Stormwater Harvesting for Alternative Water Supply in Volusia County

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In support of an alternative water supply plan for Volusia County Water Resources and Utilities Division of the Public Works Department, the feasibility of harvesting stormwater from Deep Creek and Lake Ashby was evaluated as a potential solution to meeting the projected 2030 potable water demand deficit of 7.5 million gallons per day (mgd) annual average daily flow. The evaluation focused on the optimization of the beneficial use of stormwater harvesting without infringing upon established environmental constraints in the basin. The County's alternative water supply plan was integrated into the Water Supply Plan update being prepared for the region by the St. Johns River Water Management District (SJRWMD or the District). More specifically, the alternative plan would replace less desirable water supply alternatives for Volusia County included in previous water supply planning efforts adopted by the District.

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As shown in Figure 1, both surface waters are located in south central Volusia County, within the central portion of the Deep Creek basin and in close proximity to areas of future predicted growth. The conceptual feasibility of using a county-proposed property (approximately 4,800 acres) located in the vicinity of Deep Creek and Lake Ashby to construct a reservoir for storing water from these two potential alternative supply sources was evaluated. As a storage alternative to the surface water reservoir, aquifer storage and recovery (ASR) technology was evaluated to determine the extent that ASR could be applied at the site. The surface water withdrawals are proposed to supplement limited groundwater supplies traditionally used by the County. Managing the conjunctive use of these sources will result in improved water availability and reliability. This property lies within the preservation boundaries of the Volusia Conservation Corridor and has regional importance in allowing a protected path for endangered and threatened animals such as Florida black bears, Florida panthers, bald eagles, and gopher tortoises, among others, to move throughout the state. Historically, this site has been managed as an agricultural and livestock operation by a single owner. In addition, storing water in this portion of the basin could reduce downstream flooding that has previously occurred in recent years as a result of tropical storm events. An overview of the methods used to estimate the availability, reliability, and the cost of harvesting stormwater for water supply purposes, and storing and treating the water on environmentally significant land that will be used to support future conservation and water resources development efforts, is presented.

