Integrating Water Quality & Supply Objectives in Regional Applications: A Case Study of Reuse in the Lower St. Johns River Basin

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The St. Johns River Water Management District is working with affected stakeholders collaboratively to improve water quality in the St. Johns River. Local governments and industries in the Lower St. Johns River Basin must comply with recently established total maximum daily loads (TMDL) for nutrients.

In an effort to comply with TMDL standards and further improve the water quality of the St. Johns River, the District initiated a cooperative water quality improvement effort through the Lower St. Johns River Basin Reuse and Treatment Project, assisting affected utilities in the basin by facilitating joint planning and co-funding the construction of regional reclaimed water infrastructure.

The ultimate goal of the project is to remove as much wastewater discharge from the river as is possible in an accelerated (about 10 years) manner. Preliminary analyses of the cost of complying with the TMDL illustrated that reuse is relatively expensive when compared to advanced wastewater treatment, if only the cost of nitrogen removal is considered.

In addition to meeting water quality goals, reuse projects must offset demands on potable water supplies in the Lower St. Johns River Basin; therefore, by co-funding reclaimed water infrastructure projects, the District will accelerate the local governments' plans to utilize reclaimed water as quickly as possible for water supply needs.

The regional reuse master plan for the Lower St. Johns River Reuse and Treatment Project, which includes demand projections up to 2030, was completed in two phases. The draft reuse plan for the west side of the Lower St. Johns River was completed in September 2007 and the east side was completed in August 2008. The two sides were then combined and an overall basin master plan was prepared.

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This model considered seasonal variability in the potable and reclaimed water demand

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and supply balance, water quality, and the most effective and efficient infrastructure solutions through the optimization formulation. This article presents the analysis that was conducted using the multi-parameter optimization model.

The lower St. Johns River stakeholders have identified a broad range of feasible project alternatives capable of maximizing water reuse in the basin. The stakeholders worked closely with CH2M Hill programmers to develop an optimization model as a planning-level tool to evaluate these projects. This model considered the seasonal variability in the potable and reclaimed water demand and supply balance, water quality, cost, and the most effective and efficient infrastructure solutions through the optimization formulation.

The use of reclaimed water is an important alternative for water resources management. Common uses of reclaimed water in the U.S. include irrigation, industrial uses, groundwater recharge, stream flow augmentation for fish habitat, and indirect potable reuse via augmentation of groundwater and/or surface supplies. In this study, however, use of future reclaimed water will be primarily for residential irrigation, unless otherwise noted.

Opportunities for groundwater recharge via Rapid Infiltration Basins (RIBs) were also investigated. (RIBs were used as a representative for estimating the costs of a recharge type of project. The actual feasibility at specific sites were not evaluated for this planning-level study.)

Project Objective

The objective of the Lower St. Johns River Basin Reuse Initiative Solutions Project is to assist local governments in their regional planning and permitting efforts for future water supply and wastewater management. To achieve their desired planning goals, the utilities are exploring opportunities to maximize reclaimed water reuse. By doing so, they expect to offset demands on potable water supplies and to remove wastewater discharges, particularly nitrogen, from the lower St. Johns River for compliance with TMDL allocations.

Data Collection & Analysis

The two main utilities involved in the west side effort included JEA and the Clay County Utility Authority (CCUA). The reuse and nitrogen reduction needs of the town of Orange Park and the city of Green Cove Springs were also included in the west side project.

The two main utilities in the eastside effort were JEA and the St. Johns County Utility District (SJCUD). The reuse need of the city of interconnecting the beaches was also considered. The utilities for Palatka and Hastings were not included because they are somewhat isolated from the others and plan to have no discharges to the river in the near future.

The input data for the study consisted of potable water supply, wastewater production, and reuse water demands for each service area. Figure 1 shows the study area map along with existing and future infrastructure such as wastewater treatment plants, pump stations, and pipe lines.

Input data was provided by CCUA, JEA, and SJCUD and is summarized in Table 1. For purposes of this study, facilities that are under construction or will be nearly done by 2010 were considered existing facilities. Some of these projects received cost-share monies in 2008.

