Chapter 1B: Strategies for Reengineering Water Quality Monitoring in South Florida

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SUMMARY

The water quality monitoring networks in South Florida represent a loose confederation of stations from programs and projects driven by various mandates and needs. Water quality monitoring by the South Florida Water Management District includes about 2,000 stations and 35,000 sampling events each year, and costs about $18 million annually. This effort is expected to increase by at least 30 percent as new projects are completed for the comprehensive restoration of the Everglades and surrounding watersheds. Faced with escalating costs and increasing demand for monitoring, the District needs to approach monitoring from entirely new directions. The ultimate goal of this reengineering is a less costly monitoring system that provides the same – or better – information on the status of the ecosystem and the performance of restoration components.

The National Water Quality Monitoring Council has developed a monitoring framework with six activity areas or “cogs” that guide monitoring plans. Current reengineering efforts will focus on just two: “Develop monitoring objectives” and “Design monitoring program”. These two cogs set the stage for all other activities in a reengineered information system. In order to “Develop monitoring objectives”, information needs must be clearly defined. Essential information needed from water quality monitoring in South Florida can be summarized in two broad objectives: determine the quality of waters in the region, quantifying any changes through time; and assess the effectiveness of environmental management and water quality control programs.

Lessons learned from other monitoring programs are being applied to water quality monitoring in Water Conservation Area 2A (WCA-2A). Our review of monitoring at water management structures quickly identified a wasteful practice: field crews are currently dispatched every other week to structures and take samples from those with observed flow. If the crew does not observe water flowing, then no sample is taken and the trip is wasted. Under a proposed sampling regime, called ‘biweekly if recorded flow’, crews will only be dispatched to sample at structures where flow has been recorded within the previous two weeks. This new regime would decrease the number of field trips and increase the number of samples collected during flow events.

The reengineered approach to monitoring water management structures was tested using flow records over the past four years at the S-10s, structures that move water into WCA-2A. The results of this test were promising: all flow events were sampled; consistent monthly data were provided; and the amount of usable data for the S-10 structures was increased. At the same time,

the reengineered proposal decreased the number of field trips substantially. In fact, when applied to all structures surrounding WCA-2A, triggering sampling from flow data could decrease field trips by over 50 percent, a major potential cost savings. The next phase of the WCA-2A test case will be an examination of the water quality monitoring in the marsh itself. The number of factors that must be considered is greater for marsh sampling and deciding on a core, mission-driven network will be involve substantial input from internal staff and from an interagency working group. Along the way, other issues need to be addressed such as the use of one database and one set of standard methods, an optimal sampling frequency and set of stations to meet information needs; and finding ways to satisfy secondary data users to the maximum extent possible. Collectively, the experience gained rethinking water quality monitoring in WCA-2A will guide future reengineering efforts for monitoring in other geographic areas of South Florida.

INTRODUCTION: A BASIS FOR REENGINEERING

The water quality monitoring networks in South Florida (**Figure 1B-1**) represent a loose confederation of programs initiated under various auspices and time frames, some described across many chapters in the *2008 South Florida Environmental Report – Volume I* . Water quality monitoring by the South Florida Water Management District (SFWMD or District) encompasses about 2,000 stations with 35,000 sampling events and a cost of about $18 million per year. This enormous effort is expected to increase by 30 percent as new projects are completed for the long-term restoration of South Florida over the next decade (please see Chapter 8 of this volume). This estimated increase is highly conservative in that it does not include the increased monitoring required for (1) future implementation of multiple Total Maximum Daily Loads (TMDLs) currently being developed for the region, (2) new National Pollutant Discharge Elimination System (NPDES) permits that may be required from ongoing federal litigation, and (3) other new initiatives such as Northern Everglades (see Chapter 10 of this volume). To justify and sustain water quality monitoring at this massive scale requires that responsible agency managers and the District's Governing Board have confidence that the monitoring system is optimized to meet legal, scientific, and management needs with an efficient flow of information to decision makers.

To provide integrative information from data derived from the networks shown in **Figure 1B-1** requires using data generated by varying periods of monitoring, taken at differing frequencies at locations determined from local needs without due consideration of regional and long-term information. This "network of networks" may be common in state water quality programs, but it is not likely the best means of answering critical questions for regional or long-term environmental management in a cost-effective manner. Water quality is one of the four key areas of responsibility for the District and is linked to 10 major programs in the District's Strategic Plan (SFWMD, 2007; see Chapter 1A of this volume). Furthermore, the SFER peer-review panel has recommended repeatedly that regional water quality monitoring needs to be better integrated, standardized, and optimized using tools available through the National Water Quality Monitoring Council. For example, the 2004 Everglades Consolidated Report peer-review panel recommended that, "While it is recognized that some of the new ECR monitoring efforts are configurations of existing monitoring sites, there do appear to be opportunities, with the planned changes, to carefully evaluate and perhaps, establish a more integrated monitoring effort, using new concepts and tools being developed as part of the National Water Quality Monitoring Council." (see Appendix 1-4 in SFWMD, 2004). To address the panel's long-standing concerns and to support water quality as the cornerstone of the District's mission, an integrated monitoring strategy is needed for the entire South Florida region. Addressing this need, this cross-cutting chapter is included in the *2008 South Florida Environmental Report – Volume I* to document the development of a newly proposed water quality monitoring strategy for South Florida.

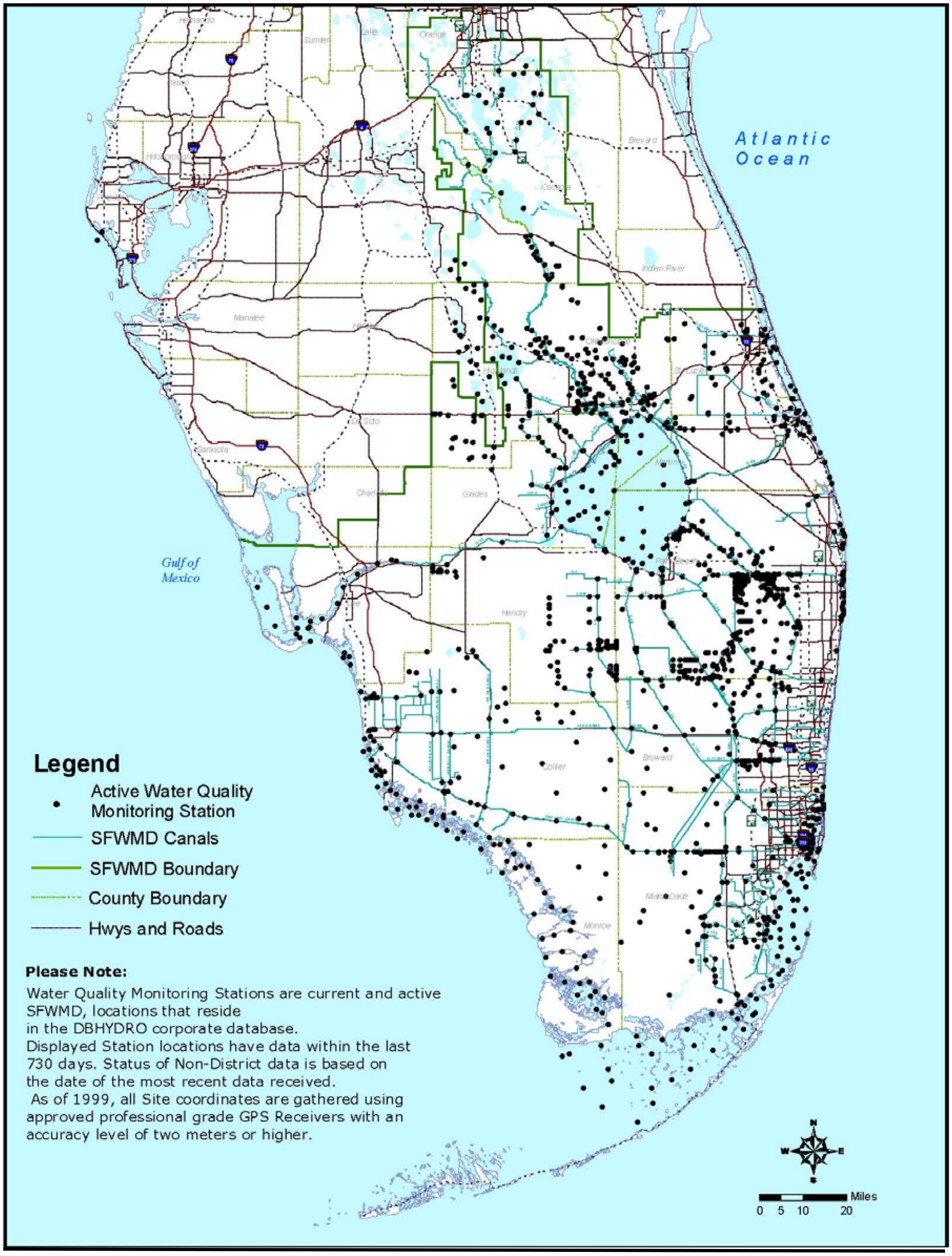

Figure 1B-1. Water quality monitoring networks in South Florida. [See also Figure 1A-3 of this volume for major regional features in South Florida.]

MONITORING STRATEGIES OF OTHER ORGANIZATIONS

Several studies of monitoring by federal agencies help set the stage for a reengineering effort in South Florida. An intergovernmental task force on water quality monitoring (USGS, 2002) concluded that changes are needed in many areas such as setting monitoring goals and objectives, allocating resources on the basis of goals, applying/linking ambient and compliance monitoring, and improving reporting. The Government Accounting Office (GAO, 2000) was critical of inconsistent and incomplete data on water quality used by U.S. Environmental Protection Agency (USEPA) in its National Water Quality Inventory of 1996 and recommended strongly the water quality monitoring be improved nationwide. In a later review (GAO, 2004), GAO discusses similar obstacles and opportunities for water quality monitoring from the perspective of federal agencies – many of their findings are applicable to South Florida. For example, at least 15 federal agencies collect water quality data, and lack of coordination in data collection and archiving is a major obstacle to information flow across agencies and regions. Differing purposes and protocols for data collection are often cited as barriers to better coordination of federal water quality programs. The GAO (2004) goes on to emphasize that federal agencies have long supported a more integrated "watershed approach" to information gathering, and states are moving toward new, more efficient monitoring approaches including (1) rotating basin strategy statewide, often on a five-year basis; (2) targeted monitoring in which only certain sites are sampled; (3) probabilistic monitoring to provide a comprehensive look at conditions on an infrequent synoptic basis; and (4) tiered monitoring strategy in which less expensive and more expedient sites are monitored first, followed by targeted or rotating approaches as needed. The findings of both these studies provide concepts to be examined in this reengineering project and more information on the monitoring strategies of states is considered below.

At a regional scale, the Chesapeake Bay Program (1996) developed a basin-wide monitoring strategy with a comprehensive framework for monitoring that generates optimal information to guide restoration and management actions. Elements of the Chesapeake Bay strategy are: consolidating a network of programs throughout the bay watershed, focusing on information needed for management decisions, taking advantage of parallel efforts across agencies, and using technical workshops to rework programs toward an ideal framework of information needs and questions. Notably, the bay strategy was needed despite repeated reviews and monitoring optimizations of regional networks. Such large-scale strategies provide the groundwork for true reengineering at a comprehensive level. Strategic concepts should be *de novo* and are not based on tinkering with or rearranging existing networks. The information in this document also is at a conceptual level to outline a strategy to guide a reengineering process for South Florida.

Many state water quality monitoring systems have been reviewed and better integrated in response to guidance from the USEPA (2003) to meet the requirements of the Clean Water Act 106(e)(1). USEPA (2003) and other earlier guidance provided by USEPA regional offices, uses 10 monitoring elements such as objectives, design, indicators, data management, and reporting to be considered by states as they review monitoring programs. No single monitoring approach can satisfy a state's diverse information needs. States use multiple designs and monitoring approaches to monitor their unique resources and information priorities. Good examples of state monitoring strategies are for the Alaska Department of Environmental Conservation (2005), Florida Department of Environmental Protection (2005); State of Oklahoma (2003); and New York State Department of Environmental Conservation (2002). The Illinois Environmental Protection Agency (2002), Minnesota Pollution Control Agency (2004), and Vermont (2005) provide very detailed and thoughtful accounts of their monitoring systems. However, these cases also illustrate how complex and difficult integration is across state agencies and ecosystem types, all with diverse monitoring objectives and approaches. These state strategies represent much more clarification and documentation than of a true reengineering of monitoring across programs.

PRIOR ATTEMPTS TO OPTIMIZE SOUTH FLORIDA MONITORING

Previous monitoring optimizations have been focused primarily on inflow and outflow structures and have not produced desired network-wide results primarily because they were focused too narrowly on specific mandates, projects or parameters rather than general information needs and the most effective network to meet those needs. For example, Permit Optimization Project (POP) (SFWMD, 2004) attempted to optimize monitoring by reviewing and consolidating information gathered under a variety of permits, primarily issued by the Florida Department of Environmental Protection. While POP was successful in reducing the monitoring required under some permits, implementation was hampered by overlapping requirements of the Settlement Agreement, a mandate which the POP team specifically chose not to address. Some of the POP recommendations on parameters were eventually implemented after discussion with the Settlement Agreement's Technical Oversight Committee and the Florida Department of Environmental Protection (FDEP).

Another large-scale optimization produced few useful recommendations on District networks (Hunt et al., 2006a; Table 3). The contracted scope of this optimization was limited to a select subset of sampling locations and parameters, and did not take field logistics into account. The majority of field-related costs (> 75%) are from staff time and transportation, and as a consequence, any optimization that fails to review the number of station visits will produce little cost savings or increases in efficiency. Furthermore, water for measuring various analytes is not collected individually, but rather grouped into specific bottles. Therefore, if a specific analyte is removed through an optimization, but other analytes are still required from the same bottle, the cost savings is limited only to the relatively minor analytical costs of one specific parameter. The limitations of this study are particularly evident in Table 3 of Hunt et al. (2006) in which sampling is recommended to be increased at some sites in Water Conservation Area 2A (WCA-2A), decreased at others and sampled by autosamplers at still others. This study did provide useful guidance on how to approach optimizations and apply data quality objectives in the process (USEPA, 2000). Part of the same study on the Water Conservation Areas (WCAs), Battelle (2006) provided conflicting results for trend analysis due to differences in statistical qualities of parameters. For example, the ability to detect a 20 percent change in concentration over five years provided dramatically different results for various parameters depending on variability (Tables 7–14; Battelle, 2006). Such results are not easily reconciled to make choices on sampling locations or parameters to be monitored.