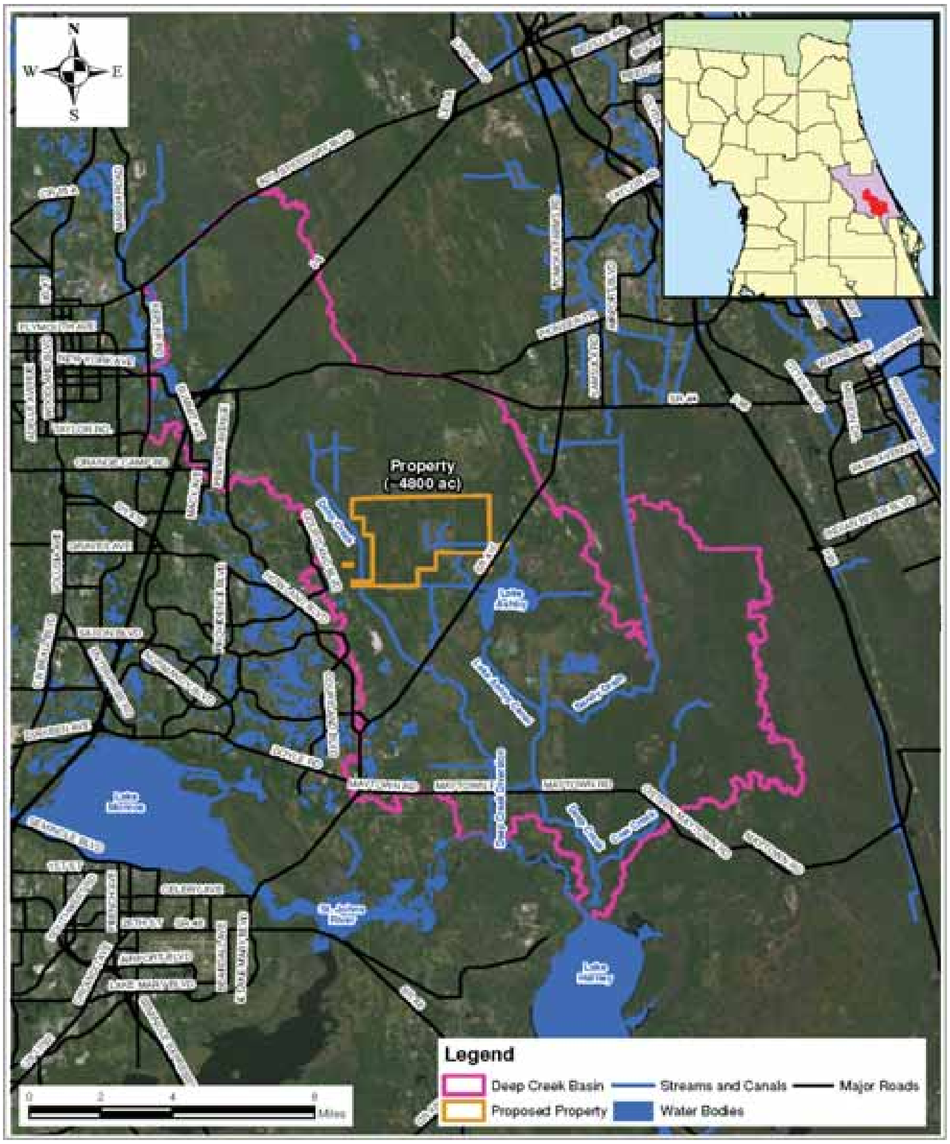

Figure 1. Location of Proposed Reservoir Site

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Deep Creek Yield Analysis

During this conceptual design evaluation, continuous simulation modeling was performed to predict flows in Deep Creek based upon long-term historical rainfall data as shown on Figure 2. The Stormwater Management Model (SWMM) Version 5 data set was used by CDM for the Deep Creek Basin to perform this continuous simulation analysis. This model was originally developed as part of the Volusia County Deep Creek Basin Stormwater Master Plan (CDM, 2009). As part of this study, the model was updated to include historical daily rainfall data for the National Oceanic and Atmospheric Administration (NOAA) DeLand rainfall station (1988-2008) and evaporation data available for north central Florida.

Predicted annual average flows in Deep Creek near the site for the period from 1988 to 2008 ranged from 8 to 212 cubic feet per second (cfs) with an average flow of 60 cfs. The Deep Creek basin lies within the jurisdictional boundaries of the District, which has primacy over water used and associated environmental issues in northeast and east central Florida. There are no minimum flow and level (MFL) criteria established by the District for Deep Creek; therefore, guidance commonly employed by the District to estimate potential water supply yields of a surface water body that would likely not harm the environment was followed for this analysis. The District typically uses a percentage of the average daily flow (8 to 12 percent) to estimate the potential water supply yield that would likely not produce any undesirable environmental impacts. Using this guidance methodology, the potential water supply yield from Deep Creek was estimated to range from 3.1 to 4.7 mgd on a daily basis and would be available approximately 22 percent of the time. However, since this system is driven by rainfall, and rainfall is variable, there are days when there is no available flow within Deep Creek to harvest. Therefore, flow equalization (storage) is essential in producing quantities of water on a consistent basis, thereby increasing the reliability of the water source.

