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WATER SUPPLY NEEDS AND SOURCES ASSESSMENT
ALTERNATIVE WATER SUPPLY STRATEGIES INVESTIGATION
PLANNING LEVEL COST ESTIMATES
DEVELOPMENT OF SURFACE WATER SUPPLY

by

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EXECUTIVE SUMMARY

This technical memorandum (TM) is the fourth in a series concerned with the feasibility of developing selected surface water sources to help meet municipal water supply needs within the St. Johns River Water Management District. The first surface water supply TM addressed data availability and development of the methodology to be used in the feasibility evaluation. The second TM addressed the selection of six candidate surface water withdrawal sites for quantitative analysis, from which five sites were determined to be technically feasible. The third TM presented the results of the quantitative water supply availability and yield analysis.

PURPOSE OF THIS TM

This TM presents the results of the cost estimation for water supply development at the following five candidate withdrawal sites:

- Lake Griffin (Haines Creek)
- St. Johns River near Cocoa
- St. Johns River near Titusville
- St. Johns River at Sanford (Lake Monroe)
- St. Johns River near De Land

In addition to site-specific treatment costs, the cost of off-line raw water storage reservoirs and treated water point-to-point transport is also addressed. A complete set of easy-to-apply cost estimating tools was developed and is presented. In most cases, costs are expressed as a function of the water supply capacity developed. In the case of treated water transport, the costs of interest are expressed as a function of flow rate and the distance transported.

RESULTS OF COST COMPARISONS

The most cost-effective candidate surface water supply withdrawal site investigated is Lake Griffin, the only true freshwater site. Each of the St. Johns River candidate withdrawl sites will require some level of membrane treatment to meet drinking water standards.

Total water treatment costs for the Lake Griffin candidate withdrawal site will range from about $0.93 per 1,000 gallons produced to about $1.04 per 1,000 gallons produced, depending on the size of the facility constructed. If an off-line raw water storage reservoir is required, these total production costs could increase by about $0.07 per 1,000 gallons. However, it is likely that a viable water supply at this site may be developed without additional off-line storage.

While the four St. Johns River sites would be somewhat more expensive to develop, their potential water supply quantities are much greater than for Lake Griffin. Total surface water treatment costs for these sites are estimated to range from $1.32 per 1,000 gallons for a large facility to about $2.00 per 1,000 gallons for smaller installations. The cost of off-line raw water storage will add about $0.05 per 1,000 gallons to these treatment costs.

Transport cost can add significantly to the overall cost of any municipal water supply. For example, the transport of 10 million gallons per day of treated drinking water for 15 miles can add $0.49 per 1,000 gallons to total water supply development costs, a substantial percentage of the treatment costs. Overall, transport costs will probably range from about $0.02 to $0.04 per 1,000 gallons per mile transported. Because of transport costs, local sources will probably be most cost-effective.

ILLUSTRATIVE EXAMPLE PROBLEMS

Two illustrative example problems are developed and presented in this TM to demonstrate proper application of the planning-level cost equations. The first example, which involves a single demand area, is a water treatment plant and treated water transport system located on Lake Griffin in Lake County.

The second example presents a surface water treatment system located on Lake Monroe on the St. Johns River near Sanford. In this example, an off-line reservoir is used and two separate demand areas are served. Together, these illustrative examples demonstrate the correct application of each type of cost equation presented in this TM.

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INTRODUCTION

This technical memorandum (TM) is the fourth in a series addressing the feasibility of developing surface water supplies to augment existing and future public water supplies within the St. Johns River Water Management District (SJRWMD). The first surface water supply TM, B.1.f, addressed data availability and development of the methodology to be used in the surface water supply feasibility evaluation (CH2M HILL 1996a). The second TM, B.1.h, addressed the selection of six candidate surface water withdrawal sites for quantitative analysis (CH2M HILL 1996b). The third TM, B.1.j, presented the results of the quantitative water supply availability and yield analysis (CH2M HILL 1996c). This analysis resulted in the selection of five of the original six candidate surface water withdrawal sites for further evaluation.

This final surface water supply feasibility TM presents the results of planning-level water supply development cost estimation for the five candidate surface water withdrawal sites. These sites include Lake Griffin, located in Lake County, and five sites located on the main stem of the St. Johns River, extending from near Cocoa, Florida, down-stream to De Land, Florida. For each of the five candidate withdrawal sites, required facility capacities (in million gallons per day [mgd]) were developed in TM B.1.j as a function of reliable water supply yield developed. These quantitative facility requirements data include the following major components:

- Off-line raw water storage reservoir
- Raw water diversion and pumping station
- Conventional surface water treatment plant
- Reverse osmosis (RO) treatment plant
- RO concentrate disposal system
- Aquifer storage recovery (ASR) system

The St. Johns River candidate withdrawal sites will require all of the major facility components listed above. The Lake Griffin site will not require RO treatment or concentrate disposal, and may not require an off-line raw water storage reservoir.

In addition, the treated water must be transported from the surface water treatment site to the public water supply demand area. Therefore, the cost of treated water point-to-point transport is also addressed in this TM.

Cost estimates are developed for major water supply system components, including off-line storage reservoirs; complete surface water treatment systems, including ASR facilities for long-term storage; and treated water transport systems. Individual cost estimates are then used to develop planning-level cost equations, which relate cost to the water supply capacity developed. These cost equations can then be used to rapidly develop cost estimates for several surface water supply alternatives, which can be used to define surface water supply development costs in the University of Florida Decision Model in subsequent phases of this investigation.

The cost equations presented in this TM can also be used to investigate surface water supply options independent of the University of Florida Decision Model application. Two hypothetical surface water supply system examples, including storage, treatment and transport, are developed and presented to illustrate proper application of these equations.

All cost estimates and cost equations presented in this TM are planning-level or "cost curve" estimates. These estimates will vary from actual project costs, which are based on detailed designs. Planning-level cost estimates are generally accurate to within plus or minus 50 percent of actual costs for the same design conditions and design criteria.

METHODS

To develop appropriate construction and operations and maintenance (O&M) cost estimates for the selected surface water sources, available information was reviewed. Individual facility cost estimates were developed from this information. These individual cost estimates were then used, along with curve-fitting techniques, to develop appropriate, generalized cost functions. This section presents a summary of the methodology used to develop the surface water facility cost equations.

LITERATURE REVIEW

A literature review was conducted to locate information that would be helpful in developing the surface water supply cost estimates. Information sources considered included reports published by SJRWMD; consultant reports, including in-house CH2M HILL reports; and technical reports prepared by state and federal agencies. Relevant documents reviewed during this phase of the investigation are listed at the end of this TM in the References, and are cited in the text where appropriate.

As part of SJRWMD's ongoing investigation of alternative water supply strategies, Law Engineering and Environmental Services, Inc. (Law 1996) developed a TM summarizing typical water supply and wastewater systems component cost information. This document was used as much as possible in developing the individual cost estimates and generalized equations presented in this TM. The information compiled by Law was supplemented, as appropriate, with additional costing information presented in engineering reports and in the engineering literature.

GENERAL FACILITIES REQUIREMENTS

The general facilities required to develop a reliable surface water source to meet municipal water supply needs are discussed in previous TMs by CH2M HILL (CH2M HILL 1996a and 1996c). The following discussion summarizes material from these earlier works as an overview of the function provided by the facilities addressed in this TM. This overview is necessary for understanding both the objectives of the surface water supply cost estimating procedure and proper application of the cost equations resulting from this effort.

The facilities required to develop a safe, reliable surface water supply include some combination of the following components (Figure 1):

- Raw water diversion structure
- Off-line raw water storage reservoir
- Water treatment plant (may include RO)
- ASR
- Finished water transport

Under favorable conditions, including a high-volume, low-variability source and limited water supply needs, the required water supply system may be developed with only a river diversion structure and a water treatment plant. However, in most situations, some type of storage will be required to provide required system reliability.

Adequate quantities of raw water will probably only be intermittently available for diversion. Storage facilities, including either raw water storage reservoirs or ASR systems, can be used to store excess water and make it available for use at a later time when needed. Storage provides the flow attenuation necessary to match a variable water supply source to a variable water supply demand.

Raw Water Diversion Structure

A raw water river diversion structure consists of a raw water intake and a pumping station. The diversion pumping station capacity (Qd) must be sized to allow diversion of the necessary volume of water, which is subject to withdrawal constraints defined by minimum streamflow requirements.

Raw Water Storage Reservoir

Off-line reservoirs are filled by pumping divertable streamflow into the reservoir. The off-line reservoir is usually built by constructing a levee around the perimeter of the reservoir site. The storage volume provided is then a function of the area enclosed and the depth to which water can be effectively impounded.

In this application, the primary function of the off-line storage reservoir is to provide water treatment system operational flexibility. There will be times during low streamflow periods when river diversion will not be allowed or when the water quality of the raw river water is not acceptable because of the treatment system provided. During these times, the off-line reservoir will allow continued

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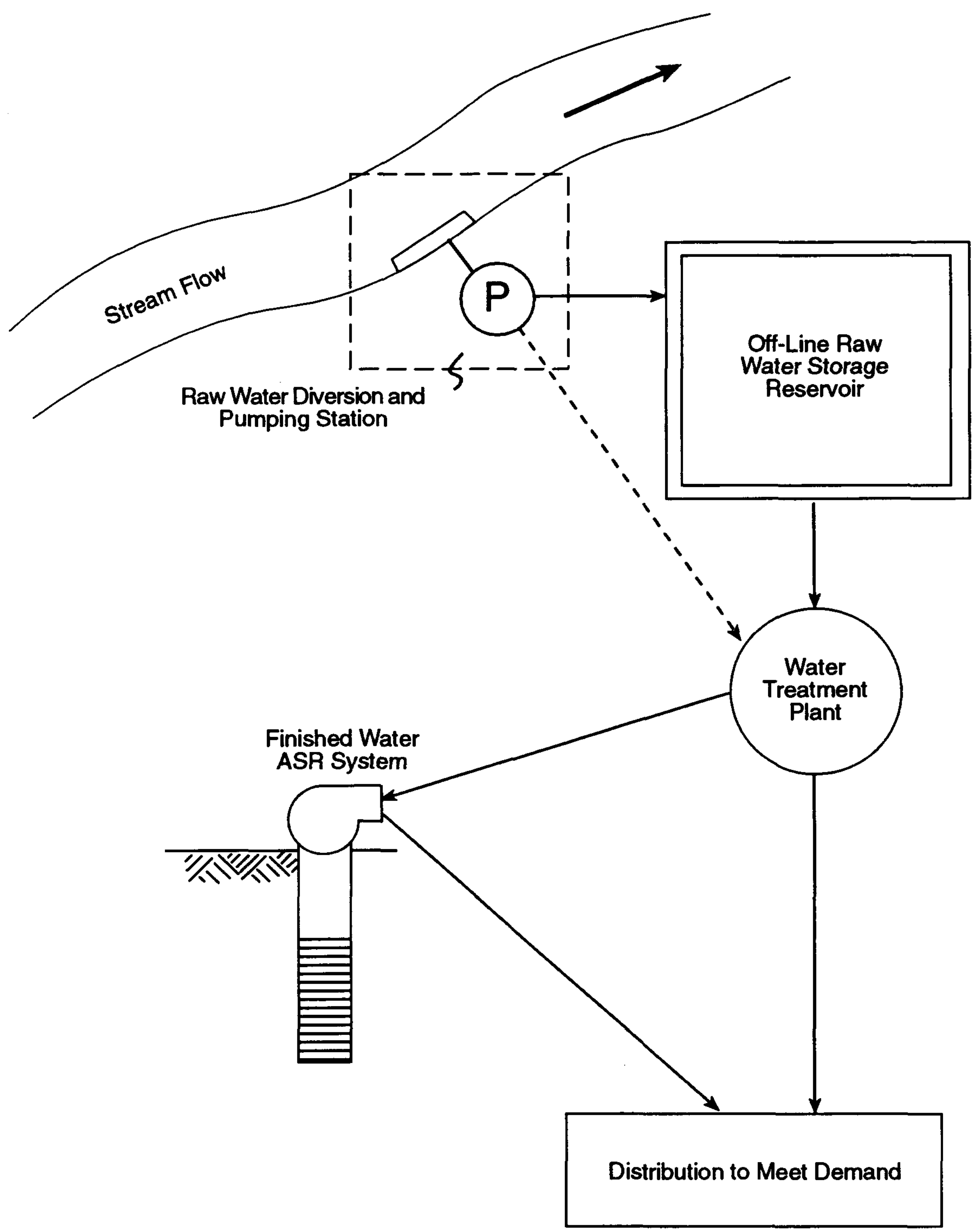

Figure 1. Facilities Required to Develop Reliable Surface Water Supply to Meet Urban Demands.

operation of the treatment plant at a reduced rate to minimize the frequency of plant shut-downs and start-ups.

Water Treatment Plant

The purpose of the water treatment plant is to provide a safe, potable finished water that meets all the necessary drinking water standards. If the raw water is of reasonably high quality, conventional treatment is usually all that is required. For surface water sources, conventional treatment usually consists of some type of clarification and filtration with disinfection. If the raw water is of poor quality, including a high dissolved minerals content, membrane treatment may also be required, which produces a waste concentrate. Therefore, the addition of membrane treatment would reduce the net water supply yield, as well as additional requirements for a concentrate disposal system.

ASR Systems

In general, ASR systems can be used to store both raw water and treated finished water (Pyne 1995). In raw water applications, the ASR system could replace the off-line raw water storage reservoir discussed previously. However, in most water supply applications implemented to date, ASR has been used to provide treated water storage, so only treated water ASR is considered here. Water processed by the water treatment plant and not needed at the time of treatment is injected into a suitable storage aquifer for later recovery and distribution. In general, the recovered water is re-disinfected, but no additional treatment is required.

ASR involves injecting water to be stored into a suitable aquifer. The native ground water is displaced by the injected water, which is then available for recovery when needed. However, some inefficiencies and losses occur, which prevent all of the water injected from ultimately being recovered and used. As water is injected, some of it mixes with the native ground water. Depending on the mixing characteristics of the aquifer and the quality of both the injected water and native ground water, only a portion of this mixture can be recovered before the water quality is unacceptable for the intended purpose.

The mixing characteristics of the storage aquifer and water quality of the native ground water are not usually as restrictive in ASR applications as they might first appear if the ASR system is developed and operated properly. Even if the native ground water quality is poor and considerable initial mixing occurs, a viable ASR system can still usually be developed by injecting an initial volume of treated water to develop a buffer between the native ground water and treated injected water. Once developed, the buffer will allow good recovery efficiencies if the injected water is not recovered, but is allowed to remain in the buffer.

The primary purpose of the ASR system in this application is to provide the storage volume necessary to ensure a reliable municipal water supply. Because surface water sources are intermittent, storage is needed to provide the desired water supply during drought periods.

Treated Water Transport

If the water treatment facility is located within the water supply service area, the finished water can be distributed directly. However, if the water treatment plant is located some distance from the municipal service area, a transport system must be provided. Depending on the transport distance and flow rates involved, booster pumping stations, additional storage tanks, and disinfection facilities may also be required. All these major components can be arrayed as needed to provide a complete surface water supply system.

The purpose of the planning-level cost equations developed here is to provide a complete set of cost-estimating tools applicable to surface water supply systems within the planning area.

SELECTED CANDIDATE WITHDRAWAL SITES

As a result of the analysis performed in TM B.1.j, *Surface Water: Availability and Yield Analysis*, five sites were selected for the cost-estimating phase of the investigation. One site, Lake Griffin, was selected from the Haines Creek/Palatlakaha Chain of Lakes watershed in Lake County (Figure 2). This site could potentially supply a portion of the future needs of northern Lake County. The remaining four candidate withdrawal sites, listed below, are all located on the main stem of the St. Johns River (Figure 3):

- St. Johns River near Cocoa
- St. Johns River near Titusville
- St. Johns River at Sanford (Lake Monroe)
- St. Johns River near De Land

Water supply development costs are addressed individually, as necessary, for each candidate withdrawal site.

