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WATER SUPPLY NEEDS AND SOURCES ASSESSMENT ALTERNATIVE WATER SUPPLY STRATEGIES INVESTIGATION SURFACE WATER AVAILABILITY AND YIELD ANALYSIS

by

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EXECUTIVE SUMMARY

This technical memorandum (TM) is the third 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 selection of six candidate surface water withdrawal sites for quantitative analysis. This TM presents the results of the quantitative water supply availability and yield analysis.

The six candidate withdrawal sites include Lake Griffin on Haines Creek, located in Lake County, and five sites located on the main stem of the St. Johns River extending from Cocoa downstream to Jacksonville. For each of the six candidate withdrawal sites, a similar series of analyses was conducted.

WATER SUPPLY YIELD

The estimated maximum reliable municipal water supply yield for each of the six candidate withdrawal sites is summarized below:

- Lake Griffin (Haines Creek) 28 mgd
- St. Johns River near Cocoa 108 mgd
- St. Johns River near Titusville 143 mgd
- St. Johns River at Sanford (Lake Monroe) 279 mgd
- St. Johns River near De Land 351 mgd
- St. Johns River above Jacksonville 419 mgd

The maximum water supply yield estimates are based on application of the previously established surface water evaluation methodology. However, because planned SJRWMD minimum flows and levels analysis for Lake Griffin may result in different, and possibly more restrictive, withdrawal criteria, only 50 percent of the calculated maximum yield, or 14 mgd, will be considered in subsequent areawide alternative water supply evaluations.

Maximum reliable yields for the Lake Griffin and St. Johns River sites are independent as they are relatively independent hydrologic systems. Thus, water supply development on Lake Griffin will not affect the potential for water supply development on the St. Johns River.

However, the maximum yield values for the individual St. Johns River sites are not independent. These values represent the cumulative amount for each individual site and all upstream sites. For example, if a 100-mgd reliable water supply were developed near Titusville, then the maximum reliable yield at De Land (or another downstream site) would be reduced by 100 mgd.

TREATMENT REQUIREMENTS

Facilities required to develop the surface water sources include a river diversion structure, an off-line raw water reservoir, a water treatment plant, and an aquifer storage recovery system. Treatment requirements vary considerably by location. For example, the Lake Griffin site is the only true freshwater site, while the St. Johns River sites will require some desalting facilities, likely reverse osmosis membrane treatment, to provide the required product water quality.

The four upstream St. Johns River sites provide raw water that can be classified as either slightly or moderately brackish under certain flow conditions. The most downstream site, the St. Johns River above Jacksonville, is tidal and has poor water quality characteristics. Raw water at this site is classified as saline, which would require extensive desalting facilities and would generate large quantities of waste concentrate.

In conclusion, five of the six candidate water supply withdrawal sites are technically viable municipal water supply sources and should be considered in subsequent phases of the alternative water supply investigations. The viable sites include Lake Griffin and the four upstream sites located on the main stem of the St. Johns River, from near Cocoa to near De Land. The most downstream site, the St. Johns River above Jacksonville, does not provide a viable municipal water supply source and should not be considered further.

FIGURES

TABLES

INTRODUCTION

This technical memorandum (TM) is the third 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 (SJRWMD). The first surface water supply TM addressed data availability and development of the methodology to be used in the feasibility evaluation (CH2M HILL, 1996a). The second TM addressed selection of six candidate surface water withdrawal sites for quantitative evaluation (CH2M HILL, 1996b). This TM presents the results of the quantitative evaluation of the six previously selected candidate withdrawal sites using the established evaluation procedure.

The six candidate withdrawal sites include Lake Griffin on Haines Creek, located in Lake County, and five sites located on the main stem of the St. Johns River extending from Cocoa downstream to Jacksonville. For each of the six candidate withdrawal sites, the following series of analyses was performed:

- Development of flow duration curves
- Determination of minimum streamflow requirements and the maximum water supply withdrawal rate
- Evaluation of the effect of water supply withdrawal on the flow duration relationship
- Evaluation of the potential water supply yield as a function of maximum installed withdrawal capacity
- Determination of streamflow water quality characteristics and water treatment requirements
- Estimation of the type and size of water supply facilities required as a function of the total reliable water supply yield developed

The analysis is primarily based on available streamflow and water quality records. First, flow duration curves for each site were developed. Then, minimum streamflow requirements and the maximum withdrawal rate were determined for each site according to flow duration curve characteristics. Once these parameters were determined, the maximum effect of water supply withdrawal on the existing streamflow duration was determined and reported for each candidate withdrawal site.