The St. John River Water Management District was in the process of developing new population and water use demands for the next district-wide water supply plan. The District developed draft projections that were under review by the utilities at the time of this study. The utilities preferred that the study use their own projections to determine the approximate future water needs. In this way, the results of this master plan will better correspond with their planning efforts.

Determination of Seasonal Components of Reclaimed Water Supply & Reclaimed Water Demand

Generally, the weekly irrigation demand

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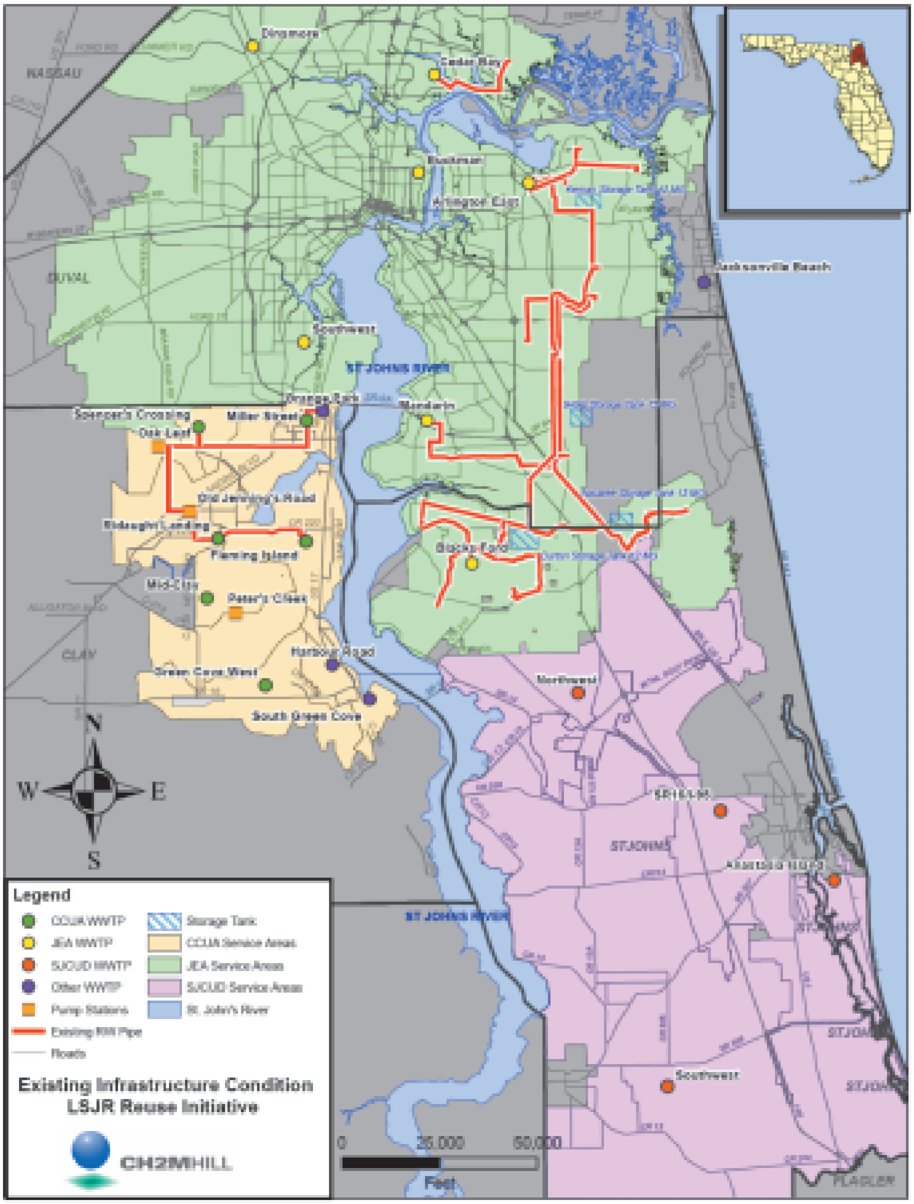

Figure 1. Existing Reclaimed Water Systems of CCUA, JEA, and SJCUD Service Areas

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for reclaimed water generated by a particular urban system can be estimated from an inventory of the total irrigable acreage to be served by the reclaimed water system and the estimated weekly irrigation rates. These rates are determined by such factors as local soil characteristics, climatic conditions, and type of landscaping.