Past optimizations of monitoring at marsh stations have been extremely limited and are not well documented. However, the need for a thorough review of marsh monitoring is very apparent from station overlap between projects such as EVPA and Threshold; stations that are relatively short distances apart (CA2-15 and U3); and stations that may not be providing the information they were designated for (STA-2 transects).

The core lessons that should be taken from these examples is that optimization processes must address the fundamental information needs of all mandates and the agency mission and must integrate the logistical issues of sampling and analysis into a rethinking process. Additionally, the optimization process must adapt sampling locations appropriately in response to local conditions including elevation, flow paths, and biogeochemistry. The next section of this chapter describes logical frameworks that can be used to do a more complete and useful job at rethinking water quality monitoring at the District.

FRAMEWORKS FOR REENGINEERING

Faced with rapidly increasing costs and demand for monitoring, agencies attempt to conduct "optimizations" to ensure that monitoring systems are focused on management needs, free of redundancy in parameters or stations, and sampled only as needed to get essential information. Over 40 such optimizations have been conducted on District monitoring systems, and mechanisms are in place to continue reviewing existing programs, bringing in new technologies, and coordinating across programs, all to maintain as much efficiency as possible. There is little more that can be gained by revising these mechanisms or conducting more traditional optimizations. This agency needs to wipe the slate clean and be willing to rethink its monitoring from entirely new approaches with a fundamental reengineering.

The National Water Quality Monitoring Council (NWQMC) has developed a general monitoring framework with six elements or "cogs" (**Figure 1B-2**). The framework is intended to guide the development or reengineering of monitoring programs as integrated systems to provide information that aids in understanding, protecting, and restoring our waters (Peters and Ward, 2003). Harmancioglu et al. (1999, Chapter 3) provide a detailed account of monitoring network design and, similar to the NWQMC, they emphasize the need to redesign networks as integrated data-management systems. The processes outlined in their Figure 3.1 are comparable to those in the NWQMC framework. Finally, a very thorough and practical set of guidelines for water quality monitoring have been developed for Australia and New Zealand (ANZECC, 2000).

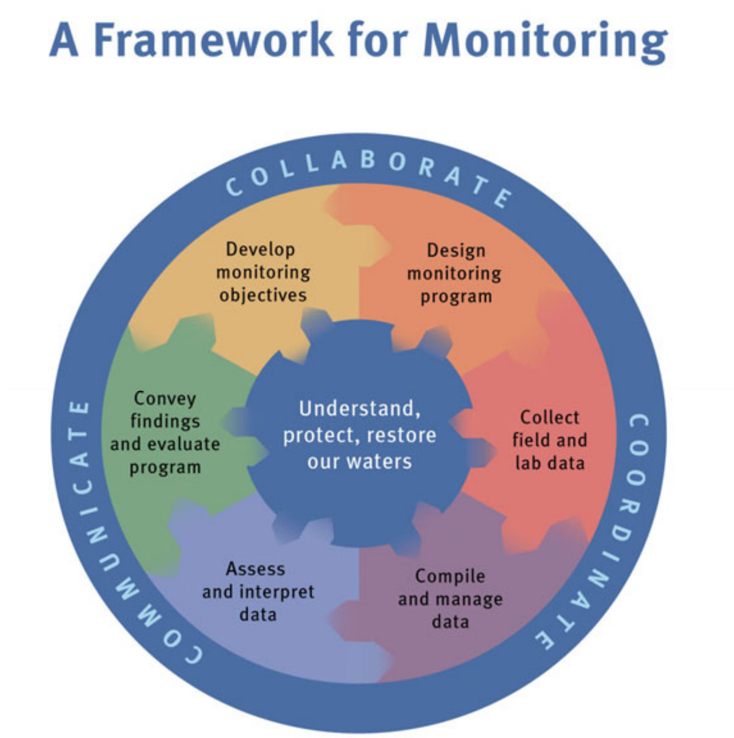

Figure 1B-2. A framework for water quality monitoring developed by the National Water Quality Monitoring Council, November 2002 (from Peters and Ward, 2003).

The District has ongoing activities and assigned staff in each element of this framework, and there are ongoing efforts to optimize efforts in all six cogs of the framework. An obvious example of this connection is this *2008 South Florida Environment Report* (SFER) and its peer review process, which reflects a major agency commitment in two cogs: "assess and interpret data" and "convey results and findings". The District's Water Quality Assessment Division has data evaluation and reporting for the annual SFER as a primary responsibility; see www.sfwmd.gov under *Organization, Environmental Resource Assessment, Water Quality Assessment*. The SFER has benefited from public review and agency commitment to its production; it has now won eight national awards for excellence (see Chapter 1A of this volume). In addition, the District's extensive efforts to develop and implement standard operating procedures, and quality assurance plans for monitoring projects (SFWMD, 2006) relate to the cog "collect field and laboratory data". The Water Quality Monitoring and Analysis divisions are devoted to producing data through field sampling and laboratory analysis. Information on field and lab aspects is available on the District's web site at www.sfwmd.gov under the *What We Do, Environmental Monitoring, Water Quality Monitoring.* Data management protocols and the District's DBHYDRO database fall within the cog "compile and manage data" and are described on the District web site at www.sfwmd.gov under *What We Do, Technical Data and Documents*. The reengineering of District water quality monitoring described here is centered only on the two remaining cogs in the framework; "Develop monitoring objectives" and "Design monitoring program". These two elements set the stage and direction for all other elements, and provide the structure from which information flows through the cogs of the framework.

A more specific example of rethinking and planning monitoring from top to bottom is provided by the framework for developing data analysis protocols developed by Adkins (1993). In essence, the framework for developing data analysis protocols detailed by this author consists of (1) identifying information needs; (2) deciding on how to deal with data attributes such as outliers, missing values, and non-normality; (3) choosing statistical methods that best meet information needs in light of data attributes; and (4) interpreting and reporting results. This framework can be used to develop data analysis protocols for any monitoring activity. The fundamental idea is to create a standard way of collecting and analyzing data to meet a particular regulatory information need or goal, thinking the process through completely in the design phase.

Adkins (1993) uses data analysis protocols with eight components to meet identified information goals for a case study involving groundwater quality monitoring for an IBM semiconductor manufacturing plant in New York. A typical monitoring protocol for this facility contains:

a. Information goal
b. Parameters to be analyzed
c. Type of sampling
d. Number of sites to be sampled
e. Sampling frequency
f. Data analysis procedures
g. Actions to be taken based on laboratory results
h. Interpretation and Reporting

The fundamental value of this approach is that it focuses monitoring effort on exactly the information required for agency purposes and establishes the flow of data by upfront planning. Protocols can replace routine monitoring specifications often applied in discharge permits and avoid the typical monitor and "we'll know it when we see it" approach. The District intends to draw heavily on the concepts embedded in this framework as District staff reengineer water quality monitoring in South Florida and will consider specifically the first five (a–e) in the monitoring protocol outlined above, which will provide structure to the monitoring design. While the use of this approach can become more difficult when multiple types of monitoring are done concurrently, great value can be added by having water quality measured in association with plant, soil and algal measurements as is being done at a subset of sites in WCA-2A.

The National Park Service (NPS, 2007) has developed a Vital Signs Monitoring System for integrated natural resource monitoring across U.S. national parks. This system is thoroughly documented and supported by a diverse set of web-based resources for park staff to use as they develop and implement their programs. Information available on designing monitoring programs is extensive and available through http://science.nature.nps.gov/im/monitor/index.cfm. Monitoring protocols described by Oakley et al. (2003) and structured generally like those of Adkins (1993) are the backbone of their guidance to parks and cover topics ranging from conceptual models, field data collection, archiving, and reporting. Long-term quality and consistency are the goals of applying protocols rigorously across the National Park System.

Closer to home, the water quality standards for phosphorus in the Everglades Protection Area [FDEP, 2006; Section 62-302.540, Florida Administrative Code (F.A.C.)], while not explicitly using the Adkins (1993), Harmancioglu et al. (1999), Oakley et al. (2003), or Peters and Ward (2003) frameworks, does accomplish many of the same objectives for efficient monitoring. The phosphorus standards specify purpose, intent and applicable definitions, and indicate how data are to be collected, screened for quality and consistency, summarized, tested, and interpreted to achieve compliance with the standards. Importantly, all aspects of these standards went through an exhaustive public review process with multiple workshops and public hearings before the Environmental Regulation Commission. Furthermore, after approval by the commission, they were subjected to an extremely thorough examination through a state administrative hearing, and all parts of the monitoring and assessment system were approved by an administrative law judge. It is difficult to imagine any monitoring system being subjected to more scrutiny than these phosphorous standards.

REDESIGNING OF WATER QUALITY MONITORING IN SOUTH FLORIDA: CLARIFYING REGIONAL OBJECTIVES

The first and foremost step in reengineering monitoring systems or designing them from the ground up is to define the objectives for monitoring – the information goals. Adkins (1993), Harmancioglu et al. (1999), ANZECC (2000), Spooner and Mallard (2003), and Ward et al. (1990) all provide differing accounts of the steps to be taken as objectives or goals are examined, but there is complete agreement among these authors and others that setting measurable objectives is the essential first step in monitoring designs. Information needs for water quality monitoring for a given geographic area must be established by (1) defining issues to be addressed either as specific mandates or as general agency responsibilities, (2) compiling information requirements for all data users, particularly decision makers, (3) gathering existing information, (4) developing an understanding or model of key attributes and concepts, and (5) setting objectives for monitoring.

Goals and objectives may actually be easier to develop for new monitoring systems with no legacy data, only limited environmental information and few mandates. For reengineering well-established networks, such as those in South Florida, the process is much more complex and decisions are difficult to make when multiple agencies and organizations have widely differing interests in the monitoring data. For all geographic areas of South Florida (see Chapter 1A in this volume), there are many years of data available, multiple technical publications over several decades, and many stakeholders and interested agencies or other parties with widely differing views of what is needed and important to track. It would not be feasible or appropriate to simply assign District staff to do all of the essential background study, as described in the five steps above, in a vacuum without substantial collaboration and iterative input from others.

For South Florida water quality monitoring, this will be done through two types of working groups: internal groups and an interagency working group with expertise in monitoring and or research and knowledge of networks in a particular geographic area. The District's Environmental Resource Assessment Department will work collaboratively with the internal group to develop proposals for reengineering. On a regular basis, staff proposals and supporting analyses will be reviewed by an interagency working group with representatives knowledgeable on the geographic setting, mandated requirements, and management information needs. The District will support logistics, develop workshop presentations, facilitate deliberations, and document progress on reengineering. This workshop process is being used in the test case for reengineering water quality monitoring in WCA-2A, as described in this chapter; this group will continue to provide input to this working draft test case. This interactive and iterative working group approach hopefully will produce reengineering proposals that are understood and supported by other agencies and organizations with a stake in water quality. Besides technical input, the District seeks collaboration and interagency support of monitoring whenever possible.

Information goals for regional environmental management are applicable to all geographic areas and provide the foundation for reengineering. The federal Clean Water Act (CWA) (40 Code of Federal Regulations 131.10) (Public Law 92-500) and Florida's 1972 Water Resources Act [Section 373.4592, Florida Statutes (F.S.)] have acted in concert to broaden the District's mission beyond drainage and flood control to include water supply, water quality, and natural systems (SFWMD, 2007). This general mission and associated monitoring has been expanded through state initiates under the Everglades Forever Act (Section 373.4592, F.S.), Lake Okeechobee Protection Act (Section 373.4595, F.S.) and most recently, the Northern Everglades Initiative (Section 373.4595, F.S.), which integrates and enhances programs to restore Lake Okeechobee and linked coastal resources. Water quality monitoring is anticipated and often expanded under these state programs and under the federal Comprehensive Everglades Restoration Plan (CERP) and the CWA TMDLs programs. In fact, more than 160 water bodies within the District have been included in the 303(d) Lists of Impaired Waters and require TMDLs. TMDL development uses existing data; TMDL implementation will undoubtedly require additional data to track progress and effectiveness of water quality programs. Water quality cuts across 10 District programs, and monitoring is the ultimate source of information on quality.

Together, state and federal mandates, and regulatory information needs, clearly require ongoing monitoring of water quality for inflows and outflows of regional ecosystems and for ambient lake, river, or marsh sites across South Florida. However, even without these statutory and regulatory requirements, the District's mission could not be fulfilled without water quality monitoring information. From an environmental management viewpoint, the information goal for water quality monitoring can be summarized in two broad goals: determine the quality of waters in the region and quantify any changes through time; and assess the effectiveness of environmental management and water quality control programs. These broad objectives are applied to protecting and improving water quality and supporting environmental decision making across the 10 programs outlined in the District's Strategic Plan (SFWMD, 2007). The Florida Department of Environmental Protection (Chapter 2 of FDEP, 2005) provides an expanded list of objectives to satisfy more specific statutory and regulatory requirements. For the most part, information to satisfy these two broad objectives would be able to meet the FDEP water quality information needs as well.

As the reengineering process continues, it will be important to add greater specificity associated linking information needs to their satisfaction for individual mandates. This will involve clarifying the approaches to two additional cogs in the monitoring framework: 'Assess and interpret data' and 'Convey findings and evaluate program'. In the context of Adkins (1993) data analysis protocols, this additional information would complete the last three elements on data analysis procedures, actions to be taken from laboratory findings and interpretation and reporting of results. As an example, Weaver and Payne (2008) use monitoring data for water quality standards compliance, and they provide a fairly detailed description of their methods for assessment and reporting. Eventually, this sort of information should be part of documentation for the monitoring system and can then be referenced each time the data are analyzed for compliance with standards.