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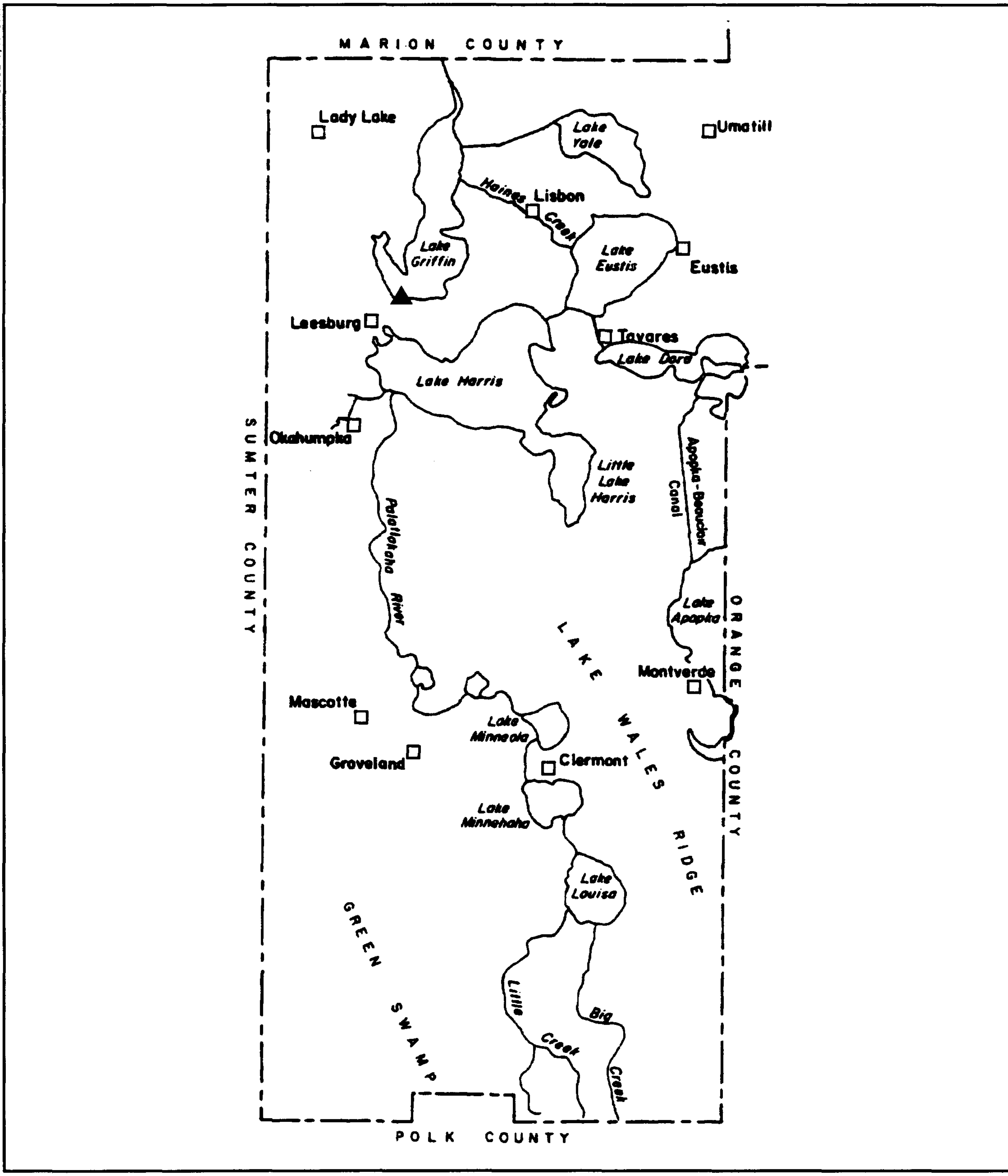
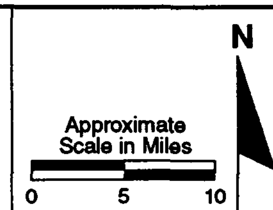


Figure 2. Location of the Lake Griffin/Haines Creek Candidate Surface Water Withdrawal Site in Lake County.

▲ Withdrawal Site

Note: The water supply withdrawal site can be located anywhere along the shore of Lake Griffin.



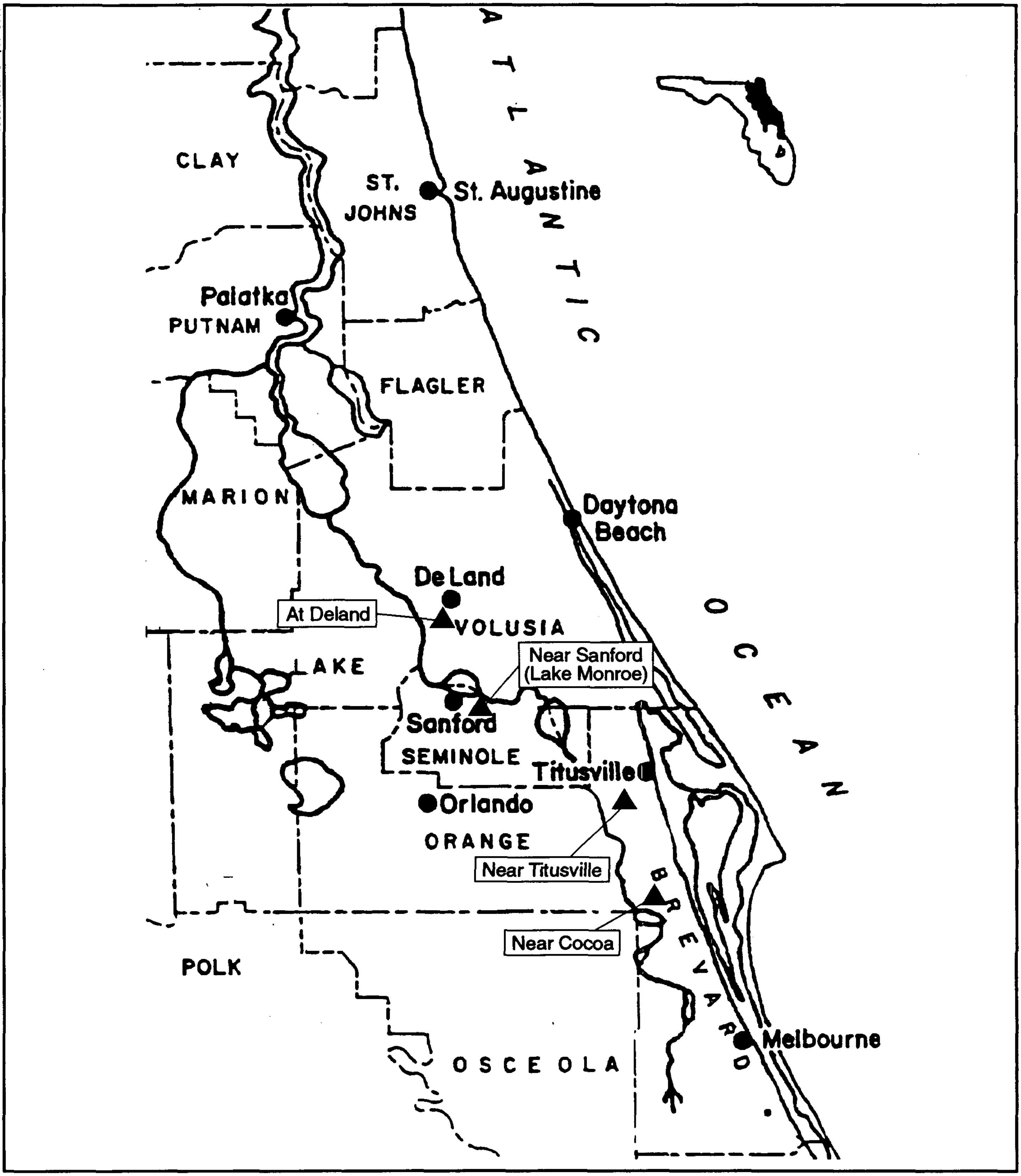


Figure 3. Locations of Candidate Surface Water Withdrawal Sites on the Main Stem of the St . Johns River.

▲ Withdrawal Site

N

Approximate Scale in Miles
0 10 20

COST PARAMETERS

Cost parameters considered in this TM were previously established by the project team and include the following:

- Construction cost
- Non-construction capital cost
- Land cost
- Land acquisition cost
- Total capital cost
- O&M cost
- Equivalent annual cost
- Annualized set-up cost
- Annualized unit cost

Economic criteria, including cost basis, non-construction capital cost factor, unit land costs, interest rate, and facilities life expectancies, have been previously established for all cost estimates developed as part of the SJRWMD Alternative Water Supply Strategies Program. These previously established criteria are used to develop the required cost estimates for the surface water facilities.

In all cases, costs are expressed as constant 1996 dollars. The interest rate or time value of money used in all calculations is 7 percent per year. Non-construction capital costs are estimates computed as 45 percent of the construction cost, while land acquisition costs are computed as 25 percent of the land value. Total capital cost is then the sum of the construction cost, land cost, non-construction capital cost, and land acquisition cost. These criteria are consistent throughout this TM and will be used for other water supply alternatives to ensure a consistent basis of comparison among the various water supply strategies under investigation.

Construction and O&M cost estimates have been developed at the preliminary planning or cost curve level for the major components required. The major facility components required for each candidate withdrawal site may include the following:

- River diversion structure
  - Intake structure
  - Pumping station
  - Pumping equipment

- Off-line raw water reservoir
  - Perimeter levee
  - Interior levees
  - Emergency spillway
  - Site preparation (clearing and grubbing)
- Conventional surface water treatment plant
  - Raw water pumping
  - Coagulation/flocculation-sedimentation
  - Filtration
  - Sludge handling facilities
  - Disinfection (primary ozone, residual chloramines)
  - Instrumentation and controls (I&C)
  - Transfer pumping
  - Ground storage tankage
  - Office/laboratory
  - General site work
- RO treatment (in addition to conventional facilities)
  - RO pre-treatment
  - RO membranes
  - Chemical addition
  - Concentrate disposal system (deep wells)
- ASR system
  - Wells
  - Pumps
  - Piping and I&C

Applicable cost data have been identified in the literature. Where necessary, cost curves or unit costs for individual items (e.g., pumping stations) or major systems (e.g., conventional surface water treatment) have been developed. Information developed by Law (1996) was used as much as possible. Using the identified or developed construction and O&M cost curves, a spreadsheet application was developed and applied to the five candidate facilities.

SURFACE WATER FACILITY REQUIREMENTS

TM B.1.j. (CH2M HILL 1996c) determined the water quality and treatment characteristics for each candidate withdrawal site (Table 1). All of the sites will require conventional water treatment, and the four St. Johns River sites will also require RO and concentrate disposal.

Table 1. Major Water Treatment Processes Required for Each Candidate Surface Water Withdrawal Site

Candidate Surface Water Withdrawal Site	Treatment Process[a]						Concentrate Disposal
			Reverse Osmosis				
	Coagulation/ Flocculation-Sedimentation	Filtration	Slightly brackish Cl < 500 mg/L	Moderately brackish Cl 500 to 1,000 mg/L	Highly brackish Cl 1,000 to 5,000 mg/L	Saline Cl > 5,000 mg/L	
Lake Griffin (Haines Creek)	✓	✓					
St. Johns River near Cocoa	✓	✓	✓ (50%)[b]				✓ (7.5%)[c]
St. Johns River near Titusville	✓	✓		✓ (63%)			✓ (12.6%)
St. Johns River at Sanford (Lake Monroe)	✓	✓		✓ (63%)			✓ (12.6%)
St. Johns River near De Land	✓	✓		✓ (67%)			✓ (13.4%)

[a] All water treatment systems will require sludge thickening and dewatering facilities, finished water transfer pumping, ground storage tankage, disinfection (ozone), and miscellaneous facilities (e.g., offices) and site work.

[b] Denotes required RO treatment capacity as a percentage of total conventional water treatment capacity

[c] Denotes required concentrate disposal capacity as a percentage of total conventional water treatment capacity

TM B.1.j. also included a long-term systems simulation and water quality and treatment requirements analysis to establish estimates of the reliable net yield for each of the trial water supply systems. The reliable yield, along with the facility capacities required to develop the yield, are reported in Table 2.

COST ESTIMATING PROCEDURE

For each surface water supply facility component (e.g., pipe, pumps, levees, conventional treatment, membrane treatment, ASR systems), relationships between capacity and land requirements, construction cost, O&M cost, and unit cost were established. Also, the anticipated economic life or service life for each facility component was established on the basis of previously established project guidelines.

Using these relationships, a complete set of cost estimates for selected major surface water supply system components was developed. Major water supply system components addressed include off-line raw water storage reservoirs, complete water treatment systems, and finished water transport systems.

Cost functions relating water supply capacity in terms of average daily flow (ADF) to costs, as well as other important design parameters, were developed from cost estimates of the individual major system components. Cost functions for off-line raw water reservoirs, surface water treatment plants, and finished water transport systems were developed for the following costs parameters:

- Construction
- Capital
- O&M
- Equivalent annual
- Unit

All other cost parameters of interest may be computed directly from these cost equations. For example, land cost can be computed from the estimated capital cost and construction cost. Based on our previously established cost estimating and economic analysis criteria, the relationship between construction cost, land cost and capital cost is as follows:

$$\text{Capital cost} = 1.45 * \text{Construction cost} + 1.25 * \text{Land cost}$$

Table 2. Surface Water Facility Requirements Summary for Range of Total Reliable Net Yield

Reliable Net Yield (mgd)	River Diversion Capacity (mgd)	Water Treatment Plant Capacity (mgd)	RO Treatment Capacity (mgd)	ASR Recovery Capacity (mgd)	RO Concentrate Disposal Capacity (mgd)
a) Lake Griffin (Haines Creek)					
5.4	6.7	6.4	0.0	8.1	0.0
10.5	13.3	12.6	0.0	15.8	0.0
15.3	20.0	19.0	0.0	22.9	0.0
19.2	26.7	25.4	0.0	28.8	0.0
23.7	33.3	31.6	0.0	35.5	0.0
28.0	40.0	38.0	0.0	42.0	0.0
b) St. Johns River near Cocoa					
19.9	25.7	24.4	11.6	29.9	1.7
39.5	51.3	48.7	23.1	59.2	3.5
58.0	77.0	73.2	34.7	86.9	5.2
75.0	102.7	97.6	46.3	112.5	7.0
91.5	128.3	121.9	57.9	137.3	8.7
108.4	154.0	146.3	69.5	162.6	10.4
c) St. Johns River near Titusville					
27.0	34.2	32.5	19.4	40.4	3.9
50.9	68.3	64.9	38.8	76.3	7.8
74.4	102.5	97.4	58.3	111.5	11.7
97.4	136.7	129.9	77.7	146.1	15.5
120.8	170.8	162.3	97.1	181.1	19.4
142.5	205.0	194.8	116.6	213.8	23.3
d) St. Johns River at Sanford					
48.6	65.3	62.0	37.1	73.0	7.4
97.4	130.7	124.2	74.3	146.1	14.9
149.9	196.0	186.2	111.4	224.8	22.3
192.0	261.3	248.2	148.6	288.0	29.7
239.2	326.7	310.4	185.8	358.8	37.2
279.1	392.0	372.4	222.9	418.6	44.6
e) St. Johns River near De Land					
62.6	82.0	77.9	49.6	94.0	9.9
124.4	164.0	155.8	99.2	186.5	19.8
189.3	246.0	233.7	148.8	283.9	29.8
242.9	328.0	311.6	198.3	364.4	39.7
304.7	410.0	389.5	247.9	457.0	49.6
350.8	492.0	467.4	297.5	526.2	59.5

Therefore, given an estimate of capital cost and construction cost, land cost can be computed as follows:

Land cost = (Capital cost - 1.45 * Construction cost)/1.25

These relationships are applicable for all major surface water supply system cost equations developed and presented in this TM. The major component cost equations will be used in the University of Florida Decision Model to represent the costs of the surface water supply alternative for each of the candidate withdrawal sites.