Alternatively, water-use records can also be used to estimate the seasonal variation in reclaimed water demand. Similarly, the historic data for the potable water supply can be used to determine the seasonal reclaimed water production.

In the present study, historic data from CCUA's Fleming Island Service Area was utilized to determine the seasonal variation in the reclaimed water supply and demand. This relatively new development was considered typical of modern land use with residential irrigation. This mixed-use service area also includes a golf course. A time series analysis was conducted to estimate the water usage mathematically (Box, Jenkins, and Reinsel, 1994; CH2M Hill, 2008).

Table 1. Available Data and Sources

Item	Source	Data Type	Remarks
Population data	GIS Associates	5-yr interval	While analyzed, it was decided not to use these estimates.
CCUA wastewater production	CCUA	Daily (1995 - 2007)	Only Miller, Fleming, Ridaught, and Mid-Clay included
JEA wastewater production	JEA	Daily 2006	
SJCUD wastewater production	SJCUD	5-yr interval	
CCUA reclaimed water demand	CCUA	Daily (1995 - 2007)	
JEA reclaimed water demand	Assumed	5-yr interval	
SJCUD reclaimed water demand	SJCUD	5-yr interval	
CCUA potable water usage	GIS Associates	5-yr interval	
JEA potable water usage	GIS Associates	5-yr interval	
Future projections of annual average wastewater effluent	CCUA	2006-2031	CCUA Service Areas
Future projections of annual average reclaimed water demand	CCUA	2006-2031	CCUA Service Areas
Future projections of annual average wastewater effluent	JEA	2005-2030	JEA Service Areas
Future projections of annual average reclaimed water demand	JEA	2005-2030	JEA Service Areas
Future projections of annual average wastewater effluent	SJCUD	2005-2030	SJCUD Service Areas
Future projections of annual average reclaimed water demand	SJCUD	2005-2030	SJCUD Subservice Areas

Optimization Model Components

The Lower St. Johns River water reuse system model was set up to find optimal solution sets for the production and distribution of reclaimed water. The model included the seasonal variability in the potable and reclaimed water demand and supply balance, water quality, cost, and the most effective and efficient infrastructure solutions through the optimization formulation. The various model components can be summarized as follows:

- Reclaimed water production (supply), dependent on available wastewater flows
- Reclaimed water demands
- Non-reclaimed effluent discharged to the St. Johns River
- Demands on potable water that are offset (water demand less reclaimed water)
- Transmission (pipes and pump stations), dependent on physical constraints of system
- Reclaimed water treatment
- Tank storage capacity
- Reservoir capacity
- Recharge (RIBs)

Planning-level cost functions were developed for each of these components. These equations become part of the formulization. Literature values or CH2M Hill internal reports were used as the basis of these estimates. As an example, the capital and operation and maintenance (O&M) cost functions for reclaimed water treatment are presented in Figure 2.

The capital costs for reclaimed water treatment facilities were calculated based on a recent report prepared for the St. Johns River Water Management District by Black and Veatch (2008). It is not the intent of the cost-estimating methodology to establish an exact treatment process, but rather to estimate the cost of general process—in this case, cloth media filter and disinfectant, appropriate for bringing the reclaimed water to the reuse standard. Thus, the capital cost of the reclaimed water treatment facility (RWT) is given as:

$$RWT\ Capital\ Cost = 0.980Q_C^{0.4461}$$

where Qc is the capacity of the reclaimed water treatment plant in mgd and RWT Cost is the capital cost in millions of dollars. Similarly, the O&M cost of the reclaimed water treatment facility is given as:

$$RWT\ O\ \&\ M\ Cost = 20.944Q_C^{-0.5606}$$

Figure 2 presents the estimated capital and O&M costs for various capacities. Similar cost functions were developed for each tech-