Lake Ashby Yield Analysis

The MFLs represent hydrologic statistics comprised of three components: water levels and/or flows, duration, and frequency. According to Chapter 40C-8, F.A.C. (SJRWMD Minimum Flows and Levels), Lake Ashby has an adopted minimum water level (Frequent Low) of 11.1 ft National Geodetic Vertical Datum (NGVD) and a maximum water level (Frequent High) of 12.3 ft NGVD. In addition, the Frequent High duration for this lake is 60 days and a return period of two years, whereas the Frequent Low duration is 120 days and a return period of five years. Therefore, any water supply withdrawals from Lake Ashby must not result in water levels that violate these criteria. For Lake Ashby, a HSPF (Hydrologic Simulation Program for FORTRAN) model developed previously in 2003 by CDM to support MFL evaluations by the District was updated with more current land use, rainfall and evaporation records, and topographical information. The revised HSPF model was used to perform continuous simulations of flow for the period from 1960 to 2008 with proposed pumping withdrawals to evaluate lake water levels relative to established District criteria. Initially, a range of constant withdrawal rates from the lake was simulated but resulted in violations of the MFLs. After several trial-and-error simulations, a seasonally varied withdrawal of 5 and 0.5 mgd, respectively, for the wet season (June through October) and dry season (November through May) was recommended from Lake Ashby in order to meet the adopted minimum Frequent Low and Frequent High elevations. This result also suggested that storage is needed to manage these seasonably available flows.

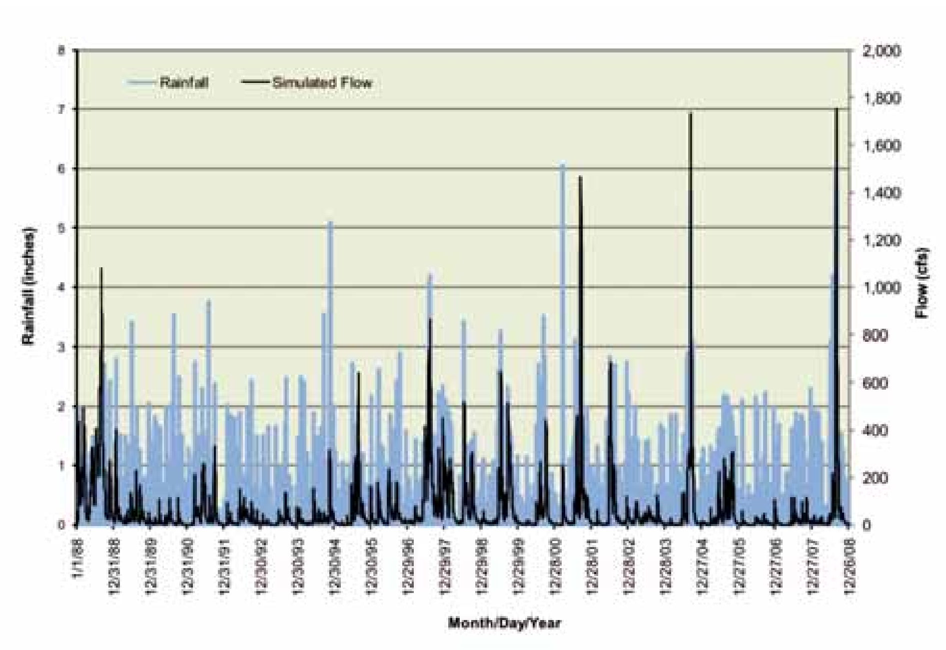

Figure 2. Simulated Deep Creek Flows Near Proposed Property and Historical Rainfall at NOAA DeLand Station (1988-2008)

Systems Model and Evaluation

The water resources data collected and evaluated, as well as modeling data from the SWMM and HSPF evaluations, were used to develop an annual water mass balance (also called a water budget) for a proposed reservoir or ASR wellfield to be located on the property. A dynamic systems model was developed using STELLA® (Systems Thinking Experimental Learning Laboratory with Animation) software to assist in the water budget analysis, as well as to conceptually size and evaluate the performance of the proposed storage options. While it has been used to address numerous water resources planning issues in Florida and throughout the United States, it was used specifically during this evaluation to integrate data from NOAA, the District, and United States Geological Survey (USGS) databases to quantify rainfall and evaporation along with output from other models, such as runoff and groundwater seepage to evaluate the dynamic interactions of the system.

