**, and/or a **staff gage** have been previously established, consideration should be given to including their location in the **WAP Transect**. If wells and/or a **staff gage** have not been established, they should be installed as close to the **WAP Transect** as possible.

The area to be assessed from the **WAP Transect** will be referred to as the **Assessment Area**. Whenever possible, the width of the **Assessment Area** will be approximately ten meters in width (including ten meters beyond the **wetland interior**). If the evaluator determines that critical information concerning the **zonation** condition of the wetland exists beyond the standard ten meter-wide **Assessment Area**, a wider **Assessment Area** may be used (up to the entire area of the wetland). However, when an **Assessment Area** greater than ten meters is used, the evaluator must 1) justify the larger transect size on the field sheet and in the database, 2) approach all critical areas at a distance from which elevations and species identification can be readily determined, and 3) accurately describe the size of the **Assessment Area** on the field sheet and in the database. Future evaluators should use the **Assessment Area** established by previous evaluators unless there is strong evidence to do otherwise. Evaluators should stay on the **WAP Transect** as much as possible to avoid unnecessary trampling of vegetation, but can walk throughout the wetland if critical for an accurate evaluation.

Establishment of Historic Normal Pool and other reference points. Once the location of the **WAP Transect** is chosen, the **historic normal pool** and **historic wetland edge** need to be established. Appendix C contains the definitions and procedures necessary to make these determinations. Once these elevations are determined, the elevations six-inches below **historic normal pool** (**NP-6**) and twelve-inches below **historic normal pool (NP-12)** should be established along the **WAP Transect**. The **NP-6** and **NP-12** elevations must be permanently marked for future reference. If possible, markers should also be placed at the **historic wetland edge**, as well as the **wetland interior**. The **staff gage** can serve as the **wetland interior** marker if it is placed appropriately. All four points should also be recorded using the Geographic Positioning System (GPS), and documented with detailed notes, for future reference.

The **NP-6** elevation, **NP-12** elevation, **historic wetland edge**, and **wetland interior** will be used to designate the three **wetlands zones** used in the WAP analysis. The area within the **Assessment Area** between the **historic wetland edge** and the **NP-6** marker is referred to as the **transition zone**. The area within the **Assessment Area** between the **NP-6** marker and the **NP-12** marker is referred to as the **outer deep zone**. The area within the **Assessment Area** between the **NP-12** marker and the **wetland interior** marker is referred to as the **deep zone**. Note that the **NP-6** and **NP-12** elevations may not necessarily coincide with existing vegetational indicators if the **hydrology** of the wetland has been altered, or due to natural short-term fluctuations.

If the **transition** or **outer deep zones** of the wetland are very narrow, an assessment of these **zones** may not be practical or appropriate. The **transition zone** or **outer deep zone** can be naturally narrow, can become narrow due to disturbance by surrounding land use activities, or can have become narrow due to **subsidence** in the wetland. If possible, the **WAP Transect** should be chosen in a portion of the wetland with a **transition zone** and **outer deep zone** that are wide enough for adequate monitoring. However, if no such area exists, or if an existing **WAP Transect** has a narrow **transition zone** or **outer deep zone**, and the assessor determines that the value of the maintaining the existing **WAP Transect** outweighs the value of moving the **WAP Transect**, the narrow **transition zone** or **outer deep zone** should not be monitored. In this case, the situation should be clearly discussed in the wetland history. A **zone** that is too narrow for practical evaluation is generally considered to be one meter or less in width (from the **historic wetland edge** to the **NP-6** elevation for the **transition zone**, or from the **NP-6** elevation to the **NP-12** elevation for the **outer deep zone**), but the determination of whether or not a **zone** is too narrow for evaluation is a decision of the assessor (subject to SWFWMD and Tampa Bay Water consensus).

In very shallow wetland systems, it may not be possible to establish an **NP-6** or **NP-12** elevation (i.e., the wetland has no **deep zone** and/or **outer deep zone**). In these cases, the situation should be clearly discussed in the wetland history.

The **WAP Transect** and supporting elevations should be fully documented (using the worksheet in Appendix F). Based on the documentation and specific wetland situation, an on-site verification may be required. If the **WAP Transect** needs to be moved during the course of wetland monitoring, all appropriate elevations should be re-established, and the information on the new **WAP Transect** must be documented.

4.0. ACTIVITIES TO BE PERFORMED AT LEAST EVERY FIVE YEARS

4.1. Soils Assessment

The evaluator should perform a thorough assessment of the condition of the soils. Any significant findings should be added to the wetland history.

The assessor should attempt to walk the entire wetland, looking for signs of soil loss or **oxidation, subsidence** caused by karst activity, soil lowering caused by compaction, or disturbance caused by other activities. Indications of the spatial distribution and depth of soil impacts should be documented. The following should be used as guidance:

- Substantial soil **subsidence/oxidation**: This condition occurs when **subsidence** greater than or equal to six inches is observed.
- Moderate soil **subsidence/oxidation**: This condition occurs when **subsidence** greater than two inches but less than six inches is observed.
- Little or no evidence of soil **subsidence/oxidation**: This condition occurs when **subsidence** less than two inches is observed, and when no other evidence of oxidized conditions is apparent.

See Appendix B for more details.

4.2. Wetland History Update

Update the original wetland history with any significant new observations based on the annual evaluations, soils assessments, and other information. The evaluator is encouraged to update the wetland history on a frequent basis, but at least every five years. Information recorded in the "Additional Information" section can be used for this purpose (see Section 5.0 below). See Appendix E for a discussion of information that should be included in the wetland history.

5.0. ACTIVITIES TO BE PERFORMED ANNUALLY

The following information must be collected annually during the May/June time period. All of the data must be entered into an approved electronic database. A form for use in data collection in the field will be provided in a separate document. The following describes the information to be collected during the annual evaluations.

WELLFIELD/PROPERTY	Identify wellfield associated with the wetland assessment (if any). If none, state property monitored, project, or regional control.
STATION ID	Identify the wetland station ID.
HISTORIC FLUCCS CODE	Identify the **historical** Florida Land Use, Cover and Forms Classification System (**FLUCCS**) code for the wetland. A table is provided in the EMP that cross-references the **FLUCCS**, Florida Natural Areas Inventory (FNAI) and SWFWMD codes.
WETLAND TYPE	Identify wetland type from Appendix D that most closely represents the wetland being assessed .
PERSONNEL	Identify organization and person(s) conducting the wetland assessment.
DATE	Date (within the May/June time period).
TIME	Time of arrival

GROUND PHOTOGRAPHY

Photos As a minimum, photos should be taken of the **wetland interior** at the **staff gage**, of the **transition zone** at the **NP-6** marker, and of the entire wetland from outside the wetland (as practical). If useful, photos should be taken in each cardinal direction at each location. Optionally, if the wetland has been monitored for several years, photos should be taken at previously-chosen photo points. In this case, the photo points must be clearly described in the wetland documentation and identified by accurate latitude and longitude coordinates (if possible) to assure photo views are the same for each assessment. The photography must be digital format, and the resolution of the submitted image files must be at least the equivalent of those obtained by a three megapixel camera at full resolution. Digital image files should be clearly labeled with wetland ID, location, and date, and stored in an appropriate database.

WATER LEVEL

Describe water level conditions in the wetland at the time of the assessment. Water levels from the **staff gage** should be noted, and an estimate of the percent of the wetland inundated should be mentioned. If there is no standing water in the wetland, an estimate of soil moisture or saturation, and, if possible, depth to water, should be made. Saturation can be determined by rolling a golf ballsized ball of soil in your palm. If soil is saturated moisture will appear on the soil and in your palm. Depth to water can be estimated by the degree of soil saturation, or through the use of the **wetland well**. The goal of this evaluation is to provide a general description of water level conditions at the time of the assessment.

VEGETATION ZONATION

The following section provides direction to assess the **composition** and **zonation** of the most common **groundcover**, **shrub**, and **tree** species in the monitored wetland. The vegetation assessment will be conducted within the **Assessment Area** from the **WAP Transect** (unless the **Assessment Area** goes beyond the standard ten-meter width, as described earlier). The purpose is to assess vegetation characteristics and distribution with respect to **hydrology**. It is assumed that normal **composition** and **zonation** of species are a result of normal wetland **hydrology**. Altered **hydrology** is assumed to affect plant community **composition** and plant species **zonation**.

Groundcover is defined as all woody species less than one meter in height, and all non-woody species (regardless of height), rooted in the ground. **Vines** originating from within the **historic wetland edge** (but not on **hummocks**) should be considered **groundcover**. For clarity, *Eupatorium* spp., *Typha* spp., and *Rubus* spp., and certain other species generally thought of as herbaceous will only be assessed as **groundcover** regardless of their height.

Shrubs and small trees are defined as woody plants greater than one meter in height and less than four centimeters **Diameter at Breast Height** (**DBH**). Shrubs usually have multiple permanent stems. When greater than one meter in height, *Hypericum* spp. and *Ilex glabra* are considered shrubs. *Myrica cerifera*, and *Lyonia* spp., and other woody plants with multiple stems that are greater than one meter tall are always assessed as **shrubs and small trees**. Cabbage palms with trunks greater than one meter tall but less than six meters are considered **shrubs**. Only **shrubs and small trees** rooted in the ground (not on **hummocks**) will be considered.

Trees are defined as woody plants that are greater than or equal to one meter in height and greater than or equal to four centimeters **DBH**. *Myrica cerifera*, *Lyonia* spp. and other woody plants with multiple stems that are greater than one meter tall are assessed as **shrub and small trees**. Cabbage palms with trunks greater than one meter tall but less than six meters are considered **shrubs**. Some non-forested wetlands such as marshes may have enough **trees** to provide useful information. The **tree** category should be scored in marsh and wet prairie systems if the evaluator believes that useful information can be obtained from scoring. Only **trees** rooted in the ground (not on **hummocks**) will be considered.

The species found in Appendix A have been determined to be common species in west-central Florida that are useful in determining the status of wetland **zonation**. Each species has been designated a **wetland zone** classification as follows:

> **Upland (U)** – Plant species that are not expected to be seen in wetlands. It is possible that a few of these species may be found along wetland edges, but are not expected throughout the **transition zone**.
>
> **Adaptive (AD)** – Plants species designated as FAC or Upland by DEP, but commonly seen in the **transition zone** in limited numbers. When **adaptive** plants are found in the **outer deep** or **deep zones**, they should be treated the same as **transition zone** plants.

Transition (T) – Plant species commonly found in the **transition zone**, and designated either FACW or OBL by DEP.

Outer Deep (OD) – Plant species commonly found in the **outer deep zone**, and designated either FACW or OBL by DEP.

Deep (D) - Plant species commonly found in the **deep zone**, and designated either FACW or OBL by DEP.

For each category of vegetation (**groundcover**, **shrub and small tree**, and **tree)**, the assessment should be performed as follows:

1) The assessor should walk along the **WAP Transect** and list the species that occur within each **zone** (within the **Assessment Area**), keeping the following in mind:

a. Only rooted vegetation growing within the **historic wetland edge** should be included in the assessment. **Floating vegetation** should not be considered in the **zonation** evaluation, but may be noted.
b. Vegetation growing on **hummocks** or upland islands should not be considered.
c. Vegetation overhanging from the uplands, such as saw palmetto, should not be considered. Keep in mind that the **historic wetland edge** is typically uneven and meandering.
d. **Vines** in the **canopy** that originate from outside the **historic wetland edge**, or from **hummocks**, should not be included in the assessment.
e. Only consider living, non-dormant vegetation in the assessment.
f. It is possible that there may be topographically higher areas within the wetland. For example, there can be areas of the wetland within the **deep zone** that are shallow enough to become less than **NP-6**. In this case, that area should be considered to be part of the **transition zone**. This may not be easy to distinguish visually, so great care should be taken to identify and document such areas.
g. If the wetland does not have a **transition zone**, **outer deep zone**, or **deep zone**, NA (not applicable) should be written in the appropriate area of the field sheet, and an explanation should be included.
h. Evaluators should stay on the **WAP Transect** to avoid unnecessary trampling of vegetation, but can walk throughout the wetland if critical for an accurate evaluation.

Scientific names should always be used when listing species. Comments and/or notes on the observed vegetation species, including those not to be considered in the **zonation** evaluation, are encouraged in the documentation. Identification in the field, even for the plants on the limited list given in Appendix A, can be very difficult. It is strongly recommended that when the assessor is unsure of determination, small non-destructive samples be taken for further study or expert identification. Useful references for species identification include Wunderlin and Hansen (2003), Tobe and others (1998), and http://www.plantatlas.usf.edu

2) Estimate the percent **cover** of each species. Each percentage should be the percent of the wetland **zone** covered by the specific species. If the entire **cover** of a species includes only one or two plants, denote the **cover** as one or two plants rather than as a percentage. When coverage is greater than one or two plants, estimate the coverage as either 5 percent, or increments of 10 percent (10, 20, 30, etc.). Note that **cover** that is significantly disturbed by paths or trails used to

enter the wetland should not be considered in the assessment. Add any notes necessary to explain the results of the percentage estimates.

3) Indicate the **wetland zone** classification for each species found in Appendix A. If the species is not found in Appendix A, no **wetland zone** designation should be assigned.

4) Using the Ranking Scale and Guidance below, indicate the category that best describes the **zonation** of each vegetation type (**groundcover**, **shrubs and small trees**, and **trees**), and provide an explanation that clearly outlines the reasons for your choice. A species is considered to have "moved" when a species with a **wetland zone** classification closer to the **historic wetland edge** is found in a **zone** closer to the **wetland interior**. Assigning half points between categories is not acceptable. For all categories evaluated, a choice of 1-5 must be made, or **NA** must be chosen.

<u>Ranking Scale</u>

1. Species with an **upland** classification have moved into the **deep zone** in high numbers and distribution.

<u>Guidance</u>:

a. For **groundcover**, "high numbers" usually means greater than 25 percent **cover**.
b. For **shrubs and small trees**, and **trees**, "high numbers" usually means greater than 5 to 10 specimens.
c. "High distribution" usually means located throughout the **zone**.

2. Species have moved in two **zones** in high numbers and distribution, and/or some species with an **upland** classification have moved into the **deep zone**.

<u>Guidance</u>:

a. For **groundcover**, "high numbers" usually means greater than 25 percent **cover**.
b. For **shrubs and small trees**, and **trees**, "high numbers" usually means greater than 5 to 10 specimens.
c. "High distribution" usually means located throughout the **zone**.
d. A "2" should be chosen if any species have moved in three **zones**, regardless of numbers and distribution.

3. Species have moved in one **zone** in high numbers and distribution, and/or some plants have moved in two **zones**.

<u>Guidance</u>:

a. For **groundcover**, "high numbers" usually means greater than 25 percent **cover**.
b. For **shrubs and small trees**, and **trees**, "high numbers" usually means greater than 5 to 10 specimens.
c. "High distribution" usually means located throughout the **zone**.
d. A "3" should be chosen if any species have moved in two **zones**, regardless of numbers and distribution.

4. Species have moved in one **zone** in enough numbers and distribution to be of concern, and/or species with an **adaptive** classification are **extensive** in numbers and distribution in the **transition zone**.

<u>**Guidance**</u>:
a. For **groundcover**, "enough numbers" usually means greater than 5 percent **cover** for all species.
b. For **shrubs and small trees** and **trees**, "enough numbers" usually means two or three specimens.
c. "Enough distribution" or "**extensive** distribution" usually means located beyond a few feet of the appropriate **zone**.
d. For **adaptive species** in the **transition zone**, "**extensive** in numbers" usually means greater than 25 percent.

5. Normal **zonation**. Some species may have migrated inward one **zone**, but they are small in number and/or right along the **zone** edge. **Adaptive species** in the **transition zone** are not considered abnormal if they are not **extensive** in numbers and distribution.

<u>**Guidance**</u>: Choose a "5" if:
a. All identified species are in their appropriate **zone**, or
b. All **groundcover** species in inappropriate **zone**s combine for less than 5 percent coverage, or
c. All species in inappropriate **zones** are within approximately one foot of the appropriate **zone**. Any topographic changes in the deeper **zone** should be carefully considered when making this decision.

NA Not enough **cover** to make evaluation

<u>**Guidance**</u>: If you feel there is not enough of the **cover** to make a meaningful score, choose NA.

Examples of species moving two **zones** include species with an **upland** classification being found in the **outer deep zone**, or species with an **adaptive** or **transition** classification being found in the **deep zone**. Examples of a species moving one **zone** include species with an **upland** classification being found in the **transition zone**, species with an **adaptive** or **transition** classification being found in the **outer deep zone**, or species with an **outer deep** classification being found in the **deep zone**.

5) Provide an explanation and any necessary comments to describe your choices.

The main factors in the rank chosen must be documented in the **explanation** section. If **NA** is chosen, clearly explain the reason, and, if a permanent condition, include in the updated wetland history.

ADDITIONAL INFORMATION

This section seeks additional information concerning the state and condition of the wetland. This information collected in this section can be used to help update the wetland history.

Some of this information may directly relate to the hydrologic condition of the wetland, while the relationship of some information to the hydrologic condition of the wetland may be unclear. Some of the information requested may assist in the eventual interpretation of wetland health. Please answer all questions to the best of your ability based on your observations – no in-depth analysis or expertise in each issue is expected. Update the wetland history with any pertinent information, especially if the new condition appears to be permanent.

Disturbance

Check the following only if it is your considered opinion that such an extensive amount of physical alteration of the wetland (clearly not related to ground-water withdrawals) has occurred that you do not believe it makes sense to use the wetland data for purposes such as MFL development, recovery assessment, etc. Such impacts could include **extensive** fill, **extensive** clearing, severe fire damage, significant fragmentation by roads or other construction, etc. If this comment is checked, please fully explain, and include the explanation in the wetland history.

____ Future users of this data may not want to analyze/compare this data with other wetlands due to the **extensive** level of non-ground-water withdrawal related disturbance.

Check the following only if it is your considered opinion that such an extensive amount of subsidence of the wetland has occurred that you do not believe it makes sense to use the wetland data for purposes such as MFL development, recovery assessment, etc. Such impacts could include severe soil loss, karstic activity that has substantially lowered the wetland bottom, etc. If this comment is checked, please fully explain, and include the explanation in the wetland history.

____ Future users of this data may not want to analyze/compare this data with other wetlands due to the **extensive** level of **subsidence**.

Vegetation Health

The following section provides direction to assess the status of **stress** and death of **shrub and small tree** and **tree** species within the wetland. As part of this section of the wetland assessment, the evaluator is asked to decide if a species is **appropriate** or **inappropriate**. A **shrub and small tree** or **tree** is **appropriate** if it is growing in a **wetland zone** appropriate for its **zone** classification. A **shrub and small tree** or **tree** is **inappropriate** if it is growing in a **zone** that is inappropriate for its **zone** classification. For example, since *Myrica cerifera* is classified as a **transition zone** species, it would be **appropriate** if it is found growing in the **transition zone**, but **inappropriate** if it is found growing in the **outer deep** or **deep zones** (assuming it is not on a **hummock**).

Stress of Appropriate Shrubs and Small Trees

In the space provided in the field sheet, indicate the category below that best describes the **stress** of all **appropriate species** of **shrub and small trees**. Include any standing **shrubs and small trees** that are dead. Do not include species growing in **hummocks**. Finally, explain your choice, including a listing of the species you consider to be **appropriate**, the **zone**s in which they are found, and the nature/symptoms of the **stress**.

____ showing little to no signs of stress
____ showing noticeable signs of stress
____ showing significant signs of stress
____ NA

Stress of Inappropriate Shrubs and Small Trees

In the space provided in the field sheet, indicate the category below which best describes the **stress** of all **inappropriate species** of **shrubs and small trees**. Include any standing **shrubs and small trees** that are dead. Do not include species growing in **hummocks**. Finally, explain your choice, including a listing of the species you consider to be **inappropriate**, the **zones** in which they are found, and the nature/symptoms of the **stress**.

____ showing little to no signs of stress
____ showing noticeable signs of stress
____ showing significant signs of stress
____ NA

Stress of Appropriate Trees

In the space provided in the field sheet, indicate the category below that best describes the **stress** of all **appropriate species** of **trees**. Unlike with **shrubs and small trees**, <u>do not</u> include any standing **trees** that are dead. Do not include species growing in **hummocks**. Finally, explain your choice, including a listing of the species you consider to be **appropriate**, the **zones** in which they are found, and the nature/symptoms of the **stress**.

____ showing little to no signs of stress
____ showing noticeable signs of stress
____ showing significant signs of stress
____ NA

Stress of Inappropriate Trees

In the space provided in the field sheet, indicate the category below that best describes the **stress** of all **inappropriate species** of **trees**. Include any standing **inappropriate trees** that are dead. Do not include species growing in **hummocks**. Finally, explain your choice, including a listing of the species you consider to be **inappropriate**, the **zones** in which they are found, and the nature/symptoms of the **stress**.

____ showing little to no signs of stress
____ showing noticeable signs of stress
____ showing significant signs of stress
____ NA

Dead and Leaning Trees
In the space provided in the field sheet, indicate the category below that best describes the presence of **leaning** and/or dead **trees** within the entire wetland. Include standing dead **trees**, **trees** that are dead on the ground, and **trees** that are known to have died during the period of wetland observation and are no longer in the wetland. Do not include any timbered **trees**, or **trees** growing on **hummocks**. Restrict the analysis to **appropriate species**. Finally, explain your choice, including your best estimate of the number or percentage of **dead and leaning trees**.

____ Little to no (normal amount of) dead and/or leaning trees
____ Noticeable amount of dead and/or leaning trees
____ Significant amount of dead and/or leaning trees
____ NA

Signs of Tree Recovery

Are young **appropriate trees** starting to grow in wetland locations in such a way that would suggest hydrologic recovery? Yes ____ No ____ Not Sure _____ Not applicable_____

Please explain your answer, including the species to which are referring, and the **zones** in which they are found.

Vines

Are **inappropriate vines** dropping leaves or dying in a way that would suggest hydrologic recovery?
Yes ____ No ____ Not Sure ____ Not applicable ____

Please explain your answer, including the species to which are referring, and the **zones** in which they are found.

The following questions can be answered for either the Assessment Area or for the entire wetland. Please include comments to explain the area being described.

Are any of the following conditions apparent and obvious (explain any checks)?

Wetland edges have been filled or disturbed	Yes ____ No____ Not Sure _____
Excessive dumping or trash in wetland	Yes ____ No____ Not Sure _____
Hog disturbance	Yes ____ No____ Not Sure _____
Significant impact from cattle (trampling, etc.)	Yes ____ No____ Not Sure _____
Vehicles driving though wetland (including bicycles)	Yes ____ No____ Not Sure _____
Insect damage	Yes ____ No____ Not Sure _____
Disease	Yes ____ No____ Not Sure _____

Are there signs of fire (comment on approximate year, expanse, and intensity)?
Yes ____ No____ Not Sure _____

Hydrology

Does the wetland have **augmentation** equipment in place? Yes __ No __ Not Sure __
If yes, was **augmentation** taking place at the time of your visit? Yes __ No __ Not Sure __

Is there clear evidence of direct stormwater inflow via a ditch or other manmade conveyance? Yes __ No __ Not Sure __

Is there clear evidence of direct drainage from the wetland via ditch or other manmade conveyance? Yes __ No __ Not Sure __

Is there a borrow pit or retention pond in the vicinity of the wetland? Yes __ No __ Not Sure __

Are there any other drainage activities in the area of note? Yes __ No __ Not Sure __

Soils

Are there any new signs of soils **oxidation** or **subsidence** (since last 5-year review)? Yes __ No __ Not Sure __

For lakes only

Indicate the category that best describes the docks for the entire lake.

Ranking Scale

1. Docks completely out of the water.
2. Docks touching the water or with <50% of the dock over water.
3. Docks >50% over water.

Is the littoral **zone** stranded? Yes ______ No ______

Protected Wildlife and Plants

Note any **protected species** of plants and animals that are observed directly or can be identified by call, tracks or scat during the wetland assessment. Also include the activity noted such as nesting, foraging, feeding, mating, resting, burrowing, etc. and any additional notes or observations.

Note any **wetland dependent species** of animals that are observed directly or can be identified by call, tracks, or scat during the wetland assessment. List birds, fishes, reptiles, mammals or amphibians.

Activity codes (M = mating, F = foraging, FT = flyover/traveling, N = nesting, OT = other)
Observation codes (O = observed, S = sign [scat, tracks, call or other signs of presence])

Appendix A. Plant list used for WAP methodology.

Botanical Name	Common Name	Synonymy	Wetland Zone
Acer rubrum	red maple		OD
Amaranthus australis	southern amaranth		T
Ambrosia artemisiifolia	common ragweed		U
Amorpha fruticosa	Bastard indigobush; false indigobush		T
Ampelopsis arborea	Peppervine		AD
Amphicarpum muhlenbergianum	blue maidencane		OD
Andropogon glomeratus	bushy bluestem		T
Andropogon glomeratus var. glaucopsis	purple bluestem		OD
Andropogon virginicus	broomsedge bluestem		AD
Andropogon virginicus var. decipiens	broomsedge bluestem		AD
Andropogon virginicus var. glaucus	chalky bluestem		U
Axonopus spp.	Carpetgrass		AD
Baccharis spp.	silverling, groundsel tree, sea myrtle		AD
Bacopa caroliniana	lemon bacopa; blue waterhyssop		OD
Berchemia scandens	alabama supplejack; rattan vine		T
Callicarpa americana	American beautyberry		U
Campsis radicans	trumpet creeper		T
Carex longii	long's sedge		T
Celtis laevigata	sugarberry; hackberry		T
Centella asiatica	Spadeleaf		T
Cephalanthus occidentalis	common buttonbush		D
Cinnamomum camphora	Camphortree		U
Cirsium nuttallii	Nuttall's thistle		T
Commelina diffusa	common dayflower		T
Conyza canadensis var. pusilla	Canadian horseweed		AD
Cornus foemina	swamp dogwood; stiff dogwood		OD
Cynodon dactylon	Bermudagrass		U
Dichondra caroliniensis	Carolina ponysfoot		AD
Digitaria floridana	Florida crabgrass		U
Diodia virginiana	Virginia buttonweed		OD
Diospyros virginiana	common persimmon		AD
Drymaria cordata	drymary; West Indian chickweed		AD
Eclipta prostrate	false daisy	*Eclipta alba*	T
Eleocharis baldwinii	Baldwin's spikerush; roadgrass		T
Erechtites hieraciifolius	American burnweed; fireweed		AD
Erythrina herbacea	coralbean; Cherokee bean		U
Eupatorium capillifolium	Dogfennel		AD

Appendix A (continued). Plant list used for WAP methodology.

Botanical Name	Common Name	Synonymy	Wetland Zone
Eupatorium leptophyllum	falsefennel		OD
Eupatorium mohrii	Mohr's thoroughwort	*Eupatorium recurvans*	AD
Eupatorium serotinum	lateflowering thoroughwort		AD
Euthamia caroliniana	slender flattop goldenrod	*Euthamia minor*	AD
Fraxinus caroliniana	Carolina ash; water ash; pop ash		D
Galactia elliottii	Elliott's milkpea		U
Gordonia lasianthus	loblolly bay		OD
Gratiola ramosa	branched hedgehyssop		T
Hydrocotyle umbellata	manyflower marshpennywort		OD
Hypericum fasciculatum	sandweed; peelbark St. John's-wort		OD
Hypericum mutilum	dwarf St. John's-wort		T
Hypericum myrtifolium	myrtleleaf St. John's-wort		T
Hypericum tetrapetalum	fourpetal St. John's-wort		AD
Ilex cassine	dahoon		OD
Ilex glabra	inkberry; gallberry		AD
Itea virginica	Virginia willow; Virginia sweetspire		OD
Leersia hexandra	southern cutgrass		OD
Lindernia grandiflora	Savannah false pimpernel		T
Liquidambar styraciflua	sweetgum		T
Ludwigia peruviana	Peruvian primrosewillow		OD
Lycopus rubellus	taperleaf waterhorehound		OD
Lyonia ligustrina var. foliosiflora	maleberry		T
Lyonia lucida	fetterbush		T
Magnolia virginiana	sweetbay		OD
Melaleuca quinquenervia	punktree		AD
Melothria pendula	creeping cucumber		T
Mikania spp.	hempvine		T
Myrica cerifera	southern bayberry; wax myrtle		AD
Nyssa sylvatica var. biflora	swamp tupelo		D
Oldenlandia uniflora	clustered mille graine	*Hedyotis uniflora*	T
Oplismenus hirtellus	woodsgrass; basketgrass	*Oplismenus setarius*	T
Osmunda cinnamomea	cinnamon fern		T
Paederia foetida	skunkvine		AD
Panicum anceps	beaked panicum		AD
Panicum rigidulum	redtop panicum		OD
Panicum verrucosum	warty panicgrass		T
Paspalum conjugatum	sour paspalum; hilograss		AD
Paspalum laeve	field paspalum		T

Appendix A (continued). Plant list used for WAP methodology.

Botanical Name	Common Name	Synonymy	Wetland Zone
Paspalum notatum	bahiagrass		U
Paspalum setaceum	thin paspalum		AD
Persea palustris	swamp bay		OD
Phyla nodiflora	turkey tangle fogfruit; capeweed	*Lippia nodiflora*	AD
Phytolacca americana	American pokeweed		U
Pinus clausa	sand pine		U
Pinus elliottii	slash pine		AD
Pinus palustris	Longleaf pine		U
Pinus taeda	loblolly pine		AD
Pluchea rosea	rosy camphorweed		OD
Polygonum hydropiperoides	mild waterpepper; swamp smartweed		OD
Psidium cattleianum	strawberry guava		AD
Ptilimnium capillaceum	mock bishopsweed; herbwilliam		T
Quercus laurifolia	laurel oak; diamond oak		T
Quercus nigra	water oak		T
Quercus virginiana	live oak		U
Rubus argutus	sawtooth blackberry	*Rubus betulifolius*	AD
Saccharum giganteum	sugarcane plumegrass	*Erianthus giganteus*	OD
Salix caroliniana	Carolina willow; coastalplain willow		OD
Sambucus nigra subsp. *canadensis*	American elder; elderberry	*Sambucus canadensis*	AD
Sapium sebiferum	popcorntree; Chinese tallowtree		AD
Schinus terebinthifolius	Brazilian pepper		AD
Scoparia dulcis	sweetbroom; licoriceweed		AD
Setaria parviflora	yellow bristlegrass; knotroot foxtail	*Setaria geniculata*	AD
Smilax bona-nox	saw greenbrier		AD
Solanum viarum	Tropical soda apple		U
Stenotaphrum secundatum	St. Augustinegrass		AD
Stillingia aquatica	water toothleaf; corkwood		D
Symphyotrichum elliottii	Elliott's aster	*Aster elliottii*	T
Taxodium spp.	Cypress		D
Toxicodendron radicans	eastern poison ivy		AD
Ulmus americana	American elm		T
Urena lobata	caesarweed		U
Vaccinium corymbosum	highbush blueberry		T
Vaccinium myrsinites/darrowii	shiny blueberry		U
Vitis rotundifolia	muscadine	*Vitis munsoniana*	AD

APPENDIX B

Definition of Wetland Assessment Procedure (WAP) Terms

Adaptive (AD) species
Plants species designated as FAC or Upland by DEP, but commonly seen in the **transition zone** in limited numbers. When **adaptive** plants are found in the **outer deep** or **deep zones**, they should be treated the same as **transition zone** plants.

Appropriate Species
Term used to describe plant species that are found in a **wetland zone** in which they would normally be expected. See the definition of **Inappropriate Species**.

Assessment Area
The area to be assessed from the **WAP Transect**. Whenever possible, the width of the Assessment Area will be approximately ten meters in width (including ten meters beyond the **wetland interior**). If the evaluator determines that critical information concerning the **zonation** condition of the wetland exists beyond the standard ten meter-wide Assessment Area, a wider Assessment Area may be used (up to the entire area of the wetland). However, when an Assessment Area greater than ten meters is used, the evaluator must 1) justify the larger transect size on the field sheet and in the database, 2) approach all critical areas at a distance from which elevations and species identification can be readily determined, and 3) accurately describe the size of the Assessment Area on the field sheet and in the database. Future evaluators should use the Assessment Area established by previous evaluators unless there is strong evidence to do otherwise. Evaluators should stay on the **WAP Transect** as much as possible to avoid unnecessary trampling of vegetation, but can walk throughout the wetland if critical for an accurate evaluation.