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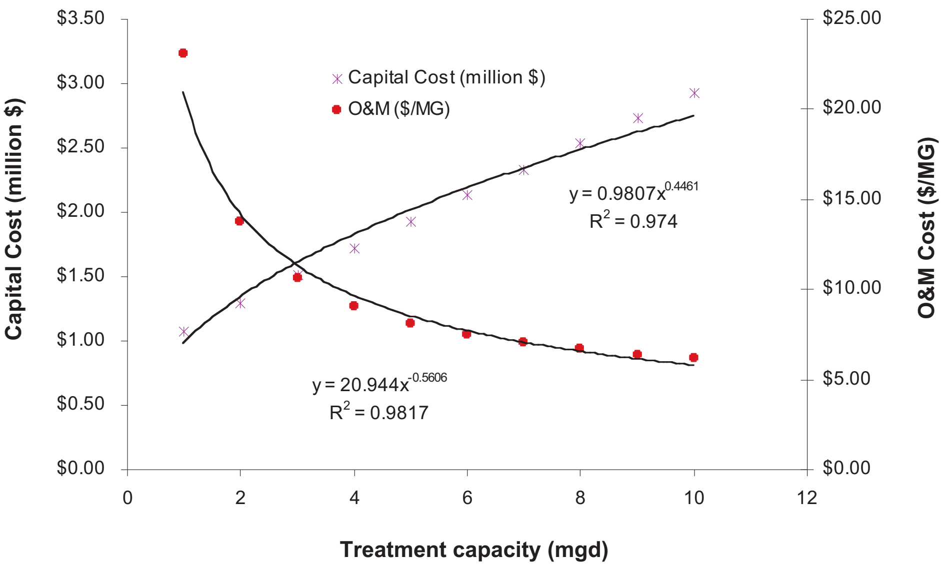

Figure 2. Reclaimed Water Treatment Capital Cost (additional to normal wastewater treatment facility)