The analysis conceptually quantifies flows for this area, using historical published information and model-estimated flows. The governing equation for this analysis is as follows:

$$\Sigma\text{Inflows} - \Sigma\text{Outflows} = \Delta\text{Storage} / \text{Time} \quad (1)$$

The inflow terms for the reservoir control volume consisted of the following:

- Rainfall
- Pumping from Deep Creek and Lake Ashby

The outflow terms for the reservoir control volume consisted of the following:

- Evaporation
- Release from the reservoir for water supply

- Spill from the reservoir (emergency overflow conditions)
- Groundwater seepage

For an ASR wellfield, rainfall, evaporation, and groundwater seepage are zero. The change in storage over time reflects changing water levels in the reservoir and an equivalent volume ASR wellfield, as well as a corresponding increase or decrease in water storage. The water budget analysis was performed using a daily time interval between 1988 and 2008. This time period includes eight high rainfall years, three low rainfall years, and 10 near average rainfall years, as defined using rainfall data for the NOAA DeLand rainfall station for the period of record (1909-2008).

During this initial evaluation phase, the systems model was used to:

- Integrate climatologic data with results from the SWMM and HSPF models for a 21-year period of record (1988 to 2008) using daily inputs of simulated Deep Creek and Lake Ashby flows, rainfall, and evaporation. An analytical groundwater mounding model (Hantush, 1967) was utilized for the project site to estimate potential seepage flows as a result of reservoir operating head. This seepage relationship was entered into the systems model in order to represent daily seepage from the reservoir.
- Develop a site-wide average annual water budget, as well as evaluate the full range of hydrologic conditions in estimating inflows, outflows, and changes in storage.
- Help guide sizing of storage facilities, including evaluation of water levels (minimum and maximum) and pump capacities.
- Predict system-wide performance considering operational constraints for each storage alternative.

The conceptual reservoir was represented in the model as a storage basin that receives inflows from simulated upstream flows at Deep Creek, Lake Ashby, and direct rainfall. The system loses water to evaporation and groundwater seepage. Two additional outflows from the reservoir consisted of water supply releases and a discharge for emergency overflows to Deep Creek. The ASR system was similarly modeled, except there were no accounted losses due to evaporation, seepage, or emergency overflows.

A combination of alternative reservoir and ASR system configurations were evaluated to store stormwater harvested from Deep Creek and Lake Ashby to help meet a water supply deficit of 7.5 mgd. To minimize the potential for catastrophic embankment failure from a dam safety perspective, a maximum operating water depth [side water depth (SWD)] of 15 ft was maintained, which resulted in a reservoir surface area of 1,630 acres. In an attempt to minimize wetland and floodplain impacts, a reservoir area of 624 acres was considered, resulting in a maximum SWD of 27 ft. All alternatives were evaluated using a 30 cfs inflow pump capacity, which was optimized in the systems analysis in order to balance cost and flow capture constraints. In addition, a minimum reservoir water level was set at 4 ft in order to prevent sediment build-up and growth of nuisance plant species (i.e., cattails).

As a result of the storage provided by the reservoir/ASR system, a firm yield volume of 7.5 mgd is available for water supply withdrawal from Deep Creek and Lake Ashby combined on an annual average basis. The annual average demand (7.5 mgd) was discretized into monthly values using seasonally varying demand fractions specific to the county. A resulting maximum month peaking factor of 1.39 was used in sizing the conceptual water treatment facility to treat a maximum flow of 10.4 mgd.