Augmentation
The procedure or practice of artificially adding freshwater to a surface-water body. Augmentation can be done as part of a mitigation measure or can be part of an overall aesthetic or functional hydrologic plan to increase the amount of water that a wetland or water body receives. Augmentation can be derived from various water sources, including ground water, storm water, or water diverted from surface flows.

Canopy
The top layer of the forest. The definition further qualifies canopy species as woody plants or palms with a main trunk at least ten centimeters in diameter at a point 1.4 meters (4.5 feet) above the base of the tree (**Diameter at Breast Height** (**DBH**)). If the **tree** is on a slope, the **DBH** is measured from the mid-point of the base of the tree on the slope. Cabbage palms are considered canopy only when greater than six meters in height. **Vines** are not considered as canopy species.

Composition
The **assemblage** of plant species that occur within a plant community or plant community **zone**. For the WAP, composition is defined as the species that make up the different **strata** in a **wetland zone**. The **strata** include **tree**, **shrub**, and **groundcover** species (if present).

Cover
The area of ground covered by the vertical projection of the aerial parts of plants of one or more species.

Deep (D) species
Plant species commonly found in the **deep zone**, and designated either FACW or OBL by DEP.

Deep Zone
The lower portion of the **WAP Transect** extending from the **NP-12** marker to the **wetland interior**. The deep zone has the longest hydroperiod and the greatest depth of the **zones** found in a wetland.

Diameter at Breast Height (DBH)
The diameter of a plant's trunk or main stem at a height of 1.4 meters (4.5 feet) above ground.

Exotic plant
A plant not indigenous to Florida.

Extensive
A description used to characterize the categories of Disturbance, Drainage or Fire that indicates that greater than 50% of the assessed portion of the wetland (as determined from the **WAP Transect**) has been influenced. (See definition of **localized**).

FAC plants (Facultative)
Species of plants that are so widespread in their distribution as to render them inappropriate for indicating inundation or soil saturation. Specifically included are **exotic plants** with a **weedy** distribution (F.A.C. Section 62-340.200).

FACW plants (Facultative Wet)
Species of plants that under natural conditions typically exhibit their maximum **cover** in areas subject to surface water inundation and/or soil saturation, but can also be found in uplands (F.A.C. Section 62-340.200).

Floating Vegetation
Any plant not rooted in the ground.

FLUCCS
The Florida Land Use, Cover and Forms Classification System. A standardized numeric code developed by the Florida Department of Transportation for the classification of land use and plant communities. The code is used to identify natural and manmade land features using number codes (levels). Typically three or four digit numbers are used. A manual with descriptions of each code is available to assist with classifications (Florida Department of Transportation, 1999).

For the WAP, Level III FLUCCS code is used to identify wetland types.

Groundcover
All woody species less than one meter in height, and all non-woody species (regardless of height), rooted in the ground. Groundcover is the lower most of the three **strata** of vegetation. For the

WAP, *Eupatorium* spp., *Typha* spp., and *Rubus* spp., and certain other species generally thought of as herbaceous even though greater than one meter will only be assessed as groundcover.

Historic (**Historical**)
Characteristics assumed to be indicators of non-impacted or pre-impacted conditions. Historical wetland characteristics occur because of decades of normal ecological conditions.

Historic Normal Pool
The **normal pool** elevation of a wetland that formed under non-impacted natural or unaltered conditions. Historic normal pool can be determined from those **normal pool** indicators that change only extremely slowly with the absence of surface water. See Appendix C for details on establishing historic normal pool.

Historic Wetland Edge
The boundary between wetland and upland vegetation and soils formed under non-impacted natural or unaltered conditions. The historic wetland edge is the landward edge of the **WAP Transect** and the landward edge of the **transition zone**. The assessment of the **transition zone** begins at the historic wetland edge. See Appendix C for details on establishing historic wetland edge.

Hummock
A raised substrate (at or above the **historic normal pool**) in a wetland generally comprised of congregated root masses associated with **trees**, **shrubs** or some species of **groundcover** such as ferns. Hummocks can also include old tree bases and stumps that have been subsequently colonized by vegetation other than or including the species comprising the majority of plant matter that constitutes the hummock. Hummocks are associated with plant growth in frequently inundated wetlands, and are not part of the wetland floor.

Hydrology
The properties that deal with the distribution and circulation of water within a wetland or upland/wetland system.

Inappropriate Species
Term used to describe plant species that are found in a **wetland zone** in which they would not normally be expected. See the definition of **Appropriate Species**.

Localized
A description used to characterize the categories of Disturbance, Drainage and Fire where less than 50% of the assessed portion of the wetland (as determined from the **WAP Transect**) has been influenced. (See definition of **extensive**).

Leaning Trees
Trees that are generally at a 30-degree angle (or greater) from vertical due to uprooting or loss of support. The reasons for leaning trees are many and varied, and include soil **subsidence** where the soil support for trees roots has been impacted to the point that a tree cannot stand, or wind throw due to severe storm events.

Normal Pool
A water level elevation based on consideration of certain biological indicators of sustained inundation, utilizing reasonable scientific judgment. See Appendix C for a discussion of these biological indicators.

NP-6
The elevation six inches below **historic normal pool**. The NP-6 represents the boundary between the **transition zone** and the **outer deep zone** of the wetland.

NP-12
The elevation twelve inches below **historic normal pool**. The NP-12 represents the boundary between the **outer deep zone** and the **deep zone** of the wetland.

OBL plants (Obligate)
Species of plants that under natural conditions are only found or achieve their greatest abundance in an area that is subject to frequent or continuous surface-water inundation and/or soil saturation. Included in this category are the littoral plants and emergent aquatics, such as *Nymphaea* spp. (water lilies), *Nelumbo* spp. (lotus), and *Nuphar luteum* (spatterdock). Some OBL plant species can be observed in uplands, especially under a controlled environment.

As defined by the USACE, OBL species are those plants that occur almost always (estimated probably > 99%) in wetlands under natural conditions (USACE, 1987).

Outer Deep Zone
The portion of the **WAP Transect** extending from the **NP-6** marker to the **NP-12** marker.

Outer Deep (OD) species
Plant species commonly found in the **outer deep zone**, and designated either FACW or OBL by DEP.

Oxidation
A condition in which organics in the soils react with free oxygen. The result of soil oxidation is loss of organic constituents and possible lowering of the soil surface. The lowering of the soil surface is also called **subsidence**.

Fire within a wetland causes rapid oxidation. Fire, under dry conditions, can burn organic soils causing soil oxidation and/or soil **subsidence**. When oxidation is recorded, special care to determine signs of fire and other environmental conditions should be noted.

Protected Species
Species that include both flora and fauna that have some degree of protection under the law by local, State, and Federal agencies. Official lists have been developed for these species.

> Federally Protected Flora and Fauna Species are listed by:
> U.S. Fish and Wildlife Service (Endangered or Threatened Species). 50 CFR 17 (animals) and 50 CFR 23 (plants)
> http://endangered.fws.gov/wildlife.htm#species
>
> State Protected Fauna Species are listed by:

Florida Game and Freshwater Fish Commission (Endangered, Threatened Species and Species of Special Concern) Rules 3927.003-.005, Florida Administrative Code (F.A.C.) http://fac.dos.state.fl.us/faconline/chapter68.pdf

Florida State Protected Flora Species are list by:
The Florida Department of Agriculture & Consumer Services (Endangered, Threatened Species and Commercially Exploited). Chapter 5B-40 F.A.C.
http://fac.dos.state.fl.us/faconline/chapter05.pdf

Saw Palmetto Fringe
The rooted base of saw palmetto (*Serenoa repens)* nearest the wetland. Care must be taken in assessing whether the saw palmetto fringe has been altered by land use practices when considering its use in setting the **historic normal pool** or **wetland edge**.

Shrubs and Small Trees
Woody plants greater than one meter in height and less than four centimeters **Diameter at Breast Height** (**DBH**). Shrubs usually have multiple permanent stems. When greater than one meter in height, *Hypericum* spp. and *Ilex glabra* are considered shrubs. *Myrica cerifera*, and *Lyonia* spp., and other woody plants with multiple stems that are greater than one meter tall are always assessed as **shrubs and small trees**. Cabbage palms with trunks greater than one meter tall but less than six meters are considered **shrubs**.

Staff Gage
A water level measuring device used to measure above-ground surface water levels in a wetland. The staff gage is normally placed in a **deep zone** of the wetland, preferably at the **wetland interior**.

Strata
The defined layers of the vegetation community found within an ecosystem **zone**. Each wetland system can contain any and all of the three following strata: **Groundcover**, **Shrubs and Small Trees**, and **Trees**.

Stress
A physiological condition of a plant, as a result of external or internal conditions, which inhibits the normal growth and functions of the plant. Stressful conditions can include too much water or too little water. Stress can occur over short or long periods of time. Severe stress to a plant can result in plant death.

Indications of physiologic stress manifested during the growing season (generally during March - September) include: reduced numbers of leaves on stems/branches (a sparsely vegetated appearance), chlorosis of leaf tissue (a pale green, yellow or red/brown hue), leaf wilting (curling at edges, drooping of normally erect leaf tissue), or abscission (leaf drop). In addition, late leaf-out at the onset of the growing season (delayed onset of growth) or premature senescence of leaves prior to the fall may be indicators of stress.

As guidance for the WAP, stress can be caused by a variety of reasons aside from water stress. The assessor should look for other factors that may be contributing to the observed stress indicators (i.e., excessive flooding of less tolerant species, insect damage, disease, fire stress, frost damage, mechanical injury/damage to bark or root systems). Suspicion of non-water related stress should be discussed in comments.

Subsidence
The lowering of the soil levels caused by a variety of mechanisms, including **oxidation**, compaction, and karst activity (sinkholes). Subsidence is evident when the lowering of soil can be measured as a decrease in the soil volume and soil structure. Soil subsidence in wetlands can occur in highly organic soils that have experienced long periods of depressed water levels. In forested wetlands, subsidence often results in tree root exposure. In non-forested wetlands, subsidence is often evident by the appearance of soil fissures. In various types of wetlands, cattle trampling and karst activity can cause subsidence, which is apparent as soil slumping between **trees** or abnormal lowering of the wetland soil surface levels.

Transition Zone
The upper portion of the **WAP Transect** extending from the **historic wetland edge** to the **NP-6** marker. The transitional zone contains one vegetation community, or an arbitrary grouping of more than one vegetation community, with a shorter hydroperiod than the **outer deep** or **deep zones**.

Transition (T) species
Plant species commonly found in the **transition zone**, and designated either FACW or OBL by DEP.

Trees
Woody plants that are greater than or equal to one meter in height and greater than or equal to four centimeters **DBH**. *Myrica cerifera*, *Lyonia* spp. and other woody plants with multiple stems that are greater than one meter tall are assessed as **shrub and small trees**. Cabbage palms with trunks greater than one meter tall but less than six meters are considered **shrubs**.
Note that trees that are greater than or equal to four centimeters **DBH** and less than ten centimeters **DBH** are considered the sub-canopy, and trees greater than or equal to ten centimeters **DBH** are considered the tree **canopy**.

Trees, Small
Woody tree species greater than one meter and less than four centimeters **DBH**. The size class is the same as **shrubs** and is intended to specify tree species at the sapling stage. Wax myrtle, *Lyonia* spp. and other woody plants with multiple stems that are greater than one meter tall are assessed as **shrub and small trees**. Cabbage palms with trunks greater than one meter tall but less than six meters are considered **shrubs**.

Upland (U) species
Plant species that are not expected to be seen in wetlands. It is possible that a few of these species may be found along wetland edges, but are not expected throughout the **transition zone**.

As defined by DEP, upland plants are those species that under natural conditions are only found or achieve their greatest abundance in an area that is considered upland.

Upland Well
A surficial aquifer monitor well installed outside of the **historic wetland edge**, as required by the EMP. Some monitored wetlands do not have upland wells due to practical considerations (such as land management conflicts, private land access problems, etc.), or have a surficial aquifer monitor well installed in the **transition zone**, which substitutes for the upland well. All monitor wells require a construction permit from the SWFWMD, must be drilled by a licensed well driller, and should be constructed using the standards set forth in Chapter 40D-3, FAC. All monitor wells

should fully penetrate the surficial aquifer underlying and in connection with the monitored wetland (as per the judgment of a professional geologist or engineer).

Vines
Vines are linear woody or non-woody vegetation that utilizes the **tree canopy**, sub-canopy, or **shrub strata**, where they exist, for physical support. Where these **strata** are not present, vines will utilize **groundcover** vegetation and the forest floor as the physical substrate for support. Only vines originating from the wetland floor (within the **Assessment Area**) should be assessed as **groundcover**, while all others should not be included in the wetland assessment.

WAP Transect
A straight line from the **historic wetland edge** to the **wetland interior**, from which vegetative assessments in the **transition zone**, **outer deep**, and **deep zone** sections are made.

Weedy
A description of indigenous and non-indigenous species that interfere with management goals and objectives and are therefore unwanted. This definition is also known by the term "natural-area weed." More generically, weed is defined by the Weed Science Society of America as "a plant growing where it is not desired." Moreover, the presence of natural-area weeds infers that conditions within that ecosystem are such that the ecosystem's typical or characteristic species are replaced with species that are not typical of the ecosystem under natural hydrological or ecological conditions.

For the WAP, only weeds growing on the ground (and not on **hummocks)** will be considered.

Wetland Delineation Line
A boundary delineating the landward extent of wetlands under the current conditions using Chapter 62-340 FAC criteria. If a wetland has experienced hydrologic or other impacts, the wetland delineation line may not correspond with the **historic wetland edge**.

Wetland Dependent Species
Wildlife species that are closely associated with wetlands. The existence of individuals of wetland dependent species is threatened if wetland function is absent or there is a significant degradation of a wetland function. Wetland water levels, the duration of water levels, and the existence of aquatic plant and animal species may affect individuals of wetland dependent species.

Wetland Interior
The deepest part(s) of a wetland.

Wetland Plant Species
Plant species that have demonstrated ability (presumably because of morphological and/or physiological adaptations and/or reproductive strategies) to achieve maturity and reproduce in an environment where all or portions of the soil within the root zone become, periodically or continuously, saturated or inundated during the growing season (Reed, 1988).

Wetland Status
Term used in the Vegetative Index of Chapter 62-340 F.A.C to describe a plant's affinity to various hydrologic conditions. See Chapter 62-340 F.A.C. for more details.

Wetland Well
A surficial aquifer monitor well installed within the **deep zone** of a wetland, preferably within the **wetland interior**, as required by the EMP. All monitor wells require a construction permit from the SWFWMD, must be drilled by a licensed well driller, and should be constructed using the standards set forth in Chapter 40D-3, FAC. All monitor wells should fully penetrate the surficial aquifer underlying and in connection with the monitored wetland (as per the judgment of a professional geologist or engineer).

Wetland Zone
One of three subdivisions of a wetland used in the application of the WAP methodology. The three **zones** include the **transition zone**, the **outer deep zone**, and the **deep zone**, and are based upon elevation below **historic normal pool**.

Zonation
The distribution of plant species within a stratum. Three vegetation **strata** are designated in the WAP (**groundcover**, **shrubs and small trees**, and **trees**). Environmental conditions that may influence zonation include but are not limited to variations in **hydrology**, direct physical disturbance, and fire.

Zone
Refers to a **wetland zone**.

APPENDIX C

Methodology for Establishing Historic Normal Pool and Historic Wetland Edge

The **normal pool** of a wetland is an elevation datum established to standardize measured water levels and facilitate comparison among wetlands. The **normal pool** elevation is commonly used in the design of wetland storm water treatment systems (SWFWMD, 1988). This level can be consistently identified in cypress swamps based on similar vertical locations of several indicators of inundation (Hull et al, 1989; Biological Research Associates, 1996). In wetlands where declining water levels have caused the downward migration of certain **normal pool** indicators, or if significant **subsidence** has occurred as to physically lower all or parts of the wetland, more persistent indicators of the unaltered **normal pool** elevation or other considerations must be used to establish the datum. The datum determined by the persistent, unaltered indicators, is herein referred to as **historic normal pool**.

The **historic wetland edge** is a concept developed specifically for the WAP, and refers to the boundary between wetland and upland vegetation and soils prior to any hydrologic impacts. In a wetland that has not experienced any negative hydrologic impacts, this boundary would be the **wetland delineation line**. However, in wetlands that may have experienced hydrologic impacts, other biologic indicators must be used to identify the **historic wetland edge**.

Historic normal pool and **historic wetland edge** elevations will be established at environmental monitoring sites within one year of the initiation of the monitoring program. As described below, the elevations of at least five replicate **normal pool** indicators will be established in the field based on biological or physical indicators of sustained inundation. The final **historic normal pool** elevations will be based on the median of these elevations, plus any appropriate offset constants (as described below). The **historic normal pool** and supporting indicators used to develop the elevation must be surveyed to NGVD 29 by a professional land surveyor. The **historic wetland edge** need not be surveyed, but a permanent marker or other means of locating the **historic wetland edge** must be established. Together with the other information included with the establishment of a monitored wetland (see Section 3.2 of the WAP Instruction Manual), the **historic normal pool** elevation, **historic wetland edge** location, and the information used to determine them must be fully documented (see Appendix F). If necessary, Tampa Bay Water and the SWFWMD will perform field evaluations to verify the various elevations.

<u>Establishing Historic Wetland Edge</u>

When present, the preferred indicator of **historic wetland edge** is the rooted base of saw palmetto (*Serenoa repens*) immediately surrounding the wetland (referred to as the **saw palmetto fringe**). Unless the **saw palmetto fringe** is used to determine **historic normal pool**, there is no need to survey its elevation, but the location should be marked or otherwise clearly recorded for use as the landward edge of the **WAP Transect** and the landward edge of the **transition zone**. This indicator may not be reliable for wetlands if there is clear evidence that the **saw palmetto fringe** has been significantly altered by land management practices. In cases where the **saw palmetto fringe** has been altered, or where no **saw palmetto fringe** exists, other indicators should be used for **historic wetland edge**. Alternatives include **historic normal pool** minus 0.25 feet (Carr and others, 2004, Shultz and others, 2004), the elevation of the base of the outermost cypress plus 0.30 feet (Carr and others, 2004, Schultz and others, 2004), or hydric soil indicators. In these cases, the final choice will be by consensus of Tampa Bay Water and the SWFWMD. If the wetland edge has been partially filled, the edge of the fill within the wetland can be considered the **historic wetland edge** (see Section 3..2 of the WAP Manual for more discussion on dealing with filled edges).

Establishing Historic Normal Pool

Historic normal pool will be set by one of the following methods (in order of priority, if present). Note that the value used as **historic normal pool** should be based on the median of at least five samples (although more samples are desirable), plus the applicable offset constant (as described below):

a. The elevation of the root crown of mature specimens of fetterbush (*Lyonia lucida*) on cypress **trees** or **hummocks**.
b. The inflection point on the buttress of cypress **trees**.
c. The lower limit of epiphytic bryophytes (aka moss collars) growing on cypress **trees** (*Taxodium* spp.).
d. The elevation of the rooted base of saw palmetto (*Serenoa repens*) immediately surrounding the wetland (referred to as the **saw palmetto fringe**). An offset factor of 0.25 feet must be added to the median value (Schultz and others, 2004). This indicator may not be reliable for wetlands if there is clear evidence that the **saw palmetto fringe** has been significantly altered by land management practices.
e. The ground elevation of cypress **trees** growing at the outside edge of the dome. An offset factor of 0.55 feet must be added to the median value (Schultz and others, 2004).
f. Indicators of hydric soil surrounding the wetland, as determined by a qualified soils scientist. This indicator may not be reliable in wetlands with evidence of significant soil **oxidation**.
g. Evidence of **historic** escarpment. This method may not be reliable in wetlands with clear evidence of significant filling along the wetland edge.
h. If none of the above indicators exist, a **historic normal pool** elevation should be proposed based on any form of evidence thought to be reasonable, including other biologic indicators, aerial photographic interpretation, etc.

A combination of any of the first three indicators is acceptable, as long as a minimum of five surveyed samples are used. The remaining four indicators should not be used in combination with other indicators.

If there is evidence that declining water levels have caused the downward migration of certain **normal pool** indicators (moss collars are particularly susceptible to this), or if significant **subsidence** has occurred as to physically lower all or parts of the wetland, only the **saw palmetto fringe** indicators may be reliable. Several sources of information and field observation should be used to make this determination, which may include investigations of **historical** aerial photography; identification of signs of severe soil **oxidation** or compaction; obvious indications of sinkhole activity; long-term declines in **hydrology** (as observed in collected data); and changes in surveyed elevations. If the **normal pool** elevation determined by the above methods is found to be significantly below the **historic wetland edge**, it may not be representative of **historic normal pool** (Carr and Rochow, 2004).

APPENDIX D

Wetland Type Definitions

All monitored wetlands should be classified as one of the following wetland types. It is recognized that some wetlands may be difficult to classify, so the evaluator will need to use scientific judgment based on field experience. However, the classification system is for convenience and data management purposes only. In the future, the classification of wetlands or the definition of wetland types may change.

For purposes of this classification system, the term "isolated" refers to a wetland system that has no significant and regular channelized inflow. For example, some cypress wetlands may have channelized outflows to riverine systems, but since significant and regular channelized inflow is absent, they are considered isolated cypress wetlands. Systems that are not isolated by this definition will be referred to as "flow" systems. The current version of the WAP is not designed for flow systems.

The wetland types are:

Cypress Isolated --- Commonly known as "cypress domes", although their shape and size vary. Pond cypress is usually the dominant tree species.

Hardwood Isolated --- Commonly known as "bay swamps" or "gum swamps". Bays and gums are usually the dominant tree species.

Marsh Isolated --- Isolated wetlands with very few or no **trees**. Marshes are typically vegetated with broad-leaved herbaceous species such as pickerelweed, duck potato, water lily, and spatterdock in deeper areas, and grasses and sedges in shallower areas. Marshes are typically 1 to 3 feet in depth.

Cypress Marsh Isolated --- Isolated wetlands with well-developed cypress and marsh areas. Typically, cypress surrounds, or nearly surrounds, the deep-water marsh area. Cypress marshes should be composed of at least 20 percent cypress **trees** or 20 percent marsh vegetation.

Wet Prairie Isolated --- Isolated wetlands with very few or no **trees**. Typically, grasses and sedges dominate both shallow and deep-water areas of wet prairies. Wet Prairies differ from marshes in being shallower (usually <1 foot deep at the deepest point).

Cypress Continuous --- Flow systems dominated by cypress (typically bald cypress). The current version of the WAP is not designed for these types of wetland systems.

Hardwood Continuous --- Flow systems dominated by hardwoods (typically pop ash, elm, gum, red maple, water oak, and laurel oak). The current version of the WAP is not designed for these types of wetland systems.

Mixed Hardwood/Cypress Continuous --- Flow systems where a mixture of hardwoods and cypress occur and neither appears dominant. The current version of the WAP is not designed for these types of wetland systems.

Marsh Continuous --- Flow systems with very few or no **trees**. Marshes are typically vegetated with sawgrass and broad-leaved herbaceous species such as pickerelweed, duck potato, water lily, and spatterdock. The current version of the WAP is not designed for these types of wetland systems.

Lake Wetlands --- Wetlands similar to those described above but occurring contiguous to lakes.

APPENDIX E

Wetland History

The Wetland History is an ongoing narrative that describes what is known about the history of the wetland health during both the period of data collection, and prior to data collection. Its main use is to give the user of data collected as part of the WAP a better perspective on the activities surrounding the wetland, observations by evaluators, and other factors that may affect the interpretation of the data. The wetland history also provides a running set of notes for current and future evaluators that should assist in WAP assessments and interpretation of WAP data.

When monitoring begins on a wetland (or when establishing a wetland history for a currently monitored wetland for which there is no existing wetland history), some research should be done to gather existing information on the wetland, and to describe what is learned. Sources of information that should be reviewed include:

a. Aerial photography, available through the SWFWMD, Tampa Bay Water, or other sources (available back to 1938 at: http://www.uflib.ufl.edu/digital/collections/FLAP/)
b. Existing reports by SWFWMD, Tampa Bay Water, and others
c. Previous experience of others who have monitored the wetland in the past

Wetland histories included in many of the Tampa Bay Water Wellfield Annual Reports are a good start.

Once the initial wetland history has been established, the WAP methodology calls for updates on at least a 5-year basis, although more frequent updates as needed are recommended. Wetland history updates should include any significant changes to the transects, monitoring devices, surrounding land uses, physical impacts to the wetland (no matter the cause), and any significant changes to wetland health or **hydrology** (no matter the cause, and including **augmentation**).

APPENDIX F

Worksheet for Supporting Transect Information

The following is a checklist of information that should be collected and documented as part of the establishment of the transect to be used for the Wetland Assessment Procedure (WAP). Depending on the wetland being monitored, thorough documentation of the transect may preclude the need for a site evaluation by SWFWMD staff. While not required, including photographs may be helpful.

General Information

1. Wetland Name (and aliases)
2. Wetland Site Number(s)
3. Wetland type (See Appendix D)
4. Location information, including county, land owner, and Section, Township, and Range of wetland
5. Map of wetland location, showing approximate location of transect
6. Explanation of why the transect was chosen
7. Has a benchmark been established near the wetland by a professional surveyor?
8. If so,
    a. Has the benchmark been clearly marked?
    b. Has the benchmark been given an identification name or number?
    c. What is the NGVD 1929 elevation of the benchmark?
    d. Have all surveys for current installations requested below been made from this benchmark (i.e. **historic normal pool** indicators, current staff gage, current wells, NP-6, and NP-12)? If these have not been surveyed in this manner please explain.

Staff Gage(s)

1. What is the identification number of the current staff gage (or gages)?
2. Was the staff gage installed by Tampa Bay Water or the SWFWMD?
3. Who performed the surveying for this gage, and was this person a professional surveyor?
4. What benchmark was used to survey this gage?
5. What is the approximate period of record for this staff gage?
6. Is the staff gage direct reading?
7. If not, what is the adjustment to convert to NGVD 29?
8. What is the dry elevation of the staff gage?
9. Please provide the above information for any other previous staff gages.

Monitor Well(s)

1. Does the wetland have both a wetland well and upland well?
2. Are there any other wells?
3. What is the identification number of each existing well?
4. Which agency installed each well?
5. Who performed the surveying for each well, and was this person a professional surveyor?
6. What benchmark was used to survey each well?

7. What is the approximate period of record for each existing well?
8. What is the top of casing elevation for each well (NGVD 29), and is this the measuring point for each well?
9. What is the ground elevation (NGVD 29) at each well (or length of casing above ground)?
10. What is the dry elevation (NGVD 29) of each well (or total depth of each well)?
11. Please provide the general construction information for each well, including casing depth, total depth, well diameter, and general construction specifications.
12. Please provide the above information for any other previous wells used to monitor this wetland.

Establishment of Historic Normal Pool

1. What indicators of normal pool were used?
2. How many indicators were used?
3. How was the historic normal pool determined?
4. When was the historic normal pool established, and who set it?
5. What are the elevations of the indicators used and the elevation of the historic normal pool determined for this wetland? How were these determined?
6. Please describe the checks for subsidence that were performed.

Historic Wetland Edge

1. What indicators of historic wetland edge were used?
2. How was the historic wetland edge determined?
3. Has a marker been placed at the historic wetland edge? If no, please describe the location of the wetland edge.
4. What is latitude and longitude of historic wetland edge marker, or marked location along the transect, and how was this determined? Note: this can be estimated.

NP-6 and NP-12

1. What are the elevations (NGVD 29) of the NP-6 and NP-12 markers, and how were they determined?
2. Who performed the surveying for the markers, and was this person a professional surveyor?
3. What benchmark was used to survey the markers?
4. Describe the markers used to designate the NP-6 and NP-12.
5. What is the latitude and longitude of the NP-6 and NP-12 markers? Note: this can be estimated.

Wetland Interior

1. Has a marker been placed at the wetland interior (end of transect)? If no, please describe the location of the wetland interior.
2. What is latitude and longitude of wetland interior (end of transect), or marked location along the transect, and how was this determined? Note: this can be estimated.

APPENDIX G

References

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Exhibit C

Environmental Management Plan

Attachment B

Wetland Assessment Procedure (WAP)
Field Form

WETLAND ASSESSMENT PROCEDURE

Wellfield / Property	Wetland Name	Wetland Type

Wetland ID	Data Owner	Data Source	Personnel	Date	Start/End	

PHOTO-DOCUMENTATION

Frame	Description	Photo Pt.	Direction

WATER LEVEL INFORMATION

Dry?	Elevation (ft)	Device	Well/Gage ID

Description

Please enter Yes (Y), No (N), or Not Sure (NS) for the following questions and provide comments/explanations.

WETLAND IMPACTS

Wetland edges filled or disturbed?	
Excessive dumping or trash in wetland?	
Hog disturbance?	
Signficant impact from cattle (trampling)?	
Vehicles through wetland (includes bicycles)?	
Insect damage?	
Disease?	

Explanation(s)

WETLAND DRAINAGE

Augmentation equipment in place?	
Augmentation occurring at time of WAP?	
Clear evidence of direct stormwater inflow?	
Clear evidence of direct drainage from wetland?	
Other drainage activities in area?	
Borrow pit/retention pond in wetland vicinity?	

Explanation(s)

FIRE

Signs of Fire?

Explanation (year, expanse, intensity)

LAKES / DOCKS

Docks completely out of water
Docks touching water or with <50% of dock over water
Docks >50% out of water
N/A

Is the littoral zone stranded? ☐

Comments

SOIL SUBSIDENCE

New signs of oxidation/subsidence?

Explanation

Future users of this data may not want to analyze / compare this data with other wetlands due to the extensive level of:

- ☐ non-groundwater withdrawal-related disturbance
- ☐ soil subsidence

GENERAL COMMENTS / OBSERVATIONS

WILDLIFE

Wildlife	Count	Evidence	Wildlife	Count	Evidence	Wildlife	Count	Evidence

WETLAND ASSESSMENT PROCEDURE

Wellfield / Property	Wetland Name	Wetland Type

Wetland ID	Area Assessed	Zone Assessment Notes

GROUNDCOVER

For each zone assessed, please document the following: species abbreviation, WAP zone (ZONE) (U, AD, T, OD, or D), percent cover (%) (5% or 10-100% in increments of 10%), count (#) (1-4), and distribution (DIST) (E=edge, B=beyond a few feet, or T=throughout).

TRANSITION ZONE

transition zone assessed? ☐

check if no groundcover ☐

SPECIES	ZONE	%	#	DIST

OUTER DEEP ZONE

outer deep zone assessed? ☐

check if no groundcover ☐

SPECIES	ZONE	%	#	DIST

DEEP ZONE

deep zone assessed? ☐

check if no groundcover ☐

SPECIES	ZONE	%	#	DIST

Groundcover Comments

ZONATION

Zonation Score: ☐ Please assign a score of 1 - 5 or 0 and provide an explanation.

Zonation Score Explanation

WETLAND ASSESSMENT PROCEDURE

Wellfield / Property	Wetland Name	Wetland Type

Wetland ID	Area Assessed	Zone Assessment Notes

SHRUB / SMALL TREES

For each zone assessed, please document the following: species abbreviation, WAP zone (ZONE) (U, AD, T, OD, or D), percent cover (%) (5% or 10-100% in increments of 10%), count (#) (1-50 or ">50"), and distribution (DIST) (E=edge, B=beyond a few feet, or T=throughout).

TRANSITION ZONE

transition zone assessed? ☐
check if no shrubs/small trees ☐

SPECIES	ZONE	%	#	DIST

OUTER DEEP ZONE

outer deep zone assessed? ☐
check if no shrubs/small trees ☐

SPECIES	ZONE	%	#	DIST

DEEP ZONE

deep zone assessed? ☐
check if no shrubs/small trees ☐

SPECIES	ZONE	%	#	DIST

Shrub/Small Tree Comments

ZONATION

Zonation Score: ☐ Please assign a score of 1 - 5 or 0 and provide an explanation.

