Lessons Learned in Operation of an Aboveground Reservoir at the Peace River Facility

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The Peace River Manasota Regional Water Supply Authority (Authority) water production facility is located in DeSoto County near Arcadia. The facilities include a 48-mil-gal-per-day (mgd) conventional surface water treatment plant, 120-mgd water intake on the Peace River, 6.5 bil gal (BG) in off-stream raw water storage (two reservoirs), and 21 aquifer storage and recovery wells. The facilities currently serve an average finished water demand of about 25 mgd in Charlotte, DeSoto, and Sarasota Counties, and the City of North Port.

The large-volume off-stream storage and the ability to harvest water at high rates enables a seasonal resource (wet season flows in the Peace River) to reliably meet most of the drinking water needs in three counties, while preserving the freshwater flow needed to support the Charlotte Harbor estuary. Water is withdrawn from the Peace River on a flow-based schedule, with most water harvested during the summer months, providing adequate stored supplies for the dry season.

Four years of management and operational data for this off-stream reservoir have shown the level of effort, challenges, and cost required to keep this off-stream reservoir system in top operating condition.

Peace River Reservoirs

The Authority has two off-stream raw water reservoirs (Figure 1).

Reservoir 1 was constructed in the late 1970s by general development as an 85-acre inground water storage facility. Essentially, Reservoir 1 is a manmade lake with a capacity of about 500 mil gal (MG), and little detailed information is available on its construction other than bottom topography.

Reservoir 2 construction commenced in December 2007 and was completed in July 2009. Reservoir 2 is a 640-acre aboveground impoundment with a live-storage capacity of 6 BG. The impoundment is formed by a highly engineered earthen berm approximately 4 mi in length. The berm is about 200 ft wide at the base, 35 ft high, and 15 ft wide at the crest. It was constructed using a balanced cut-and-fill system whereby nearly all of the material to build the berm was excavated from the interior area of the reservoir. Specialty materials, such as coarse sand used for the internal drainage system and bentonite for the interior slurry wall, were imported off site.

Figure 2 shows the cross section of the Reservoir 2 berm, highlighting the engineered features of the embankment, including soil cement on the interior slope for erosion protection, an 80 mil high-density polyethylene (HDPE) liner and bentonite slurry wall that keys into the underlying Miocene clays (about 50 ft below land surface) on the interior face of the berm to minimize leakage, an internal drainage system to improve safety and stability, and vegetated exterior slope for stability and erosion protection. The embankment (interior and exterior) and immediately surrounding area also includes 105 piezometer stations monitoring water levels in the embankment and shallow perimeter groundwater system, 14 stations monitoring flow in the embankment drain system, five extensometer sites to monitor movement in the soil cement, and 46 survey stations to monitor movement in the embankment.

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Figure 1. Two Off-Stream Raw Water Reservoirs

Exterior Slope Maintenance

The exterior of the reservoir includes approximately 50 acres of turf on a 3:1 slope. The turf covering the slope is considered a structural element of the embankment due to its importance in minimizing erosion. Initial installation of the cover on the exterior slope in the reservoir construction contract called for seeding; however, the reservoir contractor quickly discovered that keeping the slope dressed (free of erosion) while the vegetation took hold was not cost-effective, and it was proposed to sod the embankment instead. The sod type (Bermuda grass) was chosen based on its extensive root system and reported ability to hold soil under potential overtopping conditions in the reservoir.

The Bermuda grass, however, has not thrived on the well-drained embankment, and while there are areas on the embankment where this grass has remained in a serviceable condition, large areas of the turf stopped growing and were being naturally replaced by less desirable, weedy vegetation. In spite of recommendations by turf experts visiting the site, herbicide and fertilizer applications produced little improvement. Erosion (Figure 3), primarily resulting from heavy wet season rainfall in these areas, has been an ongoing maintenance issue and repairs often must be made by hand due to soggy embankment conditions, which preclude use of most equipment on the slope. An additional challenge has been to secure the repair areas so that water from upslope doesn't cause another washout at the same site before the repairs take hold.