The remainder of the feasibility analysis focused on determining surface water supply facilities requirements. The first step in this process was developing the potential yield curve for each candidate withdrawal site. The potential yield is defined as the water supply yield that could be developed if adequate storage and treatment facilities are provided and no waste is produced by the treatment process. This curve defines the relationship between the installed streamflow diversion capacity and the long-term average flow rate that can be diverted for water supply purposes. Also, this curve establishes the maximum water supply that could be developed as a function of the maximum streamflow diversion rate.

Once the potential yield curve was developed, trial water supply facilities were selected. Long-term water supply systems were then simulated to evaluate the reliability of the trial water supply systems to meet a variety of target yields. By doing so, the facilities required to meet a projected long-term demand at the desired reliability were established.

Preliminary water treatment process requirements were determined from the water quality characteristics observed at each candidate withdrawal site. Once conceptual treatment requirements were established, the net reliable yield for each trial water supply facility was estimated. The final results are relationships between net reliable water supply yield and facility requirements for each candidate withdrawal site.

This TM concludes with a proposed procedure for developing planning-level cost estimates for the required surface water supply facilities. Planning-level water supply facility cost estimates and planning-level cost functions will be the subject of the fourth and final surface water supply TM. These cost estimates will then be available for use in the University of Florida Decision Model, which will compare the surface water supply alternative with other water supply strategies.

METHODS

The methods applied to the surface water supply availability and yield analysis are fully documented in TM B.1.f, *Surface Water Data Acquisition and Evaluation Methodology* (CH2M HILL, 1996a). This section presents a summary of the methodology established in that TM.

FACTORS AFFECTING SURFACE WATER SUPPLY DEVELOPMENT

Several factors affect the technical feasibility of developing a surface water supply source, such as streamflow characteristics, minimum streamflow requirements, water supply demand characteristics, and required system reliability.

Streamflow Characteristics

Important streamflow characteristics include streamflow magnitude, streamflow variability, and water quality. The magnitude of the streamflow, which is defined as the long-term average discharge rate or watershed yield, establishes the total water resource available. In general, the larger the streamflow magnitude, the greater the potential for significant water supply development.

Streamflow variability defines the day-to-day, month-to-month, and year-to-year variation of the total streamflow. Variability can be as important as magnitude in determining the economic feasibility of developing a surface water supply source. This is because a highly variable source is more difficult to develop than a source with little variability. In general, variable sources require larger storage facilities and are therefore more expensive to develop than sources with less variable streamflow regimes.

The streamflow characteristics of magnitude and variability are defined by observed streamflow records. Fortunately for this analysis, long-term streamflow records are available at, or near, each of the six candidate withdrawal sites. Daily streamflow records are used to develop flow duration curves, which illustrate the inherent variability of the source.

The long-term monthly streamflow array for each candidate withdrawal site is used directly in the system simulation analysis.

Therefore, streamflow magnitude and variability are explicitly accounted for throughout this surface water supply feasibility analysis.

Water quality records are used to define the characteristics of the raw water available for treatment. These data are used to establish the appropriate treatment processes required to deliver high-quality product water. Treatment requirements greatly influence the cost of developing each individual candidate water supply site. For example, if desalting is required, treatment facilities will be relatively more expensive and the reliable yield will be reduced because part of the diverted flow will become waste concentrate.

Useful water quality data were available at or near each of the six candidate withdrawal sites.

Minimum Streamflow Requirements

Minimum streamflow requirements for streams and rivers within SJRWMD will be defined, in the future, by the ongoing minimum flows and levels program. However, at this time, minimum flows and levels have not been established for any of the water bodies or withdrawal sites considered in this evaluation. Thus, approximate minimum streamflow requirements were established for this preliminary evaluation of surface water supply feasibility. Once minimum flows and levels are established for the candidate withdrawal sites considered in this TM, the feasibility of developing a viable surface water supply should be re-evaluated using the site-specific minimum flows and levels criteria established by SJRWMD.

For this effort, minimum streamflow requirements are defined as the positive streamflow rate observed 95 percent of the time. This means that at least 5 percent of the time (during low-flow periods) water supply withdrawal will not be allowed. In addition, the maximum withdrawal rate considered is equal to 25 percent of the long- term average flow rate. Lesser withdrawal rates are also considered.