Zonation Score Explanation

STRESS

Signs of stress of appropriate shrubs and small trees (include dead species)

Little or None
Noticeable
Significant
N/A

Signs of stress of inappropriate shrubs and small trees (include dead species)

Little or None
Noticeable
Significant
N/A

WETLAND ASSESSMENT PROCEDURE

Wellfield / Property	Wetland Name	Wetland Type

Wetland ID	Area Assessed	Zone Assessment Notes

TREES

For each zone assessed, please document the following: species abbreviation, WAP zone (ZONE) (U, AD, T, OD, or D), percent cover (%) (5% or 10-100% in increments of 10%), count (#) (1-50 or ">50"), and distribution (DIST) (E=edge, B=beyond a few feet, or T=throughout).

TRANSITION ZONE

transition zone assessed? ☐

check if no trees ☐

SPECIES	ZONE	%	#	DIST

OUTER DEEP ZONE

outer deep zone assessed? ☐

check if no trees ☐

SPECIES	ZONE	%	#	DIST

DEEP ZONE

deep zone assessed? ☐

check if no trees ☐

SPECIES	ZONE	%	#	DIST

Tree Comments

ZONATION

Zonation Score: ☐ Please assign a score of 1 - 5 or 0 and provide an explanation.

Zonation Score Explanation

STRESS

Signs of stress of appropriate trees (do not include dead species)

Little or None
Noticeable
Significant
N/A

Signs of stress of inappropriate trees (include dead species)

Little or None
Noticeable
Significant
N/A

Dead or leaning trees (include standing dead trees and dead trees on ground that are appropriate)

Little or None
Noticeable
Significant
N/A

RECOVERY

Signs of tree recovery

Yes
No
Not Sure
N/A

Inappropriate vine death suggesting recovery

Yes
No
Not Sure
N/A

Exhibit C

Environmental Management Plan

Attachment C

Wetland Evaluation Method for Xeric-Associated Wetlands

Development of a Wetland Evaluation Method for Xeric-associated Wetlands in the Northern Tampa Bay Area

Prepared For:

TAMPA BAY WATER
Supplying Water To The Region

Tampa Bay Water
2575 Enterprise Road
Clearwater, Florida 33763-1102

Prepared by:

GPI

Greenman-Pedersen, Inc.
1000 North Ashley Drive, Suite 100
Tampa, Florida 33602

May 24, 2021

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Executive Summary

The existing Wetland Assessment Procedure method provides a field-based approach to assess the ecological condition of wetlands in the Northern Tampa Bay Area for water supply management purposes. In recognition of fundamental differences in the ecology and hydrology of those wetlands described as “xeric-associated” from the types of wetlands considered appropriate for evaluation using the WAP method, Greenman-Pedersen, Inc. (GPI) developed a new proposed field-based method for evaluation of the xeric sites.

GPI reviewed relevant literature and datasets expected to provide insights into potential elements to be included in a wetland evaluation method for xeric-associated wetlands and performed graphical and statistical analyses to identify useful factors to include in the developed method.

The proposed method relies on development of a reference water level regime specific to each site derived from post-cutback water level data and existing groundwater modeling results. Topographic/bathymetric data are also required to identify specific zones for field data collection, zones based on the Reference Water Level Percentiles.

This report includes a description of the proposed method, a blank datasheet, and a completed example datasheet. The purpose of this report is to summarize key methods, findings, and assumptions leading to the development of the proposed wetland evaluation method for xeric-associated wetlands, as well as provide recommendations for method implementation and improvement.

1.0 Introduction

The existing Wetland Assessment Procedure (WAP) method—developed by the Southwest Florida Water Management District (District) and Tampa Bay Water (2005)—provides a field-based method to assess the ecological condition of wetlands in the Northern Tampa Bay Area (NTB) for water supply management purposes. The WAP method was intended to broadly apply to various types of geographically isolated wetland systems, meaning those without significant and regular channelized inflow. Evidence has accumulated that wetlands located in a xeric soil landscape setting (i.e., xeric wetlands) tend to be deeper and exhibit water level fluctuations different than wetlands located in more mesic landscape settings like pine flatwoods (GPI 2020 and included references). Therefore, there is a need to develop a field-based evaluation method, specific to xeric wetlands, that will allow the ecological conditions of these unique wetlands to be assessed and tracked over time.

Working under Purchase Orders 20200259-00 and 20210171-00, Greenman-Pedersen, Inc. (GPI) undertook an effort to develop a field-based method for evaluating ecological conditions of xeric-associated wetlands. The intention of the method development was to allow, at a minimum, the tracking of ecological conditions of each wetland over time (i.e., a relative metric). Ideally, if practical, the developed method also would be intended to allow for useful comparisons among sites (i.e., an absolute metric). Deliverables from this effort were anticipated to include the proposed method described in a memo report, a blank datasheet, and a completed example datasheet. The purpose of this report is to summarize key methods, findings, and assumptions leading to the development of the proposed wetland evaluation method for xeric-associated wetlands, as well as provide recommendations for method implementation and improvement.

2.0 Methods

2.1 Data Review and Method Development

GPI reviewed literature and datasets expected to provide insights into potential elements to be included in a wetland evaluation method for xeric-associated wetlands, including:

- Development of a Revised Water Level Recovery Metric for Xeric-associated Wetlands in the Northern Tampa Bay Area (GPI 2020)
- Five Year Wetland Assessment (GPI Southeast, Inc. et al. 2010)
- Development of Environmental Measures for Assessing Effects of Water Level Changes on Lakes and Wetlands in the Central Florida Water Initiative Area (CFWI-EMT 2013)
- Minimum Levels Reevaluation for Lakes Brooklyn and Geneva, Clay and Bradford Counties, Florida (SJRWMD 2020)
- Preliminary Evaluation Criteria in Support of Minimum Flows and Levels for Sandhill Lakes (CH2MHill 2005)
- The Peculiar Nature of Florida's Sandhill Wetlands, Ponds & Lakes—Their Ecohydrology, Relationship with the Regional Aquifer & Importance within the Landscape (Nowicki 2019)

The work products from GPI's (2020) report "Development of a Revised Water Level Recovery Metric for Xeric-associated Wetlands in the Northern Tampa Bay Area" contain information for several time periods (including pre- and post-groundwater production cutbacks) about ecological conditions, Surficial Aquifer System (SAS) drawdown, and wetland water levels relative to historical high water levels. Three xeric-associated sites—414_S-008_Bonnet Lake, 339_NP-04_, and 483_SC-92_—were selected from among the 90 examined in GPI (2020) for more intensive review involving examining wetland histories, historical aerial photography, Digital Elevation Models (DEMs), water levels, and ecological conditions on the ground. (These sites are also referred to in this report, respectively, as STK-S-008, NOP-04, and STK-SC-92.) Historical aerial photography was provided within Tampa Bay Water's Recovery Assessment GIS system. Local DEMs were extracted from larger DEMs based on 2007 LiDAR data prepared by the District. Elevation data extracted from the District DEM was converted from North American Vertical Datum of 1988 (NAVD88) to the National Geodetic Vertical Datum of 1929 (NGVD29) for consistency with Tampa Bay Water's water level data, with conversion factors based on nearby sites in the District's Environmental Data Portal (EDP) online database interface. Water level data were obtained from Tampa Bay Water's DataMart system and the District's EDP.

A Natural Language Processing (i.e., text mining) analysis was performed on a Word document and an Excel spreadsheet prepared previously and provided as part of the meeting summary prepared for the May 2019 Consolidated Water Use Permit (CWUP) Recovery Assessment Meeting (i.e., WetlandHealth_Xeric_Expanded_Descriptions.docx, WetlandHealth_Xeric_Expanded_Data_May162019.xlsx). The Word document included brief ecological descriptions prepared by Diane Willis, M.S., GPI Senior Environmental Scientist for 80 xeric-associated sites for three different time periods (1996-2002, 2003-2007, and 2008-2014) and the Excel spreadsheet featured stressed/unstressed classifications for those site/periods. The text mining effort included creating document term matrices in R (R Core Team 2020) from corpora of wetland condition notes. The document term matrices were used to develop bigrams and trigrams of common adjacent words for wetlands with different ecological conditions.

Using the GIS polygons available from the work products from the 2010 Five Year Wetland Assessment, GPI categorized the xeric/mesic status of the 423 wetlands groundtruthed in the 2009/2010 fieldwork using a 500-foot buffer of classified soil types (as described in GPI 2016). A total of 129 wetlands were found to meet the xeric threshold of greater than 27% xeric soils in the buffer. Tabular data were joined to this subset of xeric-associated Five Year Wetland sites for further graphical analysis as well as text mining of comments recorded by the evaluators.

2.2 Preliminary Field Testing

After development of a preliminary method derived from data review, GPI Senior Environmental Scientist Diane Willis, and Chief Environmental Scientist Dan Schmutz reviewed field conditions at the three xeric-associated sites selected for more in-depth review (414_S-008_Bonnet Lake, 339_NP-04_, and 483_SC-92_) on 2021-02-22. The field review provided an opportunity for refinement of the preliminary method. On 2021-03-10, Chris Shea, Senior Environmental Analyst with Tampa Bay Water joined the two GPI environmental scientists to discuss the proposed approach and offer preliminary feedback.

3.0 Results

3.1 Existing Data Review

Review of the available literature suggests that methods for assessing the ecological and hydrological conditions at xeric-associated wetlands are very poorly developed. In fact, even the definition and nomenclature of xeric-associated wetlands is still, to some extent, under development. GPI (2016) provided a brief literature review of “xeric landscape-associated wetlands” which will not be repeated here in detail. In brief, various terms have been applied to these (often treeless) systems including “sandhill upland lakes”, “xeric wetlands”, and “ridge wetlands”.

Recent dissertation research by ReNae S. Nowicki (2019) seeks to provide a conceptual model for understanding the ecohydrology of sandhill wetlands and waters, which are found throughout the northern peninsula and Panhandle of Florida in areas where xeric uplands communities (e.g., scrub, scrubby flatwoods, and sandhill) are underlain by an unconfined or semi-confined regional aquifer. In general, wetland water level fluctuations in sandhill wetlands appear to closely follow the regional (Upper Floridan) aquifer due to either direct or indirect connection through an unconfined or semi-confined hydrogeology. Very high correlations are observed between xeric-associated wetland water levels and nearby regional aquifer wells. Direct connections occur in topographic settings where the regional aquifer head rises to the point of proximity to the surface water feature to allow actual mixing of waters, a conceptual model validated by observations at many of Nowicki’s (2019) study sites of calcium-bicarbonate water type with elevated specific conductance and calcium [$Ca2+$]. Indirect connections occur when the leakance is high (either unconfined or semiconfined) but the distance between the regional aquifer head and surface water feature is too great to allow direct mixing.

The close association with regional aquifer levels explains why xeric wetlands have been noted to exhibit astatic water level behavior—trending up and down for several years in response to multidecadal climate cycles (CH2MHill 2005). The St. Johns River Water Management District (SJRWMD) recognizes a continuum of lake types in their Minimum Flow and Level (MFL) approach ranging from “wetland lakes” at one extreme which exhibit wet and dry season stable water level patterns and have deep organic soils to “sandhill lakes” which exhibit multidecadal cycles resulting in unstable seasonally-flooded wetland vegetation with no organic soils (Mace 2015).

Given their close association with regional aquifer levels, in addition to climatic variation, the role of groundwater production also must be considered in understanding reference conditions appropriate to xeric wetlands. Lake Brooklyn, a sandhill lake located in the Keystone Heights region of Central Florida, has experienced a well-documented decline in water levels from the 1970s with typical water levels dropping about 10 feet. Analysis of rainfall climatic variations suggests that the lake responds to rainfall with a delay of 2 to 10 years and that longer-term rainfall deficits have played a significant role in lake level declines. A combination of two hydrologic models were used to quantify the contribution of groundwater pumping to changes in Lake Brooklyn levels: the North Florida Southeast Georgia (NFSEG) regional groundwater flow model and the Keystone Heights subregional transient groundwater model (KHTM). The transient model was used to simulate the interaction between groundwater and surface water features such as lakes and streams as well as changes in lake levels and stream flows due to changes in rainfall, evapotranspiration, and pumping in monthly time steps. SJRWMD concluded that groundwater production accounted for approximately 7 feet of water level decline in the lake level since the early 1980s (Sutherland et al. 2020). The precise year-to-year impact of groundwater production is understood to be highly variable among years since the effect of pumping is much greater during a dry year than a wet year.

Understanding the specific contributions of both rainfall and groundwater production to lake levels has allowed the SJRWMD to develop a new approach to MFL development involving adding back the elevation of water loss due to groundwater production to develop a "no-pumping condition" specific to a particular time period of climatic conditions evaluated. The no-pumping water levels are merged with DEM topographic/bathymetric data to examine areas of specific fish and wildlife habitat types (e.g., emergent marsh) that would be present without the pumping (i.e., a reference condition). Water level changes expected to cause a 15% reduction in specific habitat area were used to derive a series of environmental criteria considered for use in establishing specific MFLs (SJRWMD 2021).

A wide variety of wetland evaluation methods have been used to monitor wetland ecological and hydrological conditions over the history of permitting large scale groundwater withdrawals in the Northern Tampa Bay (NTB) area (Rochow 1998), including quadrat-based vegetation evaluations, aerial photointerpretation, soils assessments, tree condition evaluations, and water level and hydroperiod comparisons between control and treatment sites. A wide variety of altered conditions have been observed in wetlands located in areas of greater groundwater drawdown, including decreased water levels and hydroperiods, shifts in vegetation within wetlands from obligate wetland plants to species more commonly found in upland areas, organic soil dewatering and oxidation, soil subsidence, destructive fires, leaning trees, standing dead trees, fallen trees, thinning tree canopies, and loss of wetland-dependent wildlife (Rochow 1998).

The Wetland Assessment Procedure (WAP) introduced initially in 2000 and modified in 2005 was created to provide a consistent evaluation process to be applied as part of the Environmental Management Plan throughout the Central System wellfields included in Tampa Bay Water's Consolidated Water Use Permit (SWFWMD and Tampa Bay Water 2005). The WAP brought an increased focus on evaluating the appropriateness of groundcover, shrub, and tree species growing within specific zones defined in isolated wetlands based on their depth below the Historical Normal Pool (HNP) elevation.

With the growing awareness of the uniqueness of xeric-associated wetlands in terms of their hydrology and ecology (GPI 2020, GPI 2016, and Nowicki 2019), it is useful to determine if there are specific wetland condition elements observed in previous studies that are appropriate to apply to xeric-associated wetlands. From a hydrologic perspective, xeric wetlands are expected to show greater ranges in fluctuation and lower median water levels without degraded ecological conditions in comparison to mesic-associated wetlands, e.g., GPI (2020) concluded that median water levels of stressed xeric sites tended to have elevations more than 3.7 feet below a high water level (the 3 Percent Exceedance or PE03).

Text mining results for the the word document containing brief ecological descriptions prepared by Diane Willis, M.S. for 80 xeric-associated sites for three different time periods are presented in Figures 3.1-1 through 3.1-4. The first two figures highlight the 12 most common two-word (bigram) and three-word (trigram) phrases occurring in the text for the stressed wetland time periods. It is noteworthy that "soil subsidence" and "severe soil subsidence" are the most common bigram and trigram, suggesting the importance of this aspect of wetland condition change for defining stress status. In general, the trigrams appear more useful than the bigrams in terms of their clarity of meaning. For example, "invaded central marsh" makes more sense than the somewhat ambiguous "upper dz" although both probably refer to changes in plant composition occurring towards the center of the site. Somewhat counterintuitively, “cypress invaded central” is fairly often associated with stressed xeric wetlands because under reference hydrologic conditions the deeper sites tend to be too deep to support cypress trees in the central areas, but with altered hydrology, cypress can establish and flourish in the center.

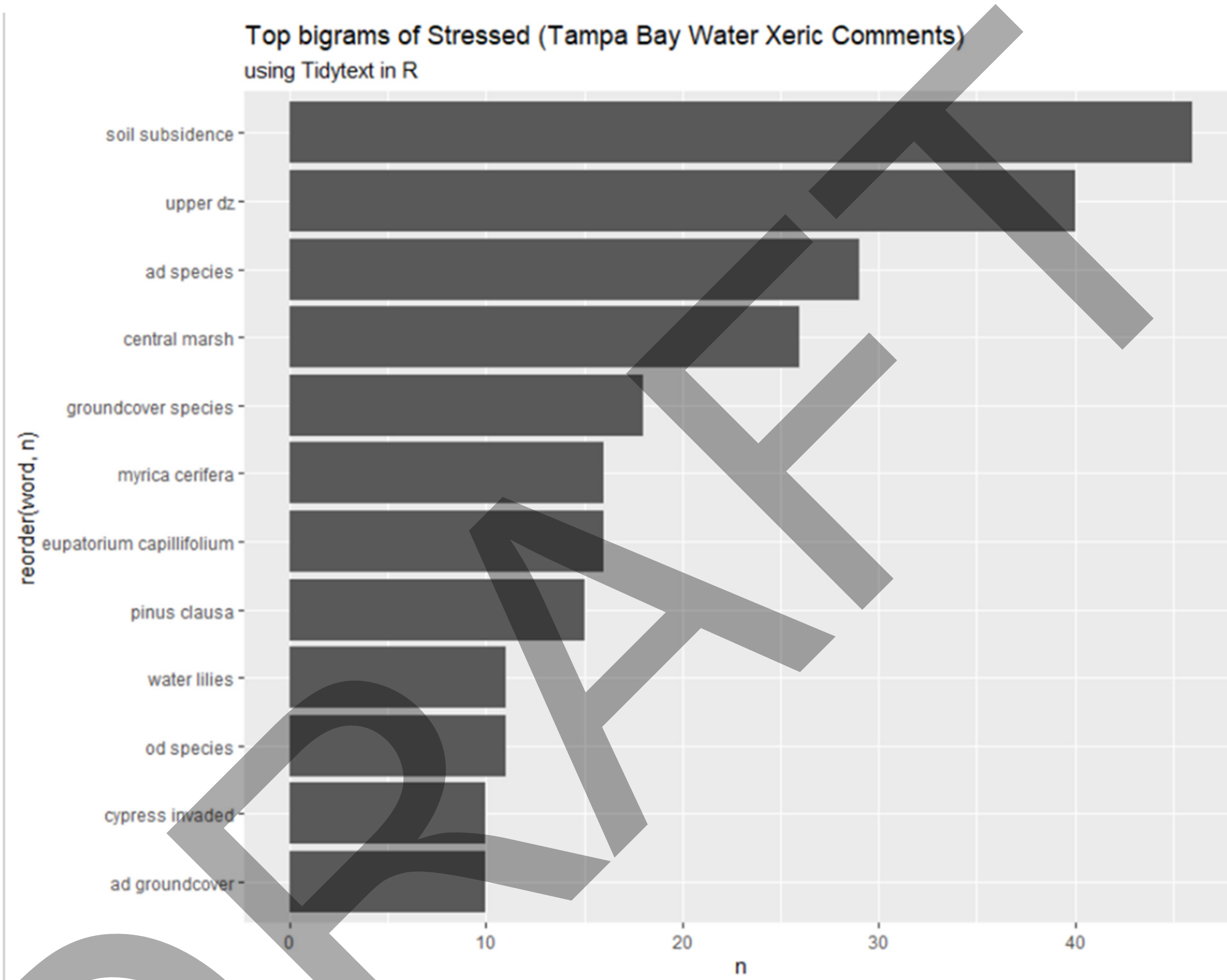


Figure 3.1-1. Top 12 bigrams from text mining analysis for stressed xeric-associated wetland time periods

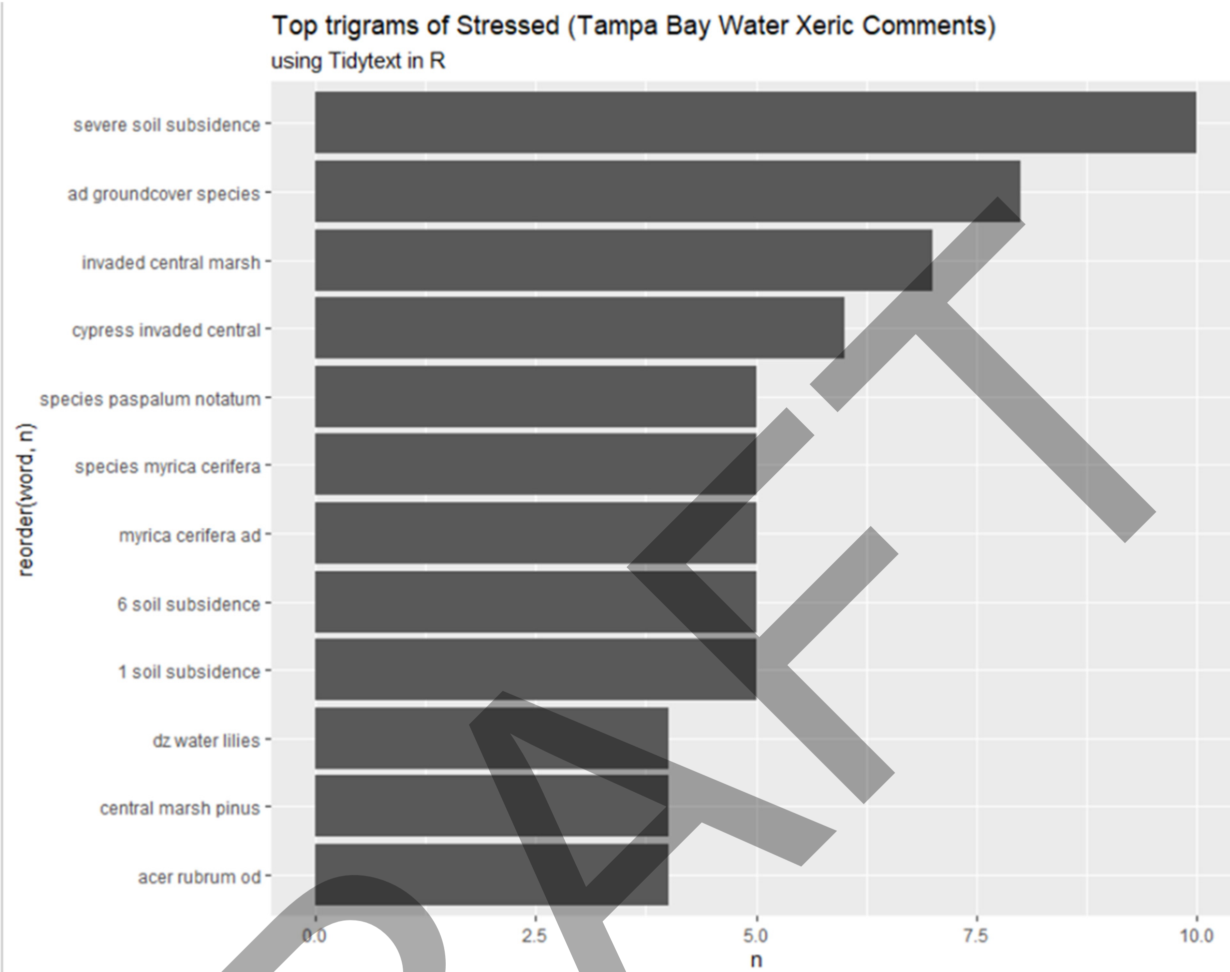


Figure 3.1-2. Top 12 trigrams from text mining analysis for stressed xeric-associated wetland time periods

The top 12 bigrams for the unstressed xeric wetland time periods are difficult to interpret without more context (Figure 3.1-3). The trigrams for the unstressed xeric wetland time periods are clearer (Figure 3.1-4), calling out situations such as "minimal shrub invasion". Some movements of adaptive species into the unstressed wetlands are noted, including wax myrtle and dog fennel.

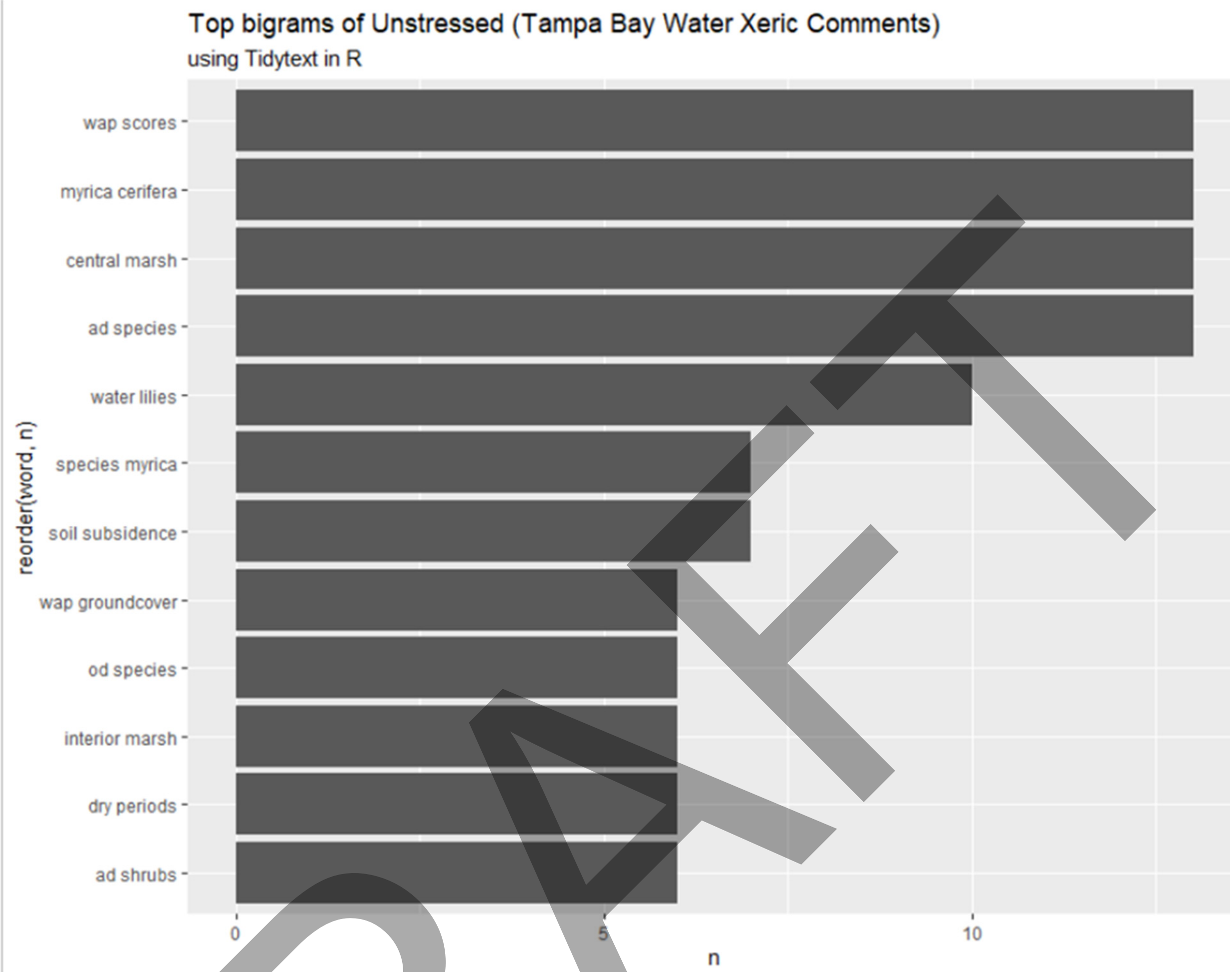


Figure 3.1-3. Top 12 bigrams from text mining analysis for unstressed xeric-associated wetland time periods

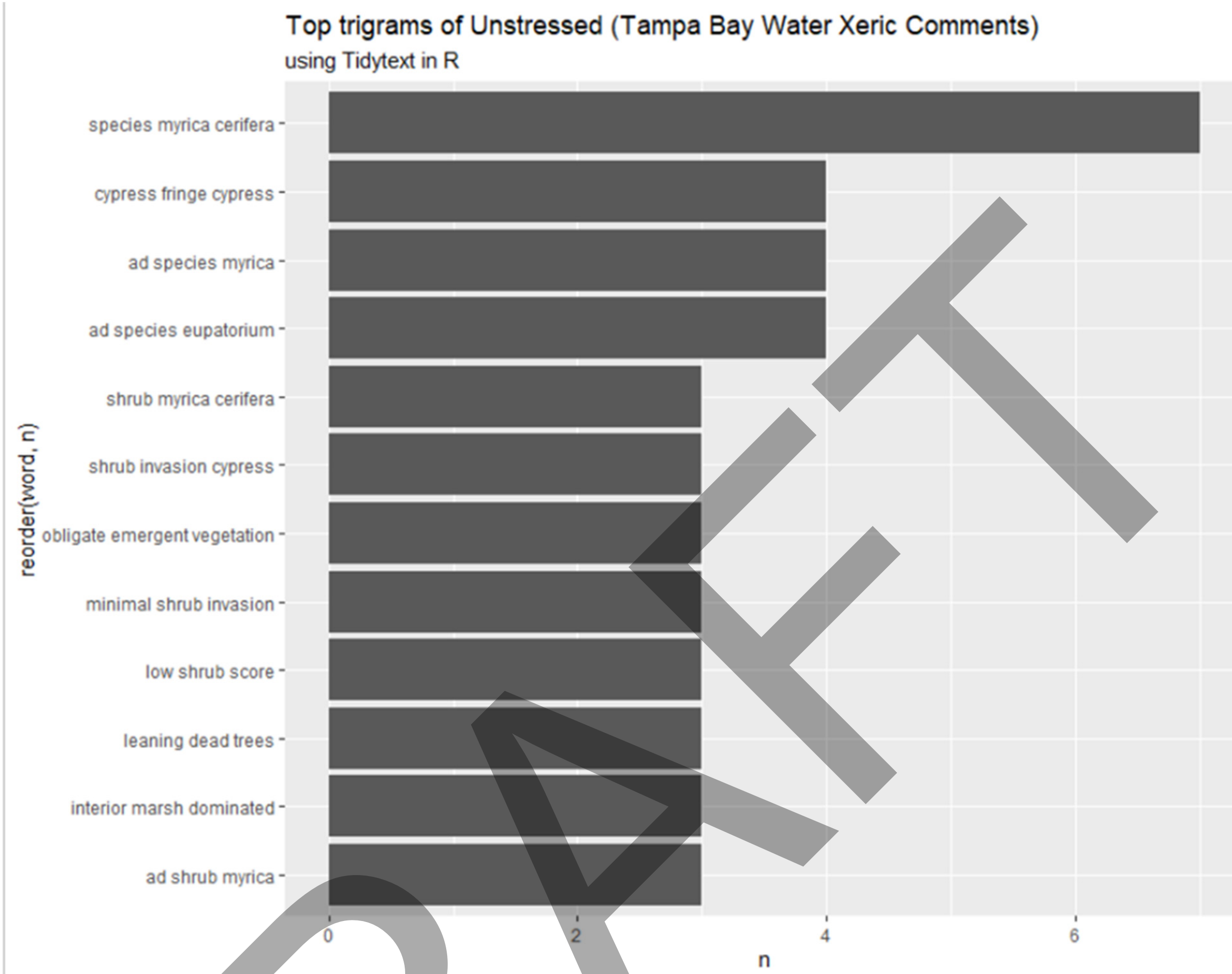


Figure 3.1-4. Top 12 trigrams from text mining analysis for unstressed xeric-associated wetland time periods

Figures 3.1-5 though 3.1-8 document the results of the text mining analysis for the 129 xeric-associated wetlands visited during the 2009/2010 Five Year Wetland Assessment. The first two figures provide bigrams and trigrams for the severely stressed sites—those with Wetland Health Assessment scores of 1 or 2 on a 5-point scale. The last two figures present bigrams and trigrams for the low or no stress sites (i.e., 4 or 5 on a 5-point scale).

Again, the trigrams appear most informative, calling out for the severely stressed sites “severe soil subsidence”, “depressed water levels”, “excessive treefall”, “10 feet lower”, etc. The low or no stress sites are described by the most common trigrams like “dense Spanish moss”, “Brazilian pepper coming”, and “adjacent residential development”. Overall, the results of the text mining analysis suggest that trigrams may provide a useful tool for identifying qualitative factors that environmental scientists are responding to in forming an overall opinion of the condition of a xeric site.