OFF-LINE RESERVOIR COSTS

Off-line reservoir costs can vary significantly, depending on the height of the perimeter levee and volume of water impounded. For example, in the water supply facilities cost TM, Law (1996) reported unit construction costs for off-line reservoirs that ranged from about $340 per million gallons (MG) for a large, shallow reservoir to more than $13,800 per MG for a smaller, deep reservoir. In addition, the value of the land required to construct the reservoir can also greatly impact overall capital and equivalent annual costs of storage reservoirs. Valuable land would tend to favor construction of deep reservoirs.

In addition to land and levee construction, the off-line reservoirs will require clearing and grubbing of the site and construction of an emergency spillway to prevent overtopping of the reservoir during major rain storms. Each of these components are included in the off-line reservoir cost estimates developed herein.

Because of the cost interactions between levee cost and land cost, off-line reservoir cost estimates were developed in two major steps. First, an analysis was undertaken to establish the most appropriate levee height, given levee construction costs and land value. Once the levee height was established, all cost parameters were estimated for a variety of total storage volumes. Raw water storage cost equations were then developed from these individual estimates.

LEVEE REQUIREMENTS

The levee requirements analysis is based primarily on previous experience in off-line reservoir costing in south Florida. Levee unit costs used in the recently completed East Coast Buffer Feasibility Analysis (CH2M HILL 1996d) conducted for the South Florida Water Management District were used, along with land unit costs established for SJRWMD's investigations of alternative water supply strategies to identify tradeoffs between levee construction costs, land costs, and total reservoir cost. In this analysis, it was assumed that a 3-foot freeboard would be provided and that 1 foot of unusable or dead storage would be required. Usable raw water storage depth is then equal to levee height minus 4 feet.

It was also assumed that new off-line raw water storage reservoirs would be located in rural areas and that a typical land value of $3,000 per acre is applicable.

The results of the levee height analysis indicate that a 20-foot levee is economically attractive under these conditions. This levee height will provide a 16-foot working depth for raw water storage. The typical section of the levee used in the off-line storage cost estimates is illustrated in Figure 4. A maintenance access strip of 20 feet and a 12-foot top width are included. Levee side slopes are 3.5 to 1.

In many cases, interior levees are required in addition to a perimeter levee. Interior levees can be used for any or all of the following reasons: to partition the reservoir into storage cells to account for topographic differences, to provide a minimum flow path to induce raw water mixing, or to provide physical sedimentation to improve treatability. Also, because available land parcels are often irregular in shape, the perimeter levee requirements are often longer than the theoretical minimum requirements, which are based on enclosing a square land parcel.

The exact requirements for perimeter and interior levees can only be evaluated on a site-specific basis. However, some provision should be made in the preliminary planning-level cost estimates for anticipated total levee requirements. Seven off-line reservoir sites investigated in the East Coast Buffer Feasibility Analysis (CH2M HILL 1996d) were examined to determine an appropriate allowance for these additional levee requirements. In each case, a minimum levee length based on a square land parcel was computed and compared with the actual total levee length (perimeter plus interior) required. For the seven sites, this ratio ranged from 1.03 to 2.01, and averaged about 1.6. This average value was used to adjust the levee lengths used in the cost estimates. For example, if a theoretical minimum levee length of 10,000 feet is computed for a given reservoir, a total length of 16,000 feet is used to estimate actual levee requirements and associated costs.

RESERVOIR COSTS AS A FUNCTION OF STORAGE VOLUME

The typical levee section presented in Figure 4 was used to establish land requirements and raw water storage volumes for a variety of off-line storage reservoirs. Construction, land, capital, O&M, and equivalent annual costs were then computed for each reservoir. Construction cost components considered include the levees, site clearing and grubbing, and an emergency spillway. O&M costs include provisions for annual levee and spillway maintenance. These

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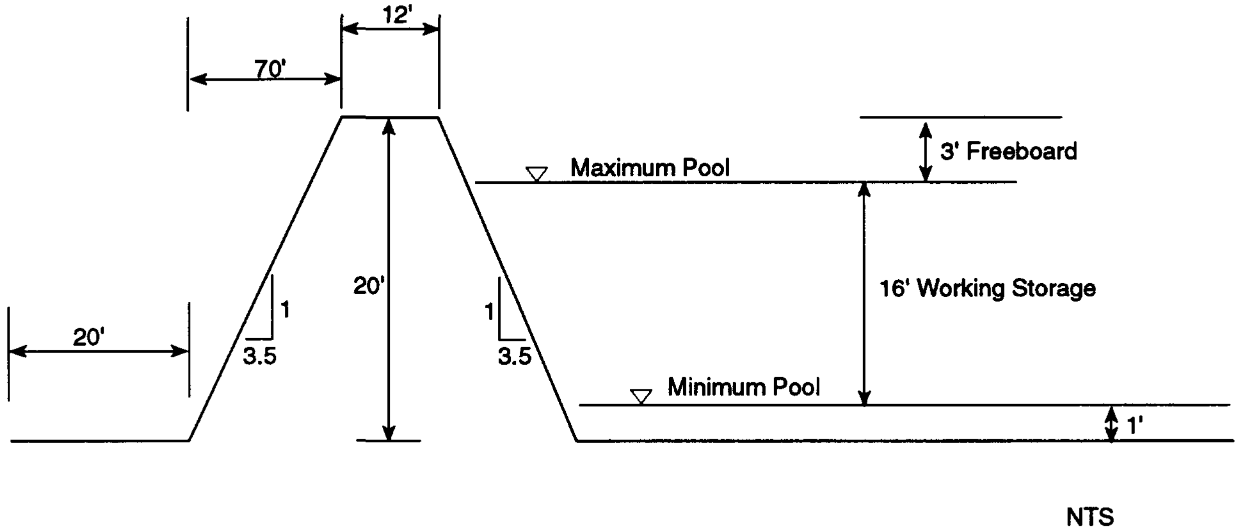

Figure 4. Typical Section of Off-Line Storage Perimeter Levee.

O&M cost are considered fixed and will not vary with the use of the reservoir; therefore, variable unit costs for off-line storage reservoirs are negligible.

Raw water pumping, either into the reservoir or directly to a surface water treatment plant, is required for all treatment systems; thus, these costs are included in the treatment system cost estimates. Raw water pumping costs are not included in the off-line reservoir cost estimates.

Curve fitting was used to establish raw water storage reservoir costs as a function of storage volume developed. These equations, which are reported in Table 3, can be used to estimate planning-level costs of off-line raw water storage reservoirs on the basis of the criteria and assumptions discussed previously.

RESERVOIR COSTS FOR CANDIDATE WITHDRAWAL SITES

The cost equations presented in Table 3 define the relationship between storage volume developed (in MG) and costs incurred. However, to be most useful when applying the University of Florida Decision Model, the cost of storage should be expressed as a function of the finished water production rate in mgd.

This is possible if the raw water storage volume requirements are related to the treated water production rate. For the purpose of this preliminary feasibility analysis, raw water storage requirements have been established as a function of raw water diversion capacity. In turn, the relationship between raw water diversion capacity and reliable yield have also been previously established. Therefore, a relationship between off-line storage cost and treated water production rate can be established.

For example, consider the St. Johns River near Cocoa. From Table 2 it can be seen that a reliable yield of 19.9-mgd can be developed with a river diversion capacity of 25.7 mgd. If the raw water storage reservoir is sized to provide a 5-day supply, based on river diversion capacity, an off-line reservoir of 128.5-MG would be required for the 19.9-mgd water supply system. The capital cost of a 128.5-MG reservoir is estimated to be $3,922,000 using the capital cost equation presented in Table 3. Similarly, the equivalent annual cost of the off-line storage reservoir is computed as $381,400 per year, or about $0.053 per 1,000 gallons of treated water.

Table 3. Cost Equation Coefficients for Off-Line Raw Water Storage Reservoirs as a Function of Storage Volume

Cost Parameter	$Cost = C * (V)^X$	
	C	X
Construction ($)	216,800	0.516
Capital ($)	268,800	0.552
Operation and Maintenance ($/yr)	7,307	0.492
Equivalent Annual ($/yr)	27,980	0.538

Notes:
All costs are expressed in 1996 dollars.
V is the effective storage volume in million gallons.
The above equation includes the cost of land, perimeter and interior levees, clearing and grubbing, and an emergency spillway. A 20-foot levee height and 16-foot working depth are assumed.

Similar calculations were made for all facilities defined in Table 2. These cost estimates were used to establish off-line reservoir costs as a function of treated water production rate. These equations, reported in Table 4, are applicable only to the candidate water supply withdrawal sites considered in this investigation.

Table 4. Cost Equation Coefficients for Off-Line Raw Water Storage Reservoirs as a Function of Treated Water Production Rate

Cost Parameter	$Cost = C * (ADF)^X$	
	C	X
Construction ($)	558,700	0.525
Capital ($)	740,100	0.561
Operation and Maintenance ($/yr)	18,030	0.500
Equivalent Annual ($/yr)	75,100	0.547

Notes:
All costs are expressed in 1996 dollars.
ADF is the average daily flow in mgd.
These equations apply only to the candidate withdrawal sites considered in this investigation. They are based on a storage volume equal to five times the water supply system daily diversion capacity.

SURFACE WATER TREATMENT COSTS

Cost equations were developed for each of the five candidate surface water supply sites. These cost equations include the following components:

- Raw water diversion structure
- Conventional water treatment plant
- RO membrane treatment plant
- Concentrate disposal
- ASR system
- Land

A schematic of the surface water treatment system is presented in Figure 5. This figure illustrates the components in the cost equations for the complete surface water supply treatment and ASR system, as well as the relationship of the treatment cost equations to the other major components, including off-line raw water storage and treated water transport.

Appendixes A through E present the individual cost estimates for each surface water treatment system considered at each candidate surface water withdrawal site. Charts illustrating the relationship between the treated water production rate and estimated costs, as well as the equations used to represent these relationships, are also included in the Appendixes.

Items included in the cost estimates and sources used to quantify construction costs, O&M costs, and land requirements follow.

RAW WATER DIVERSION STRUCTURE

The raw water diversion structure consists of a submerged intake structure, subaqueous pipeline, pump station, and supporting pumping and control equipment. The construction costs of each of these items were estimated on the basis of cost algorithms presented by Stone and Webster (1990). Land requirements and O&M costs were taken from Law (1996).

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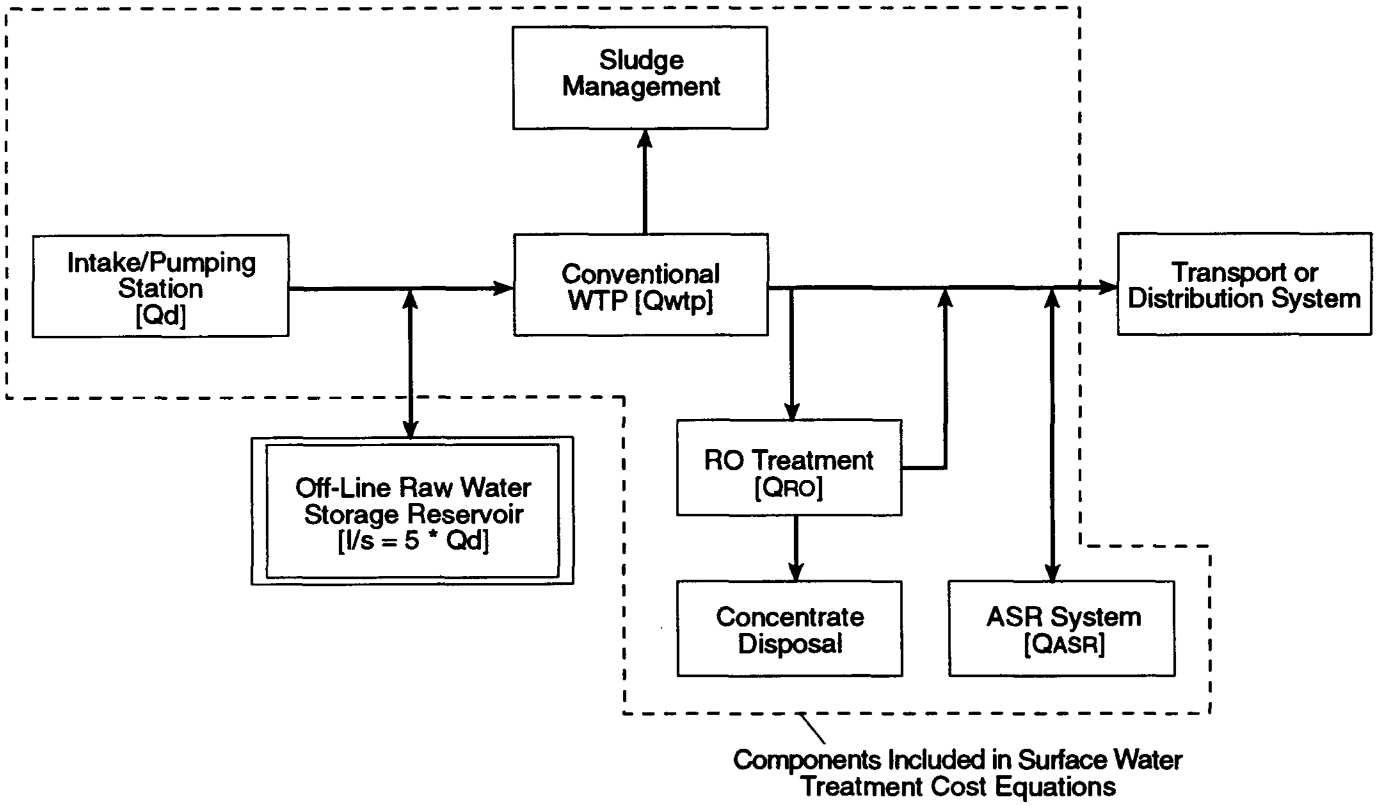

Figure 5. Major Components of Complete Surface Water Supply Storage and Treatment System.

CONVENTIONAL WATER TREATMENT PLANT

The conventional surface water treatment plant consists of coagulation, flocculation, and sedimentation treatment processes. The construction costs include all required components, such as rapid mixers, flocculation basins, sedimentation basins, and filters, and the costs associated with other integral treatment plant components. Additional plant components include sludge thickening and dewatering facilities, finished water transfer pumps, ground storage tankage, disinfection (ozone), and miscellaneous items such as offices and site development.

All cost data used to develop the conventional surface water treatment plant costs were taken from the Law cost report (1996), including criteria for estimating land requirements, O&M costs, and construction costs.

MEMBRANE TREATMENT

RO membrane treatment costs are included for four of the five candidate withdrawal sites located on the St. Johns River. These costs are a function of the maximum raw water total dissolved solids (TDS) concentration and finished water flow rate. The following RO treatment components are included in the costs: pretreatment, consisting of chemical addition and cartridge filtration; membrane trains; and post-treatment, consisting of degasifiers and chemical addition.

RO treatment construction costs are based on information presented by Stone and Webster (1990). Construction cost estimates as a function of both raw water TDS concentration and product water flow rate were developed in the Stone and Webster report. This cost information allowed development of RO treatment cost estimates that were based on the slightly to moderately brackish characteristics of the St. Johns River water.

The RO treatment requirements at each of the St. Johns River candidate withdrawal sites were established in a previous analysis by CH2M HILL (1996c). This analysis considered observed chloride concentrations in the river, as well as the relationship between chloride concentrations and river flow rate. Chloride concentrations are at a maximum when river flow rates are at a minimum. For this preliminary planning analysis, it was assumed that raw water TDS concentrations will be twice as high as chloride concentrations.

Although few TDS data are available for the St. Johns River, analysis of available brackish ground water data indicate that this 2:1 ratio of TDS to chlorides is a reasonable assumption.

The RO construction costs developed in this TM are based on a maximum raw water TDS of 2,000 milligrams per liter (mg/L) and an assumed flux rate of 10 gallons per day per square foot of membrane. Also, only 25 percent of the total diverted river flow will require membrane treatment; the majority will require conventional treatment only. If future detailed planning indicates that the maximum diverted TDS will be greater than 2,000 mg/L or that more than 25 percent of the diverted flow will require membrane treatment, the cost equations in this TM will need to be revised.