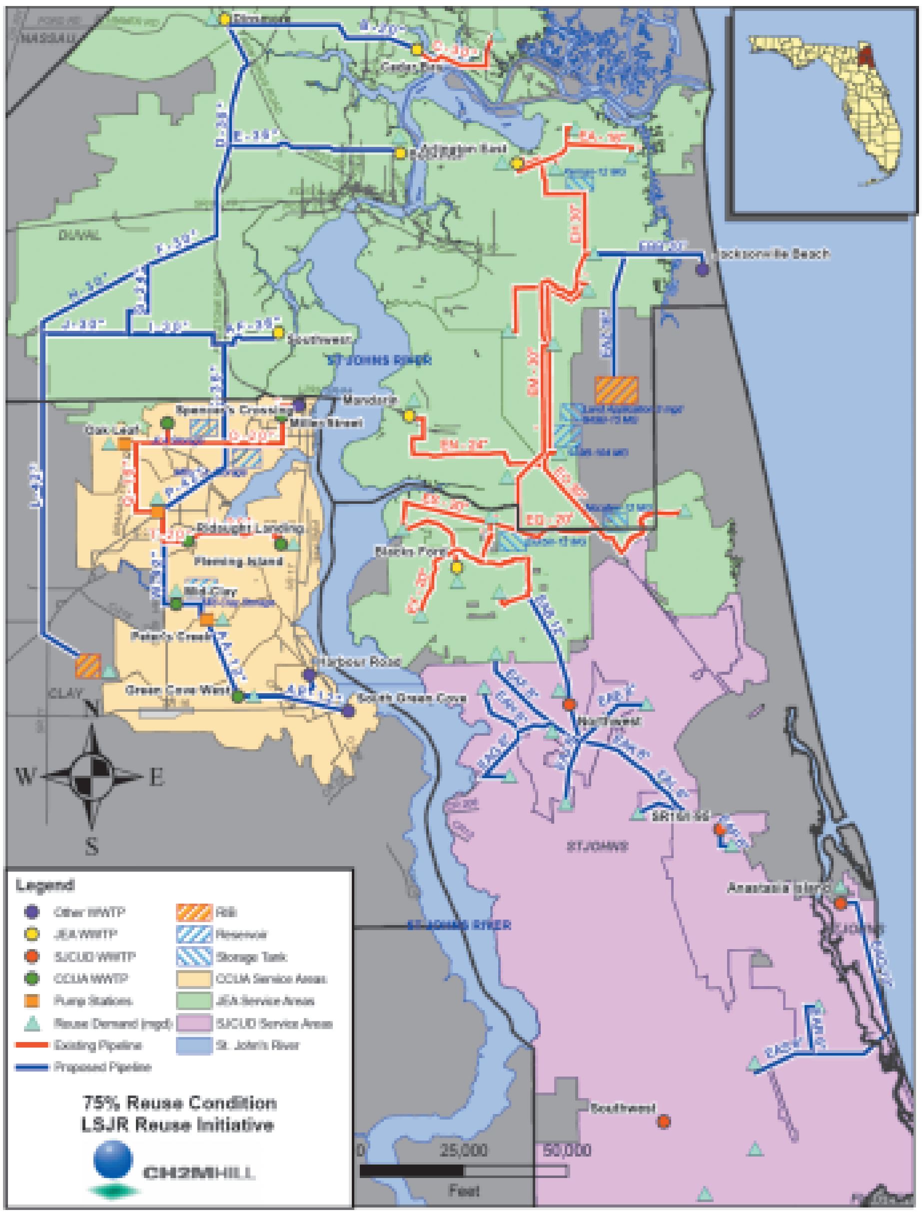

Figure 3. System Layout: 75 Percent Wastewater Reuse Target

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nology used.

Optimization Formulation

The optimization function of the Lower St. Johns River Reuse System model seeks to minimize the total performance cost of implementation for the reclamation system. Performance costs include the cost of penalties (i.e., undesirable outcomes), as well as costs associated with constructing, operating, and maintaining the system over its lifetime. The performance cost equation is:

Minimize:
Total Performance Cost = System Performance Penalties (TMDL Load, LSJR Flow) + Potable Water + Financial Performance Costs (Capital, O&M)

Penalties are enforced in terms of monetary loss and contribute to the total performance cost of the system. Penalties are incurred for the following infractions:

- Volume (flow) of wastewater discharged into the St. Johns River exceeds the target value.
- Total nitrogen load discharged into the St. Johns River exceeds the target value.
- Reuse of reclaimed water is not equal to target (applies to scenarios with reuse target percentages e.g., 60 percent, 75 percent, and 100 percent).
- Over expenditures (applies to fixed-cost budget scenario).

The optimization function also accounts for the cost of potable water. Potable water is utilized when reclaimed water supplies are not sufficient to meet reclaimed water demands. Potable water is assumed to cost $2,000 per million gallons (i.e., $2 per 1,000 gallons, assuming groundwater sources).

Constraints

The optimization function must also satisfy various physical constraints of the system in the process of minimizing the performance cost. These constraints include:

- Maximum capacity of RIBs = 52 million gallons per day (mgd)
- Maximum capacity of aboveground storage tanks = 20 million gallons (MG)

Decision Variables

The optimization model alters multiple variables in order to satisfy the optimization function, including the following parameters:

Table 2. Summary of Capital Costs Related to Combined System Expansion (mgd)

	$300 Million	60% Reuse	75% Reuse	100% Reuse
Treatment	$15,667,317	$23,248,747	$25,832,554	$30,829,611
Pipe Network	$170,574,716	$313,693,269	$404,412,406	$517,186,180
Pump Stations	$2,458,676	$4,984,237	$6,359,214	$8,698,801
Storage Reservoirs	$44,540,505	$67,606,275	$69,878,904	$20,775,236
RIBs/Land Application	$52,800,770	$70,327,681	$223,306,688	$655,027,602
Total	**$286,041,984**	**$479,860,209**	**$729,789,765**	**$1,242,111,430**

- Reclaimed water production at each wastewater treatment plant
- Reclaimed water transmission flows (proportions of available and demand)
- Reservoirs, aboveground storage tanks, and RIBs

expansion of existing pipeline connections. Pipeline routes were laid out, as well as potential land application and storage locations, with input from the utilities. Figure 3 provides the 75 percent reclaimed water-use results. This figure illustrates the general network of pipes and facilities, with the main differences between alternatives being the size of each component.