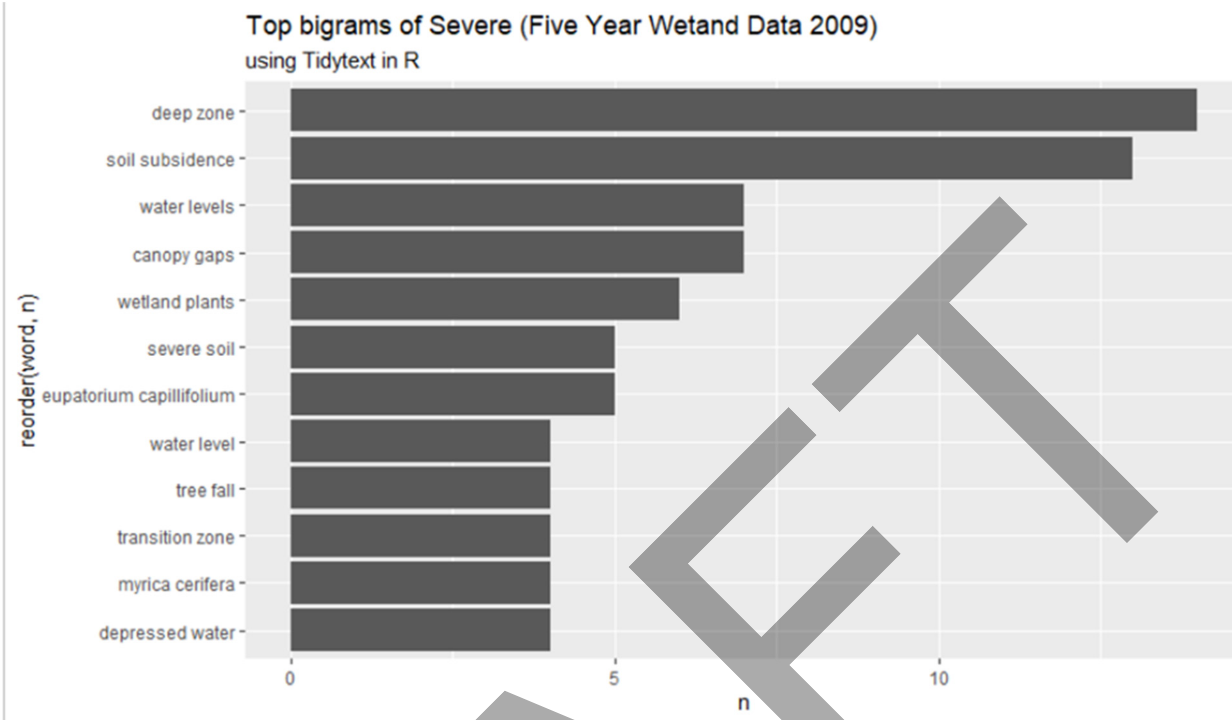


Figure 3.1-5. Top 12 bigrams from text mining analysis for severely stressed xeric-associated wetlands for 2009/2010 Five Year Wetland Assessment

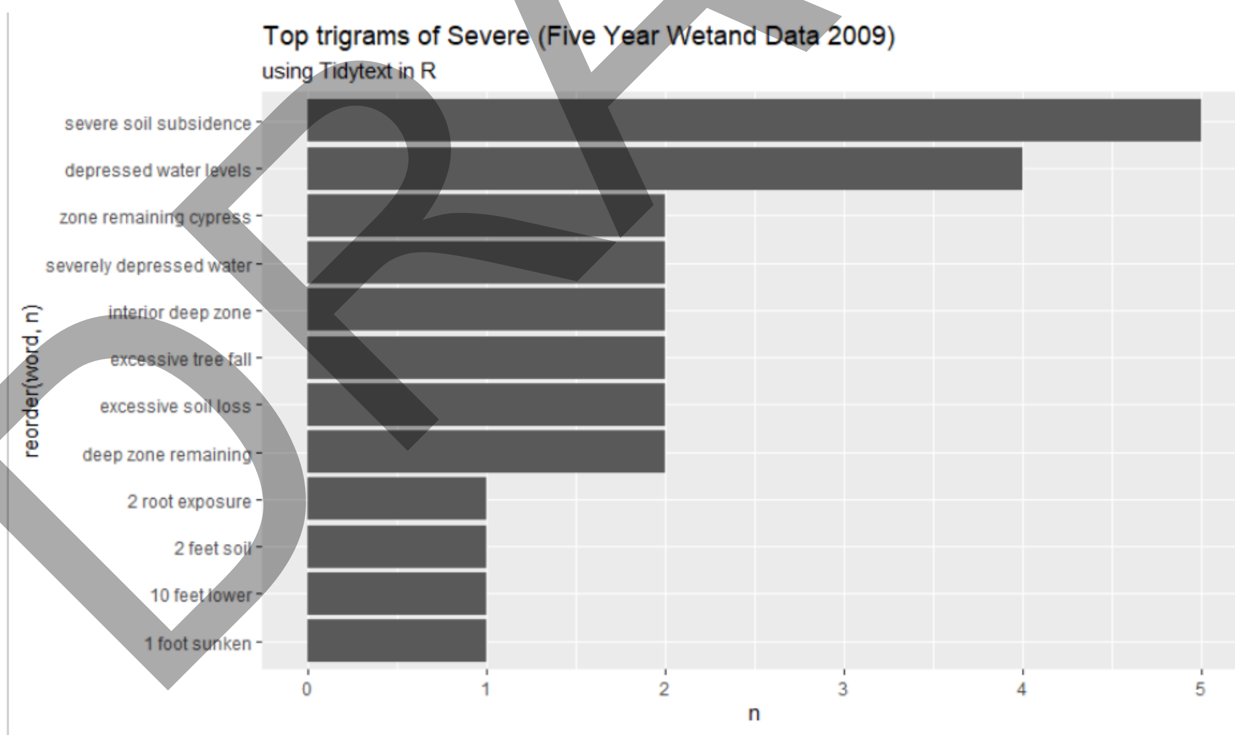


Figure 3.1-6. Top 12 trigrams from text mining analysis for severely stressed xeric-associated wetlands for 2009/2010 Five Year Wetland Assessment

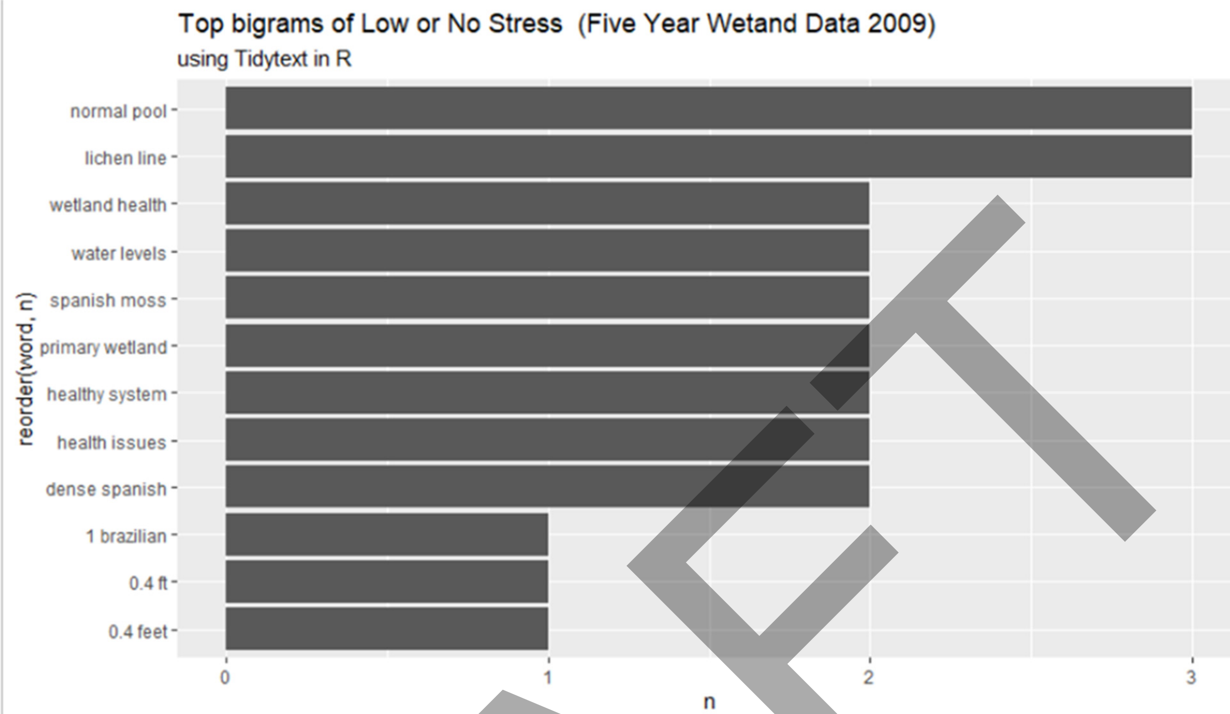


Figure 3.1-7. Top 12 trigrams from text mining analysis for low or no stress xeric-associated wetlands for 2009/2010 Five Year Wetland Assessment

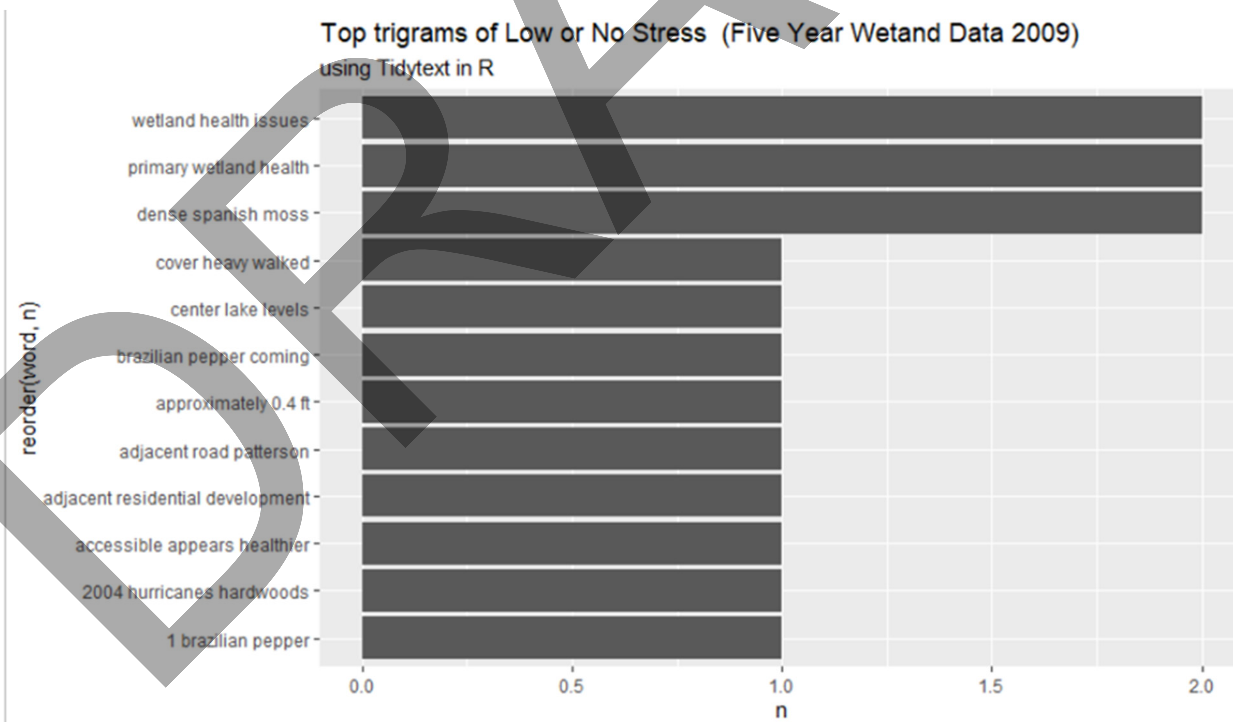


Figure 3.1-8. Top 12 trigrams from text mining analysis for low or no stress xeric-associated wetlands for 2009/2010 Five Year Wetland Assessment

In addition to many pages of text descriptions, the 2009/2010 Five Year Wetland Assessment dataset also provided semiquantitative factors in the database, intended to support the overall scoring of each site (Figure 3.1-9). Below we briefly review some variables from the Five Year Wetland Assessment database to detect possible factors useful in developing an evaluation method specific to xeric-associated wetlands. Figure 3.1-10 shows a percent stacked bar chart, meaning that the percentage occurrence of stressed and unstressed is displayed by category. In this case, unstressed wetlands only occurred in Category 3 "<10% standing dead/thin canopy". While not evaluated statistically, this pattern is suggestive of the importance of tree health in ultimately rating the overall site as stressed or unstressed. (For the purpose of these graphical evaluations, WHA scores of 1,2, and 3 were all combined into a stressed category and 4,5 represented unstressed.)

ScoreLeaning (Figure 3.1-11) also appears predictive, with no unstressed sites in Category 1 (">25% leaning"). An almost identical pattern is shown by ScoreFallen (Figure 3.1-12). ScoreDominant (Figure 3.1-13) indicates that most of the unstressed wetlands included those with >75% OBL or FACW species (Category 3). Unstressed sites tended to be those with uncommon or absent weedy plants (Categories 2 and 3 in Figure 3.1-14). An absence of fissuring or unseasonal dryness in soils (Category 3 in Figure 3.1-15) tended to occur primarily at unstressed sites. ScoreTrShSucc (Figure 3.1-16) indicates that the proportion of unstressed sites was much higher when Category 3 "tree/shrub dominance appears stable" was observed. (Figure 3.1-9 shows an earlier version of this question that only allowed two responses.) Unstressed sites tended to have normal understory horizontal zonation (Category 2 in Figure 3.1-17). Unstressed sites were more common when hydration was appropriate versus reference/controls (Category 3 in Figure 3.1-18). In evaluating current water level indicators versus historical indicators, unstressed sites tended to be those with indicators "distant at an appropriate level" (Category 3 in Figure 3.1-19).

Given the importance of understanding wetland hydrology at the Five Year Wetland Assessment sites (sites which typically lacked water level data collection), additional effort was expended in the 2009/2010 fieldwork to attempt to quantitatively document the relative elevations of various indicators (Figure 3.1-20). We observed that the most stressed sites (WHA of 1) tended to have depressed lichen lines, with the median lichen line occurring about one foot below the HNP (Figure 3.1-21).

Standing water relative to HNP tended to be lower the more stressed the sites (lower WHAs) as shown in Figure 3.1-22. Although apparently predictive of condition, the comparison of water levels among sites requires near simultaneous evaluation of large numbers of sites varying in level of stress and is expected to vary substantially among years. In addition, the sites expected to be evaluated with the method under development here likely would already have water level data collection in place.

Degrees		Quality	Points	Quality
canopy foliage	1 2 3	>50 % standing dead / thin canopy 10 - 50 % standing dead / thin canopy < 10 % standing dead / thin canopy		
leaning trees	1 2 3	>25 % leaning 5- 25 % leaning <5 % leaning		
fallen trees	1 2 3	>25 % fallen 5 - 25 % fallen <5 % fallen		
dominant plant species – (cover)	1 2 3	<50 % are OBL or FACW 50 - 75 % are OBL or FACW >75 % are OBL or FACW		
exotic & weedy plants	1 2 3	abundant uncommon absent		
soil	1 2 3	fissured, oxidized unseasonal dry absent		
tree/shrub successional trends	1 2	trees/shrubs indicate rapid change tree/shrub dominance appears stable		
understory zonation (horizontal)	1 2	understory zonation abnormal understory zonation normal		
wetland hydration	1 2 3	severely depressed vs reference controls moderately depressed vs reference controls appropriate vs reference controls		
water level indicators vs. historic (i.e. mosses, lichens, stain lines)	1 2 3	none or at tree base present, indistinct or abnormally low distinct at appropriate level		
TOTAL QUALITY POINTS =				
ADDITIONAL COMMENTS: DISTURBANCE		1 highly disturbed 2 moderately disturbed 3 undisturbed		

Figure 3.1-9. Modified wetland assessment scoring chart (included in the Five Year Wetland Assessment data collection field form)

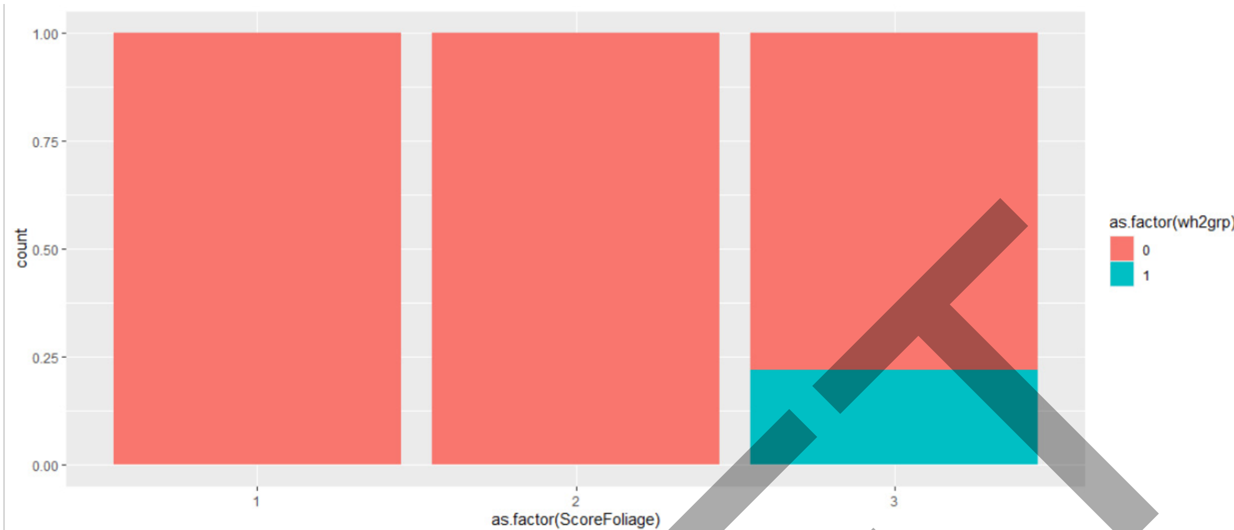


Figure 3.1-10. Percent stacked bar chart summarizing frequency of occurrence of stressed (0=red) and unstressed (1=blue) by ScoreFoliage category for the Five Year Wetland Assessment xeric wetlands

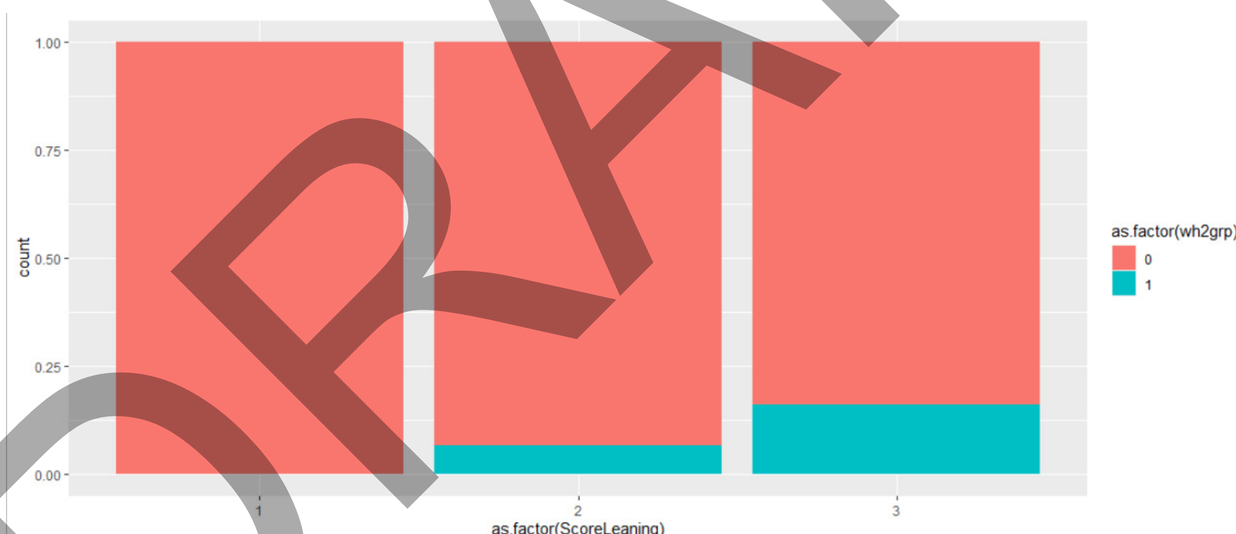


Figure 3.1-11. Percent stacked bar chart summarizing frequency of occurrence of stressed (0=red) and unstressed (1=blue) by ScoreLeaning category for the Five Year Wetland Assessment xeric wetlands

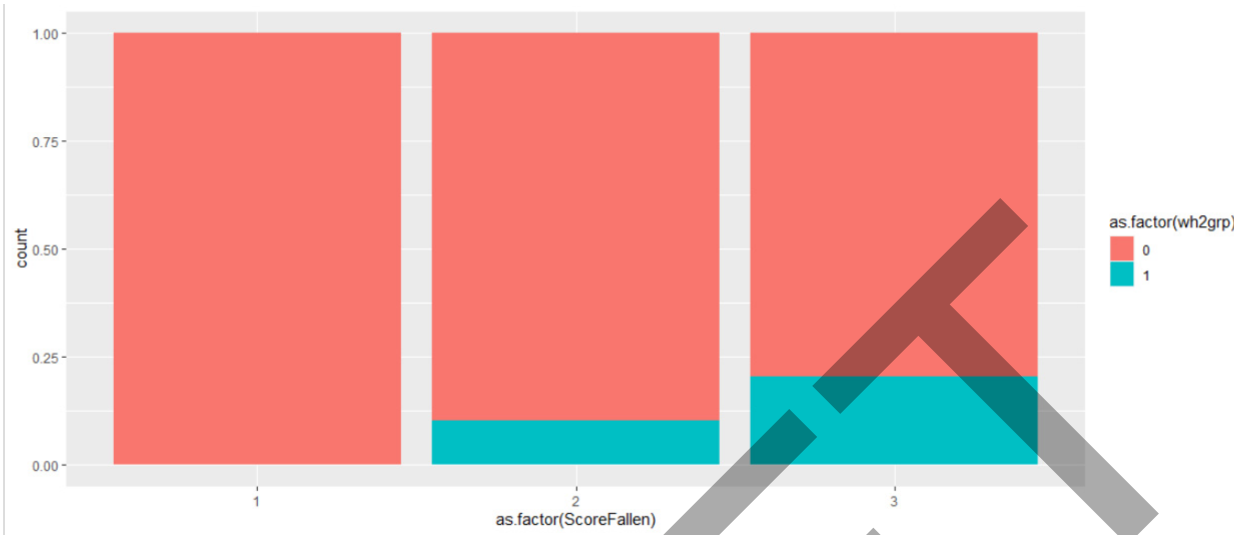


Figure 3.1-12. Percent stacked bar chart summarizing frequency of occurrence of stressed (0=red) and unstressed (1=blue) by ScoreFallen category for the Five Year Wetland Assessment xeric wetlands

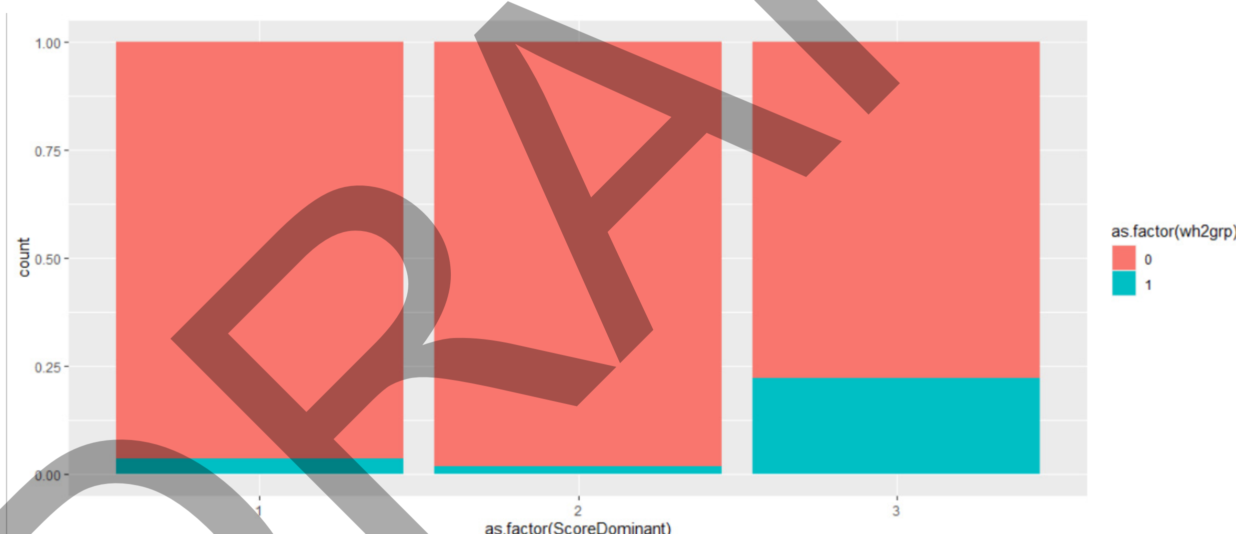


Figure 3.1-13. Percent stacked bar chart summarizing frequency of occurrence of stressed (0=red) and unstressed (1=blue) by ScoreDominant category for the Five Year Wetland Assessment xeric wetlands

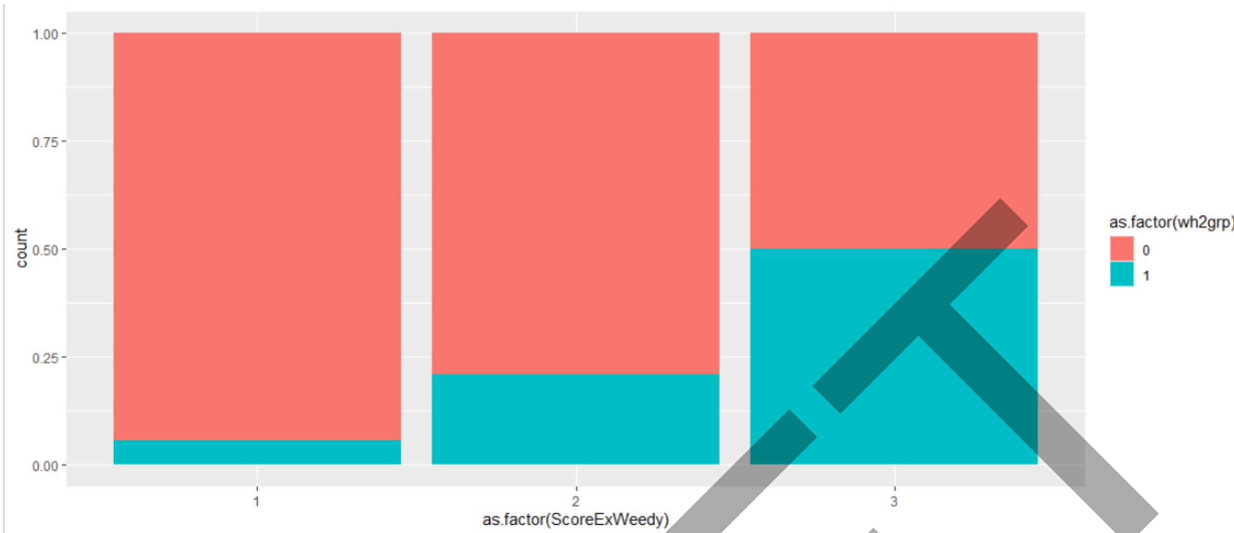


Figure 3.1-14. Percent stacked bar chart summarizing frequency of occurrence of stressed (0=red) and unstressed (1=blue) by ScoreExWeedy category for the Five Year Wetland Assessment xeric wetlands

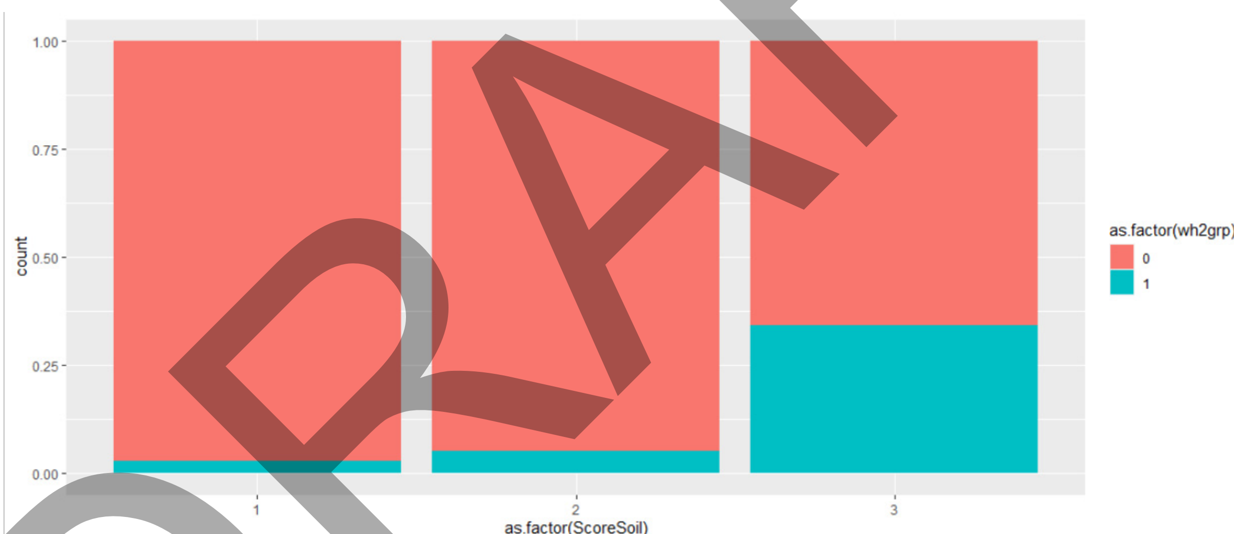


Figure 3.1-15. Percent stacked bar chart summarizing frequency of occurrence of stressed (0=red) and unstressed (1=blue) by ScoreSoil category for the Five Year Wetland Assessment xeric wetlands

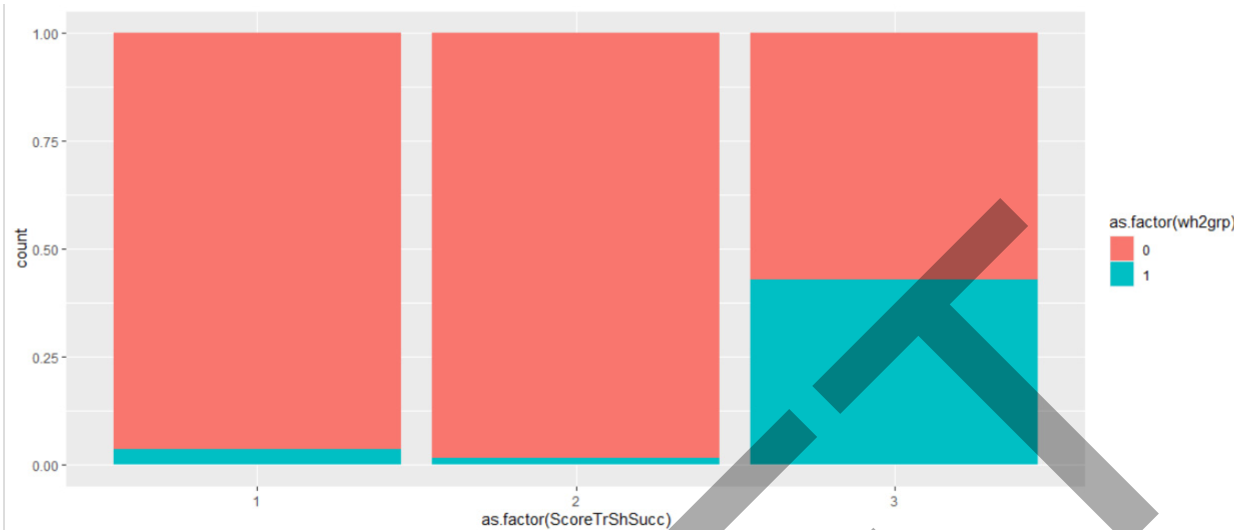


Figure 3.1-16. Percent stacked bar chart summarizing frequency of occurrence of stressed (0=red) and unstressed (1=blue) by ScoreTrShSucc category for the Five Year Wetland Assessment xeric wetlands