REDESIGNING WATER QUALITY MONITORING IN SOUTH FLORIDA: DEVELOPING AND TESTING CONCEPTS IN WCA-2A

Water quality monitoring in Water Conservation Area 2A (WCA-2A) is a great test case for network reengineering. WCA-2A (see **Figure 1A-3**) is the smallest of the three Water Conservation Areas at 442 square kilometers and is managed in cooperation with the U.S. Army Corps of Engineers and the Florida Fish and Wildlife Conservation Commission. WCA-2A was selected as a demonstration case for monitoring reengineering because (1) it is a major component of the remnant Everglades, (2) it has been monitored and studied extensively since 1990 through data from monitoring for research purposes and long-term ambient conditions, (3) it has typical environmental gradients and mosaics of marsh habitats, and (4) it has monitoring at inflow and outflow structures and in the marsh itself. This diversity of attributes allows the District to test new approaches with actual data and field experience in WCA-2A. With this wealth of information, a set of objectives will be created for both the marsh and structure components of the monitoring network. From these objectives, a comprehensive, integrated and sustainable monitoring plan will be developed for WCA-2A. Because the monitoring of marshes and structures requires significantly different levels of effort and distinct sampling approaches, the proposed monitoring plan considers marsh monitoring and structure monitoring individually. WCA-2A, with its inflow and outflow structures, is depicted in **Figure 1B-3** below. Water Conservation Area 2B (WCA-2B) at the southern end of WCA-2A is not currently monitored and is not included with WCA-2A reengineering. Using the WCA-2B area as a reference site might be considered in future reengineering efforts.

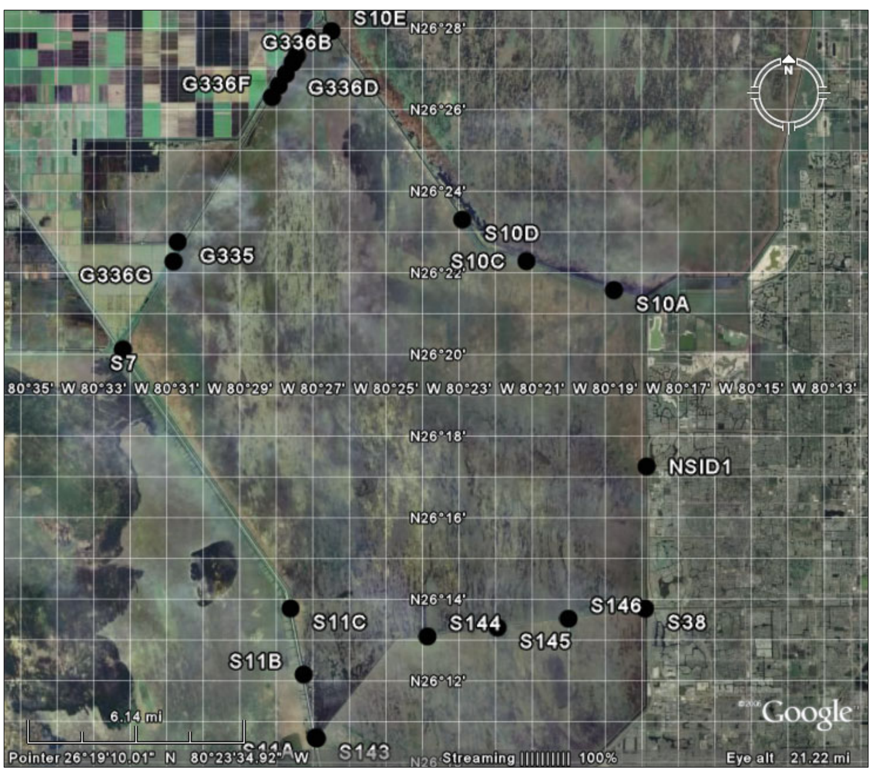

Figure 1B-3. Water quality monitoring inflow and outflow sites in Water Conservation Area 2A (WCA-2A).

MONITORING WCA-2A INFLOW AND OUTFLOW STRUCTURES

Several different types of structures operate around the periphery of WCA-2A to control inflows and outflows (**Figure 1B-3**); an example is shown in **Figure 1B-4**. Information on mandates for monitoring WCA-2A is compiled in Appendix 1B-1 of this volume. In general, Chapter 373.4592, F.S., requires that all discharges into and out of waters of the Everglades Protection Area, of which WCA-2A is a component, will be permitted if reasonable assurance is provided that (1) a discharge structure will achieve its design objectives, (2) water quality standards will be met to the maximum extent practicable, (3) discharges pose no danger to public health, safety, and (4) welfare impacts to wetlands are minimized or mitigated, (5) discharges are adequately and accurately monitored to measure progress toward achieving compliance with water quality standards, and (6) all reporting requirements are met. WCA-2A also receives discharges from the Stormwater Treatment Areas, and these discharges are subject to permitting under the NPDES (Section 402, CWA) delegated to the state under Section 403.0885, F.S. Discharges under NPDES must be monitored at a “meaningful frequency” to assure compliance with water quality standards under permit conditions which may be water quality based or technology based.

Figure 1B-4. Structure S-144, an example of an outflow structure for WCA-2A (photo by P. Lynch, SFWMD).

Sampling Method and Frequency for Inflow and Outflow Structures

The primary goal of structure monitoring is to assure that discharges meet water quality standards and to quantify constituent inputs to the area. In practice, reasonable assurance from a regulatory perspective is based on the frequency of monitoring specified in permits and other mandates. Typically, monitoring is designed around a scheduled trip that examines structures on a biweekly basis and collects samples only if flow is observed. If no flow is observed, then no samples are collected until the next two-week event. This approach is termed “biweekly if flowing” (BWF), and has a common variant which includes a default sampling event regardless of flow conditions on a monthly basis, termed “biweekly if flowing, otherwise monthly” (BWF/M). The process used in collecting samples with the existing BWF/M protocol is summarized in **Figure 1B-5a**. The critical decision point for sampling is whether or not flow is observed at the site, but preparation and travel time have already been invested. It is important to note that sampling trips in South Florida usually take substantial time in preparation and traveling to remote sites.

The BWF/M sampling regime provides 12 to 26 samples per year, depending on flow conditions. However, under this regime there is the potential for samples to be more than 55 days apart if the structure was flowing unobserved within that time period. This potential for infrequent sampling exists because collection is based on flow observation, not on flow records. Consequently, if the structure is not flowing when staff visits, no sample is collected, regardless of antecedent flow conditions. Thus, if a sample is collected during a flow event on day 1, unless flow is observed on subsequent visits, no subsequent sample is required until day 56 (the following month) and the sampling program is not out of compliance with permit conditions for sampling until the second month ends (day 60). In practice, in a review of one set of data, it was found that 30 percent of all flow events were missed because they were shorter than 14 days and went unobserved between sampling events. Additionally, the data showed that “monthly” sampling events 40 to 60 days apart occurred regularly at least once each year.

Given the obvious difference in the amount of data potentially available for quantifying inputs or outputs depending on flow conditions, it is surprising that both the regulatory and regulated agencies have sustained monitoring in such a fashion. The current situation may be maintained due to the complexity and size of the system, and the communication gap between operations and monitoring divisions. The BWF and BWF/M regimes were developed in the period between 1987 and 1991, when the initial permitting for the stormwater program occurred. At that time, structure operations were carried out through a diverse network of regional subsystems, and many structures were manually operated. This situation, combined with the lack of electronic communication, would have made communicating structure operations to monitoring staff extremely difficult. Additionally, even if discharge information was conveyed, the geographic area and number of structures would have made it impossible for staff to travel and collect samples in response to active flow events. Given these limitations, the sampling regimes strategy provided a logical way to deploy limited resources in an effective manner across large geographic areas. This reengineering process gives the agency a chance to rethink the scheme with modern communication technology.

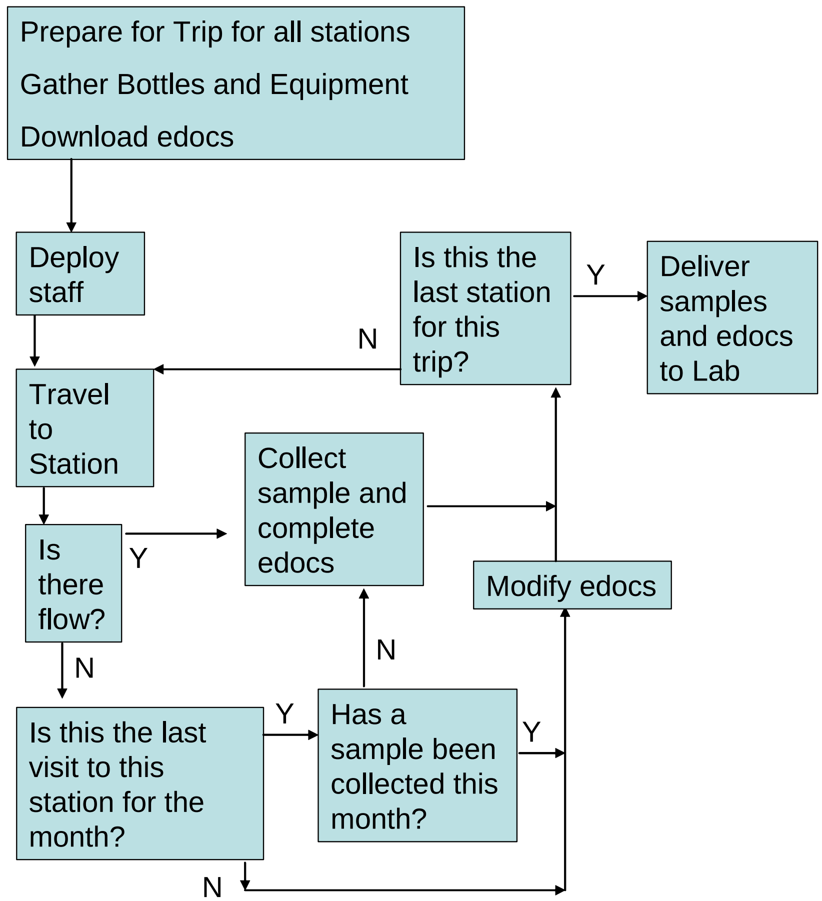

Figure 1B-5a. Flow chart for existing "biweekly if flowing, otherwise monthly" (BWF/M) sampling. "Edocs" are documents generated and maintained electronically.

Utility of Auto-samplers at WCA-2A Inflows and Outflows

As previously discussed, grab sampling in response to observed flow has the fundamental problem of failing to capture unobserved flow events. One technological solution to this problem might be the use of auto-samplers for monitoring at water management structures. Auto-samplers are simple electromechanical pumps that can be triggered in response to elapsed time or in response to an electronic signal generated by a calculated estimate of flow through a structure; Teledyne Isco, Inc., makes several models used commonly in South Florida. Time- or flow-proportional auto-samplers can collect samples during flow events and are very helpful when pollutant loads vary greatly with flow or time. Auto-samplers have been shown to provide data that are comparable to those collected by grab sampling (e.g., Ging, 1999). Both auto-sampler types are capable of generating more data and thereby capturing more of the variability for determining overall concentrations than grab sampling. Experience in South Florida suggests that differences between grab and auto sampling can be expected to vary with local conditions and parameter variability. For example, data from an 18-month study just completed at inflows to Everglades National Park (Work Order, ST061294-WO03, SFWMD) indicates that grab samples can often be less than auto samplers, but data patterns vary by parameter and site. Although parameters assessed in auto-samplers can be limited by preservation and holding-time considerations, a recent study found that total nitrogen and phosphorus can be held in auto-samplers for seven days with or without refrigeration and show no significant difference from samples processed immediately (Burke et al., 2006). Collectively, information on auto-samplers shows their potential utility when time- or flow-proportional sampling is justified for specific information needs; there are tradeoffs, however.

While such sampling automation is very appealing at first sight, auto-samplers present their own distinct problems. First, they require a significant investment in equipment and infrastructure, the majority of which cannot be easily redirected if monitoring requirements change at a particular site. A typical installation costs $3,500 for the auto-sampler itself, $6,000 for construction of a sampling platform, and $30,000 for purchase and installation of electronic instrumentation to record and communicate data to operate the system. Furthermore, in order to keep auto-samplers operational, weekly maintenance on preservatives, bottles, and tubing must be carried out, regardless of flow conditions or whether or not the auto-sampler has been in operation. At 52 trips, routine visits total several thousand dollars per year. Finally, at unattended installations, auto-samplers are the targets of significant amounts of theft and vandalism, particularly of power supplies.

Auto-samplers are also prone to missing samples. Sampling is totally dependent on an interface between sensors, communication device, automatic flow calculation, triggering device, and the auto-sampler itself. Any failure in the sensors that provide information about structure conditions, the flow calculation, or in the trigger mechanism can cause the auto-sampler to miss a sample. If even the sampler operates, the sample may be unusable if volume is insufficient to fill the bottle and neutralize the acid used for preservation. Mis-collections are also possible when reverse flow or other conditions cause the sampler to trigger when appropriate flow is not occurring. Regardless of origin, failures can happen on the order of 10 to 20 percent of the time, and when they happen, a week’s worth of data is lost. The other factor that significantly affects both auto-samplers and observation-based grabs is the amount of flow itself. When Florida enters its annual dry season, or experiences a drought, flow through structures is significantly reduced and can even cease for months at a time. Under these conditions, the number of station visits to carry out flow observations or auto-sampler maintenance remains unchanged, but the number of samples collected drastically decreases. Consequently, the ratio of work effort to samples collected can be relatively high in both sampling strategies, and conditions of no-flow can result in no information gained from ongoing field visits. It is also important to note that failures of the sampling device tend to be more frequent following periods of low flow.

An Alternative Monitoring Strategy for Grab Sampling

Given that both flow-based grab sampling and auto-samplers have serious, albeit different, flaws, a monitoring strategy is needed that both meets the objectives of monitoring discharges and minimizes the level of effort required to collect samples. The key to meeting these requirements appears to be fundamental changes in the way that the District exchanges information on structure operation. Unlike the early 1990s, the operation of structures is now highly automated, and databases on structure operations are readily available and current. These factors create an opportunity to reexamine the design of flow-based monitoring and adjust it accordingly.