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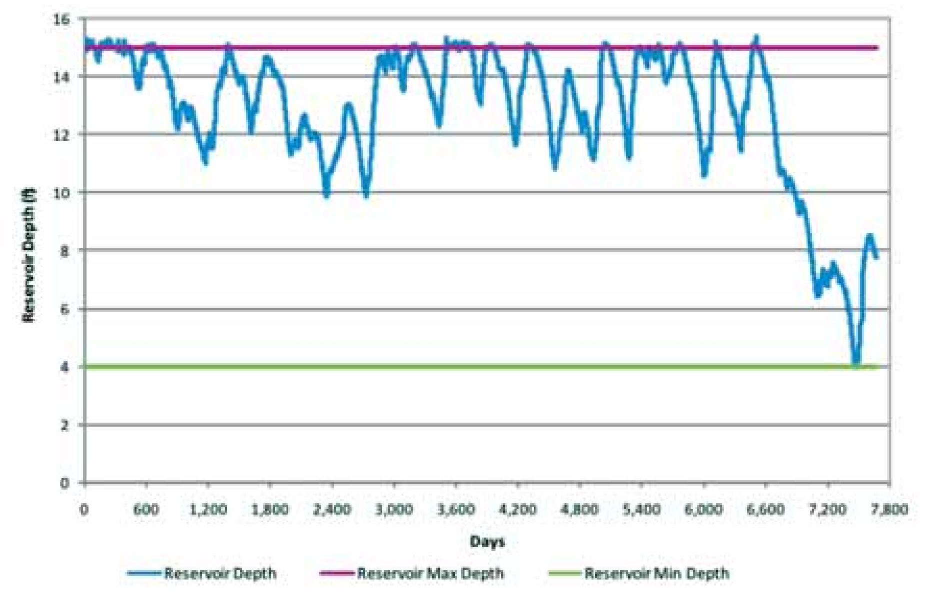

Figure 3. Reservoir Depth Summary for Optimized Area Scenario (1,630 ac / 15 ft SWD)

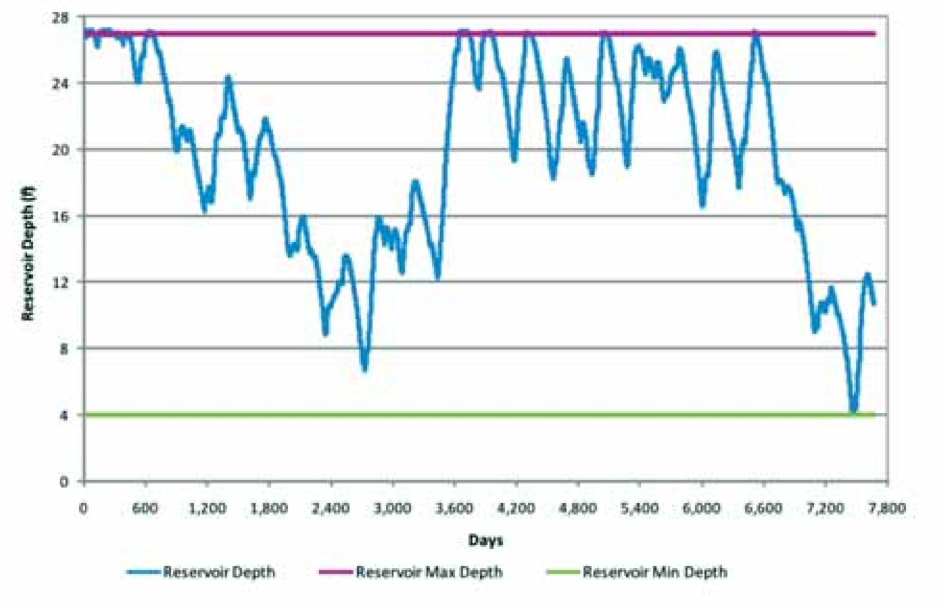

Figure 4. Reservoir Depth Summary for Optimized Maximum Depth Scenario (624 ac / 27 ft SWD)

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A time series summarizing the reservoir depth during the modeling evaluation period of 1988 to 2008 is provided in Figures 3 and 4 for the optimized area and maximum depth scenarios, respectively. The reduction in reservoir depths toward the end of the simulation period corresponds to the unusually low rainfall totals in 2006 and 2007, which were approximately 15 inches and 8 inches lower, respectively, than the historical rainfall average for the period of record (54.12 inches). A statistical analysis performed for the rainfall period of record shows that 2006 was actually a 1-in-100 year drought event. The reservoir depths begin to rebound in 2008 once the rainfall patterns returned to more average rainfall conditions.