Figure 3.1-17. Percent stacked bar chart summarizing frequency of occurrence of stressed (0=red) and unstressed (1=blue) by ScoreUHZ category for the Five Year Wetland Assessment xeric wetlands

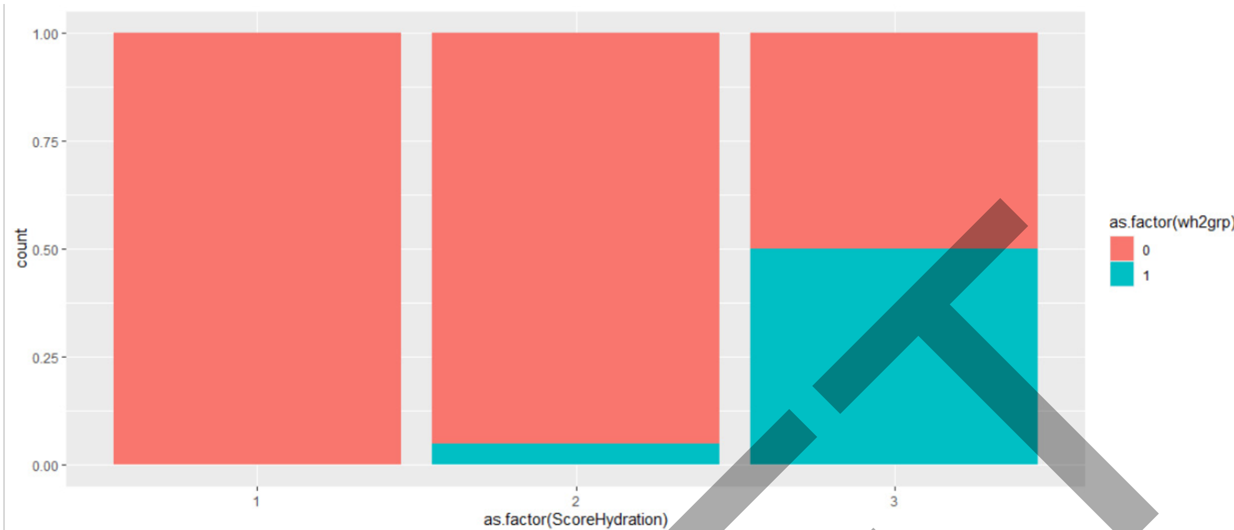


Figure 3.1-18. Percent stacked bar chart summarizing frequency of occurrence of stressed (0=red) and unstressed (1=blue) by ScoreHydration category for the Five Year Wetland Assessment xeric wetlands

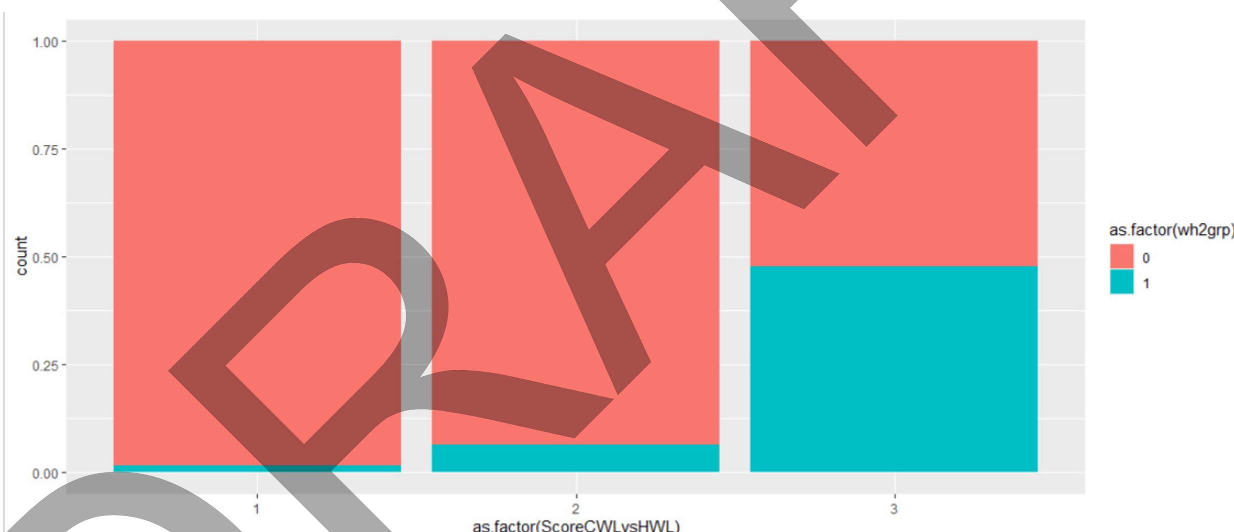
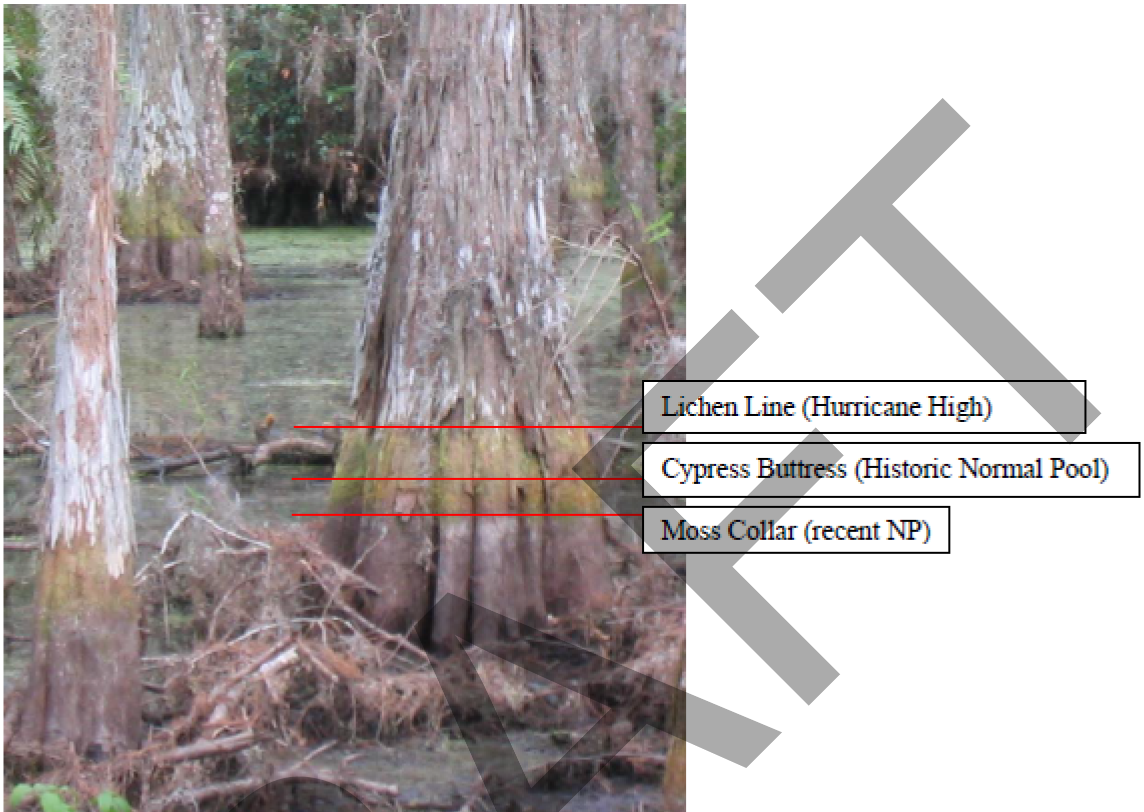


Figure 3.1-19. Percent stacked bar chart summarizing frequency of occurrence of stressed (0=red) and unstressed (1=blue) by ScoreCWLvsHWL category for the Five Year Wetland Assessment xeric wetlands

Example Hydrologic Indicators on Cypress Tree



Example Data:

Type	Indicator	Relative to HNP
Historic Normal Pool	Cypress Buttress	0 feet
Hurricane High	Lichen Line	+0.70 feet
Recent Normal Pool	Moss Collar	-0.35 feet
Water Level	Water	-1.50
Ground	Ground surface	-1.65 feet

Figure 3.1-20. Instructions given to Five Year Wetland Assessment assessors for documenting relative elevations of water level indicators.

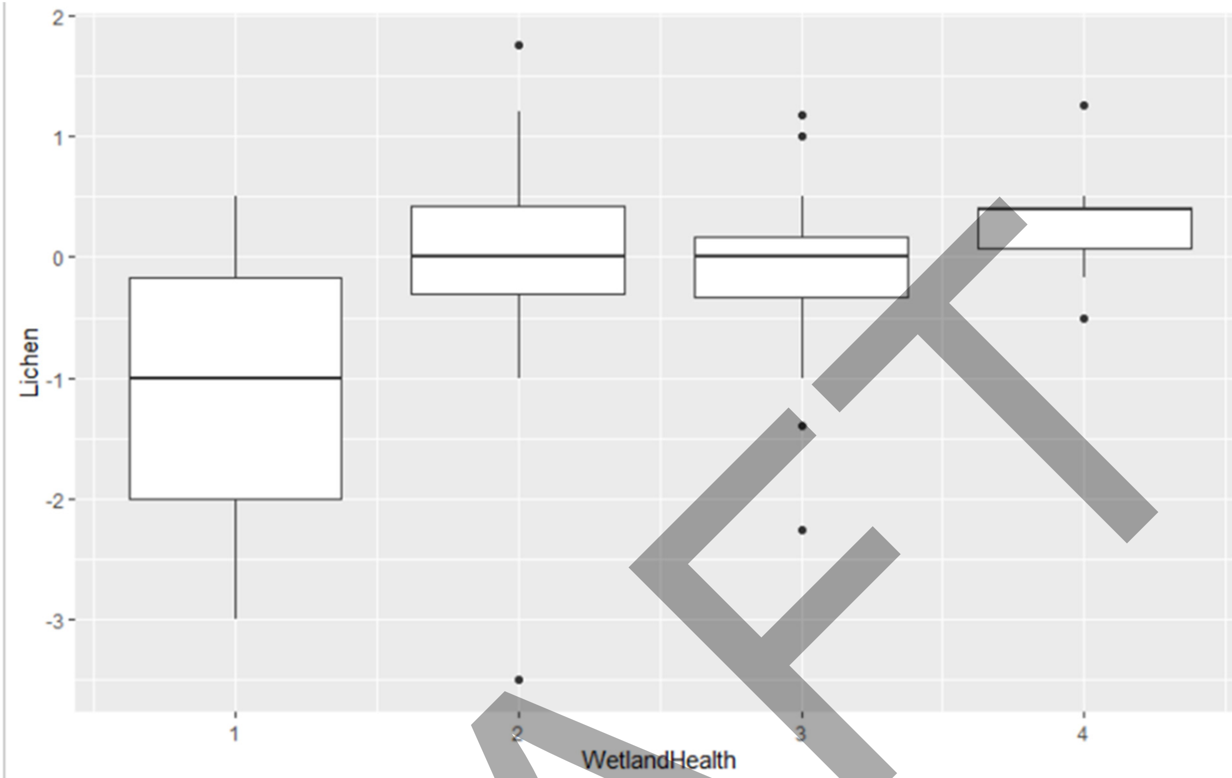


Figure 3.1-21. Comparison of elevation of lichen lines to historic normal pool indicators for xeric wetlands in different Wetland Health Assessment categories

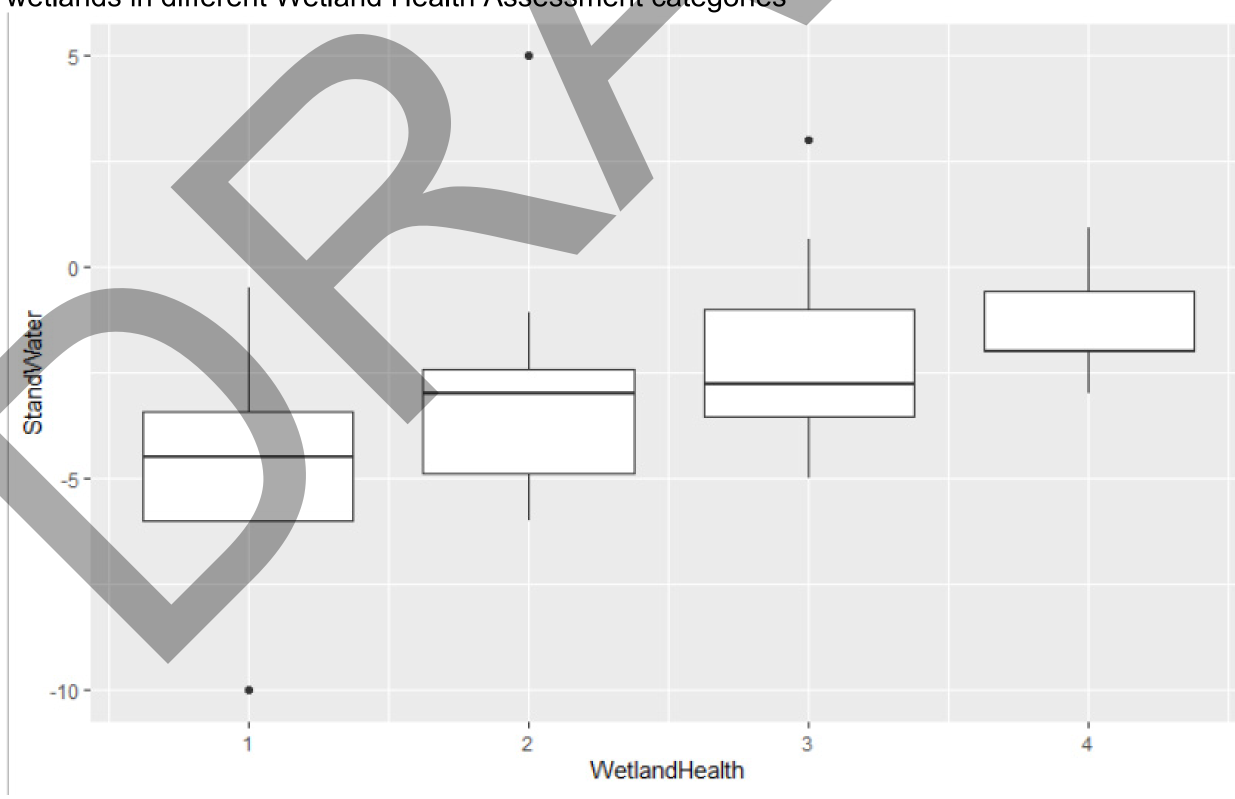


Figure 3.1-22. Comparison of elevation of water levels to historic normal pool indicators for xeric wetlands in different Wetland Health Assessment categories

Data regarding the three xeric-associated wetlands studied in some detail are presented in Table 3.1-1. Hydrographs for the period of record (POR) water level data are presented for the three sites in Figures 3.1-23 through 3.1-25. In all three cases, the central tendency of data shifted noticeably between the 1996-2002 pre-cutback period and the 2008-present (post-cutback) period. Notice that, post-cutback, all three wetlands still have some estimated Surficial Aquifer System (SAS) drawdown, but in the case of 339_NP-04_, it is minimal (Table 3.1-1). (Please note that two post-cutback periods are provided in Table 3.1-1 for remaining median SAS drawdown—2008-2014 and 2008-2018; data from the first period were available from an earlier study [GPI 2018] and the latter period data were calculated to represent more recent conditions.)

Nearby Upper Floridan aquifer wells were selected to determine if these three xeric wetlands closely tracked regional aquifer levels as predicted by the conceptual model of Nowicki (2019). Figures 3.1-26 and 3.1-27 document Upper Floridan monitoring wells near the sites of interest. STK 10 Deep was selected for comparison to 414_S-008_Bonnet Lake, Moon Lake Deep selected for comparison to 339_NP-04_, and STK Regional for comparison to 483_SC-92_.

Without any adjustment in elevation, water levels in 414_S-008_Bonnet Lake and STK 10 Deep are highly coincident (Figure 3.1-28). With some simple vertical shift adjustments for the suspected slope of the Upper Floridan potentiometric surface (documented in the figures), water levels at the other two sites also appear to closely track regional aquifer fluctuations (Figures 3.1-29 and 3.1-30).

Table 3.1-1. Xeric-associated Wetland and Lake Monthly Mean Time Series Downloaded

CompositeN	Xeric Ratio	P3_Selected	HNP	HNPdiff	Aug Status	Acres	Depth	Median SAS DDN 1996-2002	Median SAS DDN 2008-2014	Median SAS DDN 2008-2018	Ecological Condition (1990-2002)	Ecological Condition (2003-2007)	Ecological Condition (2008-2014)
414_S-008_Bonnet Lake	0.81	31.34	31.67	0.33	Past	3.34	8.73	1.95	1.23	1.16	S	S	S
339_NP-04_	0.81	45.10	44.60	-0.50	None	1.17	2.84	0.47	0.11	0.12	S	S	NS
483_SC-92_	0.60	41.03	42.80	1.77	None	4.96	9.12	2.05	0.70	0.66	S	S	Changed

Note: Changed condition for 483_SC-92_ reflects severe soil subsidence in interior marsh replacing emergents with floating plants

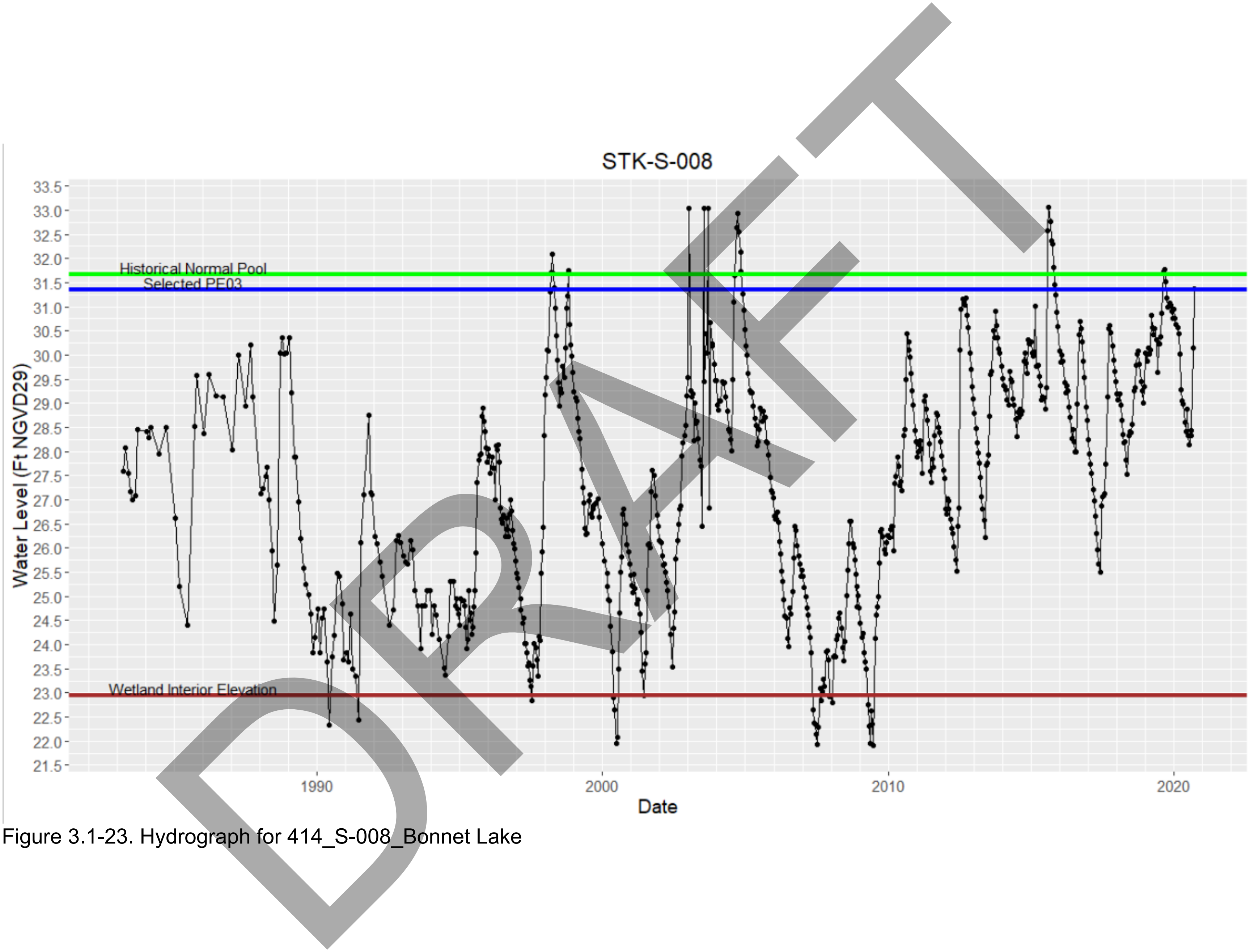


Figure 3.1-23. Hydrograph for 414_S-008_Bonnet Lake

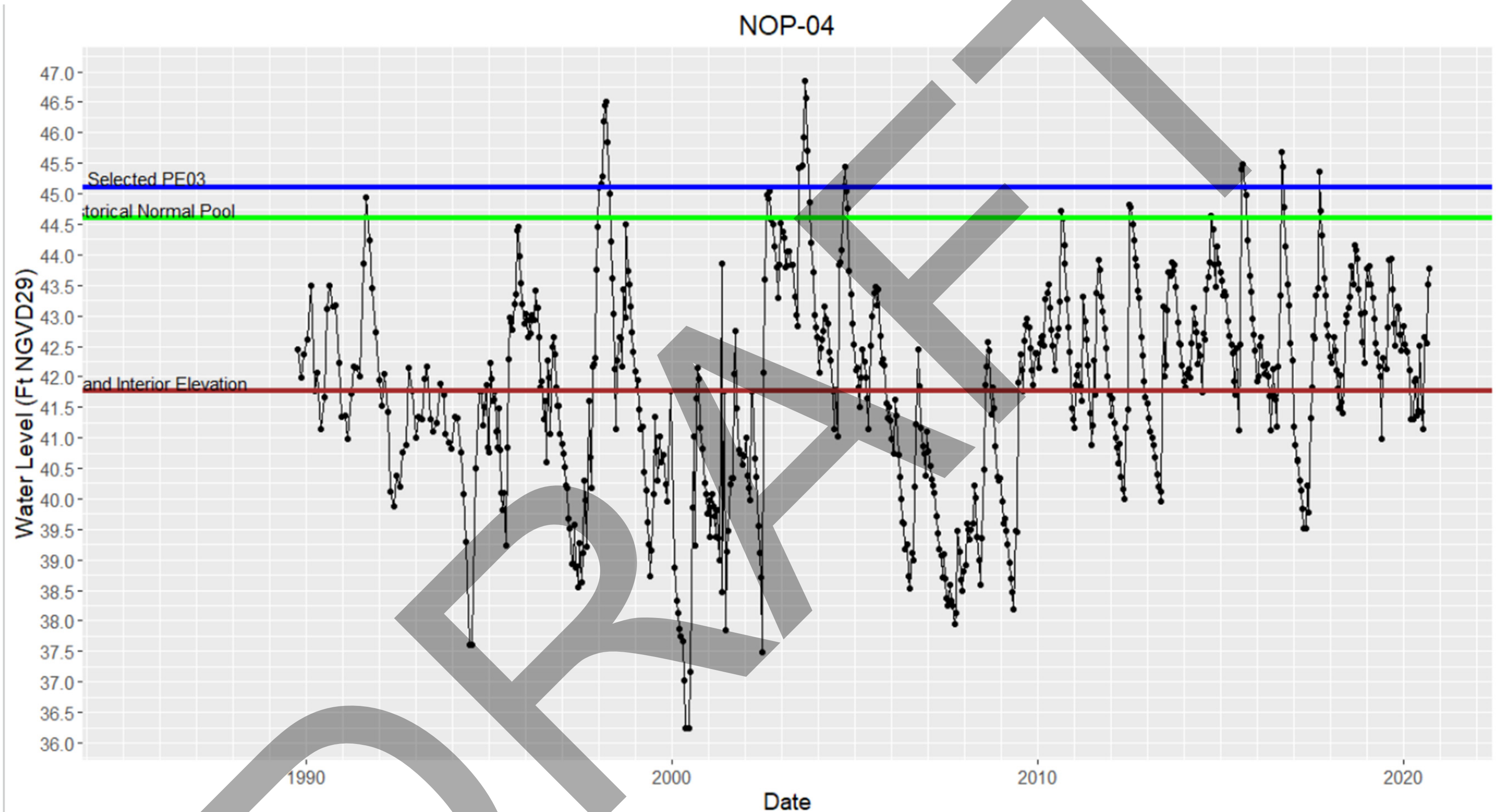


Figure 3.1-24. Hydrograph for 339_NP-04_

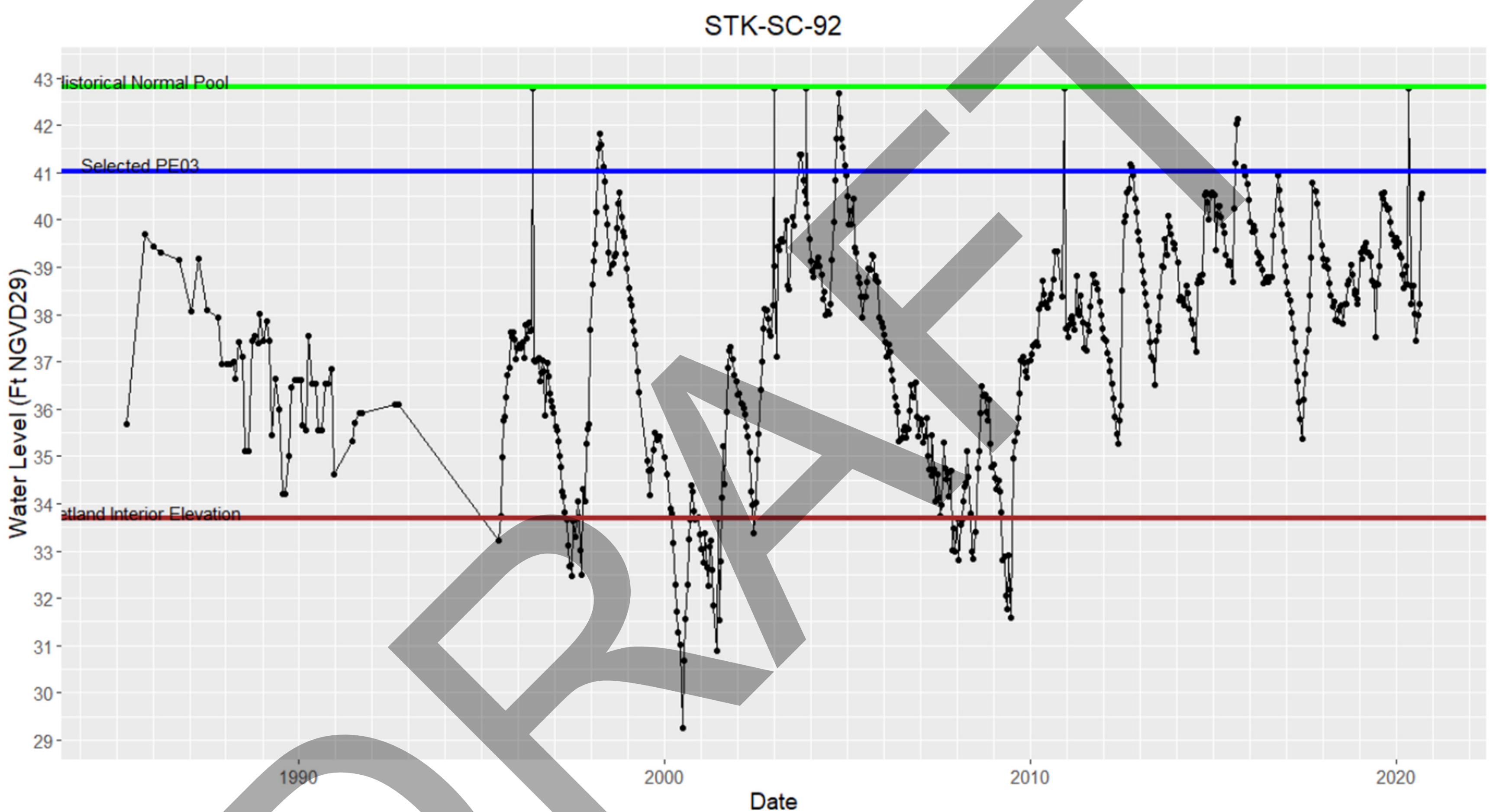


Figure 3.1-25. Hydrograph of 483_SC-92_

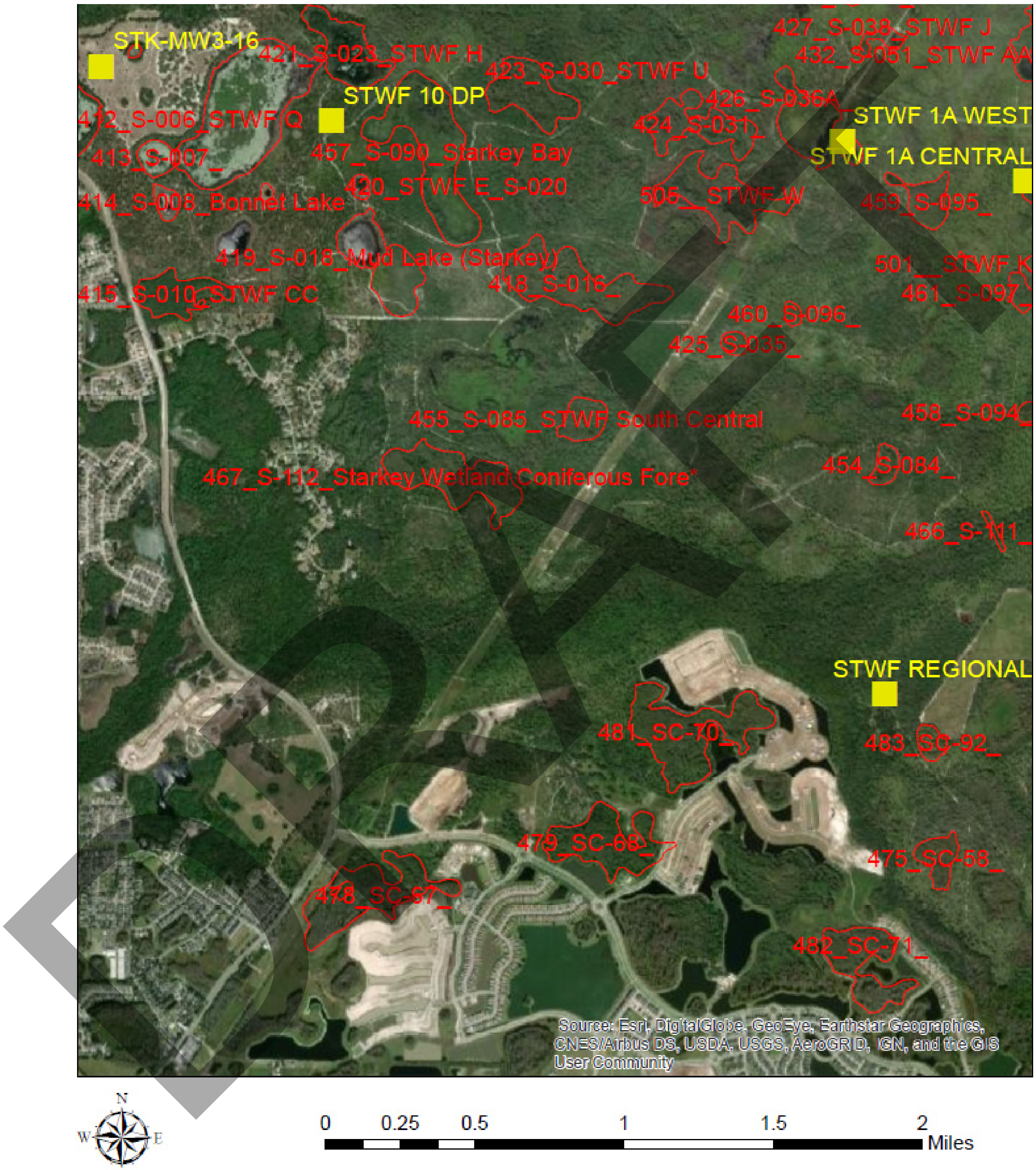


Figure 3.1-26. Map showing Upper Floridan monitoring wells near sites of interest on or near Starkey wellfield