A new type of sampling regime, based on recorded flow, is proposed as the fundamental alternative to the current grab sampling with flow observation. The goal of the new sampling regime is to improve efficiency while meeting monitoring objectives with scientifically valid data. Under this sampling design, structures would be scheduled for routine station visits, but would only be visited if flow had been recorded in the period since the last scheduled station visit. In this manner, samples would only be taken from stations that had been recently or are currently active. Unlike the BWF protocol (**Figure 1B-5a**), the decision point to deploy staff and invest significant staff time in travel is based on recorded flow conditions (see **Figure 1B-5b**) instead of observed flow conditions and is made before travel is initiated.

This new design for field visits would have several advantages over observation-based monitoring. Unlike observation-based monitoring, the new approach mandates the collection of samples if flow has occurred (observed or not) but at the same time, it eliminates travel expenses for structures that have not or are not actively flowing. For example, the BWF approach creates a sample program with a maximum of 26 flowing samples collected during 26 sampling trips. Under the new system, the structure would be sampled as "biweekly if recorded flow" (BWRF), which would still have a maximum number of samples of 26, but the station would only be visited if flow had been recorded within the last two weeks, thus conserving resources of both staff and vehicles (see **Figure 1B-6** and page 1B-22 of this chapter). More useful data would be provided by the new approach because each flow event would be linked directly to a specific sampling event within two weeks. In this manner, the failure to collect a sample for an unobserved flow event shorter than two weeks is removed as an issue. Under this design, both standard compliance and loading calculations would therefore be more robust. Additionally, the BWRF design can be modified to include a monthly default sampling for critical stations at which a minimum frequency of monthly is still needed. Biweekly if recorded flow otherwise monthly (BWRF/M) would still supply a minimum number of samples (12 per year), but has the potential to dramatically reduce the number of sampling trips down from the current 26 per year. If current monitoring operating under BWF and BWF/M were replaced with BWRF and BWRF/M respectively, none of the data currently being collected would be lost, but there is a potential for significant decreases in the number of station visits and associated staff and transportation costs. Further cost savings may be derived from replacing some auto-samplers with either BWRF or BWRF/M, but this would have to be carried out on a case-by-case basis using local conditions to determine whether such changes are appropriate.

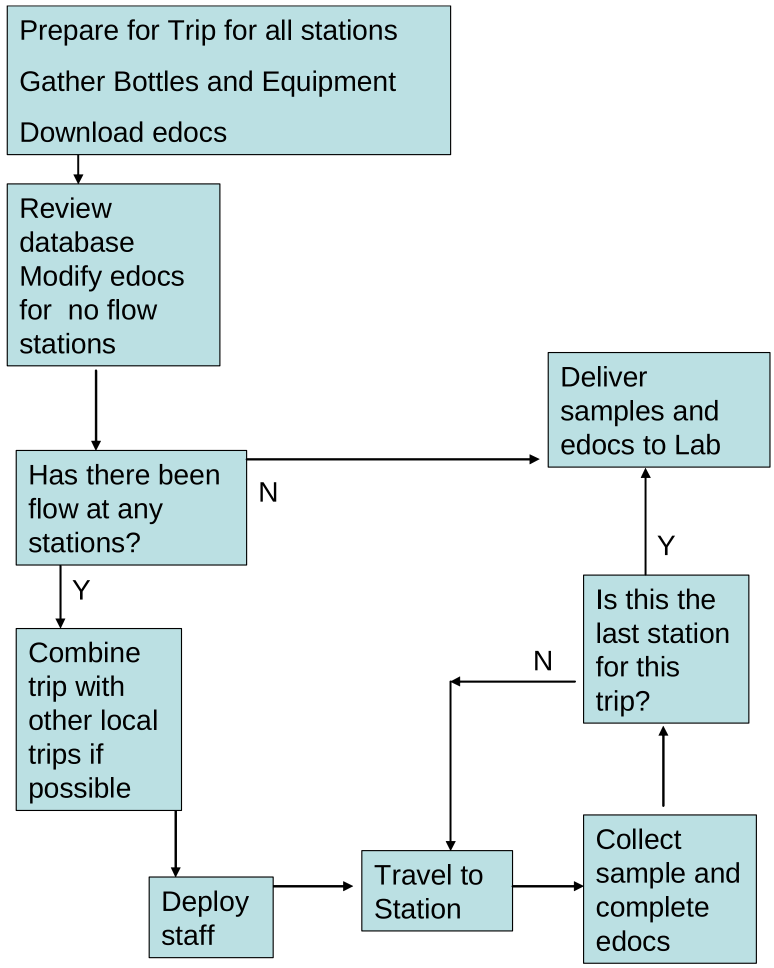

Figure 1B-5b. Flow chart for proposed "biweekly if recorded flow" (BWRF) sampling. "Edocs" are documents generated and maintained electronically.

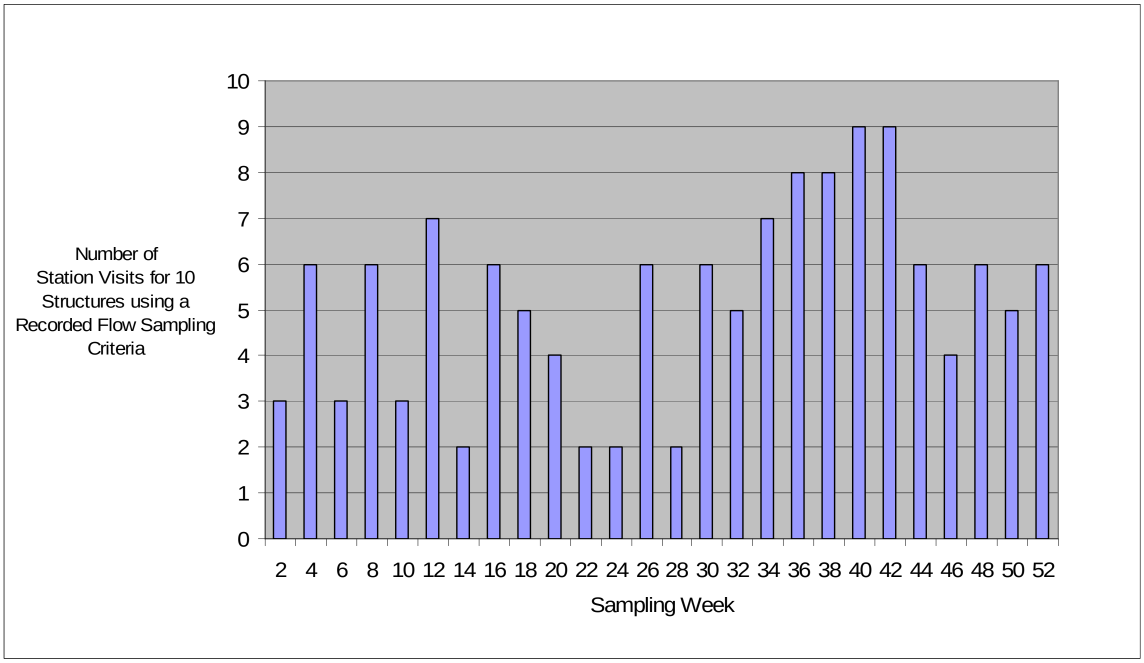

Figure 1B-6. Number of station visits for 10 structures associated with WCA-2A using the proposed "biweekly if recorded flow" criterion (**Figure 1B-5b**). Under the current "biweekly if flowing" criterion (**Figure 1B-5a**), 10 visits are required every two weeks.

INFLOW STRUCTURE SAMPLING IN 2004

S-10s: Along the northeastern edge of WCA-2A, the Hillsboro Canal collects waters from Water Conservation Area 1 (WCA-1) and discharges them through three structures: S-10D, S-10C, and S-10A (see **Figure 1B-7**). The Settlement Agreement and discharge permits provide a general requirement to monitor these structures as Everglades inflows and outflows. S-10A and S-10C are monitored at a frequency of biweekly if flowing, while S-10D is monitored biweekly if flowing, otherwise monthly. In 2004, there were 78 station visits with 26 samples taken.

S-7: At the far western corner of WCA-2A, the S-7 structure discharges waters from both the Everglades Agricultural Area (EAA) and STA-3/4. An auto-sampler is used at S-7 because it was in use when the Settlement Agreement was signed. As a result of the existence of the auto-sampler, this station was visited 52 times in 2004, with 52 samples taken. To simplify this comparative analysis, this station was assumed to have 26 grab samples for the entire year.

NSID1: Along the eastern edge of WCA-2A, NSID1 is a minor structure that handles relatively low flows from a small suburban community. This structure is sampled at a frequency of biweekly if flowing. In 2004, there were 26 station visits with only three samples collected.

Figure 1B-7. Structure S-10A, an example of an inflow structure to WCA-2A (photo by P. Lynch, SFWMD).

OUTFLOW STRUCTURE SAMPLING IN 2004

S-11s and S-143: Along the southwestern edge of WCA-2A, S-11A, S-11B, and S-11C discharge water from WCA-2A to WCA-3A (see **Figure 1B-8**). Monitoring of the S-11B is carried out biweekly if flowing, while S-11A and S-11C are sampled biweekly if flowing, otherwise monthly. S-11A also serves as a surrogate sampling station for S-143. In 2004, there were 78 station visits with 38 samples.

S-144, S-145, and S-146: Along the southern edge of WCA-2A, these three structures discharge water from WCA-2A to WCA-2B. S-144 is sampled to represent these stations and is monitored on a biweekly if flowing otherwise monthly basis. In 2004, there were 26 station visits with 14 samples.

S-38: S-38 is a discharge at the southeastern corner, supplying water into the C-14 canal. S-38 is monitored biweekly if flowing. In 2004, there were 26 station visits with 17 samples.

Figure 1B-8. Structure S-11B, an example of an outflow structure from WCA-2A (photo by P. Lynch, SFWMD).

Using the 2004 WCA-2A sampling data, the BWRF monitoring scheme can be applied to actual 2004 conditions to estimate the effects that the process would have on sample collection and resulting data on inflows and outflows. In this demonstration, the frequency of monitoring at the 10 monitoring structure stations in WCA-2A is converted either to a frequency of BWRF or BWRF/M (**Figure 1B-5b**). For the purposes of this analysis, the weekly auto-sampler at S-7 (**Figure 1B-3**) is ignored. Under this scenario, staff would have carried out a total of 136 station visits, compared to the actual number in 2004 of 260 (**Figure 1B-6**). This represents an overall reduction in station visits of 48 percent, a significant decrease in overall sampling effort and a concentration of sampling effort during periods of flow.

In contrast, the estimated amount of samples collected under BWRF would be 136 samples, compared to 107 grab samples actually collected in 2004. This suggests that the BWRF scheme would have collected more samples: 27 percent more than the number of samples actually collected in 2004 under the existing system, but with a 48 percent reduction in station visits. Furthermore, a significant difference between the two resulting datasets is that the majority of the samples collected in the new approach are associated with a specific flow event, while a significant portion of the samples collected under the standard existing schemes are associated with non-flowing events and provide little useful information on discharge quality. In fact, data analysts at the District eliminate water quality data collected when there is no flow for the calculation of loading and estimate values for no-flow conditions using flow event data before and after the no-observed-flow period of time.

Another method of looking at the data on sampling (**Figure 1B-6**) is based on work-per-unit effort. In 2004, there were 107 samples in 260 station visits or a sampling rate of 41 percent. Under the new scheme, the 118 (or 87 percent of) samples are associated with flow events, obviously a better use of staff time. In addition to changing the number of station visits and the number of samples collected, the BWRF scheme can also have an effect on the resulting statistics. For example, at S-7 in 2004, 52 grab samples were collected with an average total phosphorus (TP) concentration of 31 micrograms per liter (µg/L). Under the BWRF scheme, only 25 samples would have been collected and the average TP concentration would be estimated at 34 µg/L. In another comparison, at S-10D in 2004, 13 samples were collected with an average TP of 65 µg/L and a when-flowing average of 140 µg/L. Under the BWRF, only six samples would have been collected, producing an estimated TP concentration of 123 µg/L.

The proposed new sampling scheme would have some significant and cascading effects on staff management, project management, and budgeting. As shown in the WCA-2A demonstration project, a sampling program that currently requires visiting 10 stations every two weeks could, under routine conditions, be significantly reduced, and under drought conditions, eliminated entirely. This creates a challenge for project management to properly schedule staff time, but it is workable with some simple guidelines. Sampling trips must be grouped by geographic locale. For example, in the case of WCA-2A, it would be logical to schedule sampling of nearby Stormwater Treatment Area 2 (STA-2) by a second crew on the same day. Under high sample-load conditions, both teams would be deployed independently. Under low sample loads, such as the dry season or drought, only one team may need to be deployed, while the second team can be redirected to other projects. This redirection could be for maintenance, training, document review, or even projects in other geographic areas or with less frequent, and therefore less structured, sampling regimes. Ultimately, staff could be budgeted to carry out field work at 125 percent of a full-time equivalent, but because of the BWRF scheme, it only actually works at 100 percent. This would allow for the absorption of projects currently outsourced to contractors. It is likely that during high-flow periods, work may have to be extended to a fifth, 10-hour day per week, thus generating overtime. This overtime amount would be relatively small compared to the costs generated from using contractors.

For project management and sampling trips, the BWRF scheme is more efficient with more ability to flex stations between trips if sampling trips are scheduled in adjacent geographic areas. Thus, field trip planning using the scheme has a tendency to move projects away from large-scale regional projects towards smaller basin-scale projects, which are more flexible and manageable. At the same time, the alternative monitoring scheme creates a dilemma for budgeting. For example, 10 stations scheduled for BWRF have the potential to generate 260 station visits and samples, but are likely to actually generate considerably fewer of both (a 50 percent reduction would be 130 station visits). Consequently, there will be a tendency to attempt to budget for only 50 percent of the worst-case budget. Safeguards should be put into place to guarantee full annual funding, with an expectation of the return of a significant percentage of funds from both sample collection and analysis.