Consider, for example, a stream with positive flow 97 percent of the time and a mean flow rate of 500 cubic feet per second (cfs). The allowable diversion frequency would be 92.2 percent of the time ($0.95 \times 0.97 = 0.922$), and the maximum diversion rate would be 125 cfs ($0.25 \times 500 = 125$).

Demand Characteristics

The characteristics of the projected demand to be met by the water supply system also influences the water supply facilities required to meet the demand. For this effort, only municipal demands are considered. Demand characteristics of interest include the long-term average demand to be met, or average daily demand (ADD), the maximum daily demand to be met (MDD), and the seasonal distribution of demands. The seasonal distribution of demands is defined by the ratio of monthly demands to the ADD.

In this feasibility analysis, the targeted yields are varied over a range compatible with the expected water supply yield for a given candidate withdrawal site. The objective is to define facilities requirements as a function of demand met. The monthly demand ratios previously established for this analysis are based on the City of Cocoa operational experience reported below:

Month	Demand Ratio
Jan	0.868
Feb	0.919
Mar	1.059
Apr	1.127
May	1.149
Jun	1.070
Jul	1.084
Aug	1.067
Sep	1.002
Oct	0.944
Nov	0.892
Dec	0.879

In addition, the MDD is assumed to be equal to 1.5*ADD.

Required System Reliability

Domestic water supply systems must be highly reliable, in that they must be able to supply the desired quantity and quality of water for a high percentage of the time. In most cases, however, an inability to meet the desired target yield, or target yield deficiency, means providing only a portion of the desired yield or providing water that does not fully meet all desired quality criteria. When a yield deficiency occurs, implementation of water use restrictions is more likely to occur than a complete lack of supply.

For the purpose of this preliminary feasibility analysis, the previously established water supply system reliability target is 98.3 percent. This value is based on the allowance of an average of one monthly target yield deficiency once every 5 years.

GENERAL FACILITIES REQUIREMENTS

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

- River diversion structure
- Raw water storage
- Water treatment plant
- Aquifer storage recovery (ASR)

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 the system reliability.

Raw water will likely be available for diversion, in quantities adequate to meet the desired yield, for only a portion of the time. Storage facilities, including either raw water storage reservoirs or ASR systems, can be used to store water when it is available for later use when it is needed. Storage provides the flow attenuation necessary to match a variable water supply source to a variable water supply demand.

River Diversion Structure

A river diversion structure consists of a raw water intake and a pumping station. In most cases, some type of coarse screen or bar screen is provided to prevent damage to the pumps or other downstream treatment equipment. 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 and maximum allowable diversion rates.

Raw Water Storage Reservoir

There are two types of raw water storage reservoirs: on-stream reservoirs and off-line reservoirs. Development of on-stream reservoirs requires construction of a dam across the stream, flooding a