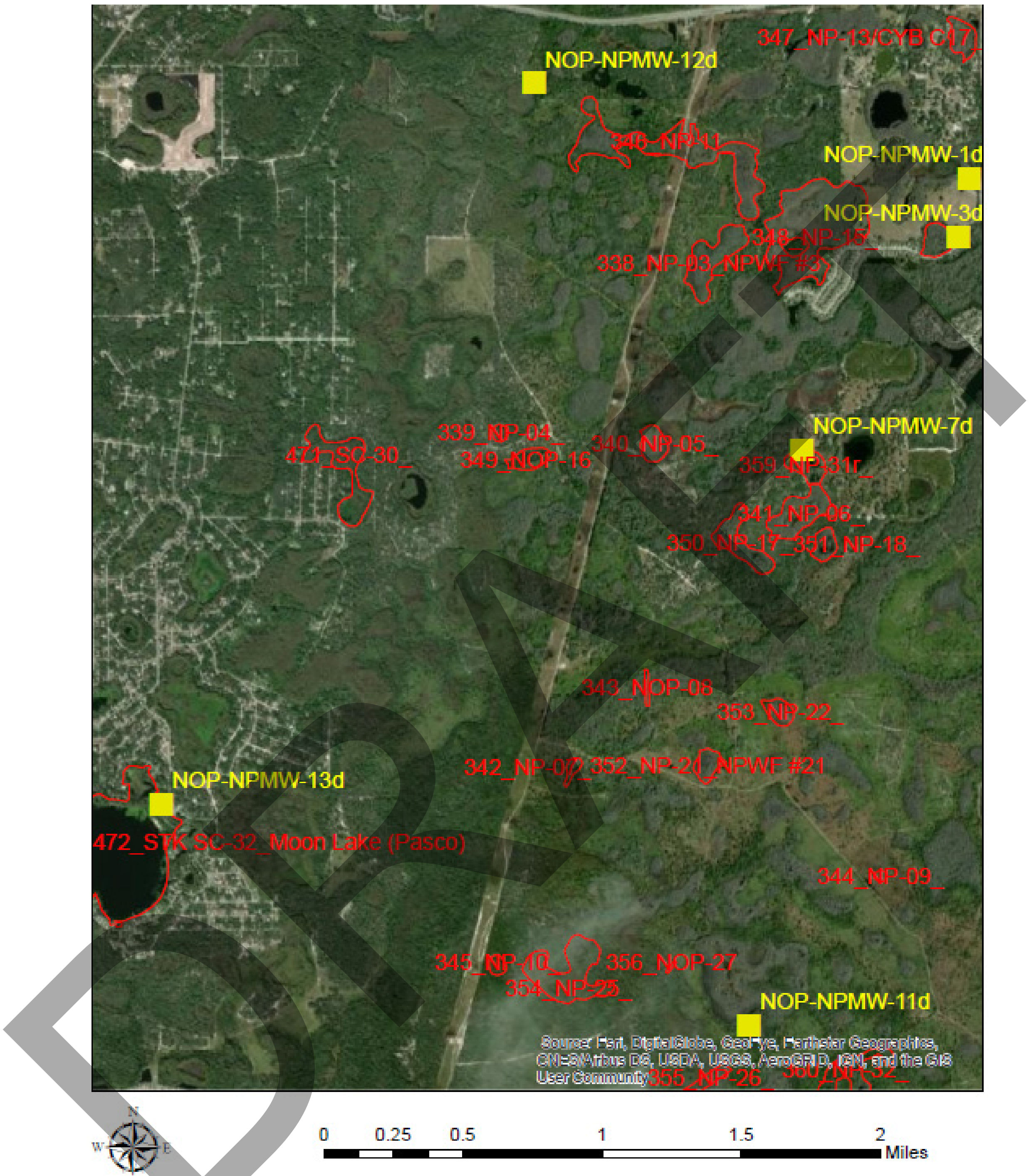


Figure 3.1-27. Map showing Upper Floridan monitoring wells near site of interest on North Pasco wellfield

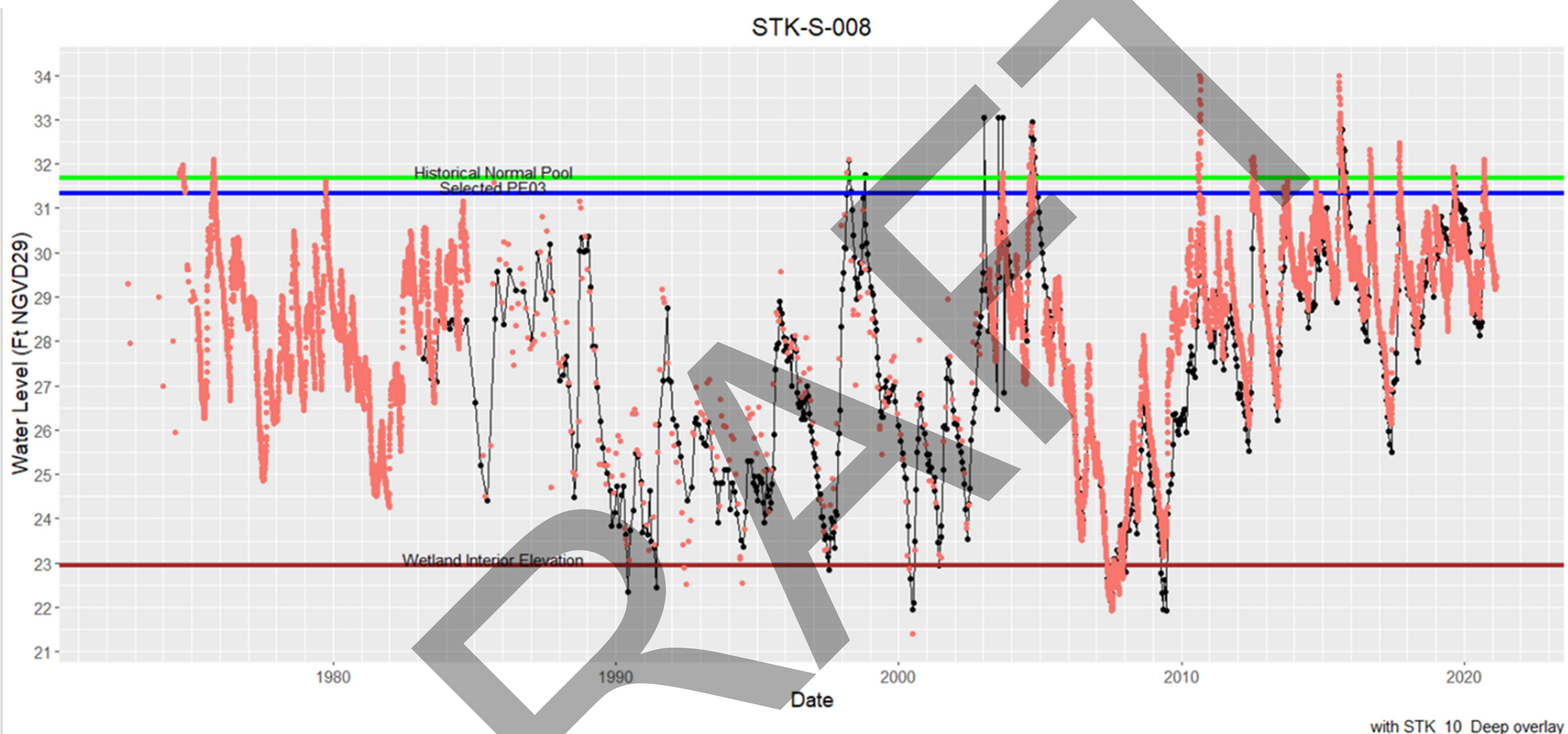


Figure 3.1-28. Hydrograph for 414_S-008_Bonnet Lake with STK 10 Deep (red) overlay

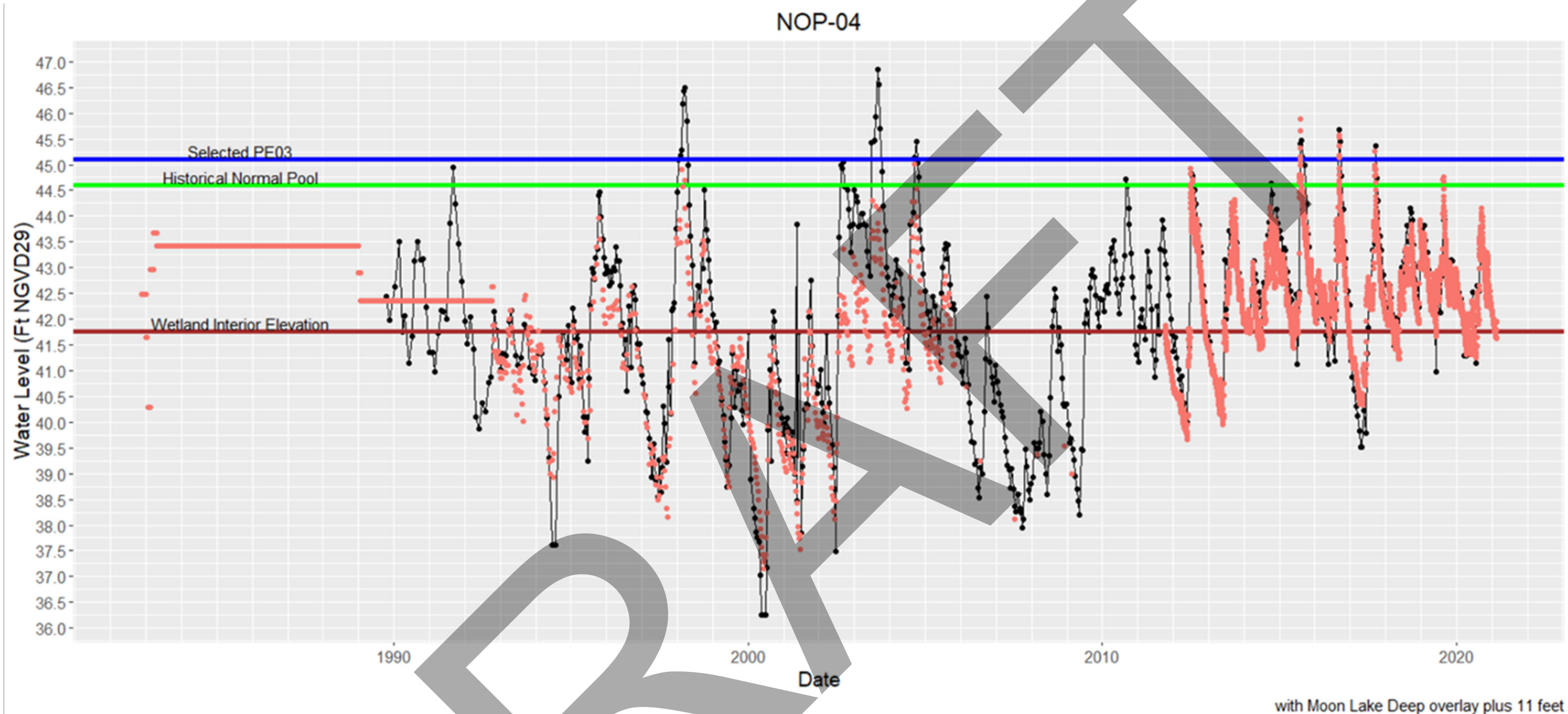


Figure 3.1-29. Hydrograph for 339_NP-04_with Moon Lake Deep (red) overlay

DRAFT

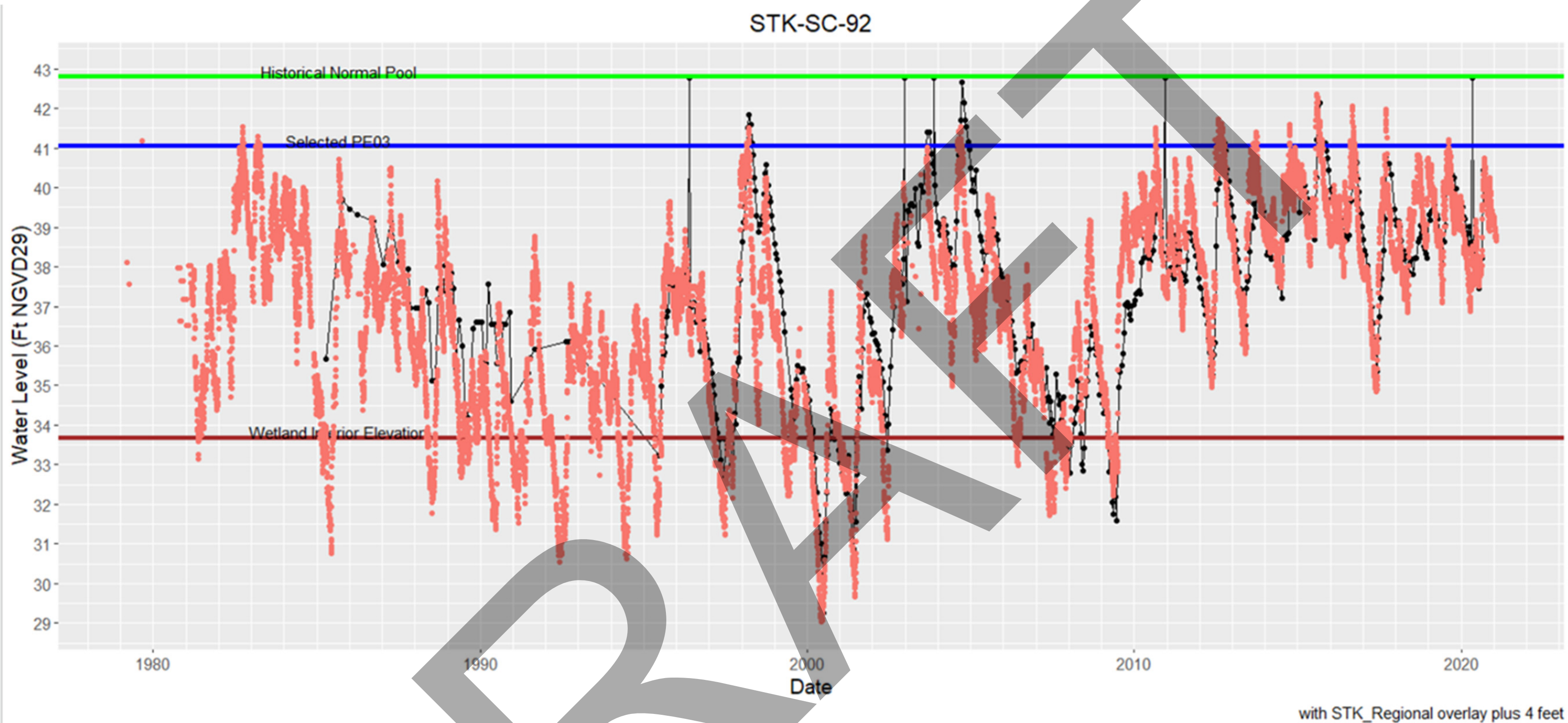


Figure 3.1-30. Hydrograph for 483_SC-92_ with STK Regional (red) overlay

Given the visually-apparent high degree of correspondence between regional aquifer levels and xeric wetland water levels, it appears reasonable to transfer hydrologic modeling results to wetland time series for the purpose of developing reference wetland time series. With reference wetland time series in hand for each site, then overlayed spatially on site topography/bathymetry, we could compare the expected hydropatterns (i.e., depth, duration, and even return interval) to the actual for a recent or historical period. In other words, instead of relying on heuristics assumed to apply to all sites in the WAP such as “less than 6 inches depth represents the transitional zone”, we could allow each xeric wetland to define its own expected hydropatterns and therefore expected habitat type zones (under reference conditions).

How can we translate the remaining modeled SAS drawdown at each site to the percentiles of water level data to estimate a reference water level regime? Some model-based insights are provided by recent work by the SJRWMD as shown in a slide from a recent presentation on the ongoing work (Figure 3.1-31). An HSPF model was calibrated to lake levels with seepage to the Upper Floridan Aquifer (UFA) considered using Darcy Law in the Special Action. Preliminary results suggest that under the modeled UFA drawdown of 4 feet, the effect on lake levels is not equal across the percent exceedances (i.e., high, medium, and low lake levels). Specifically, changes from reference levels (shown as npump in green in Figure 3.1-31) were greatest at the low lake levels such as the P90 (level exceeded 90% of the time) and smallest at the highest lake levels such as the P10 (HSW 2021). Change at the P50 (median lake levels) was intermediate.

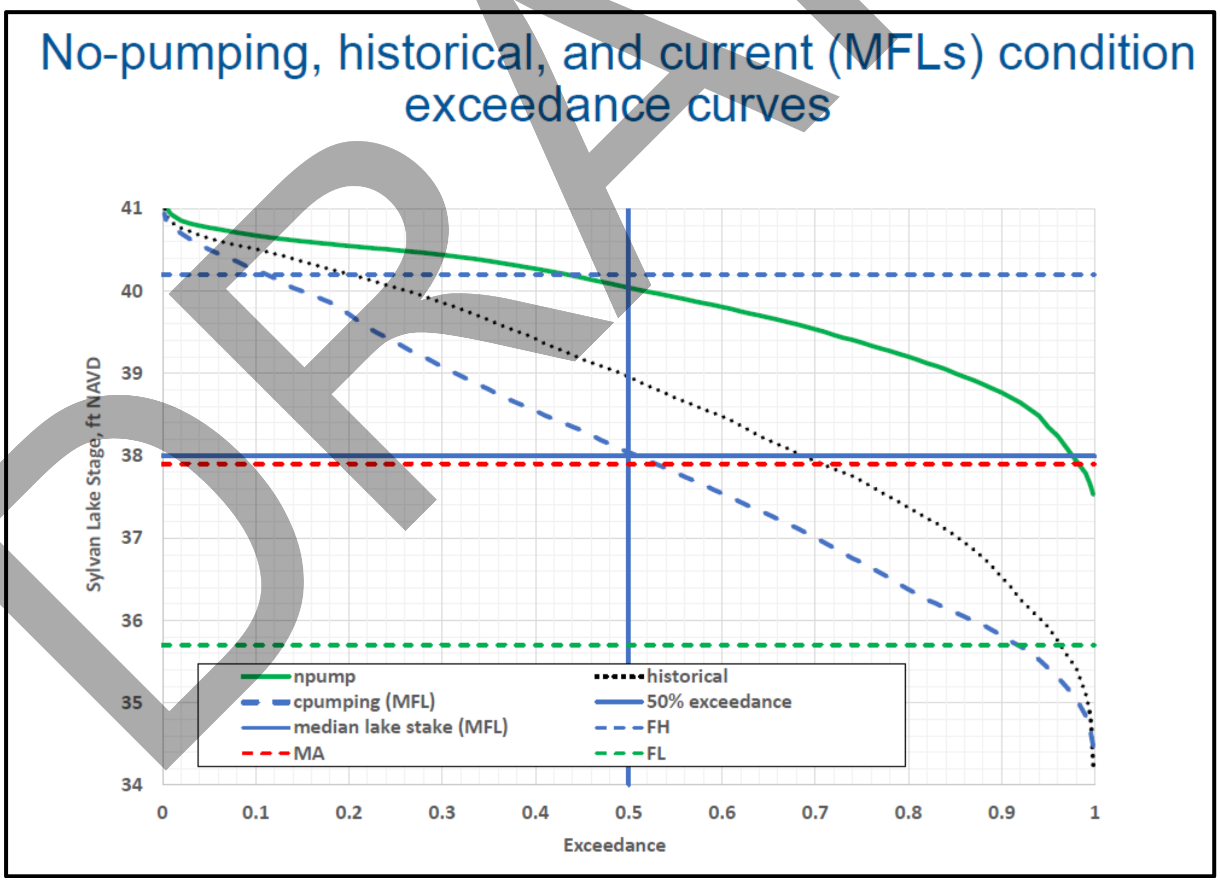


Figure 3.1-31. Draft results for ongoing MFL evaluation for Sylvan Lake by the SJRWMD

Since Tampa Bay Water's SAS modeling results for the 2008-2018 (post cut-back period) show remaining median SAS drawdown (provided in Table 3.1-1), it is reasonable that median (P50) wetland water level reference conditions for xeric sites could be estimated by simply adding back the median drawdown. Although this addresses the P50, it does not provide information about other percentiles of interest such as the P10, P25, P50, P75, P90, etc. In order to estimate how the P50 reference condition change could be translated to other percentiles, we performed analyses on all xeric wetlands with sufficient available data from GPI (2020) which represented 68 sites, as well as more specific evaluations of the three wetlands of interest.

Figure 3.1-32, based on 68 xeric wetlands included in the GPI (2020) analysis, yields results similar although not identical to those expected based on the calibrated model results presented in the previous figure (Figure 3.1-31). Note Figure 3.1-32 summarizes the changes in specific percentiles (P00, P03, P10, P25, P50, P75, P90, and P100) at 68 xeric sites between the pre-cutback period (1996-2002) and post-cutback period (2008-2018). The results are expressed as a percentage of each site's P50 change. Focusing on the middle line of the boxplots, representing the median, we can see that the higher wetland water level percentiles barely changed (e.g., P00 and P03), while the lowest water level percentile (P100) changed more than the P50—almost twice as much. The numbers associated with the medians are summarized in Table 3.1-2. However, the P90 was actually often slightly less than the P50, a finding somewhat inconsistent with the previously discussed model-based expectation.

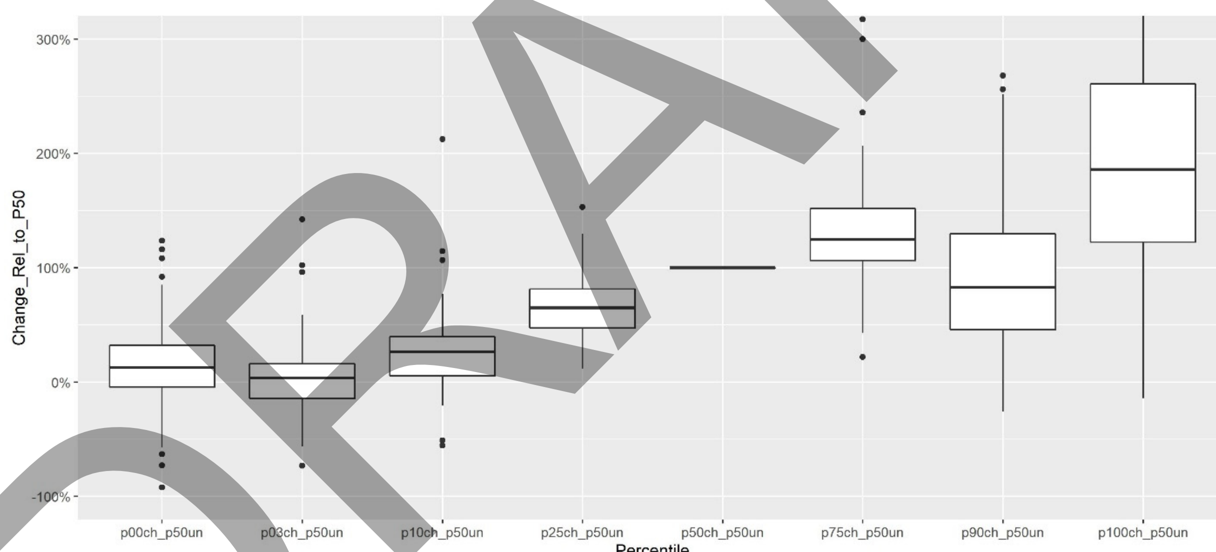


Figure 3.1-32. Boxplot of changes in percentiles for 68 xeric wetlands as percentage of each site's P50 change between 1996-2002 and 2008-2018 time periods

Table 3.1-2. Median changes in water level percentiles pre- and post-cutback at 68 sites as a percentage of each site's P50 change

percentile	as_percent_of_p50_change	n
p00ch_p50un	0.13	68
p03ch_p50un	0.04	68
p10ch_p50un	0.26	68
p25ch_p50un	0.65	68
p50ch_p50un	1.00	68
p75ch_p50un	1.25	68
p90ch_p50un	0.83	68
p100ch_p50un	1.86	68

Similar analyses of changes in percentiles relative to each site's P50 change are provided in Figure 3.1-33 and Table 3.1-3 for the three study sites. Here we can see that the highest water level percentiles mostly show negative numbers (i.e., P10 for one site, P03 for the three sites, and P00 for two of them); this is an artifact of the unusually high water levels that occurred around the 1997/1998 El Nino event falling in the pre-cutback period. It is reasonable to adjust those changes to 0 for the purpose of determining how much these higher water level percentiles would change under a no drawdown (reference) scenario.

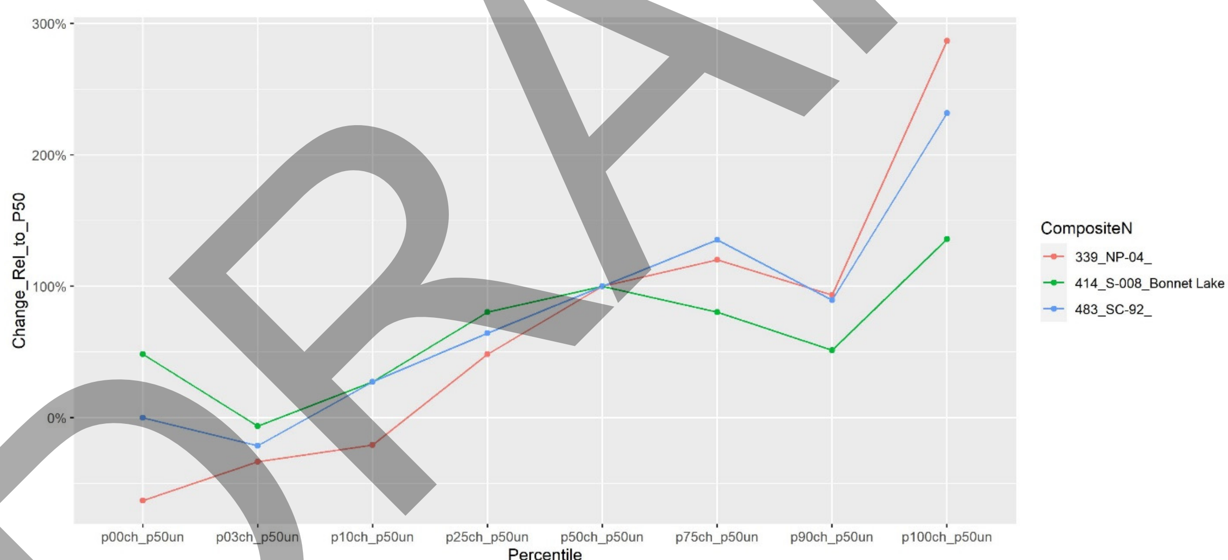


Figure 3.1-33. Changes in percentiles for three study xeric wetlands as percentage of each site's P50 change between 1996-2002 and 2008-2018 time periods

Table 3.1-3. Changes in water level percentiles pre- and post-cutback at three study sites as a percentage of each site's P50 change

Percentile	med_s8	med_np4	med_sc92
p00ch_p50un	0.48	-0.63	0.00
p03ch_p50un	-0.06	-0.33	-0.21
p10ch_p50un	0.27	-0.21	0.27
p25ch_p50un	0.80	0.48	0.64
p50ch_p50un	1.00	1.00	1.00
p75ch_p50un	0.80	1.20	1.36
p90ch_p50un	0.51	0.93	0.89
p100ch_p50un	1.36	2.87	2.32

Using the information outlined in Table 3.1-3, we could develop reference water level percentiles for 414_S-008_Bonnet Lake, for example, as follows. With 1.16 feet of remaining SAS drawdown (Table 3.1-1, based on the median for 2008-2018), we can adjust the recent (post-cutback) P50 (calculated using 2008-2018) upwards by 1.16 feet. We would consider the P10 as shifting upwards only 0.31 feet because that is equal to 0.27 of the P50 change, while the P25 would shift up by 0.80 of the P50 change (equal to 0.93 feet) and so on.

Table 3.1-4 summarizes the percentiles for pre- and post-cutback data as well as the estimated reference percentiles for each of the three study sites. These percentiles are based on all available surface water levels for the periods of analysis. Table 3.1-4 also includes the P03_Selected which was the P03 recommended in GPI (2020) for use in calculating PE03 offsets.

Table 3.1-4. Percentiles for Actual Pre- and Post-cutback Water Levels and Estimated Reference Percentiles

Site	Period	n	HNP	P03_Selected	p03	p10	p25	p50	p75
STK-S-008	Reference	266	31.67	31.34	31.25	30.76	30.55	29.59	27.53
	recent (2008-2018)	266	31.67	31.34	31.25	30.45	29.62	28.43	26.60
	Pre-cutback (1996-2002)	169	31.67	31.34	31.38	29.89	27.98	26.38	24.95
NOP-04	Reference	264	44.60	45.10	44.84	43.93	43.35	42.49	41.51
	recent (2008-2018)	264	44.60	45.10	44.84	43.93	43.29	42.37	41.37
	Pre-cutback (1996-2002)	171	44.60	45.10	45.27	44.19	42.66	41.07	39.81
STK-SC-92	Reference	253	42.80	41.03	41.01	40.50	39.64	38.95	37.94
	recent (2008-2018)	253	42.80	41.03	41.01	40.32	39.22	38.29	37.04
	Pre-cutback (1996-2002)	166	42.80	41.03	41.52	39.67	37.68	35.91	33.82

Using LiDAR derived DEMs, selected percentiles from Table 3.1-4 (P10, P25, P50, and P75) are plotted for two of the three study wetlands and presented in Figures 3.1-34 through 3.1-41. The blue lines in the figures represent the calculated reference water level percentiles; the green lines represent the post-cutback (recent) actual percentiles; and the red lines represent the pre-cutback actual percentiles. The maps provide insights regarding what percentage of the wetland would be inundated under reference conditions at specific percentiles and how this area compares to recent (i.e., post-cutback) or historical (i.e., pre-cutback) conditions. The change in area inundated at specific percentiles could be used as a score, ranging from 0 to 1 for each percentile with 1 representing no reduction in area at that percentile.

For STK-S-008 the reference P10 is expected to be not much different than the post-cutback P10, while the pre-cutback time period (1996-2002) had left a substantial margin around the edge of the site potentially exposed to upland species encroachment. A review of historical aerial photos indicated smaller sand pines were becoming visibly established by 1985 within the wetland area on the edge.

At the P25 percentile (Figure 3.1-35), the northwestern tip of STK-S-008 may still be exposed under post-cutback conditions in comparison to reference conditions, but the current situation is a large improvement over the pre-cutback area inundated at this duration. (The abrupt contour line for the deeper pre-cutback contour is the result of combining manual survey data collected by GPI with available LiDAR-derived DEM information.) At the P50 (Figure 3.1-36) and the P75 (Figure 3.1-37), the post-cutback and reference do not differ greatly due to the steepness of the wetland bathymetry in this range.