MONITORING AMBIENT MARSH CONDITIONS IN WCA-2A

Marshes in WCA-2A have been intensively monitored and researched for several decades (see **Figure 1B-9**) and there is widespread interest in the area by multiple agencies and organizations. Water quality in the area is summarized by Weaver et al. (2007) and general environmental information can be located through Sklar et al. (2007). Information available on ecology, topography, and hydrology of WCA-2A makes it a valued tool for the study of marsh responses to surface water chemistry and altered hydrology. In response to the Everglades Forever Act (Section 373.4592, F.S.) and other regulatory requirements, monitoring and research were expanded greatly in the area and more than fifteen stations were sampled intensively for studies on nutrients in surface water, groundwater, porewater, and sediments and for projects concerning nutrient impacts on periphyton, macrophytes, invertebrates, and fish. These data were used as a major source of information to develop and defend a total phosphorus criterion of 10 µg/L, now translated by rulemaking into the total phosphorus standards for the Everglades Protection Area (TP Rule, Chapter 62-303, F.A.C.).

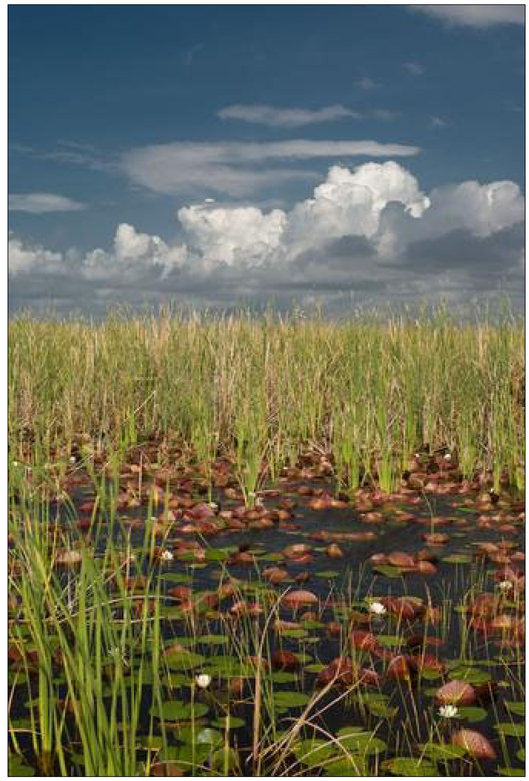

Figure 1B-9. WCA-2A has been the subject of intensive monitoring and research (photo by P. Lynch, SFWMD).

The objectives for marsh water quality monitoring overlap greatly with those for structure monitoring (see Appendix 1B-1). With a TP rule now legally established and management attention now focused on Everglades restoration, research and monitoring in WCA-2A will shift focus; stations used for either purpose should be reviewed as part of the reengineering. Marsh monitoring programs must provide data for the TP rule and other water quality standards, while at the same time, monitoring must support research on accelerated marsh recovery and long-term responses to systemwide restoration efforts. Monitoring is also required to track responses to new or relocated discharges to WCA-2A from treatment facilities, such as STAs and projects, to improve marsh hydrology. Finally, some marsh monitoring included in the federal settlement agreement and the Everglades Forever Act may still be required, although it may be modified with appropriate approvals.

The internal working group on WCA-2A monitoring was asked to provide general objectives from their various perspectives (see Appendix 1B-1). The common theme of the five general questions compiled from this group is quantification of surface water chemistry that can be used to understand how marsh responds to changes in water quality and hydrology. The questions lacked time frames, degree of change considered important, or management questions to be addressed through the data. For example, one key question for monitoring data was: How has water quality at individual stations changed in response to altered hydrology and loading, and can station-scale data be integrated to document patterns at the landscape level? As the reengineering process moves forward, objectives and goals for monitoring need to be made more specific, more closely tied to management decisions and restoration goals for a geographic area. For now, these questions, viewed as objectives, can be used to examine marsh monitoring for WCA-2A.

In many cases, stations with years of data collected for ecological studies may be redirected towards new objectives. However, some stations established for the study of water quality impacts may not necessarily be appropriate for tracking restoration efforts or standards compliance. Additionally, the wealth of data gathered under the existing monitoring and research programs provides a large body of information to evaluate monitoring for this reengineering process.

INTEGRATING MONITORING FOR RESEARCH AND ENVIRONMENTAL STATUS

In the ideal integrated, multi-purpose monitoring network, stations being used for research should be integrated with those for environmental status and trends. Lovett et al. (2007) provide a strong case for long-term monitoring as a vital component of ecosystem studies and for documentation of landscape response to initiatives under the Clean Water Act and Clean Air Act. They argue for detailed planning and continuous improvement in monitoring programs and conclude that monitoring should be fully integrated into research programs. In a study of ways to integrate U.S. programs for environmental research and monitoring, National Science and Technology Council (NSTC, 1997) provided 24 recommendations to improve monitoring nationally, and laid out a conceptual framework (**Figure 1B-10**) to achieve the goals of environmental monitoring and research across spatial and temporal scales. Most monitoring in South Florida would fall into the middle and upper segments of this pyramid and in most geographic areas, there are research and modeling projects that tend to act to integrate information, as depicted in this figure. This schematic is helpful in conceptualizing environmental research, modeling, and monitoring at various scales and degrees of site characterization. The basic message is: understand the importance of synergism between information sources and approaches to support environmental management across various scales in time and space.

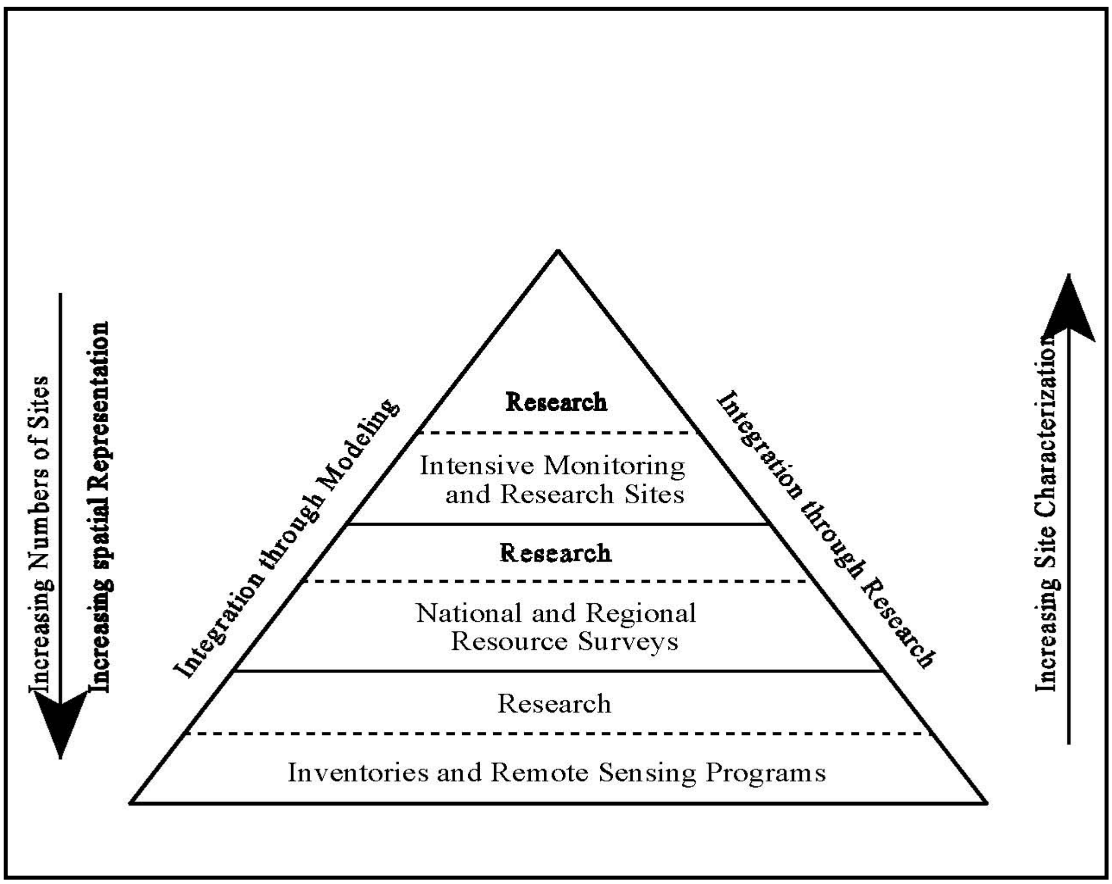

Figure 1B-10. Conceptual framework for achieving the goals of environmental monitoring and research across spatial and temporal scales (from NSTC, 1997).

While integration of research and monitoring is a priority, it is possible and worthwhile to identify differences between limited-term research monitoring involving water quality and long-term water quality monitoring for mandates and status/trends. A simple way to distinguish goals of monitoring is that monitoring for general tracking is aimed at finding out *what* is going on in an area, while monitoring for research aims to find out *why* things are happening (RECOVER contributed this idea). Based on discussion with the internal working group and on agency experience, monitoring water quality for research purposes tends to:

- Provide data on specific hypotheses in an experimental design;
- Have a more limited spatial (e.g., transect or habitat) and temporal extent (≤ 3 years);
- Collect samples using field methods and measured parameters focused on the research questions and sometimes testing new methods for measurements (Chapter 62-160.600, F.A.C., defines quality assurance for research methods and procedures);
- Store data in a research-oriented database, sometimes that of an individual research group; and
- Be published in peer-reviewed literature dependent on investigator priorities and not necessarily associated with an annual report.

Experience in South Florida suggests that some monitoring programs started for research can get "memorialized" and become long-term monitoring sites for environmental status and trends. Sites used for nutrient threshold studies and other research from 1994 to the present in WCA-2A are examples of this transition. Likewise, some stations used for research can be adopted into compliance programs, as happened for several sites in WCA-2A selected to be part of the monitoring network for the state's water quality standards for phosphorous in the Everglades Protection Area, mentioned earlier in this section.

Our goal in this reengineering effort is to apply the uniform integrative approach discussed in NSTC (1997) and to unify all long-term water quality monitoring into an integrated regional network using methods approved through the state's quality assurance mechanisms to the maximum extent practical (Chapter 62-160, F.A.C.). In most instances, it is preferred that water quality sampling (see **Figure 1B-11a**) should not be unique to original purpose or funding source, but should follow quality assurance, metadata, and other procedural requirements for the District's hydrometeorological database, DBHYDRO. Also, database updates should be continuous and standardized, and all water quality data should be publicly available for analysis by all scientists both inside and outside the District. Any long-term monitoring program should support, not constrain, research – and in fact, several major research efforts in WCA-2A are making use of water quality data collected at nearby stations and have been designed to make efficient use of this data.

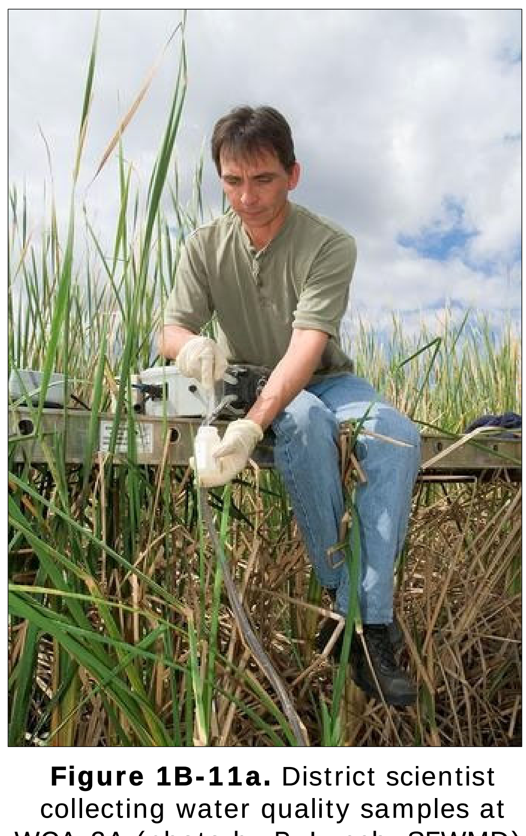

Figure 1B-11a. District scientist collecting water quality samples at WCA-2A (photo by P. Lynch, SFWMD).

With all these facts in mind, integrating monitoring for research with monitoring for other longer-term purposes may be a great goal, but also a formidable challenge. In the expert panel's report on the draft 2008 SFER (page 11), they provide guidance on integrating monitoring for long-term purposes and for research. They use a "wheel and axle" concept from Goetz (1995) as one reasonable framework for rationalizing (reengineering) a monitoring program. The Goetz (1995) process, modified from other authors, is shown in **Figure 1B-11b**. The critical starting point is a core monitoring program designed using all the cogs in the WQMC framework, supported by good documentation and reporting, and developed specifically to meet long-term information needs of the funding agency. This core monitoring network is represented by the axle in **Figure 1B-11b**. Research and other special needs are met by the wheels attached to the axle. Wheels represent additional monitoring stations added for focused, fixed-term studies planned to be compatible with the core program and also fully documented and reported. Ideally, the wheels are connected to the core network by sharing stations and standard operating procedures in a mutually beneficial manner. As the reengineering process in WCA-2A proceeds, our goal is to develop such an integrated information system with common stations and standardized procedures. Although we could not to accomplish this integration by the time of this writing, we are steadily moving toward integration – as can be seen in the remainder of this chapter.