Desktop ASR Feasibility Evaluation

A desktop ASR feasibility evaluation of the proposed property indicated that ASR is feasible in the Upper Floridan Aquifer (due to poor water quality from high iron content) and the upper part of the Lower Floridan Aquifer, where it contains mildly brackish water. The site-specific aquifer hydraulics and storage zone confinement will control the degree to which ASR is feasible at a given site. The ASR feasibility screening of the proposed property was conducted for both aquifers, which resulted in scores within the "high confidence" feasibility level. The feasibility factors used in the scoring system are (1) confining zone hydraulic conductivity, (2) storage zone transmissivity, (3) aquifer hydraulic gradient and direction, (4) recharge water quality, (5) native water quality, (6) physical, chemical, and design interaction, and (7) interfering uses and impacts.

Figure 5. Proposed ASR Wellfield Layout

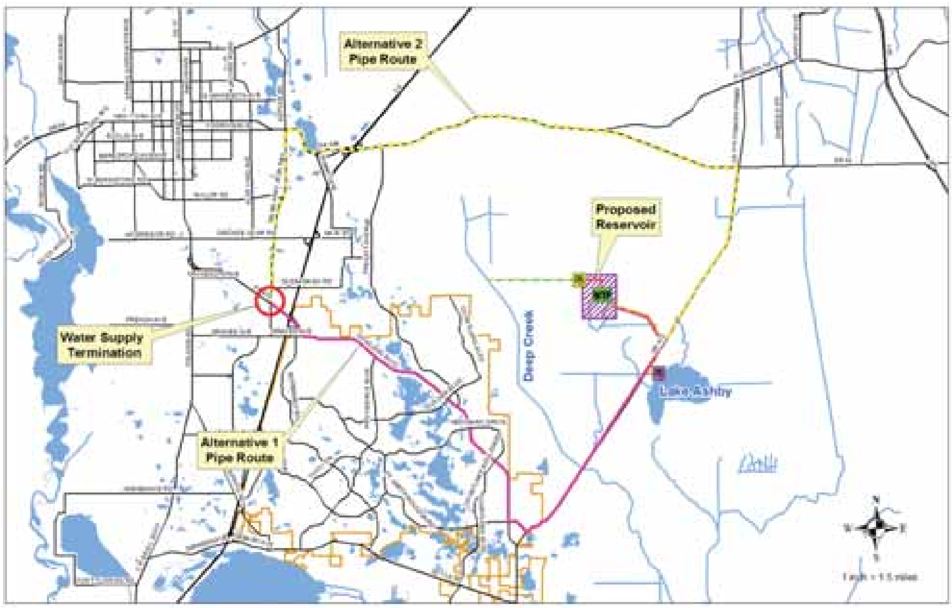

Figure 6. Alternative Pipeline Routes

A possible long-term use of an ASR facility in Volusia County is the seasonal storage of treated potable water from a surface water treatment facility that would derive raw water from the Deep Creek drainage basin. The design capacity of the potable water treatment plant (WTP) (16.7 mgd) would be based on the maximum monthly flow rate required for distribution (10.4 mgd), plus an additional 6.3 mgd, which was estimated from the systems evaluation of typical ASR operations and corresponds to the largest volume of injectate water to be treated on an annual basis.