Membrane plant O&M costs and land requirements were based on information presented by Law (1996). The variable portion of the O&M costs (unit costs) associated with membrane treatment were applied only to that portion of the total flow (25 percent) receiving membrane treatment.

CONCENTRATE DISPOSAL

Each of the withdrawal sites that require membrane treatment will also require membrane concentrate disposal. Deep well injection is assumed to be the disposal method. While deep wells are the most universally applicable concentrate disposal method, they are also one of the most costly. Therefore, if an alternative method should prove feasible at a site, some cost savings should result.

Deep well construction costs are based on information presented in Stone and Webster (1990). Deep injection wells will not incur appreciable O&M costs or unit costs and will not require additional land.

ASR SYSTEM

The construction costs for ASR systems depend on the number of ASR wells needed, which in turn depends on the total ASR capacity required and the ASR capacity of each individual well. The total ASR capacity needed for each surface water supply system has been previously established (Table 2). In previous applications, ASR capacity per well has ranged from about 0.5 mgd per well to more than 5 mgd per well. In this preliminary planning application, an ASR recovery rate of 1.5 mgd per well is used. This value is based on recent experience with the City of Cocoa ASR wellfield, the only operational treated water ASR system in the St. Johns River valley.

O&M costs were also estimated on the basis of operational experience at Cocoa, yielding a unit cost of $6,000 per year per mgd of installed ASR capacity (Pyne 1995). Land requirements were estimated to be 4 acres per ASR well, which will provide full acquisition of the ASR wellfield.

LAND

Land requirements were determined for all of the previously discussed facilities for each of the candidate withdrawal sites. Land costs are assumed to be $5,000 per acre for parcels less than 50 acres, and $3,000 per acre for parcels greater than 50 acres. These are previously established unit prices for rural land.

SURFACE WATER TREATMENT COST EQUATIONS

Tables 5 through 9 present the surface water treatment system cost equations for each of the five candidate withdrawal sites. The Lake Griffin site includes raw water diversion, conventional surface water treatment, and ASR. The four St. Johns River sites include raw water diversion, conventional surface water treatment, and ASR, as well as membrane treatment and concentrate disposal for a portion of the diverted river flow.

Total water treatment costs in terms of dollars per 1,000 gallons produced can be computed by dividing the annual cost by the annual production rate (Appendixes A through E). The lowest cost site is Lake Griffin, which has a total production cost ranging from about $0.93 per 1,000 to $1.04 per 1,000 gallons.

The St. Johns River sites are more expensive, with total estimated treatment costs ranging from $1.32 per 1,000 gallons to $1.60 per 1,000 gallons.

Table 5. Cost Equation Coefficients for Surface Water Treatment at Lake Griffin

Cost Parameter	Cost = C * (ADF)^{X}	
	C	X
Construction ($)	2,456,000	0.817
Capital ($)	3,612,000	0.815
Operation and Maintenance ($/yr)	129,500	1.083
Equivalent Annual ($/yr)	415,100	0.936

Notes:
All costs are expressed in 1996 dollars.
ADF is the average daily flow in mgd.
The above equations include the cost of a raw water diversion structure, required conventional treatment, and a treated water ASR system. The cost of an off-line raw water storage reservoir is *not* included.

Table 6. Cost Equation Coefficients for Surface Water Treatment of the St. Johns River near Cocoa

Cost Parameter	Cost = C * (ADF)^X	
	C	X
Construction ($)	3,473,000	0.825
Capital ($)	5,049,000	0.826
Operation and Maintenance ($/yr)	313,700	0.988
Equivalent Annual ($/yr)	748,100	0.917

Notes:
All costs are expressed in 1996 dollars.
ADF is the average daily flow in mgd.
The above equations include the cost of a raw water diversion structure, required conventional and RO treatment (including concentrate disposal), and a treated water ASR system. The cost of an off-line raw water storage reservoir is *not* included.

Table 7. Cost Equation Coefficients for Surface Water Treatment of the St. Johns River near Titusville

Cost Parameter	Cost = C * (ADF)^X	
	C	X
Construction ($)	3,392,000	0.845
Capital ($)	4,931,000	0.846
Operation and Maintenance ($/yr)	332,100	0.996
Equivalent Annual ($/yr)	762,600	0.932

Notes:
All costs are expressed in 1996 dollars.
ADF is the average daily flow in mgd.
The above equations include the cost of a raw water diversion structure, required conventional and RO treatment (including concentrate disposal), and a treated water ASR system. The cost of an off-line raw water storage reservoir is *not* included.

Table 8. Cost Equation Coefficients for Surface Water Treatment of the St. Johns River near Sanford (Lake Monroe)

Cost Parameter	Cost = C * (ADF)^X	
	C	X
Construction ($)	3,529,000	0.833
Capital ($)	5,127,000	0.834
Operation and Maintenance ($/yr)	396,000	0.950
Equivalent Annual ($/yr)	854,800	0.901

Notes:
All costs are expressed in 1996 dollars.
ADF is the average daily flow in mgd.
The above equations include the cost of a raw water diversion structure, required conventional and RO treatment (including concentrate disposal), and a treated water ASR system. The cost of an off-line raw water storage reservoir is *not* included.

Table 9. Cost Equation Coefficients for Surface Water Treatment of the St. Johns River at De Land

Cost Parameter	Cost = C * (ADF)^x	
	C	X
Construction ($)	3,352,000	0.845
Capital ($)	4,870,000	0.846
Operation and Maintenance ($/yr)	380,800	0.959
Equivalent Annual ($/yr)	816,800	0.912

Notes:
All costs are expressed in 1996 dollars.
ADF is the average daily flow in mgd.
The above equations include the cost of a raw water diversion structure, required conventional and RO treatment (including concentrate disposal), and a treated water ASR system. The cost of an off-line raw water storage reservoir is *not* included.

TREATED WATER TRANSPORT COSTS

In cases where water supply sources are developed some distance from the municipal demand area, finished water transport facilities must be constructed and operated to deliver the product water to the distribution system. The cost of transport will vary with flow rate and distance. In this section, planning-level transport cost equations are developed. These equations are applicable to any type of finished product water transport, regardless of source. That is, the transport cost equations presented in this TM may be applied to other water supply sources, including brackish or potable ground water, to establish the cost of point-to-point transport of treated product water.

The additional facilities required to transport treated water depend largely on transport distance. If the distance is short, water treatment plant high-service pumps can often be used to overcome the relatively small head losses involved. Likewise, additional disinfection to maintain an acceptable disinfectant residual will not be required. Therefore, for short transport distances, only an adequately sized pipeline and pipeline right-of-way would be required in addition to the water treatment facilities.

Conversely, if the transport distance is long, additional facilities may be required, such as booster pumping stations, additional ground storage for peak flow management, and disinfection facilities to maintain the required disinfectant residual.

In this analysis, the cost of transport is addressed for both the short transport and long transport systems.

OTHER COSTS

The transport cost equations presented in this TM provide for the major costs involved in point-to-point transport of treated water. In specific applications, additional costs may be incurred, such as upgrading an existing distribution system to accept additional flow, providing pressure regulators, or providing water quality compatibility between existing water supplies and a new source. It is not possible to account for such potential costs at this time. However, additional costs, if any, should be small when compared with the major costs of treatment and point-to-point transport. Also, costs associated with distribution system upgrades and water quality compatibility are likely to be incurred regardless of the new water source developed; thus, they probably would not influence which alternative source is most cost-effective.

SHORT TRANSPORT SYSTEMS

Short transport systems are applicable in situations where only a pipeline and pipeline right-of-way are required. Cost estimates for such systems were developed for an array of flow rates and distances on the basis of selected sizing and design criteria.

Appropriate pipe sizes were selected on the basis of maximum peak flow rates and maximum allowable friction loss. Pipe sizes up to 120 inches in diameter were considered. The maximum flow rate was calculated as 1.5 times the ADF. This maximum-flow to average-flow ratio of 1.5 is equal to the maximum-daily-flow to average-daily-flow ratio used in all other surface water treatment plant sizing criteria.

The maximum friction loss was set equal to 50 feet. Most high-service pumps provide on the order of 250 to 300 feet of head. Based on this total value, it seems likely that 50 feet of head could be allocated to finished water transport without incurring the need for new booster pumps. The maximum friction loss was applied to the maximum flow rate to establish required pipe size.

Using these criteria, construction costs, land requirements, capital costs, and equivalent annual costs were computed for each combination of flow rate and transport distance considered. All construction cost data and land requirements were taken directly from Law (1996). Land costs were computed on the basis of obtaining easements along existing right-of-ways. O&M costs and unit costs are considered negligible for short transport systems.

The resulting general cost equations for short treated water transport systems are presented in Table 10. These equations may be applied to any point-to-point transport of treated water where only pipe and right-of-way are required. Consider, for example, a 4-mile-long system sized to transport an average daily flow of 10 mgd (maximum flow rate, 15 mgd). The capital cost of the required land and facilities is estimated to be $4,486,000 and the equivalent annual cost is estimated to be $333,500 per year when the equations presented in Table 10 are applied. Total transport cost in dollars per 1,000 gallons is $0.091, or about 2.3 cents per 1,000 gallons per mile.

Table 10. Cost Equation Coefficients for Short Transport Systems

Cost Parameter	$Cost = C * (L)^X * (ADF)^Y$		
	C	X	Y
Construction ($)	162,800	1.247	0.458
Capital ($)	303,900	1.231	0.428
Equivalent Annual ($/yr)	22,460	1.232	0.430

Notes:
All costs are expressed in 1996 dollars.
The above equations include the cost of land and pipe only.
L = Length of the transport system in miles (5 miles maximum).
ADF = Average daily flow transported in mgd.

LONG TRANSPORT SYSTEMS

Long distance water transport will require construction of one or more booster pumping stations along with pipeline. Also, it is assumed that long distance transport will require additional disinfection facilities and ground storage tanks. Construction costs, land requirements, O&M costs, and unit costs associated with each of these additional components were obtained from Law (1996).

Booster pumping stations were assumed to produce 250 feet of total head. It was further assumed that 225 feet of head per booster station would be available to overcome pipe friction losses. Based on these assumptions, long transport systems were sized and costs were developed for an array of transport lengths, ADFs, and number of pumping stations provided. These individual estimates were then used to develop general cost equations for long treated water transport systems.

The equivalent annual costs of these transport systems varied greatly as a function of the number of pump stations provided. Figure 6, which illustrates this point, shows the annual cost for a 30-mile-long treated water transport system as a function of the ADF rate transported. Two curves are shown. The bottom curve illustrates the annual cost of a single pump station system, while the top curve illustrates the cost of a two pump station system. In each case, pipe size is limited to a maximum of 120 inches in diameter.

Figure 6 indicates that it is more cost-effective to use the fewest number of pumping stations possible. Therefore, if 200 mgd must be transported 30 miles, a one pump station system would provide the most cost-effective solution. However, if the flow to be transported is increased to 300 mgd, two pump stations are required.

Based on the economic behavior shown in Figure 6, two transport cost equations were developed. Each cost equation was developed for a given number of pumping stations. Table 11 presents the construction and capital cost equations for long transport systems, whose costs are a function of the flow rate transported and the length of transport. Table 12 presents the O&M cost equations for long transport systems. In this case, the only independent variable is the average flow rate. O&M costs are related to the pumping and disinfection facilities; therefore, they vary with flow rate and number of pumping stations.

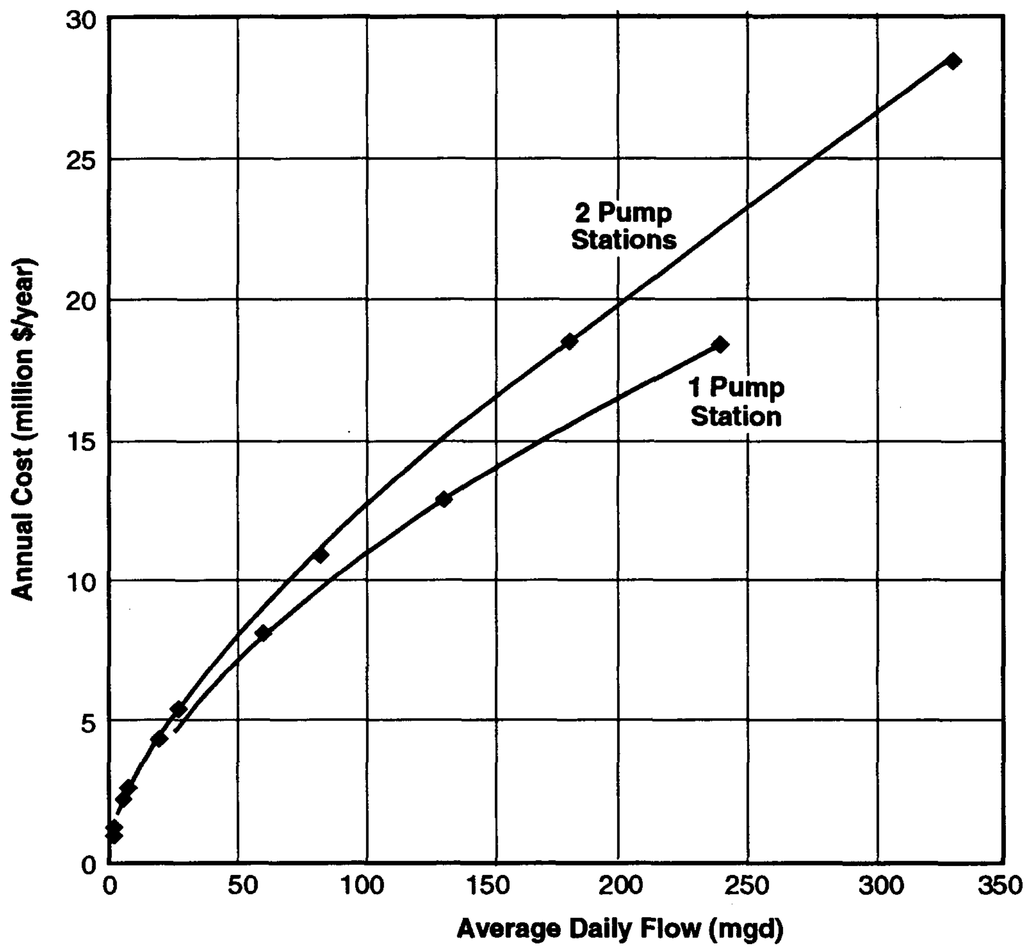

Figure 6. Annual Cost for 30-Mile Transmission System

Table 11. Construction and Capital Cost Equation Coefficients for Long Transport Systems

Number of Pump Stations	Cost Parameter	Cost = C * (L)^X * (ADF)^Y		
		C	X	Y
1	Construction	241,900	1.039	0.468
	Capital	422,900	1.044	0.440
2	Construction	332,300	0.921	0.475
	Capital	562,400	0.935	0.448

Notes:
All costs are expressed in 1996 dollars.
The above equations include the cost of land, pipe, booster pumping stations, storage tanks, and disinfection.
L = Length of the transport system in miles.
ADF = Average daily flow transported in mgd.

Table 12. Operation and Maintenance Cost Equation Coefficients for Long Transport Systems

Number of Pump Stations	O&M Cost = C * (ADF)^{Y}	
	C	Y
1	32,390	0.945
2	51,420	0.969

Notes:

All costs are expressed in 1996 dollars.

ADF = Average daily flow transported in mgd.

Table 13 presents the equivalent annual cost equations, which were derived by applying the appropriate capital recovery factor to the capital cost equation and adding the O&M costs. Although there are several coefficients, there are still only two independent variables for each equation.

The flow variable portion of the O&M cost (unit cost) is a function of the number of pumping stations. Since the pumping stations operate in series, the unit costs are additive. Unit costs are summarized as follows:

- One pump station, $0.069 per 1,000 gallons
- Two pump stations, $0.121 per 1,000 gallons

APPLICATION

Figure 7 presents guidance criteria for selecting the most appropriate transport cost equations for a given situation. Knowing both the average flow rate to be transported and the transport distance, the appropriate number of pump stations can be selected for Figure 7. This process should result in identification of a cost-effective transport system (i.e., the fewest number of pump stations required).