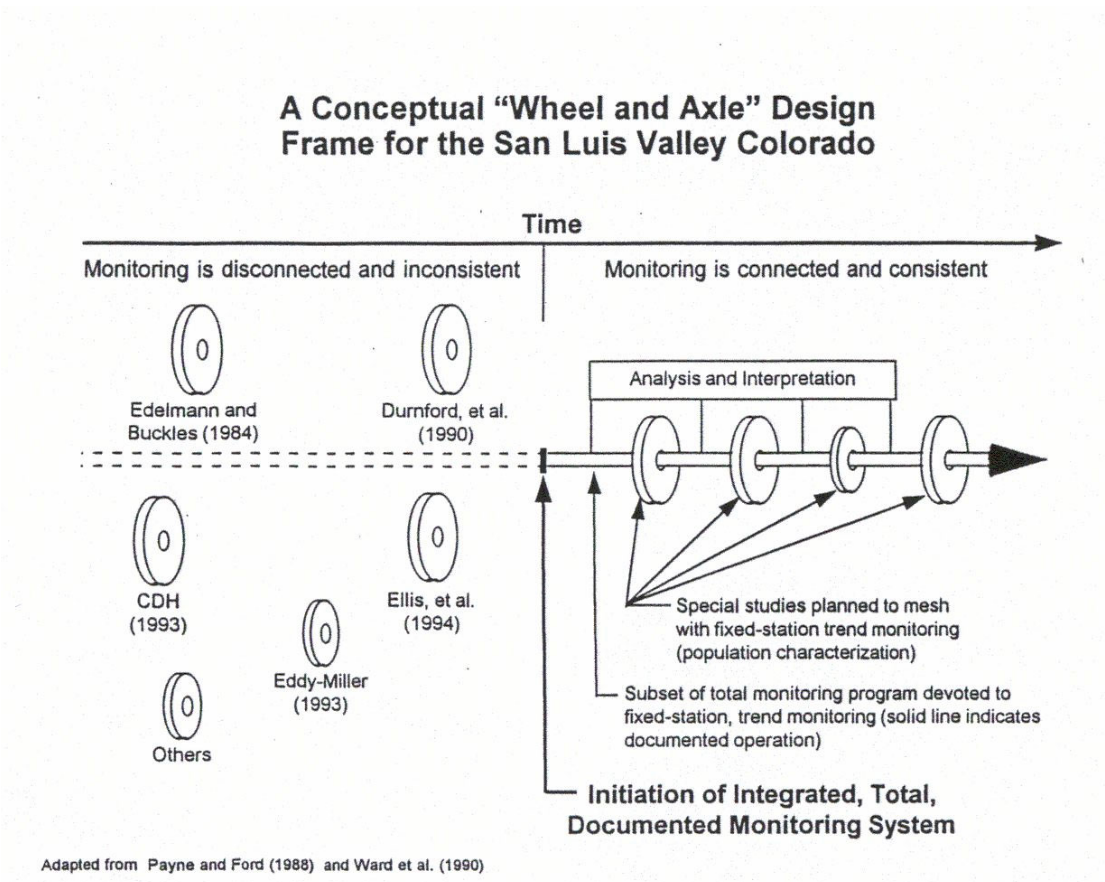

Figure 1B-11b. This "wheel and axle" concept from Goetz (1995) provides one reasonable framework for reengineering a monitoring program. The recommended core monitoring network is represented by the axle, with special-purpose additional monitoring represented by the attached wheels.

EVALUATING MONITORING SITES IN WCA-2A BY MONITORING ZONE

Reengineering of the monitoring of WCA-2A is being accomplished using a variety of data sources. Vegetation maps provide broad indications of long-term conditions in the area. Soil TP levels also reflect long-term conditions and are very important indicators of marsh conditions. Ground elevation maps provide an understanding of the potential flow paths for surface water and possible communication between stations. Using these tools, monitoring stations were grouped into zones for detailed analysis by the working groups. WCA-2A zones include: Impacted, Transitional, Unimpacted, Northern, and Western (**Figure 1B-12**).

Stations within each zone were then cross-compared for statistical differences (see Appendix 1B-2 of this volume). While the statistical analysis provided some information on differences between stations, the results were interpreted in the context of local soil, elevations and vegetation, as well as the first-hand knowledge of station characteristics. Analysis may show, for example, that the specific conductivity of two stations is significantly different, yet in the context of multiple ecological and chemical variables, that difference may be of little consequence, and the stations might be considered duplicative or redundant. In contrast, analysis may show that two stations are not significantly different, but the geography or ecology of the locale is such that monitoring at both stations is warranted for appropriate spatial and habitat coverage. Importantly, newer stations, some under the TP rule network, do not have enough data to make robust comparisons. Using other information, the majority of such stations were recommended to be kept in the network with the understanding that they will be reanalyzed in the future.

The internal working group on WCA-2A monitoring will continue to balance all available information across many variables before reaching preliminary conclusions on revising existing monitoring networks. A straw-man revised monitoring network is discussed below for each of the five monitoring zones. It is critical to remember that District recommendations on monitoring sites are based on information available to date. Further changes in station recommendations are expected as additional information on site chemistry, hydrology, ecology, field logistics and cost are considered. Also, statistical studies to date have been done on individual sites, not on characteristics of networks of sites. As the reengineering proceeds, statistical testing at the network level may alter the perceived value of one or more sites and change recommendations.

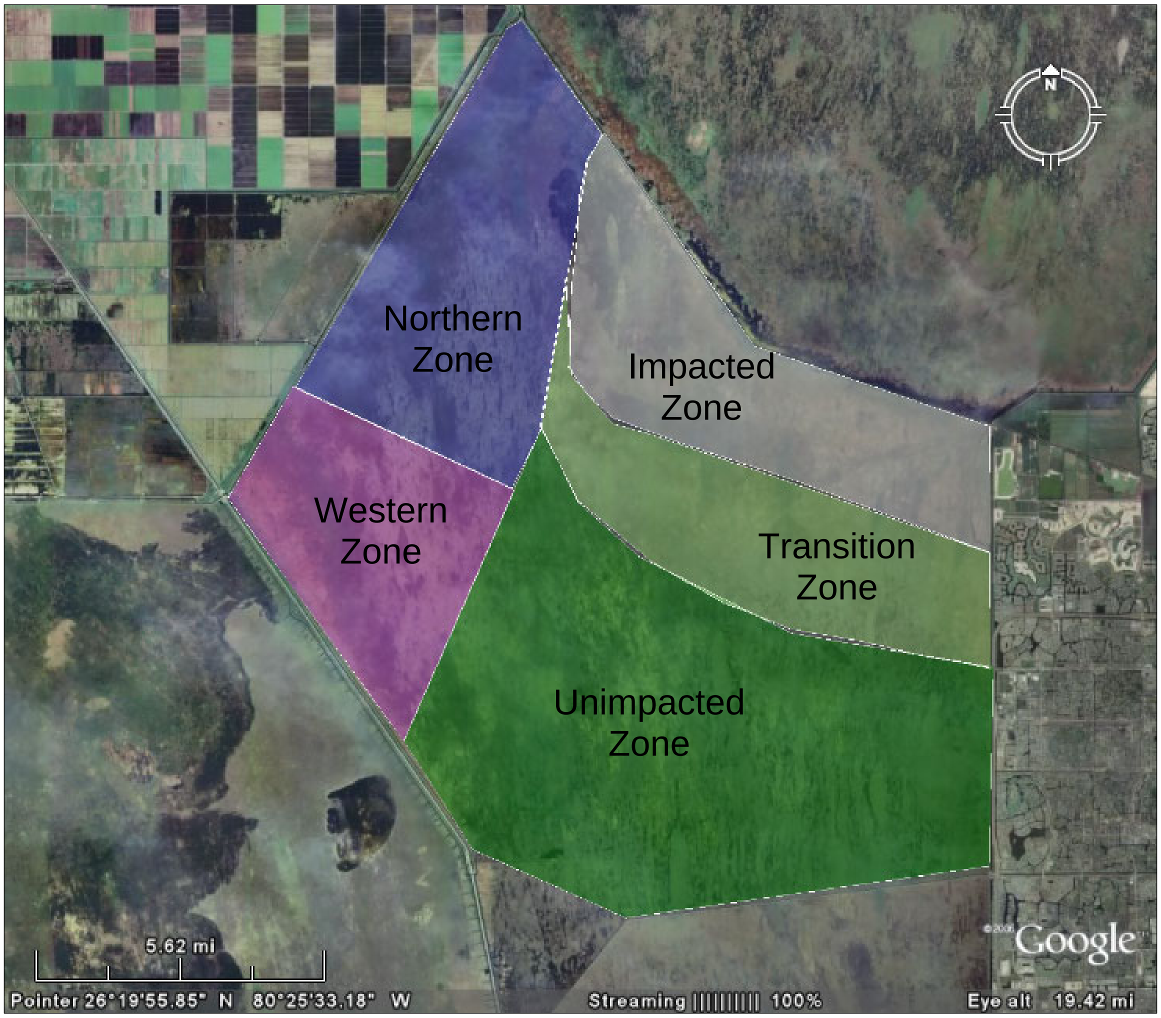

Figure 1B-12. Five monitoring zones used to analyze monitoring sites in WCA-2A.

Impacted and Transitional Zones: The Impacted Zone is immediately downstream of three water control structures S-10D, S-10C, and S-10A that move water in from WCA-1 along the Hillsboro canal. These structures have contributed to the establishment of an enriched cattail zone that has been monitored by two canal stations, F0 and E0, and four marsh stations: E1, E2, F1, and F2 (**Figure 1B-13**). Recently, the TP rule has added an additional impacted station designated CA223. The Transitional Zone is immediately downstream of the Impacted Zone and continues the nutrient gradient established by the S-10 structures. This area has been monitored by four stations: F3, F4, E3, and E4.

District staff recommends that all 11 stations in the Impacted and Transitional Zones be continued in the reengineered network. These sites are needed for long-term ecosystem tracking and are relevant to research projects and/or monitoring of discharges into WCA-2A.

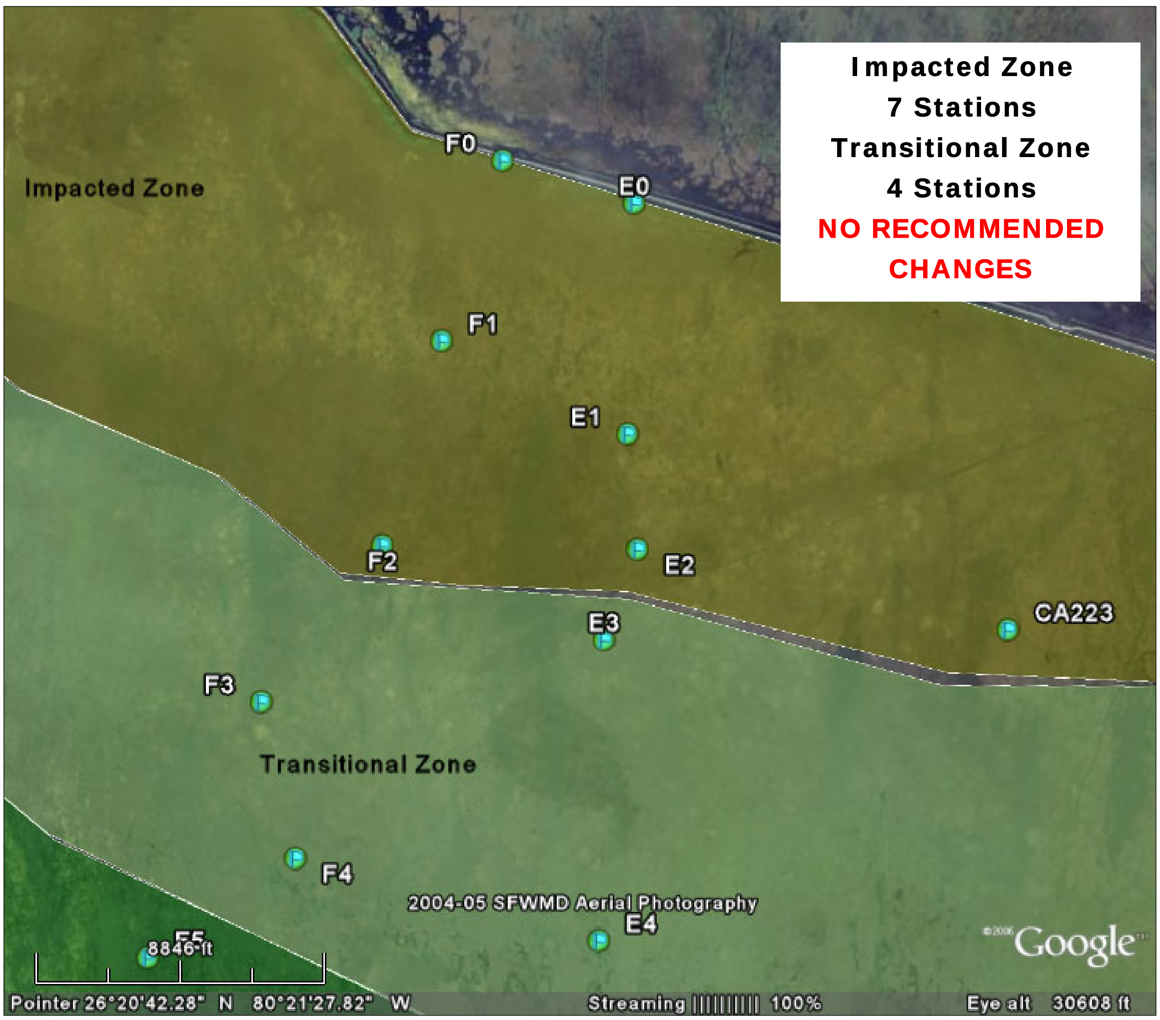

Figure 1B-13. Impacted and Transitional Zone monitoring stations in the northern portion of WCA-2A.

Unimpacted Zone: The Unimpacted Zone is immediately downstream of the Transitional Zone in the southern portion of WCA-2A, and continues the nutrient gradient established by the S-10 structures. This area has been monitored by six stations: E5, F5, U3, U2, U1, and CA215 (**Figure 1B-14**). Additionally, the TP rule has added two additional unimpacted stations designated CA222 and CA217 to improve spatial coverage.

Of these eight stations, the District recommends the elimination of only CA215. Statistical analysis found that all of these stations were not statistically different for sulfate (SO_4), but found that CA215 was significantly different from all other stations for TP. Similarly, for conductivity, U2 and CA215 were not significantly different from each other, but were significantly different from all the other stations. However, despite the statistical differences, the magnitudes of the differences were not ecologically meaningful, which lead to the recommendation for elimination. Based on the information considered to date, the Unimpacted Zone should be sufficiently represented by the other seven stations.