Early erosion repair efforts often required multiple attempts. Current repair methods have been far more successful and include good compaction of fill material, careful sod placement (eliminating gaps), installation of temporary sod strips above the repair areas to divert water from upslope, and regular watering until the repaired sod is established. All repairs since the initial sod installation have been done using Bahia rather than Bermuda sod, as experience has shown that Bahia grass provides superior coverage and erosion resistance under the well-drained embankment conditions.

In 2012, the Authority began a proactive program to convert all areas on the embankment to Bahia grass. The resodding effort was conducted in the fall when the embankment was not too wet for light equipment but will still receive some rainfall to aid in turf establishment. Figure 4 shows the ongoing sod replacement effort.

Mowing of the embankment is required to promote healthy grass and to allow the inspection of erosion features; many of these features are difficult to see, especially in uncut grass. These erosions can sometimes be detected by looking for small deltas of sand that often form where the embankment slope meets the toe ditch below an erosional feature. Mowing is scheduled twice a month in the growing season subject to embankment conditions, and as-needed during the dry season. Fourteen cuts per year are about average, and mowing costs are billed per acre cut. Mowing in wet conditions can create new erosion issues, and as such, having an experienced mowing contractor with adequate manpower and appropriate equipment to get the job done when conditions are appropriate is essential. Annual service costs are shown in Table 1.

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Table 1. Annual Service Costs

Service	Current Annual Cost
Erosion Repair	$30,000
Sod Replacement Program	$150,000
Mowing	$52,000
Herbicide, Fertilizer, etc.	$49,000

Note: Sod replacement is ongoing, with conversion from Bermuda to Bahia grass.

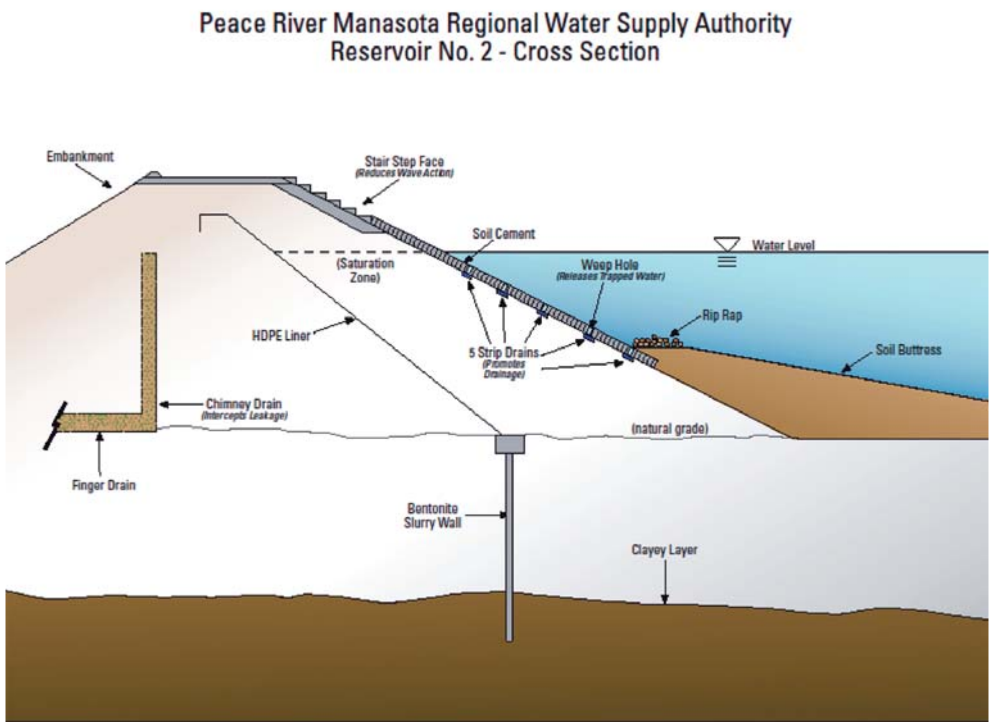

Figure 2. Reservoir 2 Cross Section

Figure 3. Erosion

Figure 4. Sod Replacement

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Lessons Learned

- Carefully consider appropriate embankment cover vegetation in the design phase, and once installed, be proactive in maintaining it.
- Erosion, especially during the summer, can develop and grow quickly, so embankment inspection must be frequent (every one to two days and after every heavy rainfall event) and repairs should be expedited.
- Make careful repairs using good quality sod. Protect the repair areas from upslope runoff and irrigate until coverage is re-established. This will reduce the need for re-repair of the same location.
- Select a well-qualified mowing contractor with the experience, proper equipment, and manpower to do a good job and stay on schedule. Low-bid might not work here.