The capital cost of each component for the four alternatives is listed in Table 2 to illustrate the relative significance of each part. Pipelines and land application will be the largest components. The cost of pipelines is high because of the need to move reclaimed water long distances between utilities or to land application sites (for the higher reuse targets). The cost of land application is high because of land cost or just the size needed.

The four expansion alternatives generate additional reclaimed water treatment capacity ranging from 31 mgd to 110 mgd (Tables 3 and 4). The additional Mandarin, Beaches, Miller Street, Fleming Island, and SR16 capac-

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Evaluation & Comparison of Alternatives

To fulfill the main objective of this project, the CH2M Hill team used the Little St. Johns River Reuse System model to evaluate the existing (2010) and four future feasible alternatives, based on the inputs provided by stakeholders for evaluation. The various objective functions that were considered for this study consisted of:

- $300 million construction costs
- 60 percent reuse target
- 75 percent reuse target
- 100 percent reuse target

Optimal infrastructure development results include the location, capacity, and cost of new and expanded pipe segments, pump stations, storage reservoirs, and RIBs for each scenario.

The ability of each alternative to meet project goals effectively was evaluated via several metrics, including the volume of water discharged into the St. Johns River (billion gallons [BG]), total nitrogen (TN) load (kg/yr) in the St. Johns River, and potable water offset (mgd). The results produced by the optimization model for each alternative are summarized and the final model project alternatives are evaluated by comparing infrastructure, cost, removal of wastewater flows from the St. Johns River and the offset potable water use associated with each scenario.

One component of the water reclamation project is the potential

Table 3. Summary of West Side Results

Scenario	Total RWT Capacit y (mgd)	Capital Cost (million $)	Annual O&M Cost (million $)	Reuse % Achiev ed	Potable Water Offset (MG/yr)	Dischar ge to SJR (MG/yr)	TN Load (kg/y r)	% TN Reducti on
Base Case - 2030 No Expansion	18.8	$0	$1	13%	1,82	20,240	813,3 18	0%
$300 Million Capital Cost Constraint	44.5	$103	$4	41%	10,60	16,495	642,7 55	21%
60% Reuse Target	55.5	$304	$8	59%	16,47	12,496	477,1 99	41%
75% Reuse Target	72.5	$506	$12	79%	17,76	6,116	240,3 03	70%
100% Reuse Target	101.5	$699	$15	99%	17,93	183	3,469	100%

*O&M Costs do not include the cost of Potable Water

Table 4. Summary of East Side Results

Scenario	Total RWT Capacity (mgd)	Capital Cost (million $)	Annual O&M Cost (million $)	Reuse % Achieved	Potable Water Offset (MG/yr)	Discharge to SJR (MG/yr)	TN Load (kg/yr)	% TN Reduction
Base Case - 2030 No Expansion	23.9	$0	$3	17%	5,11	13,668	256,384	0%
$300 Million Capital Cost Constraint	33.5	$183	$5	51%	11,57	8,836	168,925	34%
60% Reuse Target	44.5	$176	$5	62%	12,60	6,950	133,201	48%
75% Reuse Target	44.5	$224	$5	67%	12,51	5,558	100,280	61%
100% Reuse Target	55.5	$543	$6	86%	12,93	2,590	35,667	86%

*O&M Costs do not include the cost of Potable Water

Table 5. Summary of Annual O&M Costs Related to Combined System Expansion (mgd)

	$300 Million	60% Reuse	75% Reuse	100% Reuse
Treatment	$181,675	$217,395	$228,069	$241,541
Pipe Network	$6,147,915	$9,513,314	$11,706,455	$14,494,198
Pump Stations	$825,664	$1,286,147	$1,706,056	$2,264,563
Storage Reservoirs	$1,186,030	$1,647,346	$1,692,798	$710,725
RIBs/Land Application	$528,008	$703,277	$2,233,067	$6,550,276
Total	**$8,869,313**	**$13,367,487**	**$17,566,557**	**$24,261,310**

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ities are constant across all four expansion alternatives. In all scenarios, the majority of the proposed capacity expansion is to occur in the JEA west service area, which is necessary to achieve the target percent reductions because the Buckman Water Reclamation Facility is so large.