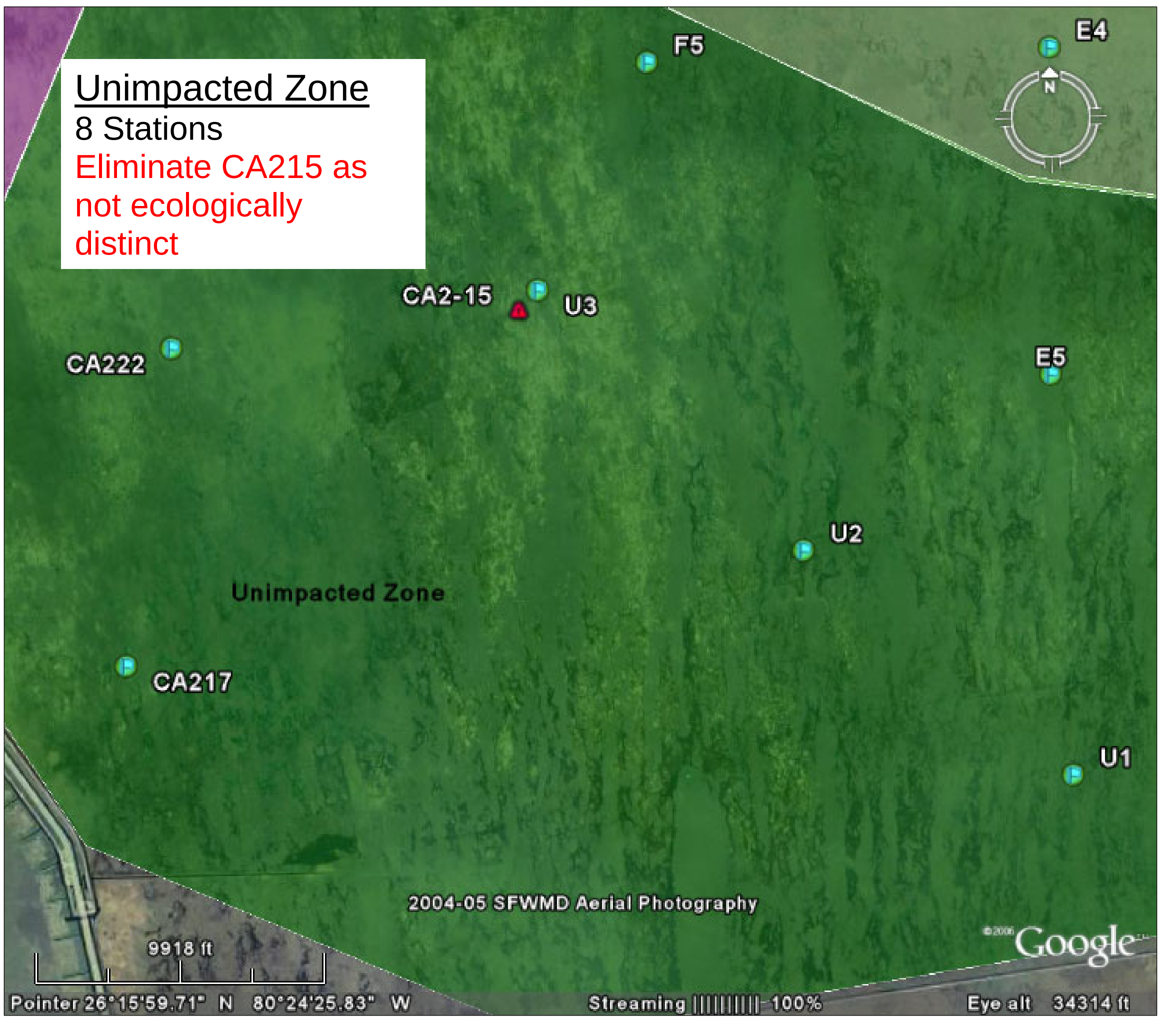

Figure 1B-14. Unimpacted Zone monitoring stations in southern WCA-2A**.**

Northern Zone: The Northern Zone is immediately to the east and south of the STA-2 discharge culverts G336A through G336F. It is characterized by a relatively steep rise in topography that limits the flow of water into the deeper marsh to the east, directing it southwest parallel to the L6 levee. This area has been monitored by 13 stations: N.25, N1, N2, N4, C.25, C1, C2, C4, S.25, S1, S2, S4, and CA27 (**Figure 1B-15**). The TP rule then added an additional unimpacted station designated CA26 for a total of 14.

Of these stations, the District recommends the elimination of six (N4, C1, C4, S.25, S2, and CA27). This is justified by the lack of significant water quality or ecological differences between several of the stations. N1 was representative of all other N-designated stations for conductivity and SO_4, and was representative of N.25 for TP. C2 was found to be representative of C1 and N4 for all three analytes. S1 was found to be representative of S.25 for all three analytes. S4 was found to be completely representative for C4 and S2. The recommended set of monitoring stations creates a transect (N.25, N1, C.25, S1, and S4) that follows the flow contours, while at the same time places stations in the areas of higher topography (N2, C2, and CA26) to act as reference stations.

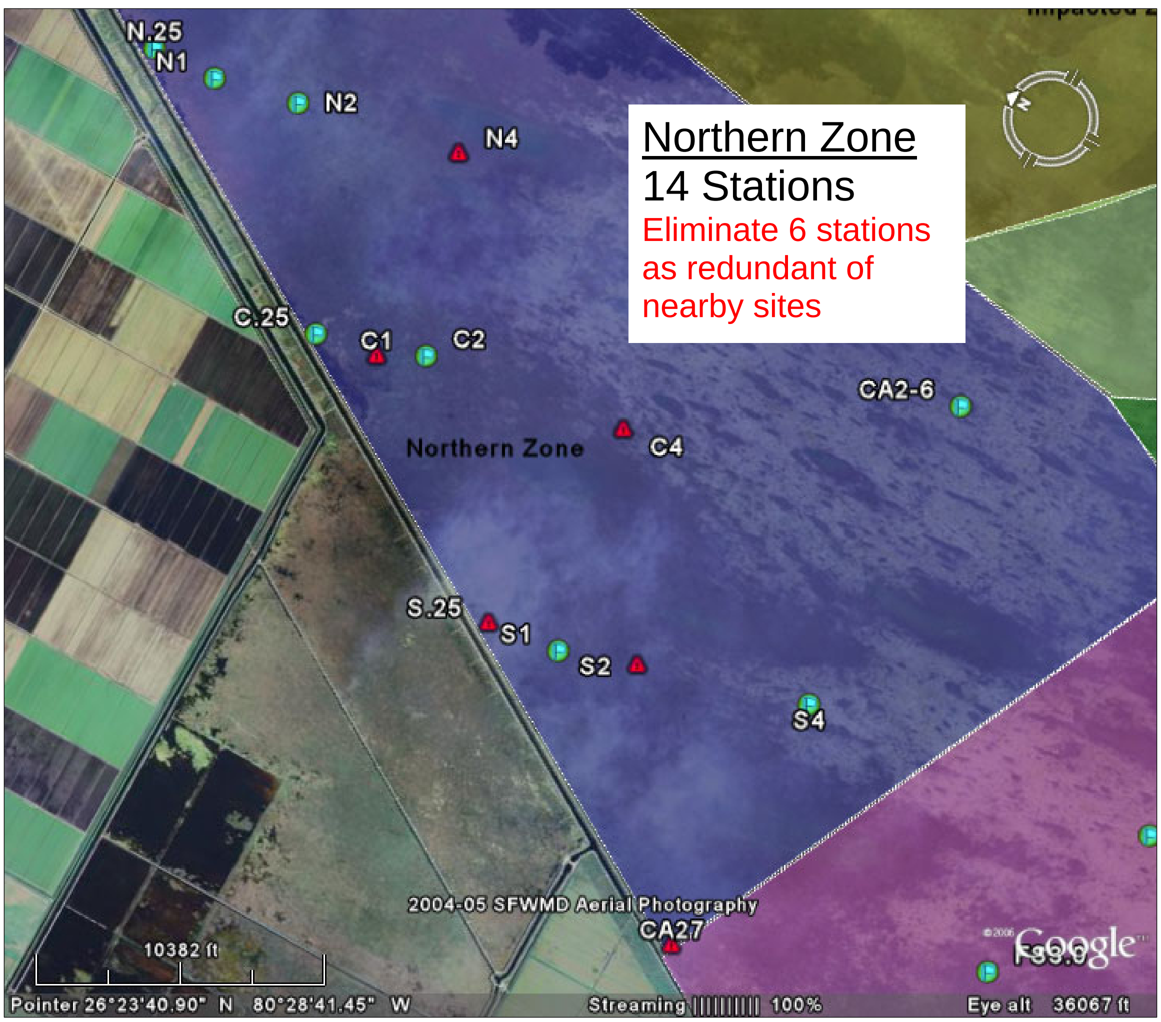

Figure 1B-15. Northern Zone monitoring stations in WCA-2A.

Western Zone: The Western Zone is an area immediately east of structure S-7. This area has been monitored by six stations FS.25, FS1.0, FS2.0, FS3.0, CA29, and CA28 (**Figure 1B-16**). Recently, the TP rule added two stations designated 404Z1 and CA224.

The District recommends continued monitoring of six stations in this area: 404Z1, FS.25, FS1.0, FS3.0, CA29, and CA224. Statistical analysis of data from this area shows wide variation in surface water conditions which warrants further monitoring. Stations CA28 and FS2.0 were found to be redundant of nearby sites based on their general ecology and chemistry.

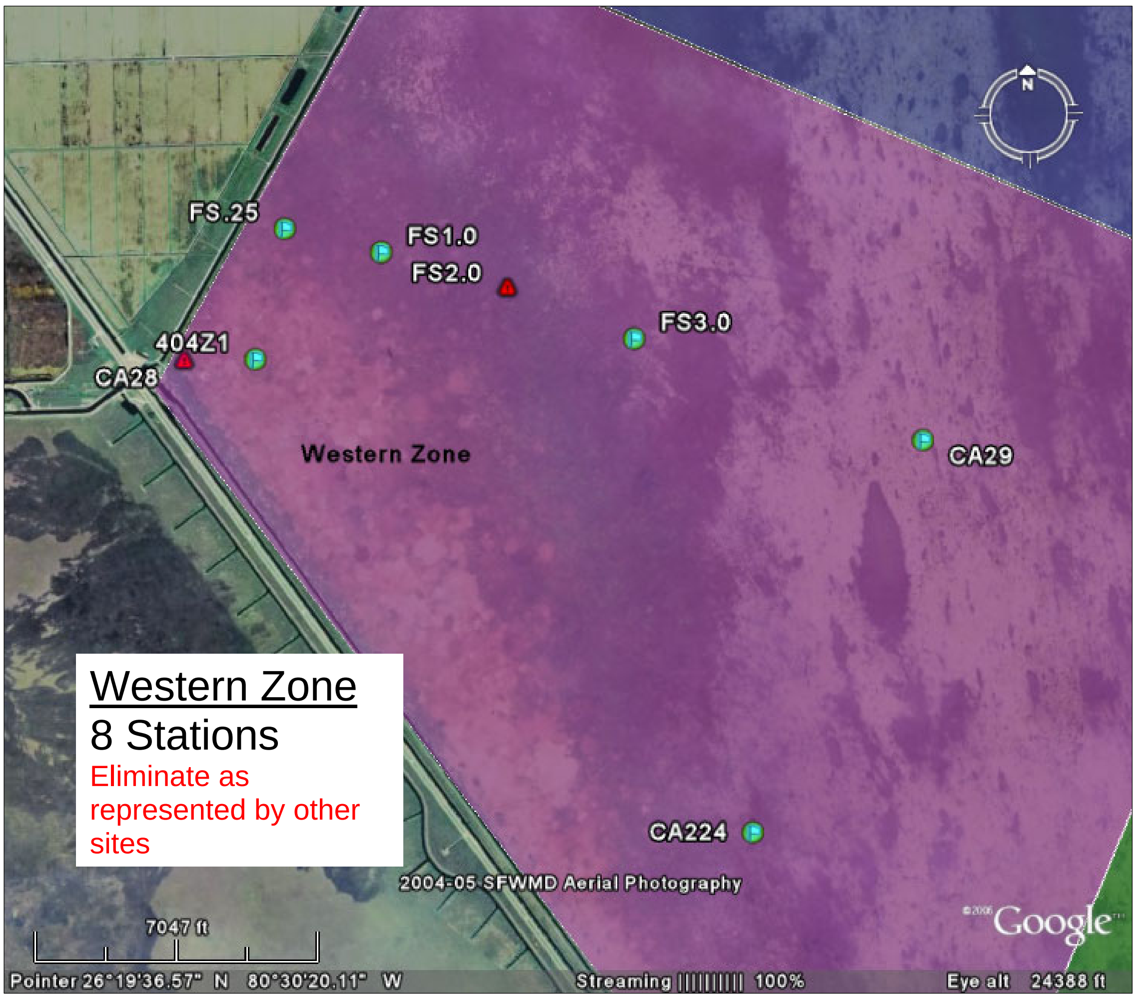

Figure 1B-16. Western Zone water quality monitoring stations in WCA-2A.

SAMPLING FREQUENCY FOR MARSH MONITORING

A variety of alternative sampling frequencies have been proposed for study during the reengineering process. These have included sampling frequencies for different stations based on level of enrichment, with fewer samples in less impacted sites; hydrologic season, with fewer samples in the dry season, and rotating basins, with fewer samples during average years and more on a three-to-five-year basis. Review of these suggestions has shown that such designs may have serious logistical issues and fail to meet some legal requirements, particularly the monthly requirement of the TP rule. These frequencies may also fail to provide all the data necessary to meet some project specific needs. Of all the options that have emerged, a frequency of monthly for all stations appears to be optimal, at least for this first iteration of review. While this frequency does not represent a change for most of the stations, it is a reduction in the biweekly collection under the EVPA program. More quantitative study of various sampling frequencies and their influence on information flow will be done in the near future.

If both the recommended station and frequency changes are made for WCA-2A, which includes the reduction of nine stations and monthly sampling for all, then the overall reduction in monitoring effort for the entirety of WCA-2A can be determined. Under the existing programs, 41 stations in WCA-2A were visited a total of 57 times per month (this includes biweekly stations and overlapping programs) or 684 site visits per year. Under the proposed marsh monitoring program, 32 stations would be sampled monthly for a total of 32 visits per month or 384 station visits per year. This represents a 44 percent reduction in station visits and would generate many thousands of dollars in cost savings in helicopter use, and substantial staff time for collection, analysis, data storage, and reporting. Obviously, more investigation is needed on alternative sampling regimes as the reengineering proceeds.