Reservoir Roadway Maintenance

Approximately 5 mi of roadway are maintained in conjunction with the reservoir. This includes 4 mi of reservoir perimeter roads and a 1-mi access road. The road surface is marl/shell material. The perimeter roadway is elevated 2 to 8 ft above the bottom of the toe ditch at the base of the embankment and the surrounding land surface. Steep side slopes on the embankment between the toe ditch and perimeter road and poor sod establishment/coverage along the roadway edge have required considerable maintenance, as heavy rains tend to wash out sections of this interior slope (Figure 5).

At several of the worst erosion locations, permanent low-profile gravel discharge structures have recently been installed to deliver water directly from the road to the toe ditch. While gravel discharge structures are not feasible everywhere, Authority reservoir management staff has learned through experimentation that successful repair on the interior slope of the roadway can be accomplished by notching the road at the edge of the shell and filling the notch with quality soil and then with Bahia sod so that it is level with the shell road when complete. While repairs continue, a multiyear program to make these changes around the entire perimeter road is underway.

Mowing of the inside roadway slope is difficult under normal circumstances, but it is made more difficult by erosional features. Mowing here is conducted as part of the embankment mowing event and also includes the toe ditch (see annual mowing costs in Table 1). Table 2 shows the costs for erosion repair, as well as the multiyear program to reduce future erosion problems on the perimeter roadway through the correction method described.

Lessons Learned

- Avoid slopes greater than 3:1; they are difficult for all maintenance requirements.
- The interface between the sodded side slope and the roadway needs to be well-defined and carefully constructed. Sod should be bedded in good soil and compacted level with the road shoulder to prevent erosion.
- Specific stormwater discharge locations from roadway to perimeter ditch (or swale) should be contemplated in design.

Figure 5. Interior Slope Washout

Table 2. Erosions Repair Costs

Service	Current Annual Cost
Erosion and Roadway Repair	$16,000
Proactive Modifications to Reduce Erosion	$35,000

Regulatory Compliance: Environmental

Multiple compliance efforts are included in the management of the reservoir. These were generally borne from the environmental resource permitting (ERP) process and involve monitoring of wetland water levels and shallow groundwater conditions adjacent to the reservoir, and monitoring and management of wetland mitigation areas. Such efforts were intensive in the first few years of operating the reservoir. These efforts have been reduced with time as wetland success criteria were met, and evaluation of perimeter data indicate that the reservoir is not having any deleterious effect on nearby wetlands or shallow groundwater conditions. Monitoring and reporting efforts associated with the reservoir embankment safety are discussed separately.

Construction of the reservoir impacted about 165 acres of wetlands. On-site mitigation (on the 6000-acre RV Griffin Reserve) resulted in the restoration and enhancement of about 1055 acres of wetlands. Maintenance, monitoring, and regulatory reporting associated with the mitigation areas is conducted by outside contractors and managed by Authority staff. These efforts are ongoing for a sixth and possibly final year. Costs for the program have declined through time as many wetlands have reached their success criteria and were released by regulators (see Table 4). However, some long-term effort to control exotics will continue on wetlands, even after release.

In addition to the mitigation effort, monitoring of wetland water levels and surficial aquifer groundwater conditions around the perimeter of the reservoir is required. The effort included water level monitoring at 17 shallow wetland piezometers and 16 surficial aquifer monitor wells, and periodic water quality sampling at the surficial aquifer monitor wells. Data collection and evaluation efforts were initially conducted through professional services contracts, but in recent years most data collection has been assumed by Authority staff.