Short transport systems (pipeline only) should be used when the transport distance is less than 5 miles. One or more pump stations will be required for greater distances. In most situations, only the short system or one pump station equations will be used. The ADF must be greater than about 180 mgd before a multiple pump station configuration is required.

For example, consider the transport of 10 mgd for 15 miles. In this case, a one pump station system would be selected. The capital cost for this system is estimated to be $19,682,000 and the equivalent annual cost is estimated to be $1,770,000 per year, which corresponds to a total unit transport cost of $0.487 per 1,000 gallons, or about 3.2 cents per 1,000 gallons per mile. Clearly, treated water point-to-point transport costs can be a substantial portion of the total water supply system costs for remote water supply sources.

Table 13. Equivalent Annual Cost Equation Coefficients for Long Transport Systems

Number of Pump Stations	Annual Cost = $C1 * (L)^X * (ADF)^Y + C2 * (ADF)^Z$				
	C1	X	Y	C2	Z
1	32,040	1.044	0.440	32,390	0.945
2	43,180	0.935	0.448	51,420	0.969

Notes:
All costs are expressed in 1996 dollars.
The above equations include the cost of land, pipe, booster pumping stations, storage tanks, and disinfection.
L = Length of the transport system in miles.
ADF = Average daily flow transported in mgd.

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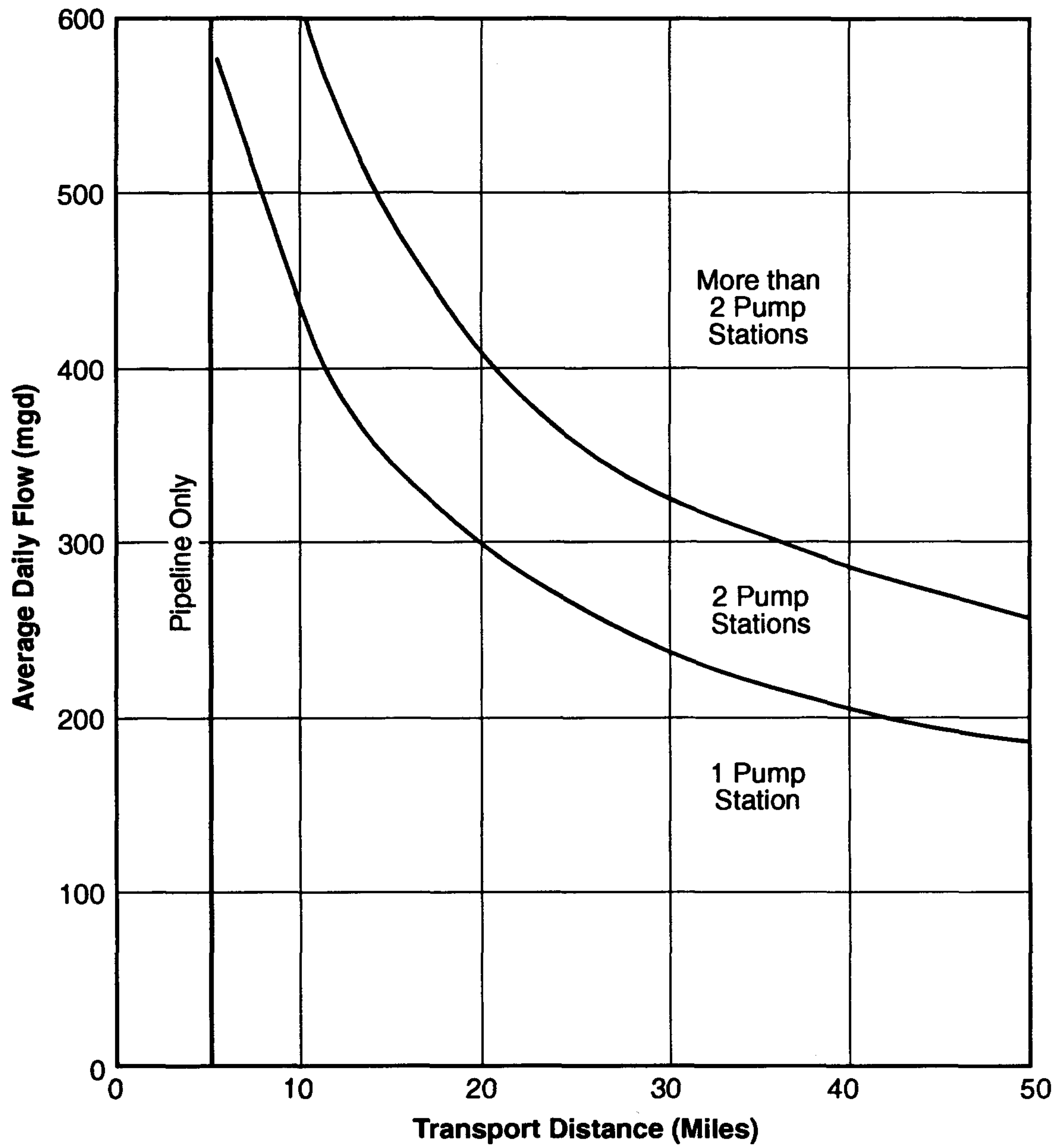

Figure 7. Criteria for Selection of Appropriate Number of Pumping Stations

EXAMPLE APPLICATIONS

Two hypothetical surface water supply systems are defined and evaluated in this section to illustrate the correct application of the planning level-cost equations. These examples are derived for illustrative purposes only and are not intended to represent actual alternatives to be evaluated for regional water supply plan development.

The first example is a surface water supply and transport system located on Lake Griffin. This example illustrates application of the Lake Griffin treatment cost equations as well as point-to-point transport to a single demand center. The second example is a surface water supply and transport system located at Lake Monroe on the St. Johns River near Sanford. This example illustrates application of the off-line storage reservoir cost equations, the Lake Monroe treatment cost equations, and point-to-point transport to two separate demand centers.

LAKE GRIFFIN

In this example, the water supply source is Lake Griffin in Lake County. The example water supply system provides an average daily flow (ADF) of 10 mgd and serves a demand center located 8.5 miles from the treatment plant site. Furthermore, it is assumed for this application that an off-line raw water storage reservoir will not be required. Therefore, the major cost components are a water treatment plant and treated water transport system.

Treatment Costs

Treatment costs, including the cost of a raw water diversion structure, conventional surface water treatment plant, and ASR system, are a function of the ADF produced, which is calculated by using the following equation:

$$\text{Cost} = C * (\text{ADF})^{X} \qquad (1)$$

The coefficients for the above equation for the Lake Griffin withdrawal site are reported in Table 5. These coefficients and the cost estimates obtained by applying Equation 1 to a 10-mgd treatment plant are shown below:

Cost Parameter	C	X	Cost ($)
Construction	2,456,000	0.817	16,115,000
Capital	3,612,000	0.815	23,591,000
O&M	129,500	1.083	1,568,000
Equivalent Annual	415,100	0.936	3,582,000

The unit production cost of treatment can be computed by dividing the equivalent annual cost ($3,582,000 per year) by the annual volume of treated water (10 mgd). In this case, the unit cost of treatment is equal to $0.981 per 1,000 gallons. ($3,582,000/[10*1,000*365]).

Transport Costs

Finish water transport of 10 mgd ADF (15-mgd maximum flow rate) for a distance of 8.5 miles will require a single pump station transport system incorporating the selection criteria presented in Figure 7. Construction and capital costs are computed by applying Equation 2, shown below:

$$\text{Cost} = C * (L)^{X} * (ADF)^{Y} \qquad (2)$$

The appropriate construction and capital cost equation coefficients are reported in Table 11. These coefficients and the cost estimates obtained by applying Equation 2 are shown below:

Cost Parameter	C	X	Y	Cost ($)
Construction	241,900	1.039	0.468	6,566,000
Capital	422,900	1.044	0.440	10,878,000

The O&M cost associated with the transport system is computed by applying Equation 3, shown below:

$$\text{O\&M Cost} = C * (ADF)^{Y} \qquad (3)$$

Table 12 presents the coefficients for the single pump station transport system O&M cost equation. From Table 12, C = 32,390 and Y = 0.945. Applying these coefficients to a 10-mgd ADF transport system yields an estimated O&M cost of $285,400 per year.

The equivalent annual cost (AC) of the treated water transport system is estimated by applying Equation 4, shown below:

$$AC = C1 * (L)^{X} * (ADF)^{Y} + C2 * (ADF)^{Z} \qquad (4)$$

Table 13 presents the coefficients for the single pump station transport system equivalent annual cost equation. From Table 13, C1 = 32,040, X=1.044, Y= 0.440, C2= 32,390, and Z = 0.945. Substitution of the coefficients and design parameters into Equation 4 yields an estimated annual cost of treated water transport of $1,110,000 per year.

Dividing the annual cost ($1,110,000 per year) by the annual treated water transport volume (10 mgd) yields an estimated unit transport cost of $0.304 per 1,000 gallons. Given the transport distance of 8.5 miles, this would be equivalent to about 3.6 cents per 1,000 gallons per mile transported.

Total Costs

For the Lake Griffin example, total cost is equal to the sum of the treatment and transport costs. The total estimated capital cost for this 10-mgd surface water supply system is $34,469,000, and the total estimated production cost is $1.285 per 1,000 gallons.

LAKE MONROE

The Lake Monroe example is somewhat more complex, as illustrated in Figure 8. In this case, an off-line raw water storage reservoir is included and two separate demand areas are served. The first demand area is located 12 miles from the water treatment plant and requires an ADF of 15 mgd. The second demand area requires 8 mgd and is located only 3 miles from the water treatment facility. Therefore, the water treatment facility must supply an ADF of 23 mgd (34.5 mgd maximum day demand), and both a short transport system and long transport system are required to serve the two separate demand areas.

Off-Line Reservoir Costs

Off-line reservoir costs are estimated by applying Equation 5, shown below:

$$Cost = C * (ADF)^{X} \qquad (5)$$

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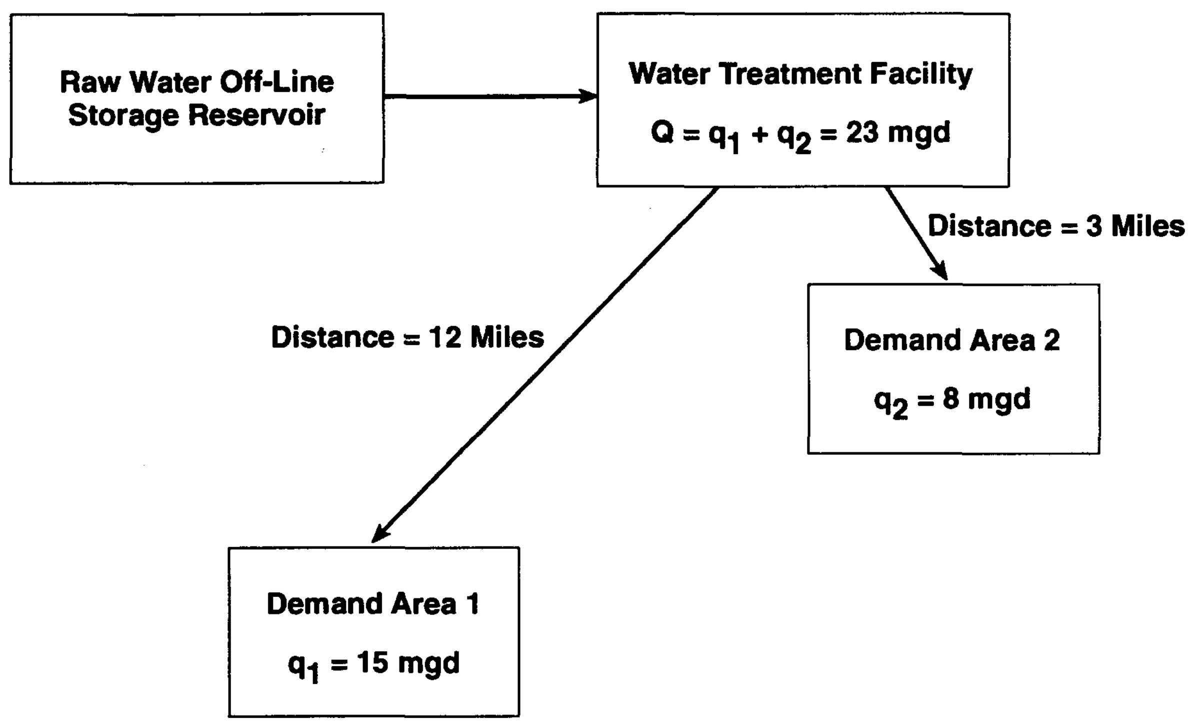

Figure 8. Illustrative Example of Surface Water Supply Cost Equations Application for Lake Monroe.

The coefficients for the above equation are reported in Table 4. These coefficients and the cost estimates obtained by applying Equation 5 are listed below:

Cost Parameter	C	X	Cost ($)
Construction	558,700	0.525	2,898,000
Capital	740,100	0.561	4,298,000
O&M	18,030	0.500	86,470
Equivalent Annual	75,100	0.547	417,400

The unit production cost of the off-line storage reservoir is $0.05 per 1,000 gallons, based on an estimated annual cost of $417,400 per year and an average annual treated water production rate of 23 mgd.

Treatment Costs

Treatment costs, including the cost of a raw water diversion structure, conventional surface water treatment plant, RO treatment, and an ASR system, are a function of the average daily flow produced, as defined by the following equation:

$$\text{Cost} = C * (\text{ADF})^X \qquad (1)$$

The coefficients for the above equation for the Lake Monroe withdrawal site are reported in Table 8. These coefficients and the cost estimates obtained by applying Equation 1 are shown below:

Cost Parameter	C	X	Cost ($)
Construction	3,529,000	0.883	48,080,000
Capital	5,127,000	0.834	70,070,000
O&M	396,000	0.950	7,786,000
Equivalent Annual	854,800	0.901	14,414,000

The unit production cost of treatment can be computed by dividing the equivalent annual cost ($14,414,000 per year) by the annual volume of treated water (23 mgd). In this case, the unit cost of treatment is $1.717 per 1,000 gallons.

Long Transport System Costs

The long transport system provides treated water transport to demand area No. 1 (Figure 8). The system is 12 miles in length and delivers a 15-mgd ADF (22.5-mgd peak flow rate). Based on the criteria presented in Figure 7, a one pump station system is selected for this application. The cost equations and coefficients for the Lake Monroe demand area No. 1 transport system are the same as the equations and coefficients used for the Lake Griffin example previously presented. The estimated costs associated with this 12-mile-long, 15-mgd transport system are summarized below:

Construction Cost = $11,358,000
Capital Cost = $18,637,000
O&M Cost = $418,600 per year
Equivalent Annual Cost = $1,831,000 per year

Dividing the estimated annual cost ($1,831,000 per year) by the annual treated water transport volume (15 mgd) yields a unit transport cost of $0.334 per 1,000 gallons. Given the transport distance of 12 miles, this is equivalent to about 2.8 cents per 1,000 gallons per mile transported.

Short Transport System Costs

The short transport system provides treated water transport to demand area No. 2. In this case, the transport distance is only 3 miles and the ADF transported is 8 mgd. Only pipeline and right of way will be required, and no additional pumping is included. The cost of a short transport system is estimated by applying the following equation:

$$\text{Cost} = C * (L)^{X} * (ADF)^{Y} \qquad (2)$$

The appropriate coefficients are reported in Table 10. These coefficients and the cost estimates obtained by applying Equation 2 are shown below:

Cost Parameter	C	X	Y	Cost ($)
Construction	162,800	1.247	0.458	1,661,000
Capital	303,900	1.231	0.428	2,861,000
Equivalent Annual	22,460	1.232	0.430	212,600

Dividing the annual cost ($212,600 per year) by the annual treated water transport volume (8 mgd) yields an estimated unit transport cost of $0.073 per 1,000 gallons. Given the transport distance of 3 miles, this is equivalent to about 2.4 cents per 1,000 gallons per mile transported.