Only treated water in surplus of demand (amount of water above the 7.5 mgd deficit) would be stored in the ASR wells. Any amount at or below the 7.5 mgd demand will be treated at the surface WTP and sent directly to distribution. The maximum subsurface storage volume of the ASR system was set equal to 4.7 billion gallons, which resulted in the available storage volume from a conceptual reservoir footprint of 624 acres and 23 ft of live storage. The maximum amount of storage capacity for the ASR wells is estimated to be 9.2 mgd. This would require approximately six to twelve ASR wells with a firm capacity of 0.5-2 mgd each. One well is planned for reliability.

The ASR wells must be adequately spaced so that approximately 4.7 billion gallons of storage is provided. This storage volume is equivalent to a reservoir size of 624 acres with a live storage of 23 ft. Using the equation for volume of a conical section and radial flow away from the ASR well, the radius of influence of each well can be determined as follows:

$$V = \pi r^2 h \varphi \qquad (2)$$

Where:
V = *target storage volume* (ft^3)
π = *3.1416*
r = *radial distance away from the well (ft)*
h = *height of the storage zone (ft)*
φ = *effective aquifer porosity (decimal)*

To realize a total storage volume of 4.7 billion gallons of storage using 11 wells yields a storage capacity of 427 million gallons per well. The height of the storage zone (length of open-hole section) was assumed to be 100 ft and the effective porosity of the aquifer in the storage zone was assumed to be 0.2. From this analysis, the radius of influence during injection is 953 ft and the wells must be spaced at least 1,900 ft apart to prevent hydraulic interference between ASR wells. A preliminary layout of the 12 ASR wells (11 primary and one backup) at the site is shown in Figure 5.

Based on the available hydrogeologic data, an ASR system would be feasible at the proposed property. Although the desktop evaluation of the available hydrogeologic data suggests that ASR is feasible at this site, ASR feasibility depends upon site-specific hydrogeologic conditions and cannot be predicted solely from regional data. The major unknown variables are the transmissivity and water quality of the anticipated storage zone in either the lower part of the Upper Floridan Aquifer or the upper part of the Lower Floridan Aquifer. Therefore, it is recommended that a test well should be installed at the site to confirm the preliminary assumption used in this analysis.

Development of Water Supply Options

An evaluation of possible water supply options from Deep Creek and Lake Ashby was developed based on delivering an annual average of 7.5 mgd of either potable water or reuse water. As determined from the systems analysis, approximately 70 percent of the water would be supplied from Deep Creek and 30 percent of the water would be supplied from Lake Ashby. In one group of options, stormwater would be harvested and sent to a large reservoir located on the property for flow equalization, treated on-site, and sent to distribution. In the second set of options, the stormwater would be treated first to potable water standards and temporarily stored in ASR wells. When needed, the stored water would be withdrawn from the ASR wells, chlorinated, and distributed. For all of the options, the water would be conveyed through a pipeline to a water main at the intersection of CR 472 and Martin Luther King Boulevard in DeLand. As shown in Figure 6, two alternative routes, a north route and a south route, were considered for the delivery destination for the water (CR 472 and Martin Luther King Boulevard) to supply the Deltona North service area, which is serviced by Volusia County Utilities.

Conceptual Estimate of Costs

Consistent with the District's conceptual planning level costing methodologies, estimates of probable cost were prepared for the 10 different alternatives evaluated as shown in Table 1. Three main variables were used to determine the options: storage type (surface reservoir or ASR wells), water supply type (potable or reuse augmentation), and the route of the pipeline (north or south to the point of delivery). The intake canal, intake pump station, discharge water treatment plant pump station, and discharge pipeline size were considered to be the same for every option. The remaining components were varied depending on the option being evaluated. The treatment facility varied according to the storage type. An open reservoir could be used to provide potable water or water for reuse augmentation, whereas ASR wells would be used to provide potable water. The treatment facility cost varied depending on the level of treatment—potable water supply or reuse augmentation.