Figure 3.1-34. STK-S-008 P10 Reference (blue), Post-cutback (green), Pre-cutback (red)

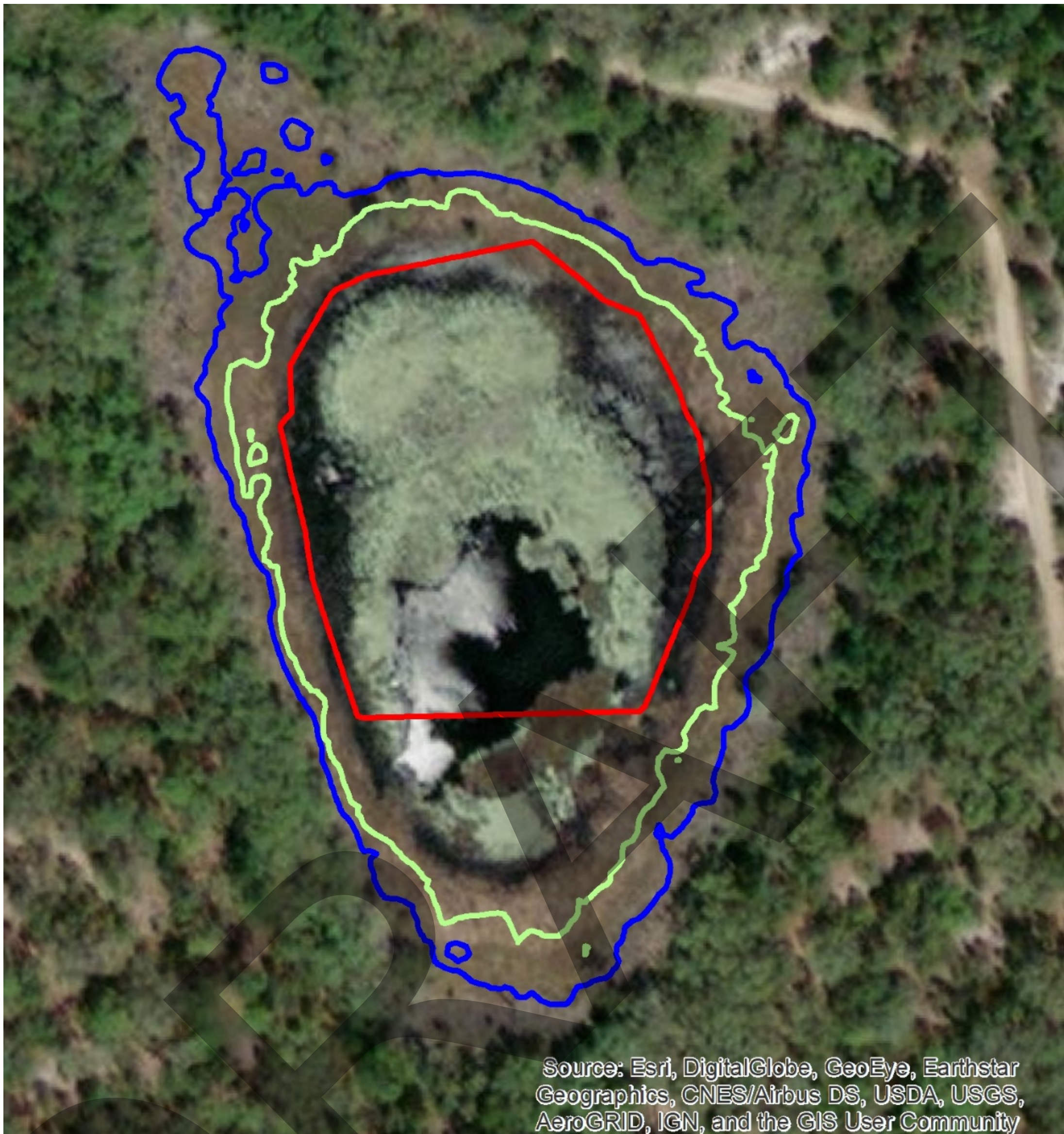


Figure 3.1-35. STK-S-008 P25 Reference (blue), Post-cutback (green), Pre-cutback (red)

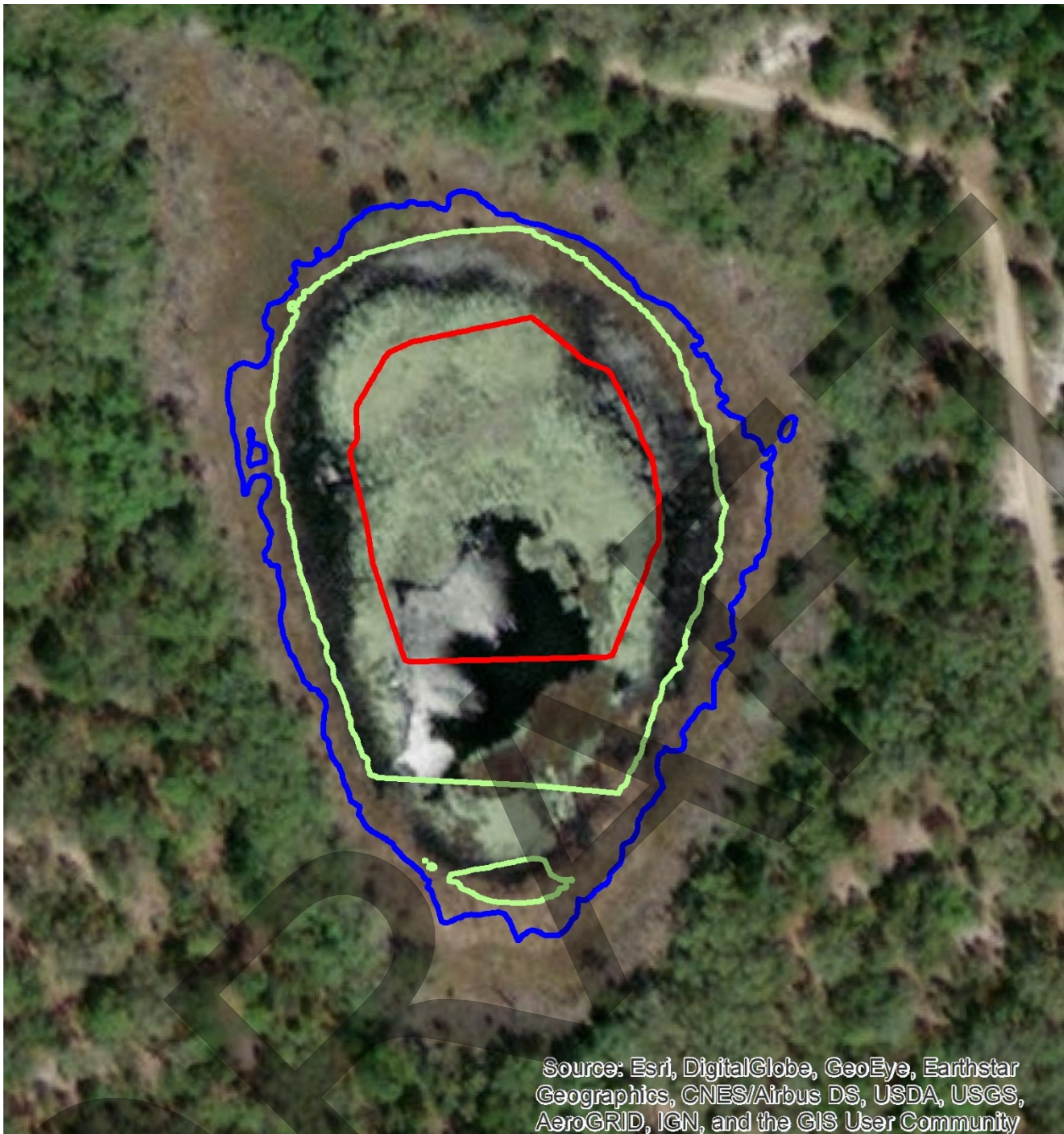


Figure 3.1-36. STK-S-008 P50 Reference (blue), Post-cutback (green), Pre-cutback (red)

Figure 3.1-37. STK-S-008 P75 Reference (blue), Post-cutback (green), Pre-cutback (red)

For NOP-04 the reference P10 was set equivalent to the recent P10 at 43.93 Feet NGVD29 (i.e., zero added to the recent P10), so only the blue line is visible in Figure 3.1-38. The pre-cutback P10 is actually slightly higher at 44.19 Feet NGVD29 due to the 1997/1998 El Nino conditions. Visually, these lines define the edge of the wet prairie system surrounding the cypress dome.

At the P25 percentile (Figure 3.1-39), the reference and post-cutback are nearly identical, but the pre-cutback (red line) leaves most of the wet prairie inundated for a shorter duration. Note that the reason the reference and post-cutback are so similar relates to the fact that there is only 0.12 feet of SAS drawdown remaining at this site, so adding back a percentage of that to the post-cutback yields only a small difference.

At the P50 (Figure 3.1-40) we can see the wet prairie is exposed but the cypress dome is inundated for both the reference condition and the post-cutback, but for the pre-cutback situation—the dome is nearly completely dry. On many of their MFL lakes studies, the SJRWMD has used an elevation near the mean elevation of thick organic soils (i.e., histosols or those with histic epipedon) to define a minimum average level requiring approximately 50% of a year of inundation with a return interval of around 1.5 years to achieve “muck soil maintenance” (Neubauer et al. 2008). It is likely that lower water levels in the past led to the observed signs of soil subsidence seen in the interior of NOP-04 (6-9 inches of subsidence measured in center and 2-3 inches in most interior areas).

The P75 percentile (Figure 3.1-41) was below ground for the pre-cutback (red) condition, but above ground in deeper pockets of the cypress dome under the reference (blue) and post-cutback (green) condition.

Figure 3.1-38. NOP-04 P10 Reference (blue), Post-cutback (green), Pre-cutback (red)

Figure 3.1-39. NOP-04 P25 Reference (blue), Post-cutback (green), Pre-cutback (red)

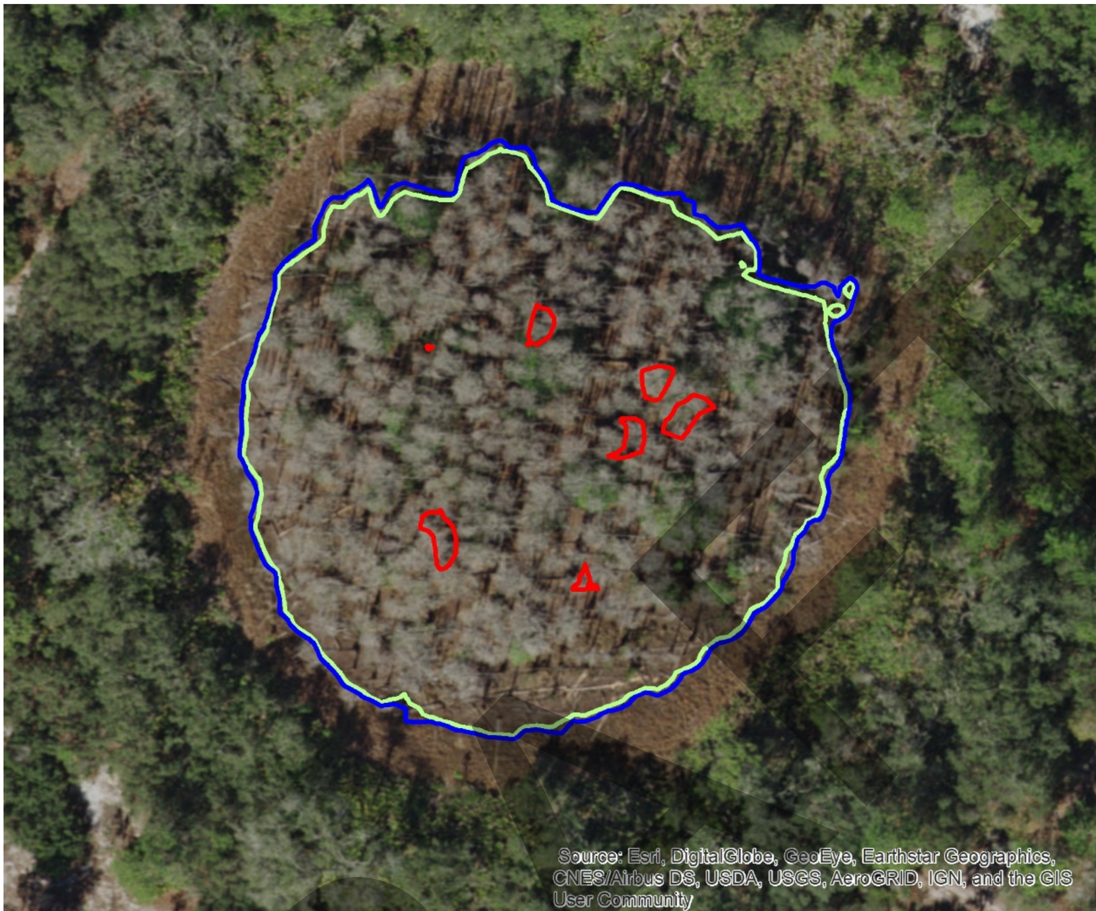


Figure 3.1-40. NOP-04 P50 Reference (blue), Post-cutback (green), Pre-cutback (red)

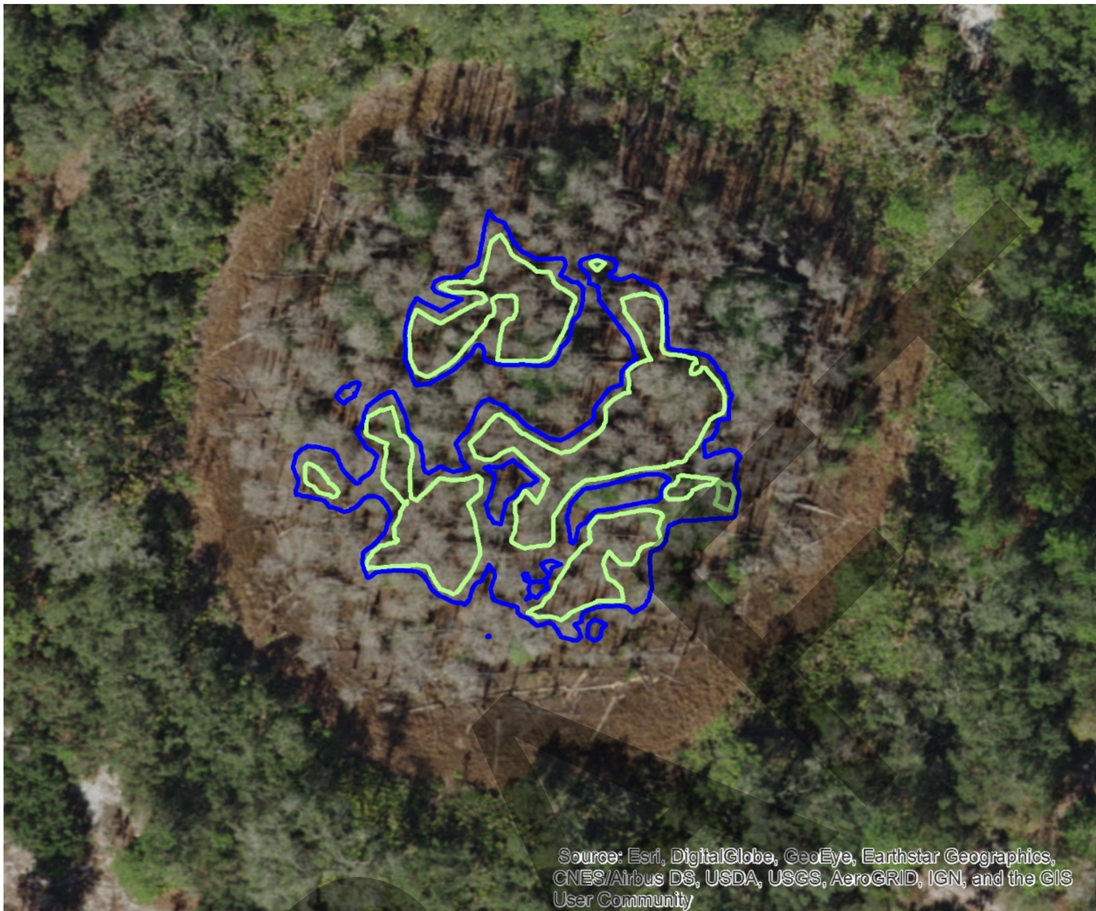


Figure 3.1-41. NOP-04 P75 Reference (blue), Post-cutback (green), Pre-cutback (red)

3.2 Proposed Evaluation Methods

Based on the data gathered and analyzed in this report, combined with insights from a limited field effort, we propose the following methods for evaluation of xeric-associated wetlands. It is assumed that the wetland to be analyzed has sufficient historical water level data and topographic/bathymetric data, as well as groundwater modeling results.

3.2.1 Transect Set-up

1. Develop estimate of Reference wetland hydrology.
    a. Calculate P50 of recent water level data (i.e., 2008-present or best available)
    b. Add back to the P50 the estimated Surficial Aquifer System (SAS) drawdown for the available modeling recent modeling results (e.g., 2008-2018 median). Result is the Reference P50 Elevation.
    c. Other Reference Percentile Elevations are derived using actual measurement of change in percentiles as a function of P50 for the 1996-2002 to 2008-2018 period. For example, if the P10 increased only 33% as much as the P50 between these periods then the Reference P10 would be calculated as SAS drawdown multiplied by 33%, with that amount added to the recent water level data P10.

   d. If data for the wetland related to actual relative change are limited or appear unrepresentative due to rarer events at the extremes, consider using the median relative changes by percentile derived from an analysis of 68 xeric-associated wetlands (Table 3.1-2): P3 (0.04*SAS drawdown), P10 (0.26*SAS drawdown), P50 (1.00*SAS drawdown), P100 (1.86*SAS drawdown).
2. Use Reference Percentile Elevations and survey techniques to establish poles located along a representative transect at the following elevations: P3, P10, P50, P100 (if possible) to facilitate field evaluations during the end of the dry season (April 15 – June 15). The field evaluation will be conducted in three zones: P3-P10, P10-P50, P50-P100.
3. Survey a topographic transect along the transect line to the deepest part of the system. Elevation measurements will be recorded at various length intervals (5 ft, 10 ft, and 20 ft) to adequately characterize the topography and transect features. When possible, additional perpendicular survey transects across the wetland, including the deepest point, are recommended to improve the characterization of the site topography/bathymetry.
4. Determine the expected or known historic FLUCCS type in each zone using a combination of the Reference Percentile Elevations, historical aerial imagery, and current field conditions.
5. Identify soil characteristics by zone using standard USDA-NRCS (2010) methods. The primary focus of the initial soils characterization will be on the depth of organic soils, as well as the extent of hydric soils observed along the field transects (SJRWMD 2006). Methods include removing all loose leaf-matter and other plant parts to expose the soil surface; digging a hole to describe the soil profile to a depth of at least 20 inches and, with the use of the completed soil description, specifying which hydric soil indicators have been matched. The following soil features, if present on the transect, will be identified and the location marked along the transect line so that soil surface elevations can be determined for the following features:
   a. Landward extent of hydric soils
   b. Landward extent of surface organics
   c. Landward extent of histic epipedon (surface organic horizon 8-16 inches thick)
   d. Landward extent of histosols (>16-in thick surface organic horizon)

3.2.2 Wetland Evaluation: GIS

1. Areal changes in the Reference Percentile Zone areas may be used as quantitative measures of changes in expected wetland condition (annually or less frequently)
   a. Use available Digital Elevation Models (DEMs) supplemented with ground and/or remote survey to estimate historic depths and areas of inundation at the Reference Percentile Elevations.
   b. Calculate locations of Recent Percentile Elevations using recent data (e.g., post-cutback period).
   c. Estimate change in area for each Percentile Elevation Zone and provide as a percentage reduction from reference condition.
   d. Consider calculating zone area-weighted change as an overall GIS-based measure of difference from the expected reference condition.

3.2.3 Wetland Evaluation: Field

1. Groundtruthed Wetland Condition may be assessed annually in the April 15 – June 15 end-of-dry-season period using the attached form (provided as a blank form in Appendix A and populated with NOP-04 data in Appendix B).
    a. Take at least six photos at consistent locations at each sampling event. At one of the outer poles (P3 or P10, whichever has the best view of the wetland edge) take photos in three directions (left, waterward, right). The other photos will be taken at the P50 pole in three directions (left, waterward, right) to get a view of the interior of the wetland.
    b. Obtain a staff gauge reading at the gauge in the center of the wetland. If there is no standing water in the wetland, obtain a reading at the central well. Measure water depths at the P3, P10, and P50 marker poles. Estimate the percentage of the wetland area that is inundated with standing water.
    c. If there are any karst features (i.e., sinkholes) within or near the wetland, measure the approximate dimensions (height, width, and depth) and obtain GPS coordinates at each one.
2. Compare whether each zone of interest (i.e., P3-P10, P10-P50, and P50-P100) has a current FLUCCS type consistent with the reference condition. Provide an overall score of stressed (0) or unstressed (1) at the top of the form by zone (half point allowed, i.e., 0.5).
    a. Evaluate specific factors by zone as shown on the attached datasheet. For the vegetation in each stratum, write in the scientific name and FDEP designation (UPL, FAC, FACW, or OBL) for each dominant, co-dominant, and common species as well as all "relevant" species. (We recommend that the FDEP designation eventually be replaced after further research with designations based on quantitative data and autecological studies regarding associations of individual species with habitat type.) Relevant species in this context are either those appropriate for the Reference FLUCCS Habitat Type or inappropriate for the type (entered on separate lines noted as "appropriate" or "inappropriate" for ease of scoring). For relevant species, visually note where within the zone each one occurs (e.g., near the edge or throughout). Each of the following questions will be answered:
        i. Groundcover (abnormal or normal zonation of relevant appropriate and inappropriate species). The emphasis is on identifying those species useful for identifying whether the zone being evaluated is consistent with the Reference FLUCCS condition.
        ii. Shrubs (abnormal or normal zonation of relevant indicator species)
        iii. Trees (abnormal or normal zonation of relevant indicator species, stressed/standing dead, leaning, fallen)
        iv. Soils (annual documentation of subsidence or fissuring). Every five years, repeat the more detailed soils characterization performed during site set-up.
        v. Fire history (year, extent, intensity)
        vi. Recent water level indicators relative to historic in each zone
        vii. Disturbance in each zone

b. The column to the right can be used as a preliminary scoring guide to complete the overall scoring of each assessed zone at the top of the sheet as either 0 (stressed) or 1 (unstressed).
c. Record wetland-dependent wildlife observed and their activities.
d. Provide general comments/explanations regarding overall site observations pertinent to the site evaluation.

4.0 Recommendations for Method Refinement

This report has summarized key methods, findings, and assumptions leading to the development of the proposed wetland evaluation method for xeric-associated wetlands, as well as provided recommendations for method implementation and improvement. We recognize there are many aspects of the method that may benefit from refinement through further research as well as pilot data collection and analyses. The following suggestions are offered as potential areas for refinement.

1. Prepare more detailed instructions relating to each of the items on the field datasheet.
2. Identify a group of xeric-associated sites representing reference or near-reference conditions for use for evaluator training and further method refinement.
3. Develop a training program and implement annual training.
4. Improve available topographic/bathymetric data, consider:
    a. Aerial LiDAR acquisition throughout the study area during an extreme drought.
    b. Drone-based LiDAR or photogrammetry, combined with ground survey to refine topography for specific wetlands.
    c. Traditional survey transects
    d. Sonar collection using watercraft for continuously flooded systems.
5. Develop GIS-based summary of depth/duration inundation characteristics within zones to support FLUCCS classifications.
6. Develop expected groundcover, shrub, and tree lists based on Reference FLUCCS Habitat Type. Potential sources of data include:
    a. Surface Water Inundation Dewatering Signatures from the SJRWMD (including depth, duration, and return interval by habitat type and for selected species)(Epting 2007)
    b. Wetland Plant Zonation Study prepared by GPI for the SWFWMD (GPI Southeast, Inc. 2010)
    c. The Sarasota County T. Mabry Carlton, Jr. Memorial Reserve wet prairie and marsh quadrat dataset
    d. The WAP plant list
    e. Other autecological species-specific research papers
7. Perform additional studies (statistical or water budget model-based) on how groundwater modeling results may best be used in the development of reference percentiles for xeric wetlands.

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Appendix A. Blank Xeric-Associated Wetland Field Evaluation Form

SAMPLE XERIC WETLAND EVALUATION FIELD FORM

Wellfield:	SiteID:	Date:	Firm:	Personnel:
	WID:	Start Time:	Finish Time:	

Photo Documentation

Frame	Photo P	Direction
	P3	W
	P3	NW
	P3	NE
	P50	W
	P50	NW
	P50	E

Water Level Information

Device	Elevation (ft)
P3 pole	
P10 pole	
P50 pole	
Staff gauge	
% Inundated	

Stressed/Unstress 0, 0.5 or 1

Zone	Score
P3 -P10	
P10 - P50	
P50 - P100	
Total Sum:	

Karst Features: (sinkholes)

Dimensions	GPS Coordinates

	Abnormal=0 Normal=1
Zone: P03 - P10 **Length:** **Reference FLUCCS Habitat Type:**	
Current FLUCCS Habitat Type:	
Groundcover (Appropriate):	
Groundcover (Inappropriate):	
Shrubs (Appropriate):	
Shrubs (Inappropriate):	
Trees (Appropriate):	
Trees (Inappropriate):	
Standing Dead/Stressed: (>50%, 10-50%, <10%), **Leaning:** (>25%, 5-25%, <5%), **Fallen:** (>25%, 5-25%, <5%)	
Subsidence/Fissuring (Quantitative):	
Fire History (year, extent, intensity):	
Recent Water Level Indicators Relative to Historic:	
Inundation/Saturation/Soil moisture:	
Disturbance (e.g. dredging, filling, hog rooting, cattle grazing, roads):	
Zone: P10 - P50 **Length:** **Reference FLUCCS Habitat Type:**	
Current FLUCCS Habitat Type:	
Groundcover (Appropriate):	
Groundcover (Inappropriate):	
Shrubs (Appropriate):	
Shrubs (Inappropriate):	
Trees (Appropriate):	
Trees (Inappropriate):	
Standing Dead/Stressed: (>50%, 10-50%, <10%), **Leaning:** (>25%, 5-25%, <5%), **Fallen:** (>25%, 5-25%, <5%)	
Subsidence/Fissuring (Quantitative):	
Fire History (year, extent, intensity):	
Recent Water Level Indicators Relative to Historic:	
Inundation/Saturation/Soil moisture:	
Disturbance (e.g. dredging, filling, hog rooting, cattle grazing, roads):	
Zone: P50 - P100 **Length:** **Reference FLUCCS Habitat Type:**	
Current FLUCCS Habitat Type:	
Groundcover (Appropriate):	
Groundcover (Inappropriate):	
Shrubs (Appropriate):	
Shrubs (Inappropriate):	
Trees (Appropriate):	
Trees (Inappropriate):	
Standing Dead/Stressed: (>50%, 10-50%, <10%), **Leaning:** (>25%, 5-25%, <5%), **Fallen:** (>25%, 5-25%, <5%)	
Subsidence/Fissuring (Quantitative):	
Fire History (year, extent, intensity):	
Recent Water Level Indicators Relative to Historic:	
Inundation/Saturation/Soil moisture:	
Disturbance (e.g. dredging, filling, hog rooting, cattle grazing, roads):	

Wetland-dependent Wildlife (Activities: calling, observed, foraging, track, scat, nest, other)

General Comments/Explanation

Appendix B. Xeric-Associated Wetland Field Evaluation Form Example (NOP-04)

SAMPLE XERIC WETLAND EVALUATION FIELD FORM

Wellfield: NOP	SiteID: NP-4	Date: 2/23/21	Firm: GPI	Personnel: DS/DW
	WID: 339	Start Time: 14:00	Finish Time: 14:45	

Photo Documentation

Frame	Photo Pt	Direction
1	P3	W
2	P3	NW
3	P3	NE
4	P50	W
5	P50	NW
6	P50	E

Water Level Information

Device	Elevation (ft)
P3 pole	0
P10 pole	0
P50 pole	0
Staff gauge	0.81
% Inundated	40%

Stressed/Unstress 0, 0.5 or 1

Zone	Score
P3 -P10	1
P10 - P50	1
P50 - P100	1
Total Sum:	3

Karst Features: (sinkholes)

Dimensions	GPS Coordinates
None	

	Abnormal=0 Normal=1
Zone: P03 - P10 **Length: 0' - 8'** **Reference FLUCCS Habitat Type: 421 - Xeric Oak** **Current FLUCCS Habitat Type: 421 - Xeric Oak**	**1**
Groundcover (Appropriate): Sparse	1
Groundcover (Inappropriate): None	1
Shrubs (Appropriate): Serenoa repens (UPL) dominant and healthy, trunks growing somewhat above ground.	1
Shrubs (Inappropriate): None	1
Trees (Appropriate): None in this zone, mature Quercus virginiana (UPL) upslope.	NA
Trees (Inappropriate): None	NA
Standing Dead/Stressed: (>50%, 10-50%, <10%), **Leaning:** (>25%, 5-25%, <5%), **Fallen:** (>25%, 5-25%, <5%)	NA
Subsidence/Fissuring (Quantitative): None	1
Fire History (year, extent, intensity): Palmetto edge burned in 2014. No new signs.	1
Recent Water Level Indicators Relative to Historic: Below ground	1
Inundation/Saturation/Soil moisture: Moderately coarse texture - 50-75% soil moisture deficiency at 4' along transect	1
Disturbance (e.g. dredging, filling, hog rooting, cattle grazing, roads): No signs in zone.	1
Zone: P10 - P50 **Length: 8' - 40'** **Reference FLUCCS Habitat Type: 643 - Wet Prairie** **Current FLUCCS Habitat Type: 643 - Wet Prairie**	**1**
Groundcover (Appropriate): Amphicarpum muehlenbergianum (FACW) and Xyris elliottii (OBL) co-dominant throughout zone (10' - 40').	1
Groundcover (Inappropriate): Andropogon brachystachyus (FAC) common from 12' - 20'.	0.5
Shrubs (Appropriate): Occasional mature Lyonia lucida (FACW) near upper edge of zone from 8'-12'.	1
Shrubs (Inappropriate): None	1
Trees (Appropriate): None. It is normal to have no trees in this habitat type.	1
Trees (Inappropriate): None.	1
Standing Dead/Stressed: (>50%, 10-50%, <10%), **Leaning:** (>25%, 5-25%, <5%), **Fallen:** (>25%, 5-25%, <5%)	NA
Subsidence/Fissuring (Quantitative): None	1
Fire History (year, extent, intensity): Fire in 2014 burned into P10 - P50 zone. No new signs.	0.5
Recent Water Level Indicators Relative to Historic: No trees or shrubs in this zone to show hydrologic indicators. However, there is very little duff or leaf litter accumulation, suggesting fluctuating water	1
Inundation/Saturation/Soil moisture: Medium texture - 25-50% soil moisture deficiency at 10' along transect, saturation at 35'	1
Disturbance (e.g. dredging, filling, hog rooting, cattle grazing, roads): Historic hog rooting (minimal rooting and wallows) in P10 - P50 zone. No new signs.	1
Zone: P50 - P100 **Length: 40' - 100'** **Reference FLUCCS Habitat Type: 621 - Cypress** **Current FLUCCS Habitat Type: 621 - Cypress**	**1**
Groundcover (Appropriate): Occasional clumps of Woodwardia virginica (FACW) on higher places in center. Small amounts of other FACW and OBL species throughout zone.	1
Groundcover (Inappropriate): Amphicarpum muehlenbergianum (FACW) common near edge (40' - 55').	0.5
Shrubs (Appropriate): Appropriate: Lyonia lucida (FACW) common on hummocks throughout zone. A few mature Litsea aestivalus (OBL) (state endangered) on ground at 50' - 55', many Litsea saplings in interior high spot. Several Taxodium ascendens saplings (OBL) in upper zone from 40' - 60'.	1
Shrubs (Inappropriate): Occasional Ilex cassine (OBL) on ground in upper zone from 40' - 60'.	1
Trees (Appropriate): Dense mature Taxodium ascendens (OBL) throughout zone, smaller trees in upper zone from 40' - 60'. Most trees appear healthy and green, but there are several standing dead and fallen	1
Trees (Inappropriate): None	1
Standing Dead/Stressed: (>50%, 10-50%, **<10%**), **Leaning:** (>25%, 5-25%, **<5%**), **Fallen:** (>25%, **5-25%**, <5%)	0.5
Subsidence/Fissuring (Quantitative): 6-9 inches subsidence measured in center; 2-3 inches in most areas.	0
Fire History (year, extent, intensity): No evidence of fire in interior.	1
Recent Water Level Indicators Relative to Historic: Lichen lines and poorly defined moss collars at similar elevation as poorly-defined historic cypress buttress swelling. Lyonia roots elevations highly variable.	1
Inundation/Saturation/Soil moisture: Inundation begins at 45' along transect	1
Disturbance (e.g. dredging, filling, hog rooting, cattle grazing, roads): None	1

Wetland-dependent Wildlife (Activities: calling, observed, foraging, track, scat, nest, other)

mosquitofish (observed)

General Comments/Explanation

Wetland in good condition, only slight movement of wet prairie species into cypress. Occasional FAC species not far into wet prairie. Moderate soil subsidence and treefall, but not recent.