Total Costs

For the Lake Monroe illustrative example, total costs include the cost of off-line storage, water treatment, and transport. For the entire 23-mgd system, which serves two demand areas, the total capital cost and equivalent annual cost are $95,868,000 and $16,875,000 per year, respectively. The total estimated unit production and transport cost is $2.01 per 1,000 gallons.

Considering the costs associated with each individual demand area, the total unit production cost equals the off-line storage production cost, the water treatment production cost, and the individual transport costs. For demand area No. 1, the total estimated unit production cost is equal to $2.10 per 1,000 gallons. For demand area No. 2, the total estimated unit production cost is $1.84 per 1,000 gallons.

As can be seen from these examples, economic feasibility of the surface water alternative is a function of source characteristics (withdrawal site), the size or scale of the facilities developed, and transport volumes and distances.

SUMMARY AND RECOMMENDATIONS

SUMMARY

A complete set of planning-level surface water supply cost estimating equations has been developed for SJRWMD's Water Supply Alternatives Evaluation Program. The cost equations are applicable to SJRWMD's alternative water supply planning area and include off-line storage reservoirs, complete surface water treatment systems, and treated water point-to-point transport systems.

The cost equations are applicable only for preliminary planning, for which they were derived. The treatment cost equations apply to the five selected candidate surface water withdrawal sites and are not directly transferable to other withdrawl sites.

The transport cost equations are somewhat more general and may be applied to a variety of treated water transport situations, regardless of the origin of the treated water. That is, the transport cost equations presented in this TM may be used to estimate the cost of point-to-point transport of treated drinking water obtained from brackish ground water sources, potable groundwater sources, or other sources, in addition to surface water sources.

RECOMMENDATIONS

It is recommended that the cost equations presented in this TM be used as the basis for estimating the cost of surface water supply development in the University of Florida Decision Model application and other areawide water supply alternative evaluations. It is also recommended that the treated water transport cost equations presented in this TM be used as the basis for estimating finished water transport cost, regardless of the treated water's original source.

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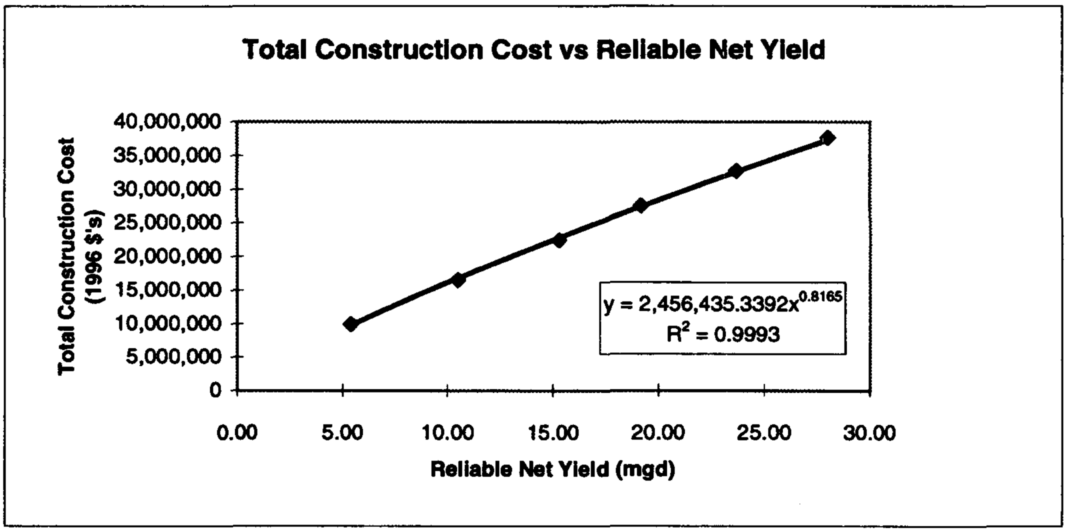
Appendix A
Treatment Cost Estimates and Equations for Lake Griffin

Table A1
Lake Griffin
Summary of Costs

Reliable Net Yield (mgd)	Total Construction Cost ($)	Total Capital Cost ($)	Total O&M Cost ($/yr)	Total Annual Cost ($/yr)	Unit Cost ($/1000gal)
5.40	9,869,091	14,487,180	820,547	2,051,118	0.1260
10.50	16,490,296	24,102,280	1,614,054	3,659,530	0.1260
15.30	22,417,419	32,776,014	2,425,926	5,205,368	0.1260
19.20	27,590,313	40,344,099	3,230,598	6,650,842	0.1260
23.70	32,694,500	47,820,311	4,018,105	8,070,306	0.1260
28.00	37,647,643	55,075,765	4,826,377	9,491,887	0.1260



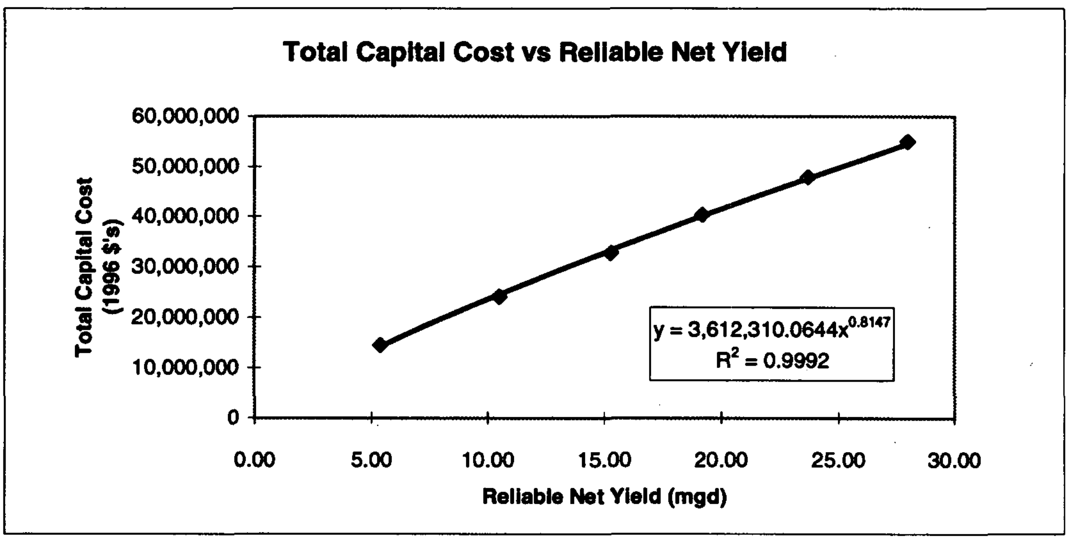
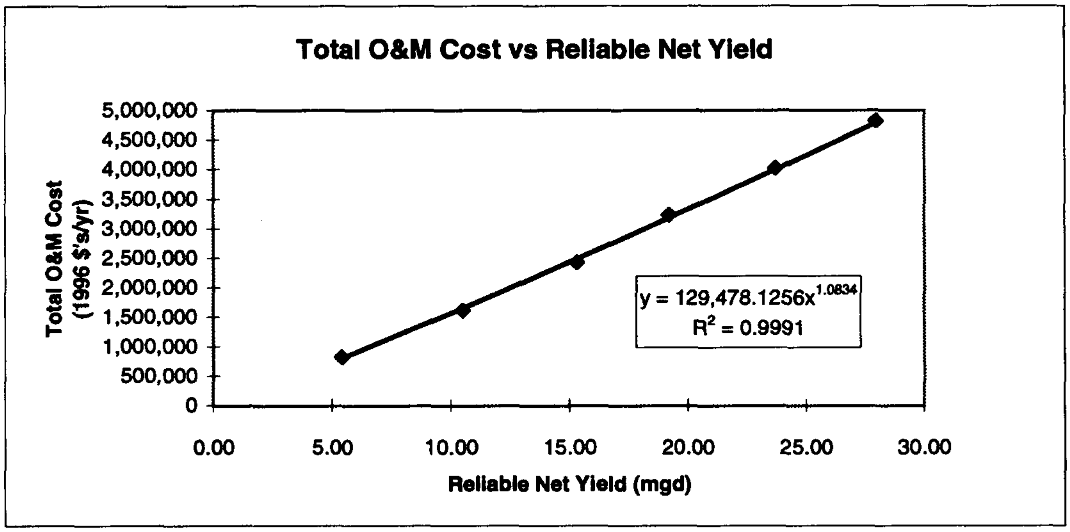


Table A2 Lake Griffin Summary of Costs					
Reliable Net Yield (mgd)	**Total Construction Cost ($)**	**Total Capital Cost ($)**	**Total O&M Cost ($/yr)**	**Total Annual Cost ($/yr)**	**Unit Cost ($/1000gal)**
5.40	9,869,091	14,487,180	820,547	2,051,118	0.1260
10.50	16,490,296	24,102,280	1,614,054	3,659,530	0.1260
15.30	22,417,419	32,776,014	2,425,926	5,205,368	0.1260
19.20	27,590,313	40,344,099	3,230,598	6,650,842	0.1260
23.70	32,694,500	47,820,311	4,018,105	8,070,306	0.1260
28.00	37,647,643	55,075,765	4,826,377	9,491,887	0.1260



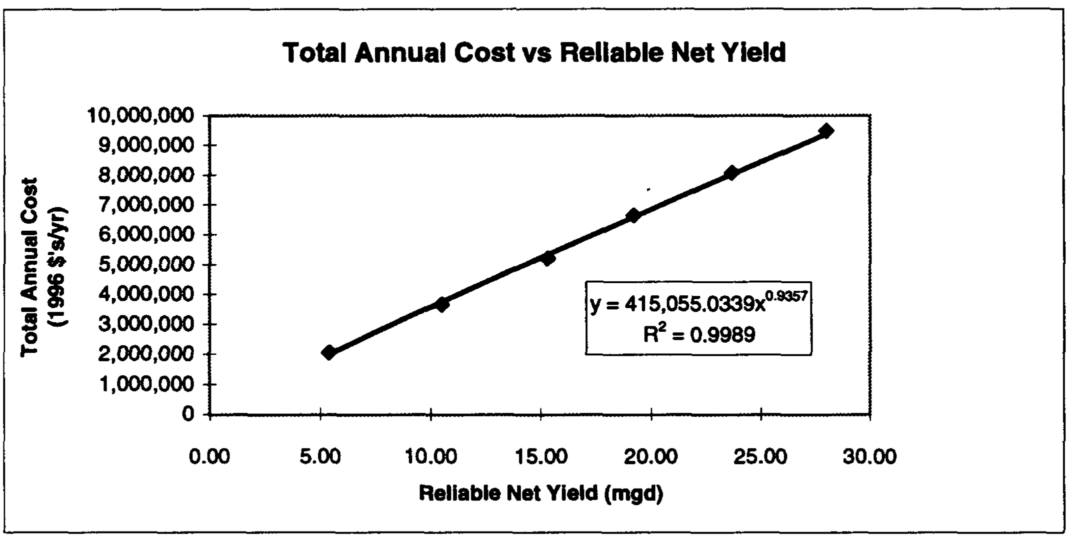
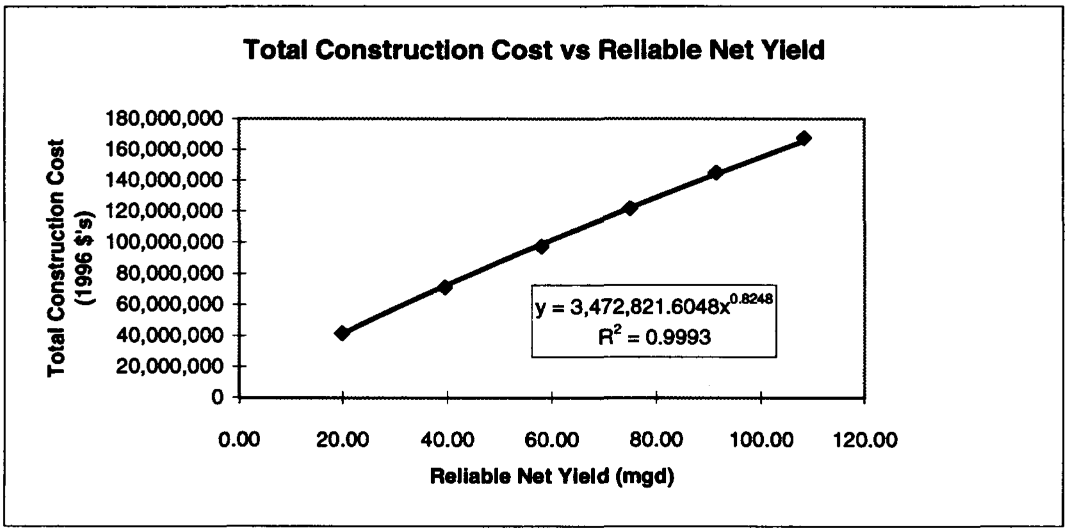


Table A3
Lake Griffin
Summary of Costs

Reliable Net Yield (mgd)	Total Production Cost ($/1000gal)	Unit Cost ($/1000gal)	Setup Cost ($/1000gal)
5.40	1.041	0.126	0.915
10.50	0.955	0.126	0.829
15.30	0.932	0.126	0.806
19.20	0.949	0.126	0.823
23.70	0.933	0.126	0.807
28.00	0.929	0.126	0.803
Mean	0.956	0.126	0.830
Standard Deviation	0.043	0.000	0.043

Appendix B
Treatment Cost Estimates and Equations for the St. Johns River Near Cocoa

Table B1 St. Johns River near Cocoa Summary of Costs					
Reliable Net Yield (mgd)	**Total Construction Cost ($)**	**Total Capital Cost ($)**	**Total O&M Cost ($/yr)**	**Total Annual Cost ($/yr)**	**Unit Cost ($/1000gal)**
19.90	41,550,332	60,610,867	6,117,811	11,803,082	0.1935
39.50	70,881,787	103,481,313	11,630,783	21,362,736	0.1935
58.00	97,427,106	142,296,231	17,001,190	30,399,950	0.1935
75.00	121,857,554	178,023,430	22,241,313	39,022,108	0.1935
91.50	145,036,815	211,928,269	27,388,106	47,379,778	0.1935
108.40	167,696,959	245,085,523	32,490,790	55,616,384	0.1935



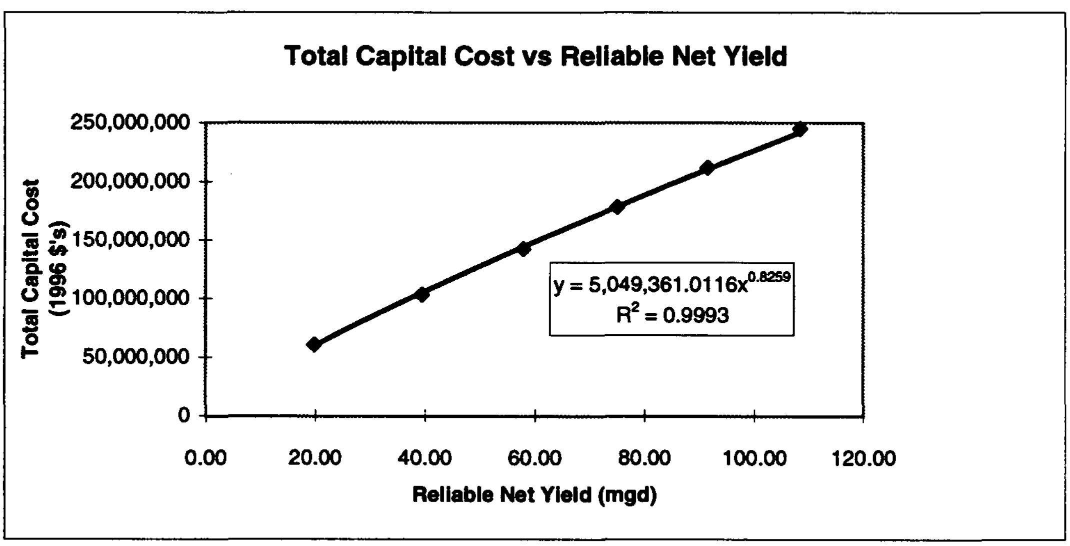
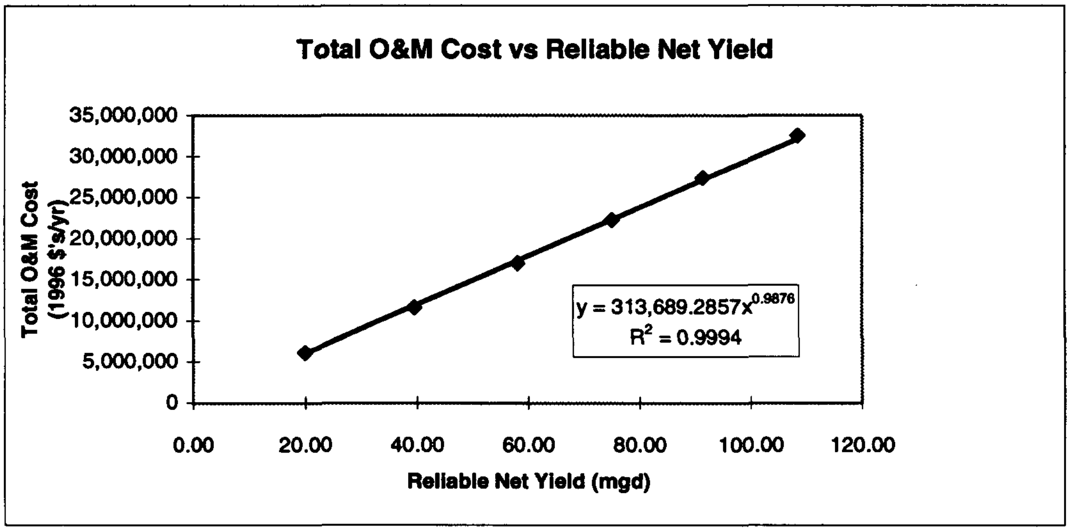