SELECTING WATER QUALITY MONITORING PARAMETERS

The discussion of parameters has begun with the WCA-2A test case, but the information developed here can be applied to monitoring in other geographic areas, at least as a starting point. Under the existing water quality programs, monitoring parameters vary considerably from single constituents (TP in the TP rule) to constituents of uncertain utility, such as alkaline phosphatase activity or chlorophyll at structures. Parameters may also include highly specialized constituents like the trace metals cadmium, copper, and zinc seldom found in detectable amounts in marshes. In a unified monitoring program, sharing common stations and a standard frequency, different parameter sets for different stations represent problematic complexity starting with field logistics, through data generation and including quality assurance and data base management. Based on these concerns, a reengineering goal should be to have a standard water quality parameter set agreed upon for all stations regardless of previous sampling history or project requirements.

After some initial discussion with the internal working group and based on input from several authorities, a preliminary standard parameter set would include the following:

Nutrients	Ions	Others	Field Measurements
TP	Ca	TSS	Temperature
OPO_4	Mg	TOC	Dissolved Oxygen
TKN	Na		Conductivity
NO_X	K		pH
	SO_4, SiO_2		
	Cl		

Debate still exists over the need for sampling for NH_3, used in the past to calculate NH_{4+}, which has been associated with some areas of concern in marsh. Weaver et al. (2007) provide both data and interpretation on un-ionized ammonia as a water quality concern for two sites in WCA-2A. Additional discussion is needed to justify this parameter at all sites in WCA-2A.

There is still some discussion over the efficacy of the current method for monitoring *in situ* physical parameters including temperature, pH, conductivity, and dissolved oxygen. Under the current method, a single data point at a discrete time collected by a data sonde is used to represent the conditions at a station. However, research has shown that these parameters vary significantly on a diel and weekly basis, and therefore, may not be reasonably represented by a single data point taken at the time of sampling. This large diel variability was dealt with for dissolved oxygen by a site-specific alternative criterion for marshes that adjusts *in situ* data for diel fluctuations based on an equation developed from extensive diel studies. Other parameters do have a site-specific criterion. As an alternative to single-point measurements, it has been suggested that sondes be deployed at select stations on a quarterly basis for five days of hourly sampling collection. The exact number and location of such sampling has yet to be determined.

OTHER ISSUES TO RESOLVE

In addition to resolving the parameter issues, there are other minor issues that must be resolved in order to fully integrate the monitoring of WCA-2A and elsewhere in the region.

- The first, and relatively simple, issue is which laboratory to use. Under existing programs, much of the monitoring is delivered to the SFWMD laboratory, while some work (like the Threshold Project) is shipped to the FDEP laboratory in Tallahassee, FL. Under the integrated program, to reduce logistics problems and save shipping costs, all samples would be delivered to the SFWMD laboratory and resulting data stored in DBHYDRO.
- One significant difference between water quality monitoring for research versus long-term tracking is the use of unique collection protocols. Routine monitoring in marshes currently operates under a logistical guideline which precludes sample collection when water depths are less than 10 cm. FDEP has approved this sampling process as part of the interagency laboratory and field quality assurance process. However, researchers working on long-term restoration efforts continue to sample even when contiguous water is no longer present in the marsh. This methodological difference will have to be addressed and resolved before a comprehensive monitoring plan can be implemented.
- It is acknowledged that monitoring of media other than surface waters is currently being carried out by the research group, including periphyton, sediment, vegetation,

and macroinvertebrates. Staff in the monitoring group will need significant amounts of training to absorb this ecological monitoring.

- Under the section of this redesign dealing with structure monitoring, the District was able to develop a fundamental paradigm shift that significantly altered the purpose, frequency, and timing of monitoring inflows and outflows. In the section dealing with ambient marsh monitoring, such a paradigm shift did not seem to occur; the current recommendations on marsh sites are a necessary optimization, but are not sufficient for reengineering. On the other hand, there appears to have been a real change in the underlying principles of how WCA-2A is monitored and why. Rather than deal with monitoring stations on a project-by-project basis, the agency now seems to view stations as providing information on the area as a whole. This represents a fundamental change in thinking and is a first milestone of reengineering.

REDESIGNING WATER QUALITY MONITORING IN SOUTH FLORIDA: ADDITIONAL SUBJECT AREAS TO BE ADDRESSED IN THE REENGINEERING

The WCA-2A test case has done exactly what was intended. It allowed us to see how easily the ideas from the literature and other monitoring programs could be put into action for a specific area. The test case demonstrated that moving to fundamental rethinking of monitoring is still largely a work in process. Real reengineering will require continuing pilot studies of concepts, trial reengineering attempts in other geographic regions of South Florida, and continuing investigation of new approaches to monitoring in all its aspects. As information improves, the District will need to revisit monitoring programs on a rotational basis to apply lessons learned. Ideally, the SFER panel's repeated recommendations on improving South Florida monitoring and reporting could be done in one grand fell swoop at a regional level. Realistically, our agency does not have the staff resources for this huge effort – and enough is not known to work at a regional level at this time. The District seeks a more integrated system with far more consistent information and will continue to work through our programs to reach this end point. Better tools and more experience will help achieve this goal.

Without implying priority, the following represents some subjects and activities that deserve further consideration to facilitate the reengineering:

1. Evaluate the implications of using different sampling frequencies and sampling intervals.

Recognizing that field visits are a major cost and that most objectives for monitoring are long-term, focusing sampling events to produce more information per unit effort is worthy of serious study, even for compliance with water quality standards. Although logistics is a major limiting factor to variable sampling intervals, the following should be considered:

- Bimonthly or seasonally adjusted sampling for geographic areas <u>not</u> undergoing any management change and with water quality known to be in compliance with standards and relatively stable;
- Using local surrogate sites when data demonstrate good predictive capability for estimating water quality for a group of inflow or outflow sites (e.g., S-10s, or S-11s); and
- Reducing wasted site visits in marsh sampling by applying a no-fly protocol based on stage readings and relationships with water depth at sampling sites (EDEN network may be useful in developing these relationships).

In their guidelines for Australia and New Zealand, ANZECC (2000) suggests using known variability of target measurement when deciding on the frequency of measurements. The USGS (2002) stresses the need to use monitoring resources based on water quality goals, water body condition, and uses of the data, and they urge flexibility in monitoring designs. Ward et al. (1990) describe a detailed statistical approach to sampling frequency. Greve et al. (2003) used quantitative analyses to assess sample sizes needed to produce a desired precision, and reasonable power to detect trends in Colorado's Big Thompson Watershed. An excellent example of optimization using a strong statistical approach is the Dutch Coastal Zone in which Swertz et al. (1997) were able to justify reducing stations from 76 to 32 while shifting priorities in several constituents. At a minimum, the District needs to use existing data to assess how biweekly, monthly, bimonthly, and quarterly sampling compares in detecting change and to use this information in making final recommendations on either fixed or variable sampling intervals. The agency also must consider difficulties associated with variable sampling intervals for detecting trends; fixed frequencies and long-term data collection is most suited to detecting trends (e.g., Whitfield, 1988).

2. Using available data, investigate information outputs from various configurations of networks.

To date, the District's statistical work has used a conservative approach to station redundancy (see Appendix 1B-2 of this volume). These analyses have been very helpful for considerations of sampling sites, although more complex approaches like cluster analysis are being applied to WCA-2A as well for additional information. However, existing data also needs to be used to quantify the affect of various numbers and locations of stations on our ability to detect status and trends.

3. Explore the use of a reference-site approach to get more information from a network.

In Volume 2 of their guidance on monitoring, the National Oceanic and Atmospheric Administration (2005) provides habitat by habitat facts relevant to the design and implementation of restoration monitoring of coastal resources. A real strength of NOAA (2005) is the application of reference sites to environmental monitoring programs. This design is very important in systems subject to large interannual variability and long-term climatic cycles. As pointed out in Chapter 15 of the NOAA report, reference sites can be distinguished in three ways: (1) background reference sites used to bracket conditions in a habitat being restored ("reference domain"), (2) degraded reference sites reflecting conditions without intervention, and (3) standard reference sites reflecting conditions in the area without degradation. Other sites being restored are expected to move from degraded conditions to conditions at the sites within the standard reference sites.

Importantly, standard reference sites do not necessarily mirror historical conditions, but do reflect functional components of the ecosystem under current, minimally disturbed circumstances. References sites should be as close as possible to those sites to which they are being compared. Sites can never be identical but should reflect the bounds of expectation for the restoration.

There is no known instance where a reference-site approach has been used for water quality monitoring, and it may not prove useful in South Florida. Nevertheless, some additional investigation of the literature and some trial applications of reference sites using existing data might offer some additional information for network designs and better ways of using data for detecting change. One possibility might be to use WCA-2B, southeast of WCA-2A, as a reference site.

4. Examine the use of non-traditional statistical methods to design networks and interpret data.

If the efficiency of monitoring is to be improved, then reevaluation of both data analysis methods and design to support those methods is vital. As Griffin et al. (2001) emphasize, data analysis methods are not consistently used within and between organizations, and there are no standard methods recommended across the nation. In fact, even the required state 303(d) and 305(b) reports assessing water resources lack peer reviewed and agreed upon methods for analysis.

Most analysts use hypothesis testing as a basic approach to data. There is considerable debate about whether this traditional way of null hypothesis testing is optimal for water quality, which involves many constituents and is often intertwined with other objectives like water transfers for flood control, water supply, or environmental management. Griffin et al. (2001) also point out that in other fields such as medical studies, methods like equivalence testing, meta-analysis, and Bayesian statistics can produce more objective and valid information than standard hypothesis testing. These and other non-traditional data analysis methods deserve study for possible use in South Florida monitoring.

New statistical approaches in this reengineering have two aspects: network design and statistical inference. If non-traditional approaches were found to be workable, then they might allow different network designs, parameter types, and sampling frequency. For environmental restoration in which water quality needs to be viewed more collectively than simply testing one parameter at a time, non-traditional methods using multiple data sets could be very practical. For example, an emerging statistical approach, termed "model selection", is based on information theory and involves evaluating alternative models for support from existing data. Models with their underlying hypotheses can then be ranked as to their relative support by the data. Model selection is being applied in many fields including environmental studies (Johnson and Omland, 2004; Anderson et al., 2000) and should be investigated for this reengineering. Whether this or any other non-traditional method would require more or less data remains for investigation.

5. Find ways to evaluate the relative importance of primary (original) or secondary uses of data in determining value and priority of monitoring.

To date, the reengineering process has revealed major differences in how technical professionals view monitoring and justify continuing to monitor. In recent interagency workshops, the District has received feedback that all monitoring should continue unchanged because data might be useful for future, unpredictable needs. We agree that future needs must be considered, but view this as an argument for creating an integrated, streamlined information system, not as an argument for maintaining an existing network without optimization.

Participants in the interagency workshops also argued that monitoring should be continued if the data are being used either internally or by individuals from other organizations not involved in network design or operation. Some participants have requested that the District conduct surveys to locate all data users inside and outside the agency and use this information to justify existing networks. The problem is that all data can be used by someone (and most is used eventually) and there is no means to evaluate the value of data use outside the funding agency. Are three data users enough, or should there be seven? Often the original purpose of the data collection can be met by modifying a network, but secondary uses of data have created "new" uses and needs for information that might not be met with modification. This subject will need additional study and discussion, but clearly the information needs of the funding agency should probably take precedence, and data use itself is not reason to continue monitoring. After all, a better-designed and well-maintained water quality network could lead to more data use outside the funding agency in the long run.

Another unforeseen complication of the reengineering derives from would-be users of data who have no current need for the data, but who assert that the data may be needed to address some future legal, regulatory, or research needs, and therefore should be continued without considering costs. This is related to Ward's insurance argument described as a "desire to insure against future findings that could create legal or regulatory problems" (Ward et al., 1990). An undercurrent of this situation is that the unintended users usually have not participated in the water quality information flow process. This creates concerns over appropriateness of using the data as "found" data in that unintended use occurs without planning for the monitoring system or data analysis. Ward et al. (1990) has suggested that "Since no data analysis methods were established prior to collection, any efforts to analyze the data are suspected of having some bias. This is especially true when there are disagreements over the findings of a data analysis effort. When such disagreements arise, it is very difficult to address the issues at hand because arguments do not separate the means of generating information from the results." Additionally, because the unintended work product is unknown to the monitoring system, there is no bottom-up review of the application and integrity of the data for that purpose; this can be a serious flaw in any eventual product.

The monitoring for insurance argument suffers from similar problems, as well as significant logic, budgetary, and practical constraints. The fundamental problem with this argument is that it is unconstrained and can be employed to justify the continued monitoring of any parameter, at any frequency, and for any duration. Virtually every general reference on water quality monitoring does not support this argument – clear, quantifiable objectives are always up front. Furthermore, it is the responsibility of monitoring system managers to periodically review and optimize monitoring systems relative to their objectives, and unknown or unforeseen data uses can not be included in these reviews. Precluding optimizations based on either insurance or unknown future use rationales can waste limited resources. If unintended uses of data support the agency's mission directly, high priority is easily justified and monitoring should be continued. As uses of the data at a site become less and less relevant to the agency's mission and decision support, and more and more removed from the original intent of monitoring, determining priority can be difficult and subjective. These problems are expected to reoccur as each geographic area of South Florida moves through the reengineering process and a better decision support system to deal with them would be helpful.

CONCLUDING THOUGHTS ON THE REENGINEERING

It has been nearly one year since the District first began its effort to rethink water quality monitoring. This chapter reflects much of what the District has learned so far and reflects attempts to crystallize directions for the WCA-2A test case and beyond. The agency recognizes that serious challenges lie ahead on many fronts, but also sees great opportunity to reconstruct water quality monitoring into an integrated information system with sustainability and cost-effectiveness. In doing so, the District seeks to end up with a regional system that has most of the "seven habits of highly effective monitoring programs", as paraphrased below based on Lovett et al. (2007):

1. Design around clear information needs.
2. Include review, feedback, and adaptation in the design.
3. Choose measurements carefully.
4. Maintain data quality and consistency.
5. Incorporate long-term data accessibility.
6. Report on the monitoring data continually.
7. Include monitoring within an integrated information system to support research, modeling, regulatory compliance, and long-term resource management.

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