The cost reduction from 2010 to today (see Table 4) for the wetland mitigation program reflects release of many of the wetlands by the Florida Department of Environmental Protection (FDEP) and the U.S. Army Corps of Engineers as these systems reached success criteria. Current costs for the perimeter monitoring reflect laboratory costs for groundwater samples and evaluation of data by consultants to meet annual reporting requirements. Much of the perimeter program has been eliminated because the monitored systems showed no impacts associated with the reservoir.

Lessons Learned

- Initial monitoring costs tend to be high, but can be reduced in time as success criteria are met and understanding of the effect of the reservoir system on surrounding areas evolves.
- Audit monitoring programs. The FDEP has been receptive to requests for reduction in monitoring when presented with good supporting data.

Regulatory Compliance: Embankment (Safety)

Ensuring that the reservoir system functions safely and as designed is a continuous and critical effort requiring daily coordination among Authority staff, outside experts, and regulators. The Authority has one staff member dedicated solely to monitoring reservoir and nearby conditions, collection and review of data, maintaining reservoir monitoring equipment, scheduling repairs, and preparation of monthly compliance reports.

The embankment interior and exterior, and immediate surrounding area, includes 105 piezometer stations continuously monitoring water levels in the embankment and the shallow perimeter groundwater system, 14 seepage flume stations monitoring flow from the embankment drainage collection system, five extensometer sites intended to monitor movement in the soil cement, 46 survey stations established to monitor movement in the embankment, and a weather station. Data from most of the monitoring sites are collected, stored, and transmitted via an automated data acquisition system (ADAS) to the Authority's water resources office on site for review and assessment.

The ADAS system facilitates collection and processing of large volumes of data very effectively, and the data collection efforts have proven to be worthwhile. Some issues with the system and exceptions to the "worthiness" of the data collection effort are briefly discussed:

- The seepage flumes are intended to continuously measure water movement through the embankments drainage system, potentially identifying leakage through the HDPE liner on the interior of the embankment. In addition to the seepage flumes, there are seven outfall locations from the drainage system where flow is manually measured twice weekly by Authority staff. Iron bacterial slime from the perimeter's surficial groundwater system also enters the internal drain system, regularly fouling the seepage flumes and making the electronic data from these units unreliable. In addition, seepage flumes are located in manholes and require confined space measures for service. Data collected manually at the outfalls however are consistent and reliable and show that the system responds only to rainfall conditions thus far.

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Table 4. Program Costs

Program	2010 Cost	Current Cost
Wetland Mitigation Cost	$210,100	$98,300
Perimeter Monitoring	$65,000	$23,000

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- Extensometers on the soil cement flat plate (interior of the reservoir) consist of a high-tension stainless steel cable with one end affixed to the soil cement near the base of the embankment and the other to a fixed monitoring station near the top of the embankment. These are intended to measure movement in the soil cement. Experience has shown that these instruments are most effective at collecting debris at the water's edge, and as resting locations for alligators; they also respond to thermal conditions. Aside from the conclusion that the soil cement is not moving, no other useful information has been obtained.
- The ADAS recording and communication equipment is located in 21 National Electrical Manufacturers Association (NEMA) 4X boxes at various locations along the crest and base of the reservoir. The NEMA 4X was selected as a weatherproof box to keep moisture from fouling the electronic equipment; however, experience has shown that moisture condenses inside these boxes, causing premature failure of equipment. The installation of vents in the boxes has alleviated the issue.

In addition to the ongoing monitoring program described, the ERP for the reservoir includes specific engineering inspection, testing, and reporting requirements during operation of the reservoir system. An embankment performance monitoring plan (MWH, July 31, 2009) developed for the Authority also contains special testing and monitoring of the system.

Table 5 identifies the physical special inspections and monitoring (no ADAS) requirements. Comparison is made between efforts required early in the reservoir operations (2010) and current ones (2013-2014). Some of these special inspections have been eliminated or their frequency has been reduced after review of the data.