Table B2
St. Johns River near Cocoa
Summary of Costs

Reliable Net Yield (mgd)	Total Construction Cost ($)	Total Capital Cost ($)	Total O&M Cost ($/yr)	Total Annual Cost ($/yr)	Unit Cost ($/1000gal)
19.90	41,550,332	60,610,867	6,117,811	11,803,082	0.1935
39.50	70,881,787	103,481,313	11,630,783	21,362,736	0.1935
58.00	97,427,106	142,296,231	17,001,190	30,399,950	0.1935
75.00	121,857,554	178,023,430	22,241,313	39,022,108	0.1935
91.50	145,036,815	211,928,269	27,388,106	47,379,778	0.1935
108.40	167,696,959	245,085,523	32,490,790	55,616,384	0.1935



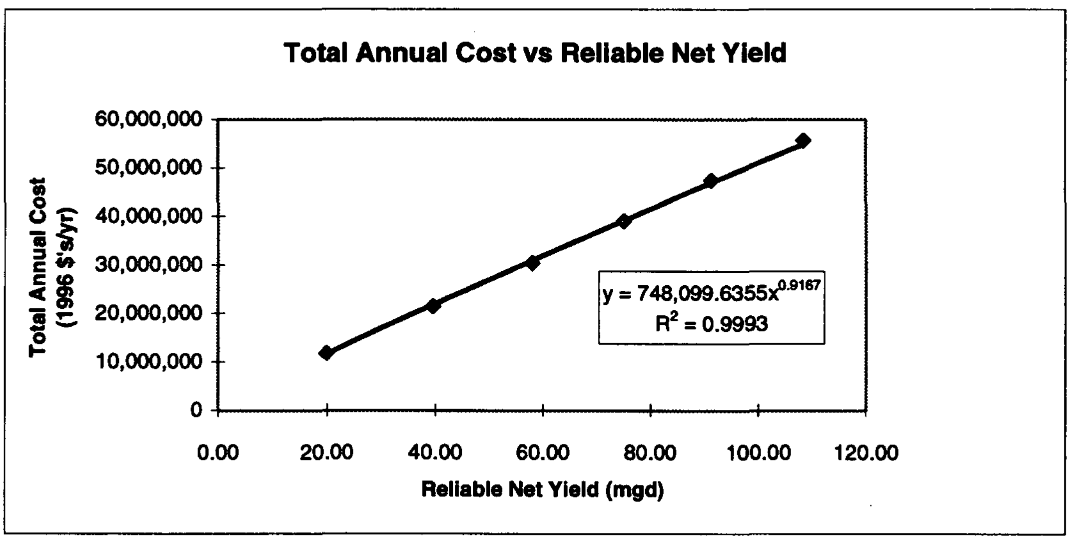
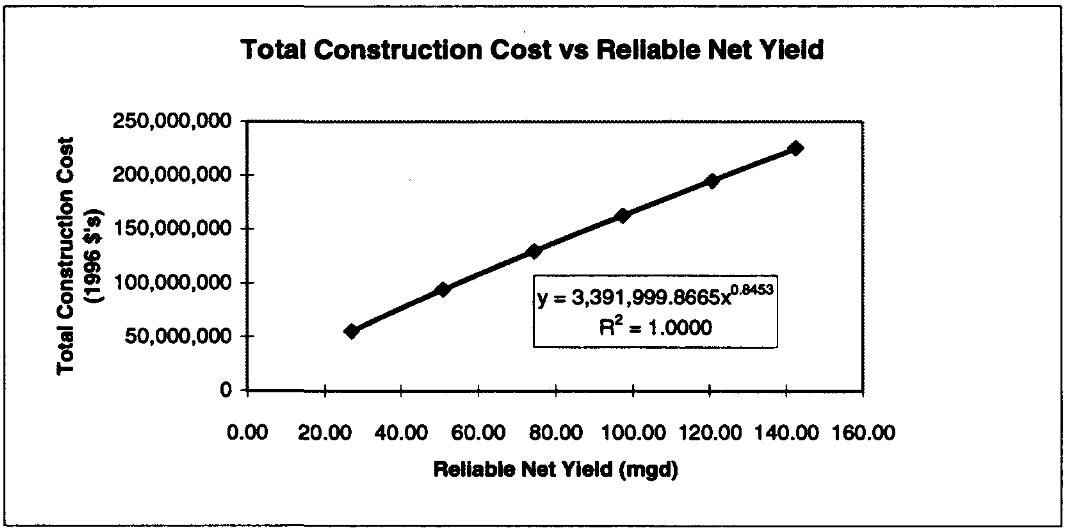


Table B3 St. Johns River near Cocoa Summary of Costs			
Reliable Net Yield (mgd)	**Total Production Cost ($/1000gal)**	**Unit Cost ($/1000gal)**	**Setup Cost ($/1000gal)**
19.90	1.625	0.194	1.431
39.50	1.482	0.194	1.288
58.00	1.436	0.194	1.242
75.00	1.425	0.194	1.232
91.50	1.419	0.194	1.225
108.40	1.406	0.194	1.212
Mean	1.465	0.194	1.272
Standard Deviation	0.082	0.000	0.082

Appendix C
Treatment Cost Estimates and Equations for the St. Johns River Near Titusville

Table C1
St. Johns River near Titusville
Summary of Costs

Reliable Net Yield (mgd)	Total Construction Cost ($)	Total Capital Cost ($)	Total O&M Cost ($/yr)	Total Annual Cost ($/yr)	Unit Cost ($/1000gal)
27.00	55,119,161	80,411,428	8,816,036	16,468,176	0.1935
50.90	93,877,179	137,037,230	16,710,172	29,798,276	0.1935
74.40	129,315,775	188,843,121	24,355,952	42,412,801	0.1935
97.40	162,642,556	237,580,744	31,813,145	54,538,961	0.1935
120.80	194,810,503	284,641,932	39,142,269	66,368,514	0.1935
142.50	225,355,133	329,326,542	46,394,012	77,903,867	0.1935



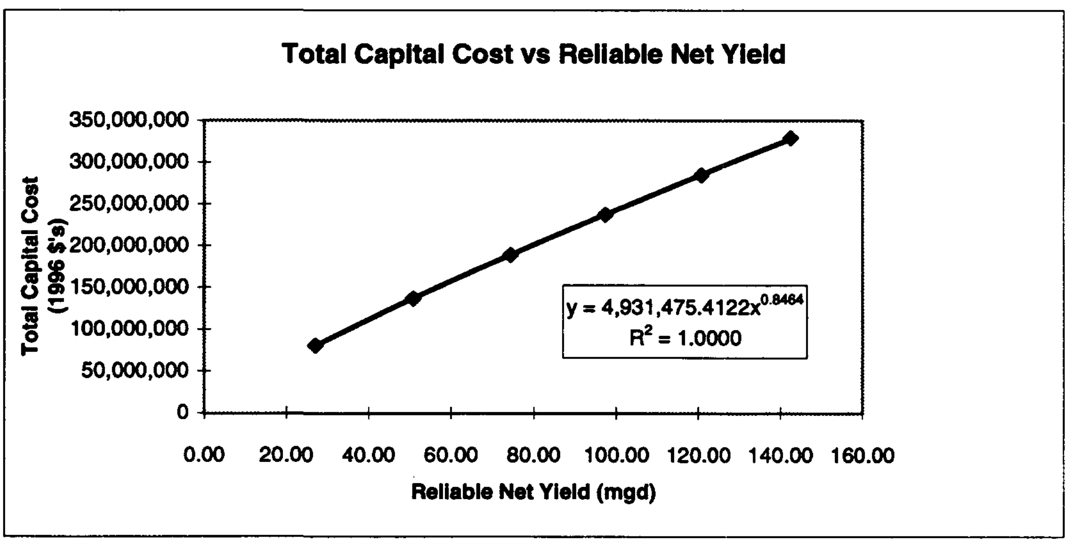
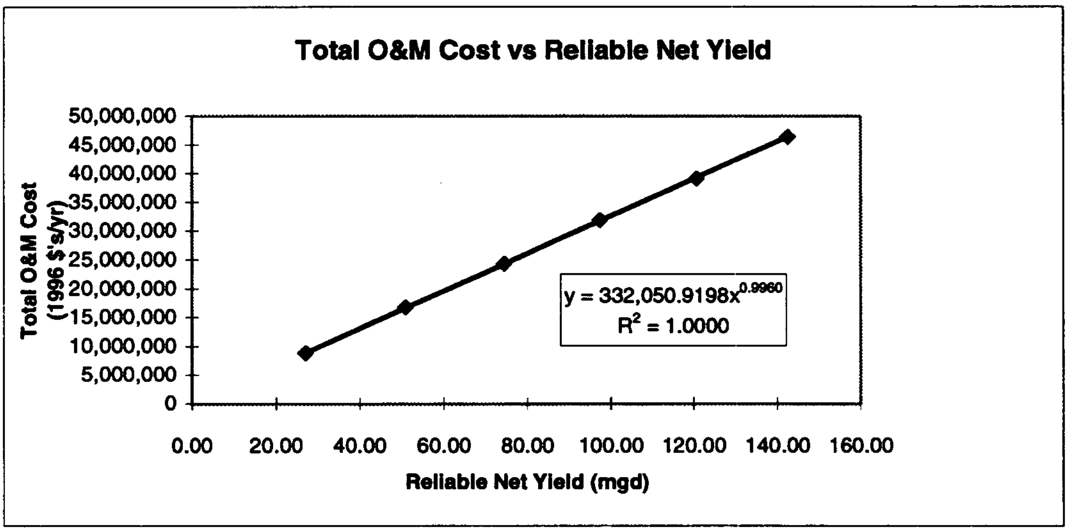


Table C2
St. Johns River near Titusville
Summary of Costs

Reliable Net Yield (mgd)	Total Construction Cost ($)	Total Capital Cost ($)	Total O&M Cost ($/yr)	Total Annual Cost ($/yr)	Unit Cost ($/1000gal)
27.00	55,119,161	80,411,428	8,816,036	16,468,176	0.1935
50.90	93,877,179	137,037,230	16,710,172	29,798,276	0.1935
74.40	129,315,775	188,843,121	24,355,952	42,412,801	0.1935
97.40	162,642,556	237,580,744	31,813,145	54,538,961	0.1935
120.80	194,810,503	284,641,932	39,142,269	66,368,514	0.1935
142.50	225,355,133	329,326,542	46,394,012	77,903,867	0.1935



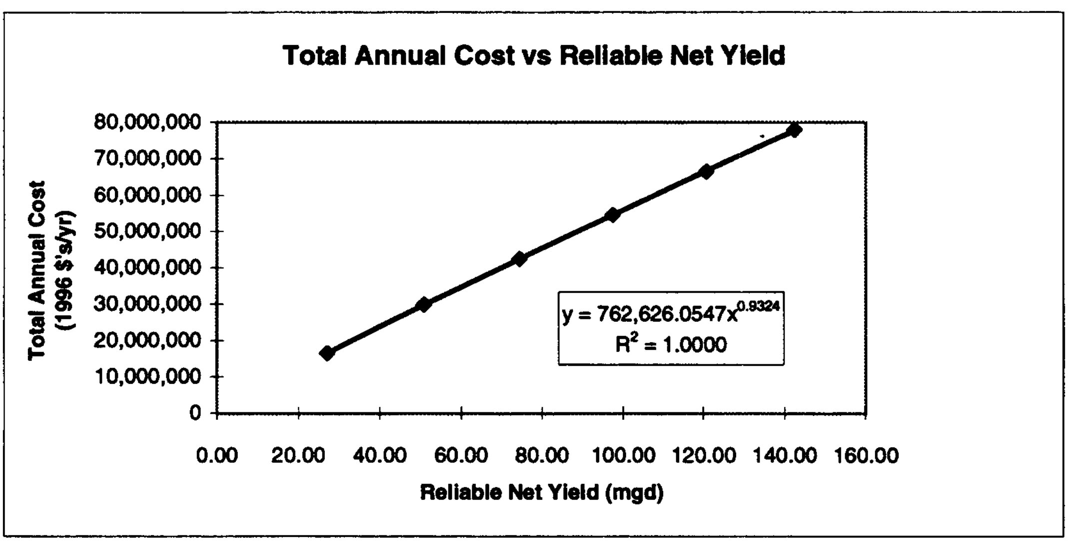
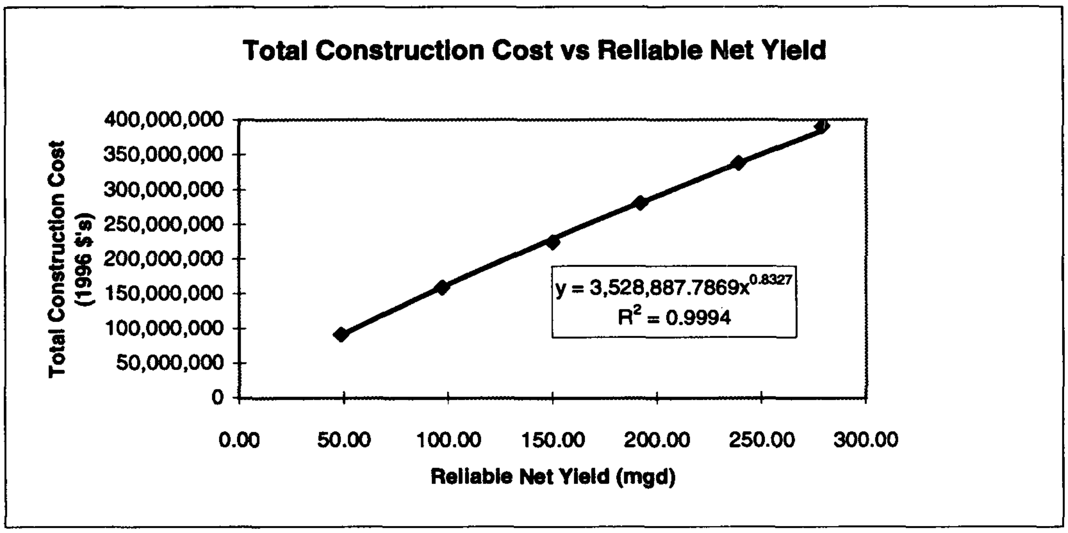