The interconnection between CCUA and Green Cove Springs facilities has recently been made at the Harbour Road Wastewater Treatment Facility. Thus, while the city of Green Cove Springs generates the reclaimed water, it is being used in the CCUA service area. Future use of the South Green Cove wastewater for reuse is tied to some new developments in the region that lie in both the Green Cove Springs and CCUA service areas.

As mentioned previously, Palatka and Hastings, while in the LSJR basin, are not in this study because they do not discharge into the river and their systems are isolated. The annual operations and maintenance costs associated with each alternative are presented in Table 5.

Conclusions & Recommendations

A summary of the basin-wide results used to evaluate the five alternatives is presented in Table 6. For purposes of this evaluation, the use of a RIB or land application system for land application is considered part of the reuse program because the actual effectiveness of recharging the aquifer is unknown.

The main goal of removing wastewater discharges from the St. Johns River, however, would be attained by including some form of land application; thus, RIBs were proposed to be used on the west side and a more generic land application on the east side to allow for disposal during periods when irrigation demand did not meet the reclaimed water production. Additional storage is needed to fully utilize the reclaimed water generated in Clay County.

The base case is the amount of future reuse water demand that could be met if no additional pipelines and reclaimed treatment is provided. While not likely to occur, it provides a low-end estimate for comparison purposes only. The base-case scenario fails to meet discharge and TN load reduction targets.

In contrast, the 100-percent reduction alternative more than meets water quality targets and provides 30.9 BG/yr of potable water offset, but the capital cost of this scenario ($1.242 billion) is over four times the current budgeted construction cost ($300 million). The $300 million and 60- and 75-percent reuse alternatives increase reuse capacity substantially, achieve satisfactory water quality results, and offset potable water supplies by 22, 26 and 31 BG/yr respectively.

It is important to note that the approach taken does not consider interim steps needed to achieve the next highest reuse level. Rather, each result meets the given goal ($300 million, 60-percent reuse, etc.) in a non-sequential fashion, so these results can be used to see what the optimum system would be if, for example, 75-percent reuse were your goal.

In the 75-percent case, the amount of storage or certain pipe sizes may be lower than the 60-percent reuse system, so a utility would not build as large of pipeline in some segments if 75 percent were the goal. Consequently, it is up to the utilities to use these results to determine what the targeted system would be in 2030 and then complete implementation plans to meet their goal. While their systems may not be the same as the "optimum" layout when finished, there should not be a large difference.

References

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- CH2M HILL (2008). Lower St. Johns River Reuse and Treatment Project,Phase II: Combined East and West River Reuse Initiative Solutions. Prepared for St. Johns River Water Management District, JEA, St. Johns County Utility Department, and Clay County Utility Authority. September 2008.

Table 6. Summary of Combined East and West Side Results

Scenario	Total RWT Capacity (mgd)	Capital Cost (million $)	Annual O&M Cost (million $)	Reuse % Achieved	Potable Water Offset (MG/yr)	Discharge to SJR (MG/yr)	TN Load (kg/yr)	% TN Reduction
Base Case - 2030 No Expansion	42.7	$0	$4	14%	6,931	33,908	1,069,702	0%
$300 Million Capital Cost Constraint	78.0	$286	$8	45%	22,174	25,331	811,680	24%
60% Reuse Target	100.0	$480	$13	60%	29,073	19,447	610,401	43%
75% Reuse Target	117.0	$730	$17	75%	30,268	11,673	340,583	68%
100% Reuse Target	157.0	$1,242	$21	94%	30,865	2,773	39,136	96%

*O&M Costs do not include the cost of Potable Water