Table 6 shows a comparison of 2010 and current costs for embankment monitoring, inspection, and compliance reporting. Reductions in embankment monitoring and reporting costs reflect a reduction in the frequency of some monitoring, and Authority staff assuming increased responsibility for monthly reporting. None of these costs include Authority staff time.

Lessons Learned

- Full-time staff with appropriate expertise is needed to inspect, manage, and maintain the reservoir.
- Initial monitoring costs tend to be high, but can be reduced with time as confidence is gained in reservoir operation and management.
- Iron bacteria are common in earthen embankments and can foul automated monitoring equipment in the seepage system. Hand measurement of flow at the outfalls is more effective.
- Extensometers on the interior soil cement have produced interesting, but otherwise unuseful, data.
- The NEMA 4X boxes intended to protect reservoir monitoring electronics have instead been a source of moisture condensation. Ventilation of the boxes has resolved the issue.

Table 5. Physical Inspections and Monitoring Requirements

Compliance Requirement	2010 Frequency	Current Frequency
Embankment Performance Monitoring Report	Monthly	Monthly
Annual Engineering Inspection and Report	Annual	Annual
Quarterly Engineering Inspection and Report	Quarterly	Eliminated
Comprehensive Annual Reservoir Report	Annual	Annual
Subsidence Surveying (1)	Monthly	Quarterly
Sidescan Sonar Bottom Survey (2)	Every two years	Every two years
Embankment Safety Training	Annual	Annual
Emergency Action Plan Update	Annual	Annual
Stormwater System Inspection	Annual	Annual
Third-Party Inspections (on behalf of FDEP)	Monthly	Monthly

(1) Subsidence monitoring was initially elevation (z) 1x/month, and vertical and lateral survey (xyz) quarterly. In 2012, monitoring requirement changed to quarterly xyz only.

(2) Required sidescan sonar survey goes from once every two years to once every five years in 2019.

Table 6. Costs for Embankment Monitoring, Inspection, and Compliance Reporting

Program	2010	Current
Embankment Monitoring and Reporting	$400,000	$300,000
Monitoring System Maintenance (ADAS)	N/A (1)	$37,500 (2)

(1): Monitoring system maintenance in 2010 conducted under warranty.

(2): Includes annual calibration of monitoring equipment and equipment repair/replacement.

Conclusions

Active management of the Authority's 6-BG off-stream, aboveground reservoir helps keep the facility in top operating condition. The management program includes care of over 50 acres of embankment; 5 mi of perimeter and access roadway; environmental and groundwater monitoring of surrounding areas; management of wetland mitigation areas; daily inspection of the embankment; extensive monitoring of in-, on-, and near-embankment conditions; and a host of engineering inspections. A well-trained, experienced staff is critical to the success of this program. While this reservoir requires considerable management and care, this facility has been essential to supporting use of seasonal resources from the Peace River as an environmentally sustainable, highly reliable public water supply.

Maintenance of the reservoir embankment and roadway system has been a learning experience. Lessons go back to the design phase in selection of the appropriate turf for local conditions. Prompt attention to, and quality repair of, any erosion, especially on the embankment, is critical as these erosions tends to grow quickly. Because the majority of mowing takes place in the wet season when the embankment is most subject to damage by operation of heavy equipment, having a well-qualified mowing contractor with appropriate manpower and equipment to get the job done timely and effectively minimizes repair needs.

In general, regulatory compliance has been more time-consuming and costly than expected; however, maintenance of wetland mitigation areas, and monitoring and reporting for permit compliance, has been significantly reduced through time, as have associated costs. Reductions are the result of regulatory release of mitigated wetlands, elimination of ineffective monitoring, and demonstration that the facility is operating as designed and permitted. The FDEP has been quite receptive to revisions and reductions in environmental monitoring with appropriate supporting data.

Some monitoring has been found impractical, such as the high-tech seepage flumes that are continuously clogged with iron bacterial slime from the embankment drainage system. Hand measurement of flow at seepage outfalls is more useful and consistent. Extensometers on the flat plate soil cement (interior of the reservoir) are problematic to maintain as they are easily fouled and have indicated that the soil cement is not moving at those monitored locations, which is visually obvious.