Table C3 St. Johns River near Titusville Summary of Costs			
Reliable Net Yield (mgd)	**Total Production Cost ($/1000gal)**	**Unit Cost ($/1000gal)**	**Setup Cost ($/1000gal)**
27.00	1.671	0.194	1.478
50.90	1.604	0.194	1.410
74.40	1.562	0.194	1.368
97.40	1.534	0.194	1.341
120.80	1.505	0.194	1.312
142.50	1.498	0.194	1.304
Mean	1.562	0.194	1.369
Standard Deviation	0.066	0.000	0.066

Appendix D
Treatment Cost Estimates and Equations for the St. Johns River Near Sanford

Table D1 St. Johns River near Sanford Summary of Costs					
Reliable Net Yield (mgd)	Total Construction Cost ($)	Total Capital Cost ($)	Total O&M Cost ($/yr)	Total Annual Cost ($/yr)	Unit Cost ($/1000gal)
48.60	90,564,109	132,194,267	16,024,515	28,649,540	0.1935
97.40	158,899,259	232,141,153	30,551,623	52,719,210	0.1935
149.90	223,790,813	327,150,505	44,595,416	75,774,071	0.1935
192.00	280,668,507	410,384,696	58,271,381	97,415,448	0.1935
239.20	338,041,441	494,413,339	71,807,196	118,933,478	0.1935
279.10	390,159,070	570,711,265	85,080,391	139,506,517	0.1935



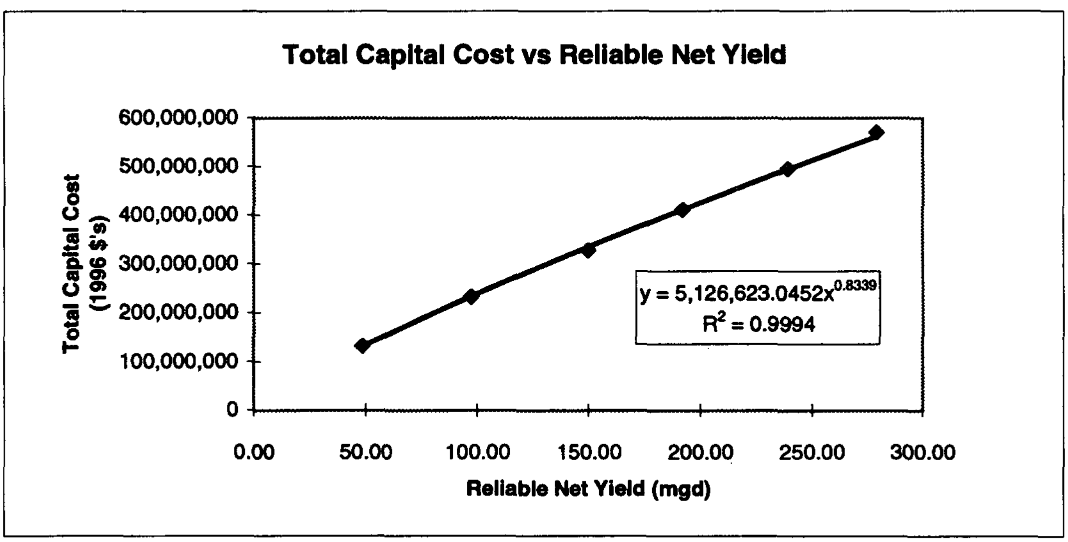
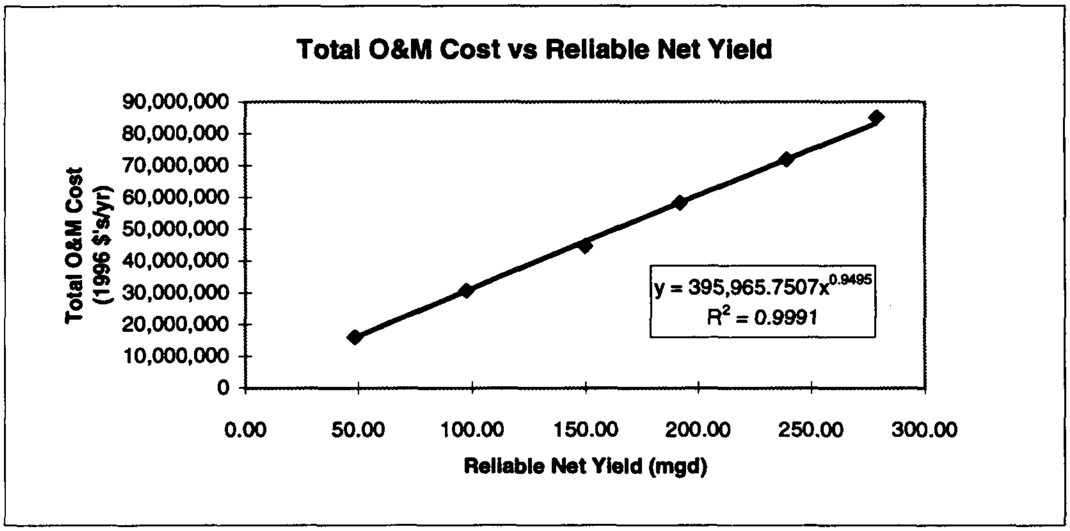


Table D2
St. Johns River near Sanford
Summary of Costs

Reliable Net Yield (mgd)	Total Construction Cost ($)	Total Capital Cost ($)	Total O&M Cost ($/yr)	Total Annual Cost ($/yr)	Unit Cost ($/1000gal)
48.60	90,564,109	132,194,267	16,024,515	28,649,540	0.1935
97.40	158,899,259	232,141,153	30,551,623	52,719,210	0.1935
149.90	223,790,813	327,150,505	44,595,416	75,774,071	0.1935
192.00	280,668,507	410,384,696	58,271,381	97,415,448	0.1935
239.20	338,041,441	494,413,339	71,807,196	118,933,478	0.1935
279.10	390,159,070	570,711,265	85,080,391	139,506,517	0.1935



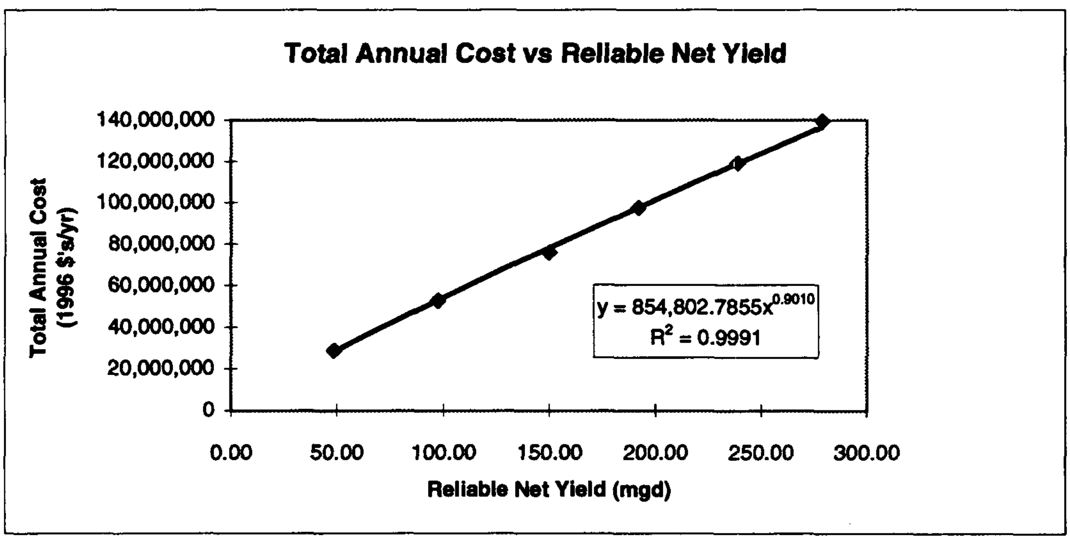
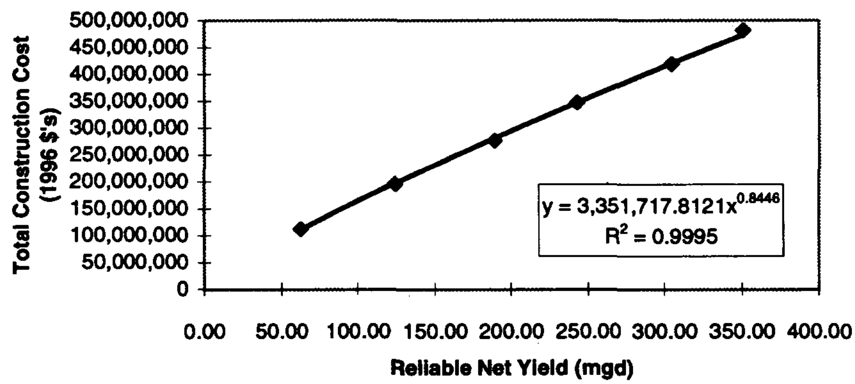


Table D3 St. Johns River near Sanford Summary of Costs			
Reliable Net Yield (mgd)	**Total Production Cost ($/1000gal)**	**Unit Cost ($/1000gal)**	**Setup Cost ($/1000gal)**
48.60	1.615	0.194	1.422
97.40	1.483	0.194	1.289
149.90	1.385	0.194	1.191
192.00	1.390	0.194	1.197
239.20	1.362	0.194	1.169
279.10	1.369	0.194	1.176
Mean	1.434	0.194	1.241
Standard Deviation	0.099	0.000	0.099

Appendix E
Treatment Cost Estimates and Equations for the St. Johns River at De Land

Table E1 St. Johns River near De Land Summary of Costs					
Reliable Net Yield (mgd)	**Total Construction Cost ($)**	**Total Capital Cost ($)**	**Total O&M Cost ($/yr)**	**Total Annual Cost ($/yr)**	**Total Unit Cost ($/1000gal)**
62.60	111,485,702	162,777,691	20,357,861	35,952,496	0.1935
124.40	195,986,166	286,394,984	38,736,303	66,160,139	0.1935
189.30	275,866,496	403,362,147	56,532,384	95,084,569	0.1935
242.90	346,531,087	506,797,145	73,839,703	122,305,341	0.1935
304.70	418,738,915	612,591,120	90,969,480	149,485,189	0.1935
350.80	481,388,867	704,291,880	107,754,113	175,101,917	0.1935

Total Construction Cost vs Reliable Net Yield



Total Capital Cost vs Reliable Net Yield

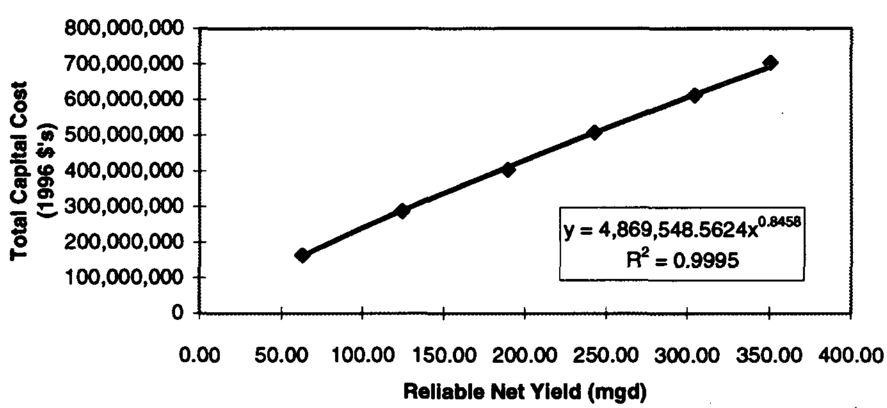
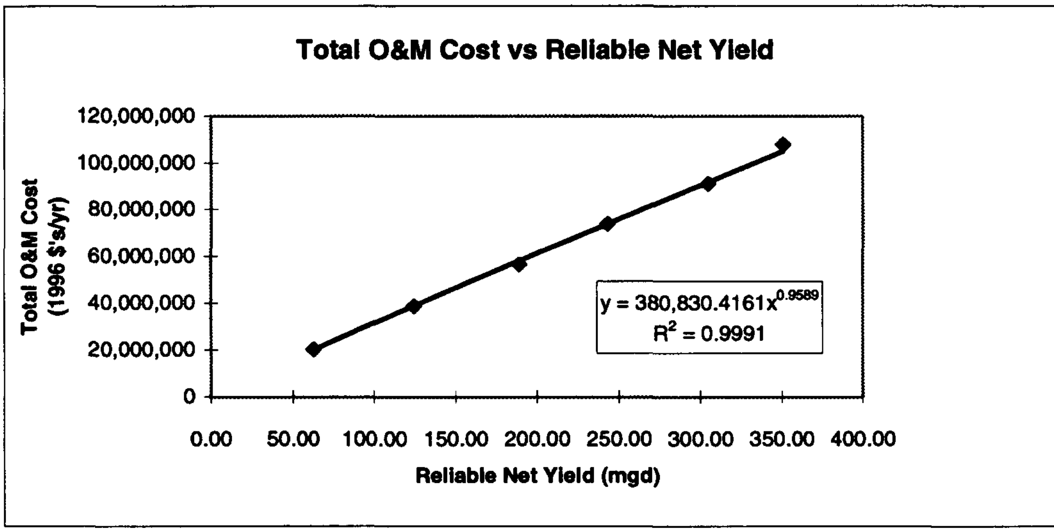


Table E2
St. Johns River near De Land
Summary of Costs

Reliable Net Yield (mgd)	Total Construction Cost ($)	Total Capital Cost ($)	Total O&M Cost ($/yr)	Total Annual Cost ($/yr)	Total Unit Cost ($/1000gal)
62.60	111,485,702	162,777,691	20,357,861	35,952,496	0.1935
124.40	195,986,166	286,394,984	38,736,303	66,160,139	0.1935
189.30	275,866,496	403,362,147	56,532,384	95,084,569	0.1935
242.90	346,531,087	506,797,145	73,839,703	122,305,341	0.1935
304.70	418,738,915	612,591,120	90,969,480	149,485,189	0.1935
350.80	481,388,867	704,291,880	107,754,113	175,101,917	0.1935



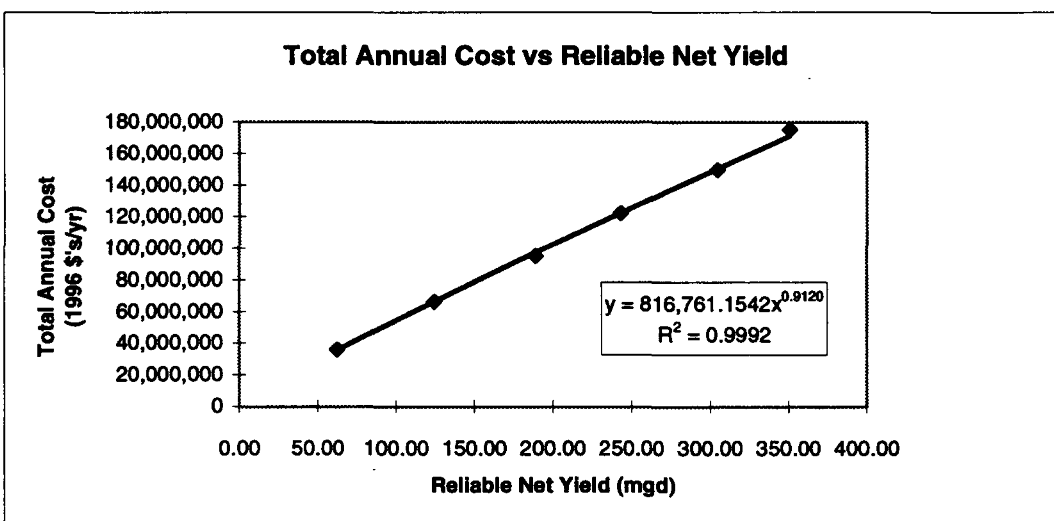


Table E3
St. Johns River near De Land
Summary of Costs

Reliable Net Yield (mgd)	Total Production Cost ($/1000gal)	Total Unit Cost ($/1000gal)	Setup Cost ($/1000gal)
62.60	1.573	0.194	1.380
124.40	1.457	0.194	1.264
189.30	1.376	0.194	1.183
242.90	1.380	0.194	1.186
304.70	1.344	0.194	1.151
350.80	1.368	0.194	1.174
Mean	1.416	0.194	1.223
Standard Deviation	0.086	0.000	0.086