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Estimates of capital cost for a 7.5 mgd average annual water yield range from $117 million to $168 million. Of the potable water options, the ASR well options and the 62-acre reservoir options are the most economical. This is primarily due to the cost of storage of the water. Costs for the reservoir options are expected to be significantly higher if off-site soils need to be imported from long distances for construction. The capital costs developed for the surface water reservoir options are largely a function of the proposed reservoir component cost. The capital costs developed for the ASR options are driven by the potable WTP costs and the number of wells (estimated at 11 primary and one backup for this evaluation). It should be noted that installation of the ASR wells (and construction costs) can be phased to account for actual water supply needs. The reservoir option does not allow for this flexibility, since the reservoir would need to be constructed all at once to store the entire volume associated with the projected deficit. Consequently, associated costs to construct the reservoir would not be able to be spread over time.

Summary

From this conceptual design evaluation, ASR is the most economical and feasible option for equalization storage and will require potable water treatment prior to injection into the ASR wells. Also, the water will need chlorination upon recovery prior to sending the water to distribution. Since the reservoir option is land intensive, a greater percentage of the proposed property would be used to construct the reservoir and associated buffer zone (1,000 to 2,000 acres, or approximately 40 percent of the total site acreage) as opposed to an ASR system (approximately three acres for 12 wells, or 0.1 percent of the total site acreage). The ASR and associated pretreatment needs are compatible with a wide variety of land uses at the proposed site due to its compact footprint.

Costs for compensating storage and wetland mitigation for the ASR well options are significantly less (10 to 40 times) than for the reservoir options. Also, since all of the storage is in the subsurface with ASR, there will be no loss of water to evaporation or seepage. Another important consideration associated with the reservoir options is dam safety, since these facilities would be classified as high hazard impoundments and would impose a public safety risk in the event of a potential levee failure.

Based on lowest cost, likelihood for funding, and environmental constraints, a recommendation for two alternative water supply development options were made to the District for inclusion in its Water Supply Plan update. Both of these storage options (reservoir or ASR system) are proposed to satisfy the County's future potable water needs by utilizing a sustainable water supply from Deep Creek and Lake Ashby and maximizing the benefits of equalization storage. In addition to the water resources development benefit, the evaluated property includes habitat needed for the conservation of federal and state listed endangered and threatened species. The land is also critical in providing flood protection for existing and future populations, protecting surface and groundwater quality, and providing resource-based recreation. Finally, this project may provide some numeric nutrient criteria and total maximum daily load benefits through stormwater harvesting (flow capture) and treatment.

Table 1. Description of Water Supply Options and Conceptual Costs

Option No. [1]	Storage Type	Water Supply Type	Route Direction	Total Capital Cost [2]	Total Equivalent Annual Cost [3]	Unit Production Cost [4]
				($ Millions)		($/1,000 gal)
1	Reservoir (1,630 ac)	Potable	South	$164	$18	$6.41
2			North	$168	$18	$6.57
3	Reservoir (624 ac)	Potable	South	$139	$14	$5.27
4			North	$147	$15	$5.47
5	Reservoir (1,630 ac)	Reuse	South	$157	$17	$6.30
6			North	$163	$18	$6.42
7	Reservoir (624 ac)	Reuse	South	$133	$14	$5.15
8			North	$139	$14	$5.29
9	ASR System	Potable	South	$117	$14	$5.24
10			North	$123	$15	$5.61

[1] All options are proposed to provide an average annual yield of 7.5 mgd for water supply distribution.
[2] Conceptual capital costs include storage facility, treatment, and conveyance. This includes construction costs plus 45 percent markup (20 percent contingencies, 20 percent non-construction capital costs, and 5 percent mobilization/demobilization).
[3] Total equivalent annual costs include annualized capital costs plus annualized on-site wetland mitigation, compensating storage, and operations and maintenance (O&M) costs. Costs do not include estimates for proposed property acquisition or off-site soil import.
[4] Unit production cost is equal to total equivalent annual cost divided by 7,500 gallons (average annual rate of delivery of water).

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