Exhibit C

Environmental Management Plan

Attachment D

Control Sites for the Environmental Management Plan

WetlandID	TBW_SiteName	WMD_SiteName	wetland type	CTSID	Wellfield	RecoveryStatus	Monitored by
2	CBR-Q02		isolated xeric-associated	1524	CBR	Recovered	TBW
9	CBR-Q10		isolated xeric-associated	1531	CBR	Recovered	TBW
10	CBR-Q12		other	1532	CBR	Recovered	TBW
13	CBR-Q16		isolated xeric-associated	1535	CBR	Recovered	TBW
14	CBR-Q17		isolated xeric-associated	1536	CBR	Recovered	WMD
17	CBR-Q20		isolated xeric-associated	1539	CBR	Recovered	TBW
38	CBR-T08A		isolated xeric-associated	1558	CBR	Recovered	WMD
103	COS-102717		isolated xeric-associated	2968	COS	Recovered	TBW
106	COS-C142717		isolated xeric-associated	2969	COS	Recovered	WMD
107	COS-EC222717		isolated mesic-associated	2972	COS	Recovered	WMD
110	COS-NC262717		isolated xeric-associated	2974	COS	Recovered	WMD
112	COS-NW332717		other	2977	COS	Recovered	TBW
125	CYB-05		isolated mesic-associated	5755	CYB	No Cut Back, Meets Metric	TBW
126	CYB-06		isolated mesic-associated	1468	CYB	No Cut Back, Meets Metric	WMD
127	CYB-09		other	1490	CYB	No Cut Back, Meets Metric	TBW
130	CYB-13		isolated mesic-associated	1507	CYB	No Cut Back, Meets Metric	TBW
131	CYB-14		isolated mesic-associated	1500	CYB	No Cut Back, Meets Metric	TBW
134	CYB-17		isolated mesic-associated	1480	CYB	No Cut Back, Meets Metric	WMD
138	CYB-21		isolated mesic-associated	1494	CYB	No Cut Back, Meets Metric	TBW
139	CYB-22	Trout Creek	connected	5758	CYB	No Cut Back, Meets Metric	TBW
140	CYB-23		isolated mesic-associated	1486	CYB	No Cut Back, Meets Metric	TBW
143	CYB-26	Trout Creek	connected	5759	CYB	No Cut Back, Meets Metric	TBW
147	CYB-30		isolated mesic-associated	1460	CYB	No Cut Back, Meets Metric	WMD
148	CYB-31	Trout Creek	connected	5762	CYB	No Cut Back, Meets Metric	WMD
150	CYB-33		isolated mesic-associated	1478	CYB	No Cut Back, Meets Metric	TBW
151	CYB-34		isolated mesic-associated	1470	CYB	No Cut Back, Meets Metric	TBW
152	CYB-37		connected	5763	CYB	No Cut Back, Meets Metric	TBW
156	CYB-C16		other	1485	CYB	No Cut Back, Meets Metric	WMD
166	CYC-C14		other	1488	CYC	Recovered	TBW
170	CYC-C20		isolated xeric-associated	3616	CYC	Recovered	TBW
178	CYC-C40	Quail Hollow Tributary to Cypress Creek	connected	3638	CYC	Recovered	TBW
181	CYC-C101		isolated xeric-associated	1453	CYC	Recovered	TBW

WetlandID	TBW_SiteName	WMD_SiteName	wetland type	CTSID	Wellfield	RecoveryStatus	Monitored by
187	CYC-W01		connected	3625	CYC	Recovered	TBW
193	CYC-W09		isolated mesic-associated	3623	CYC	Recovered	TBW
194	CYC-W10		connected	1491	CYC	Recovered	TBW
201	CYC-W20		isolated mesic-associated	1508	CYC	Recovered	TBW
207	CYC-W30	Dye's Crossing	connected	11687	CYC	Recovered	WMD
208	W30S	Dye's Crossing	connected	11688	CYC	Recovered	WMD
209	CYC-W31		isolated mesic-associated	1471	CYC	Recovered	TBW
211	CYC-W33		isolated mesic-associated	1458	CYC	Recovered	TBW
213	CYC-W36		isolated mesic-associated	3630	CYC	Recovered	WMD
215	CYC-W39		isolated mesic-associated	1459	CYC	Recovered	TBW
231	CYC-W57		connected	3618	CYC	Recovered	WMD
232	CYC-W58		isolated mesic-associated	3600	CYC	Recovered	TBW
255	ELW-WC102716		connected	2981	ELW	Recovered	TBW
257	MBR-09	Clay Gully	connected	3551	MBR	Recovered	TBW
259	MBR-11		isolated mesic-associated	3553	MBR	Recovered	TBW
265	MBR-36	Wild Hog Slough	connected	3559	MBR	Recovered	TBW
270	MBR-80	Wild Hog Slough	connected	3564	MBR	Recovered	WMD
275	MBR-90		isolated mesic-associated	3567	MBR	Recovered	TBW
287	MBR-106	Wild Hog Slough	connected	3579	MBR	Recovered	TBW
339	NOP-04		isolated xeric-associated	3190	NOP	Recovered	TBW
340	NOP-05		isolated xeric-associated	3191	NOP	Recovered	TBW
371	S21-E182718	Turkey Ford Lake	other	2994	S21	Recovered	TBW
377	NWH-NW012817	Rocky Creek	connected	2996	NWH	Recovered	TBW
378	NWH-NW072818		isolated mesic-associated	3006	NWH	Recovered	TBW
381	NWH-SW082818		isolated mesic-associated	3007	NWH	Recovered	TBW
382	NWH-WC102817		isolated mesic-associated	2997	NWH	Recovered	WMD
387	S21-EC222718		other	3019	S21	Recovered	TBW
393	S21-SE212718		connected	3017	S21	Recovered	TBW
395	S21-WC212718		other	3018	S21	Recovered	TBW
406	SOP-SC162618		connected	3025	SOP	Recovered	TBW
440	STK-S-064		isolated mesic-associated	3250	STK	Recovered	TBW
475	STK-SC-58		isolated xeric-associated	3287	STK	Recovered	TBW
483	STK-SC-92		isolated xeric-associated	3295	STK	Recovered	TBW

WetlandID	TBW_SiteName	WMD_SiteName	wetland type	CTSID	Wellfield	RecoveryStatus	Monitored by
489	STK-T-09		other	3280	STK	Never Impacted	TBW
544	Cross Bar 6		lake		CBR	Recovered	TBW

Exhibit C

Environmental Management Plan

Attachment E

Reference Sites for the Environmental Management Plan

Wetland ID	TBW Site Name	WMD Site Name	Wetland Type	CTSID	Wellfield	Recovery Status	Monitored by
105	COS-C042817		connected	2978	COS	Recovered	TBW
108	COS-EC332717		connected	2976	COS	Recovered	TBW
114	COS-SC332717		connected	2966	COS	Recovered	TBW
116	COS-SE142717		connected	2970	COS	Recovered	TBW
135	CYB-18		connected	5757	CYB	No Cut Back, Meets Metric	TBW
145	CYB-28		connected	5760	CYB	No Cut Back, Meets Metric	TBW
154	CYB-C10		connected	5764	CYB	No Cut Back, Meets Metric	TBW
155	CYB-C12		connected	5765	CYB	No Cut Back, Meets Metric	TBW
179	CYC-C100		connected	3598	CYC	Recovered	TBW
183	CYC-C103		connected	3633	CYC	Recovered	TBW
169	CYC-C19		connected	3599	CYC	Recovered	TBW
176	CYC-C33		connected	3603	CYC	Recovered	TBW
177	CYC-C39		connected	3608	CYC	Recovered	TBW
180	CYC-W25		connected	3607	CYC	Recovered	TBW
284	MBR-103		connected	3576	MBR	Recovered	TBW
285	MBR-104		connected	3577	MBR	Recovered	TBW
269	MBR-79	MBWF Sawgrass Marsh	connected	3563	MBR	Recovered	SWFWMD
	Five Mile Creek		connected		NOP	NA	USGS
380	NWH-SC062818		connected	3004	NWH	Recovered	TBW
384	S21-322718		connected	3022	S21	Recovered	TBW
388	S21-NC092718		connected	3011	S21	Recovered	TBW
398	SOP-PC282618	SPWF - 1	connected	3026	SOP	Recovered	SWFWMD
399	SOP-PT322618	SPWF - 3	connected	3029	SOP	Recovered	SWFWMD
400	SOP-PTC332618		connected	3032	SOP	Recovered	TBW
442	STK-S-067	STWF P	connected	3252	STK	Recovered	SWFWMD
504	STWF V		connected	6603	STK	Recovered	SWFWMD
502	Starkey O		connected	6601	STK	Recovered	SWFWMD
490	STK-T-10		connected	3281	STK	Never Impacted	TBW
233	CCS-5		connected	6564		Recovered	SWFWMD
314	Cypress Creek ELAPP Riverine		connected	6586		Recovered	SWFWMD
241	Mertz Riverine		connected	6572		Recovered	SWFWMD

Wetland ID	TBW Site Name	WMD Site Name	Wetland Type	CTSID	Wellfield	Recovery Status	Monitored by
104	COS-162717		isolated mesic-associated	2971	COS	Recovered	TBW
162	CYC-C06		isolated mesic-associated	1475	CYC	Recovered	TBW
185	CYC-C105		isolated mesic-associated	1504	CYC	Recovered	TBW
164	CYC-C11		isolated mesic-associated	1482	CYC	Recovered	TBW
174	CYC-C24		isolated mesic-associated	1474	CYC	Recovered	TBW
243	ELW-C132716		isolated mesic-associated	2985	ELW	Recovered	TBW
244	ELW-EC112716	EWWF 1	isolated mesic-associated	2982	ELW	Recovered	SWFWMD
245	ELW-NC222716	Pine Ridge Cypress Dome	isolated mesic-associated	2986	ELW	Recovered	SWFWMD
251	ELW-SC272716	Lansbrook East	isolated mesic-associated	2987	ELW	Recovered	SWFWMD
277	MBR-93		isolated mesic-associated	3569	MBR	Recovered	TBW
278	MBR-94		isolated mesic-associated	3570	MBR	Recovered	TBW
279	MBR-96		isolated mesic-associated	3571	MBR	Recovered	TBW
352	NOP-21		isolated mesic-associated	3203	NOP	Recovered	SWFWMD
346	NOP-11		isolated mesic-associated	3197	NOP	Never Impacted	TBW
344	NOP-09		isolated mesic-associated	3195	NOP	Never Impacted	TBW
353	NOP-22		isolated mesic-associated	3204	NOP	Never Impacted	TBW
358	NOP-30		isolated mesic-associated	3208	NOP	Never Impacted	TBW
367	NWH-142817		isolated mesic-associated	3000	NWH	Recovered	TBW
394	S21-SW292718		isolated mesic-associated	3021	S21	Recovered	TBW
396	S21-WC342718		isolated mesic-associated	3023	S21	Recovered	TBW
402	SOP-PC332618	SPWF South Cypress	isolated mesic-associated	3030	SOP	Recovered	SWFWMD
403	SOP-PSE282618	SPWF - 6	isolated mesic-associated	3027	SOP	Recovered	SWFWMD
404	SOP-PSW332618		isolated mesic-associated	3031	SOP	Recovered	TBW
405	SOP-PTE332618	SPWF - 2	isolated mesic-associated	3033	SOP	Recovered	SWFWMD
397	SOP-NE152618		isolated mesic-associated	3024	SOP	Never Impacted	TBW
428	STK-S-039		isolated mesic-associated	3237	STK	Recovered	TBW
429	STK-S-042		isolated mesic-associated	3238	STK	Recovered	TBW
433	STK-S-052		isolated mesic-associated	3242	STK	Recovered	TBW
435	STK-S-054	STWF L	isolated mesic-associated	3244	STK	Recovered	SWFWMD
436	STK-S-055		isolated mesic-associated	3245	STK	Recovered	TBW
438	STK-S-062		isolated mesic-associated	3248	STK	Recovered	TBW

Wetland ID	TBW Site Name	WMD Site Name	Wetland Type	CTSID	Wellfield	Recovery Status	Monitored by
441	STK-S-065	STWF S	isolated mesic-associated	3251	STK	Recovered	SWFWMD
459	STK-S-095		isolated mesic-associated	3269	STK	Recovered	TBW
461	STK-S-097		isolated mesic-associated	3271	STK	Recovered	TBW
462	STK-S-099		isolated mesic-associated	3272	STK	Recovered	TBW
484	STK-STWF- Central-01		isolated mesic-associated	3214	STK	Recovered	SWFWMD
487	STK-STWF- Z		isolated mesic-associated	3217	STK	Recovered	SWFWMD
447	STK-S-073	STWF Eastern	isolated mesic-associated	3257	STK	Never Impacted	SWFWMD
465	STK-S-109	STWF FF	isolated mesic-associated	3275	STK	Never Impacted	SWFWMD
445	STK-S-070		isolated mesic-associated	3255	STK	Never Impacted	TBW
448	STK-S-074		isolated mesic-associated	3258	STK	Never Impacted	TBW
456	STK-S-089		isolated mesic-associated	3266	STK	Never Impacted	TBW
464	STK-S-108		isolated mesic-associated	3274	STK	Never Impacted	TBW
488	STK-T-07		isolated mesic-associated	3279	STK	Never Impacted	TBW
478	STK-SC-67		isolated mesic-associated	3290	STK	Never Impacted	TBW
482	STK-SC-71		isolated mesic-associated	3294	STK	Never Impacted	TBW
443	STK-S-068	STWF DD	isolated mesic-associated	3253	STK	Never Impacted	SWFWMD
444	STK-S-069	STWF M	isolated mesic-associated	3254	STK	Never Impacted	SWFWMD
450	STK-S-076	STWF R	isolated mesic-associated	3260	STK	Never Impacted	SWFWMD
449	STK-S-075	STWF S-75	isolated mesic-associated	3259	STK	Never Impacted	SWFWMD
240	Correctional Facility Cypress Marsh		isolated mesic-associated	6571		Recovered	SWFWMD
239	Correctional Facility Cypress		isolated mesic-associated	6570		Recovered	SWFWMD
42	PASCO TRAILS		isolated mesic-associated	11667		Recovered	SWFWMD
242	Pheasant Run (Quail Hollow) Cypress		isolated mesic-associated	6573		Recovered	SWFWMD
408	Rt 54 Nelson		isolated mesic-associated	6588		Recovered	SWFWMD
	Green Swamp 1		isolated mesic-associated			NA	SWFWMD
	Green Swamp 2		isolated mesic-associated			NA	SWFWMD
	Green Swamp 3		isolated mesic-associated			NA	SWFWMD
	Green Swamp 4		isolated mesic-associated			NA	SWFWMD
	Green Swamp 5		isolated mesic-associated			NA	SWFWMD
	Green Swamp 6		isolated mesic-associated			NA	SWFWMD

Wetland ID	TBW Site Name	WMD Site Name	Wetland Type	CTSID	Wellfield	Recovery Status	Monitored by
	Green Swamp 7		isolated mesic-associated			NA	SWFWMD
	HRSP Cypress		isolated mesic-associated			NA	SWFWMD
52	CNR-C5		isolated mesic-associated			NA	TBW
53	CNR-C6C		isolated mesic-associated			NA	TBW
55	CNR-C7	Cone Ranch Cypress 3	isolated mesic-associated			NA	SWFWMD
345	NOP-10		isolated xeric-associated	3196	NOP	Recovered	TBW
350	NOP-17		isolated xeric-associated	3201	NOP	Recovered	TBW
351	NOP-18		isolated xeric-associated	3202	NOP	Never Impacted	TBW
362	NOP-36		isolated xeric-associated	3212	NOP	Never Impacted	TBW
372	NWH-EC072818		isolated xeric-associated	3005	NWH	Recovered	TBW
379	NWH-SC042818		isolated xeric-associated	3003	NWH	Recovered	TBW
401	SOP-PSW282618		isolated xeric-associated	3028	SOP	Recovered	TBW
411	STK-S-005	STWF A	isolated xeric-associated	3219	STK	Recovered	SWFWMD
412	STK-S-006	STWF Q	isolated xeric-associated	3220	STK	Recovered	SWFWMD
418	STK-S-016		isolated xeric-associated	3226	STK	Recovered	TBW
420	STK-S-020	STWF E	isolated xeric-associated	3228	STK	Recovered	SWFWMD
421	STK-S-023	STWF H	isolated xeric-associated	3229	STK	Recovered	SWFWMD
424	STK-S-031		isolated xeric-associated	3233	STK	Recovered	TBW
425	STK-S-035		isolated xeric-associated	3234	STK	Recovered	TBW
427	STK-S-038	STWF J	isolated xeric-associated	3236	STK	Recovered	SWFWMD
454	STK-S-084		isolated xeric-associated	3264	STK	Recovered	TBW
415	STK-S-010	STWF CC	isolated xeric-associated	3233	STK	Never Impacted	SWFWMD
471	STK-SC-30		isolated xeric-associated	3284	STK	Never Impacted	TBW
476	STK-SC-59		isolated xeric-associated	3287	STK	Never Impacted	TBW
495	River Ridge High School		isolated xeric-associated	6594		Recovered	SWFWMD
9	CBR-Q10		isolated xeric-associated	1531	CBR	Recovered	TBW
17	CBR-Q20		isolated xeric-associated	1539	CBR	Recovered	TBW
21	CBR-Q24		isolated xeric-associated	1543	CBR	Recovered	TBW
106	COS-C142717		isolated xeric-associated	2969	COS	Recovered	TBW
110	COS-NC262717		isolated xeric-associated	2974	COS	Recovered	TBW
181	CYC-C101		isolated xeric-associated	1453	COS	Recovered	TBW

Wetland ID	TBW Site Name	WMD Site Name	Wetland Type	CTSID	Wellfield	Recovery Status	Monitored by
170	CYC-C20		isolated xeric-associated	3616	CYC	Recovered	TBW
493	J.B. Starkey 3		isolated xeric-associated	6592	STK	Recovered	SWFWMD
339	NOP-04		isolated xeric-associated	3190	NOP	Recovered	TBW
340	NOP-05		isolated xeric-associated	3191	NOP	Recovered	TBW

Exhibit C

Environmental Management Plan

Attachment F

Treatment Sites for the Environmental Management Plan

WetlandID	TBW_SiteName	WMD_SiteName	Wetland Type	CTSID	Wellfield	RecoveryStatus	Monitored by
1	CBR-Q01	CBARWF Q-1	isolated mesic-associated	1523	CBR	Improved, Not Fully Recovered	TBW
5	CBR-Q05		isolated xeric-associated	1527	CBR	Improved, Not Fully Recovered	WMD
6	CBR-Q06	Kitchen Sink	isolated xeric-associated	1528	CBR	Improved, Not Fully Recovered	TBW
7	CBR-Q07		isolated xeric-associated	1529	CBR	Improved, Not Fully Recovered	TBW
8	CBR-Q08		isolated xeric-associated	1530	CBR	Improved, Not Fully Recovered	TBW
11	CBR-Q14		isolated mesic-associated	1533	CBR	Improved, Not Fully Recovered	TBW
12	CBR-Q15		isolated xeric-associated	1534	CBR	Improved, Not Fully Recovered	TBW
16	C25		isolated mesic-associated	1463	CYC	Improved, Not Fully Recovered	WMD
18	CBR-Q21		isolated mesic-associated	1540	CBR	Improved, Not Fully Recovered	TBW
22	CBR-Q25	CBARWF Stop #7	isolated mesic-associated	1544	CBR	Improved, Not Fully Recovered	WMD
23	CBR-Q26		isolated xeric-associated	1545	CBR	Improved, Not Fully Recovered	TBW
34	CBR-T01		isolated xeric-associated	1554	CBR	Improved, Not Fully Recovered	TBW
35	CBR-T02A		isolated xeric-associated	1555	CBR	Improved, Not Fully Recovered	TBW
39	CBR-T10		isolated mesic-associated	1559	CBR	Improved, Not Fully Recovered	TBW
113	COS-SC272717	Cosme WF Wetland	isolated mesic-associated	2975	COS	Improved, Not Fully Recovered	WMD
132	CYB-15		isolated mesic-associated	1464	CYB	Not Fully Recovered, Continued Wellfield Impact	TBW

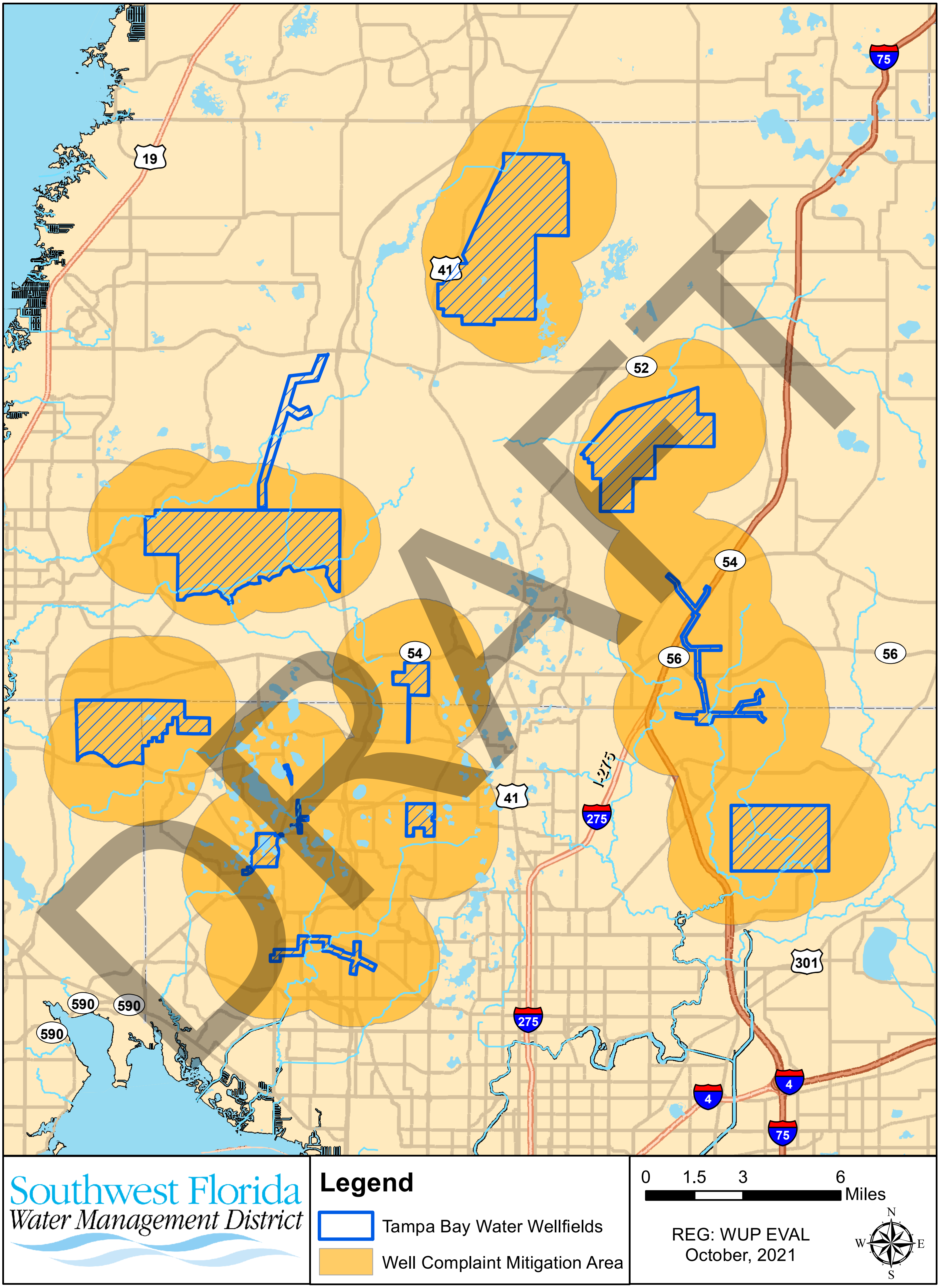
WetlandID	TBW_SiteName	WMD_SiteName	Wetland Type	CTSID	Wellfield	RecoveryStatus	Monitored by
153	CYB-A	CBRWF A	isolated mesic-associated	1493	CYB	Not Fully Recovered, Continued Wellfield Impact	TBW
163	C08	Cypress Creek @ SR52	connected	3615	CYC	Improved, Not Fully Recovered	TBW
182	CYC-C102	Quail Hollow Elementary School	isolated mesic-associated	1461	CYC	Improved, Not Fully Recovered	TBW
184	CYC-C104	Patty Fesmire Site	isolated mesic-associated	1496	CYC	Improved, Not Fully Recovered	TBW
188	W02A		isolated mesic-associated	1499	CYC	Improved, Not Fully Recovered	TBW
189	CYC-W03	CCWF W-3 Marsh	isolated mesic-associated	1505	CYC	Improved, Not Fully Recovered	TBW
196	CYC-W12	CC W-12 Sentry Wet'l.	isolated mesic-associated	1476	CYC	Improved, Not Fully Recovered	TBW
198	CYC-W16	CCWF "D"	isolated mesic-associated	1455	CYC	Not Fully Recovered, Continued Wellfield Impact	WMD
200	CYC-W19	W-19	isolated mesic-associated	1501	CYC	Improved, Not Fully Recovered	WMD
204	CYC-W23		isolated mesic-associated	1487	CYC	Improved, Not Fully Recovered	WMD
205	CYC-W27		isolated mesic-associated	3636	CYC	Improved, Not Fully Recovered	WMD
210	CYC-W32		isolated mesic-associated	1479	CYC	Not Fully Recovered, Continued Wellfield Impact	TBW
214	CYC-W37	CCWF "C"	isolated mesic-associated	3602	CYC	Improved, Not Fully Recovered	TBW
216	CYC-W40	CCWF X-1	isolated mesic-associated	1497	CYC	Improved, Not Fully Recovered	TBW
217	CYC-W41	CCWF W-41	isolated mesic-associated	1502	CYC	Improved, Not Fully Recovered	TBW

WetlandID	TBW_SiteName	WMD_SiteName	Wetland Type	CTSID	Wellfield	RecoveryStatus	Monitored by
220	CYC-W43	East Tributary	connected	3637	CYC	Improved, Not Fully Recovered	TBW
221	CYC-W44	CCS-3 Snake Crossing	connected	3597	CYC	Improved, Not Fully Recovered	WMD
222	CYC-W45	CCWF X-2	isolated mesic-associated	1481	CYC	Not Fully Recovered, Continued Wellfield Impact	TBW
223	CYC-W46	CCWF "B"	isolated mesic-associated	1489	CYC	Improved, Not Fully Recovered	WMD
227	CYC-W51		connected	3639	CYC	Improved, Not Fully Recovered	TBW
228	CYC-W52		isolated mesic-associated	1466	CYC	Improved, Not Fully Recovered	TBW
229	CYC-W55		isolated mesic-associated	1473	CYC	Not Fully Recovered, Continued Wellfield Impact	TBW
230	CYC-W56	CCWF "G'	isolated mesic-associated	3300	CYC	Improved, Not Fully Recovered	TBW
234	CCWF "F"	CYPRESS CREEK F, CCWF "F"	isolated mesic-associated	6565	CYC	Not Fully Recovered, Continued Wellfield Impact	WMD
235	Conners Cypress Marsh	Conners Cypress Marsh	isolated mesic-associated	6566	CYC	Improved, Not Fully Recovered	WMD
249	ELW-NW062717	EWWF East (Lk. Dan) Cypress	isolated mesic-associated	2990	ELW	Improved, Not Fully Recovered	TBW
252	ELW-SW062717		isolated xeric-associated	2991	ELW	Improved, Not Fully Recovered	WMD
254	ELW-SW272716	Lansbrook West	isolated mesic-associated	2988	ELW	Impacted Due to Other Causes	WMD
258	MBR-10		isolated mesic-associated	3552	MBR	Not Fully Recovered, Continued Wellfield Impact	WMD

WetlandID	TBW_SiteName	WMD_SiteName	Wetland Type	CTSID	Wellfield	RecoveryStatus	Monitored by
262	MBR-29	MBWF South Cypress Marsh	isolated mesic-associated	3556	MBR	Improved, Not Fully Recovered	WMD
263	MBR-30		isolated mesic-associated	3557	MBR	Improved, Not Fully Recovered	TBW
266	MBR-37		isolated mesic-associated	3560	MBR	Improved, Not Fully Recovered	TBW
273	MBR-88	MBWF Clay Gully Cypress	isolated mesic-associated	3565	MBR	Improved, Not Fully Recovered	TBW
276	MBR-91		isolated mesic-associated	3568	MBR	Improved, Not Fully Recovered	WMD
280	MBR-97		isolated mesic-associated	3572	MBR	Improved, Not Fully Recovered	TBW
281	MBR-98		isolated mesic-associated	3573	MBR	Improved, Not Fully Recovered	TBW
283	MBR-102	Clay Gully	connected	3575	MBR	Improved, Not Fully Recovered	WMD
286	MBR-105	Clay Gully	connected	3578	MBR	Improved, Not Fully Recovered	TBW
290	East Branch Clay Gully	East Branch Clay Gully	connected	6576	MBR	Improved, Not Fully Recovered	WMD
291	MBWF East Cypress Marsh	MBWF East Cypress Marsh	isolated mesic-associated	6577	MBR	Improved, Not Fully Recovered	WMD
292	MBWF Trout Creek Marsh	MBWF Trout Creek Marsh	isolated mesic-associated	6578	MBR	Improved, Not Fully Recovered	WMD
295	MBWF X-1	MBWF X-1	isolated mesic-associated	6581	MBR	Improved, Not Fully Recovered	WMD
342	NOP-07		isolated mesic-associated	3193	NOP	Improved, Not Fully Recovered	WMD
383	S21-272718		isolated mesic-associated	3020	S21	Improved, Not Fully Recovered	TBW
390	S21-NE212718		isolated mesic-associated	3015	S21	Improved, Not Fully Recovered	TBW

WetlandID	TBW_SiteName	WMD_SiteName	Wetland Type	CTSID	Wellfield	RecoveryStatus	Monitored by
431	STK-S-046		isolated xeric-associated	3240	STK	Improved, Not Fully Recovered	TBW
434	STK-S-053		isolated mesic-associated	3243	STK	Improved, Not Fully Recovered	TBW
439	STK-S-063		isolated mesic-associated	3249	STK	Improved, Not Fully Recovered	TBW
451	STK-S-080		isolated xeric-associated	3261	STK	Improved, Not Fully Recovered	TBW
468	STK-S-113		isolated mesic-associated	3278	STK	Improved, Not Fully Recovered	WMD
491	Anclote South Wet Prairie	Anclote South Wet Prairie	isolated mesic-associated	6590	STK	Improved, Not Fully Recovered	WMD
496	Starkey Wet Prairie	Starkey Wet Prairie	isolated mesic-associated	6595	STK	Improved, Not Fully Recovered	WMD
542	Lost Lake		Lake		CBR	Improved, Not Fully Recovered	TBW

Exhibit F
Well Complaint Mitigation Map


DRAFT
19
41
52
54
54
56
56
41
I-275
275
275
75
75
4
4
301
590
590
590
Southwest Florida
Water Management District
Legend
Tampa Bay Water Wellfields
Well Complaint Mitigation Area
0 1.5 3 6
Miles
REG: WUP EVAL
October, 2021
N
S
E
W