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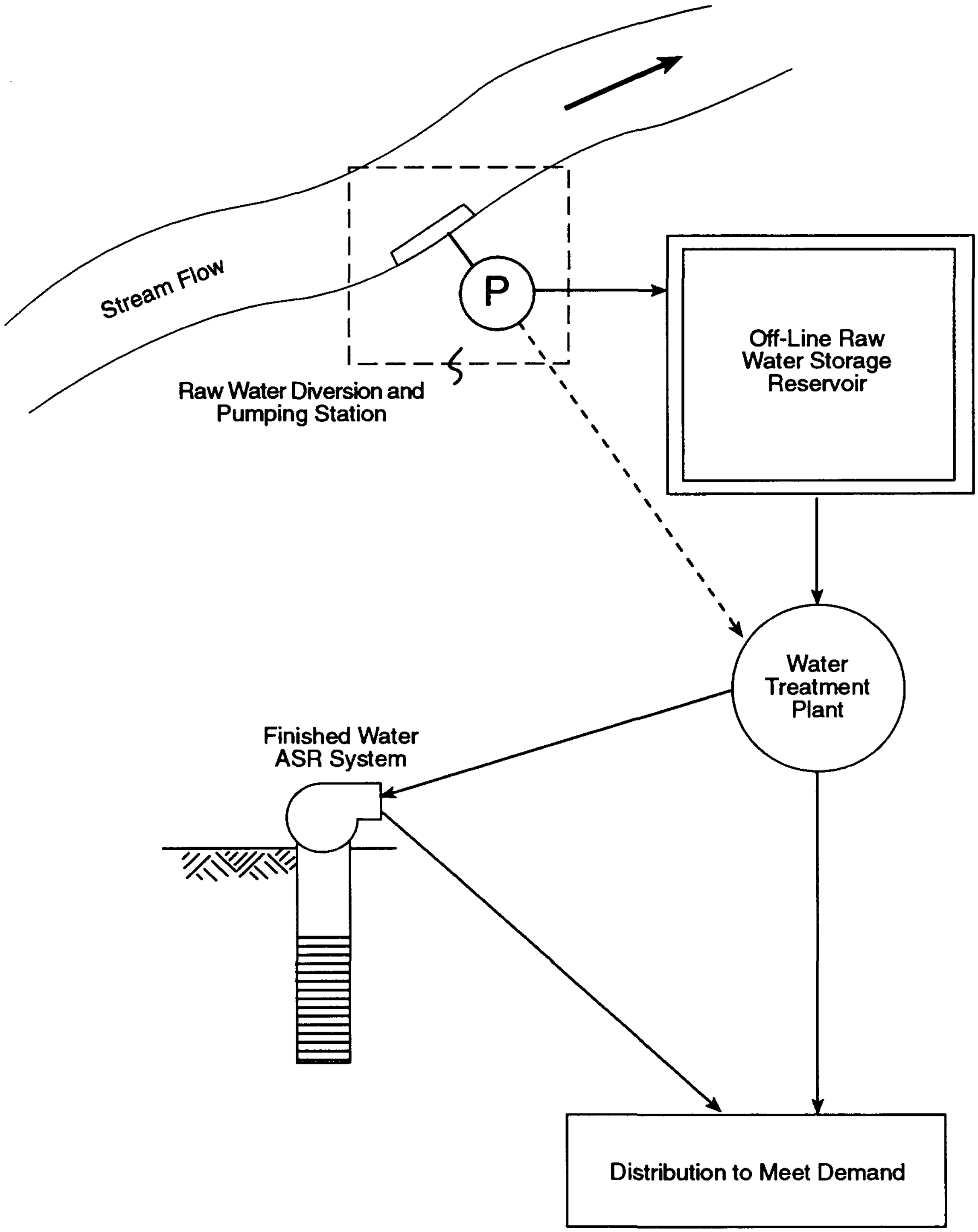

Figure 1. Facilities Required to Develop Reliable Surface Water Supply to Meet Urban Demands.

portion of the upstream valley and subsequently providing the required water supply storage. Off-line reservoirs, which are constructed adjacent to the free-flowing stream, 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 impounded.

Both on-stream and off-line reservoirs receive additional inflow from direct rainfall and incur water losses through lake evaporation. Under certain conditions, additional water could also be lost by seepage.

In Florida, construction of on-line reservoirs is difficult because stream valleys are wide and favorable dam sites are rare. In addition, the construction of on-line reservoirs greatly impacts the natural flow regime of a stream, often flooding productive adjacent wetlands. In contrast, off-line reservoirs do not interfere with the natural streamflow regime and, therefore, are less environmentally disruptive than on-line reservoirs. However, off-line reservoirs are usually located on or near floodplains, where they may impact wetlands.

For this preliminary feasibility analysis, only off-line reservoirs will be considered and their use will be minimized. Priority will be given to using ASR as the primary storage method; however, off-line raw water storage will be used to provide a buffer between the river diversion structure and the water treatment plant, providing some flexibility in operation. The presence of a raw water storage reservoir will allow the plant to operate during short periods when streamflow diversion is not allowed because of minimum streamflow requirements.

A minimum off-line raw water storage reservoir that provides 5 days of operational storage is included in this analysis.

Water Treatment Plant

The purpose of the water treatment plant is to provide a safe, potable finish water that meets all necessary drinking water standards. If the raw water is of reasonably high quality, then conventional treatment is usually all that is necessary. 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, addition of membrane treatment would result in reduction of the net water supply yield, as well as additional requirements for a concentrate disposal system.

The quality characteristics of the raw water define treatment requirements and, in part, treatment costs. However, the demands to be met and the amount and type of storage provided will define the treatment capacity (Qt) requirements. If no finish water storage is provided, by an ASR system for example, then the treatment plant must be sized to meet the maximum day demands (Qt = MDD). Or, if finish water storage is provided, the treatment plant can be somewhat smaller because maximum day demands can be met from finish water storage.

ASR Systems

In general, ASR systems can be used to store both raw water and treated finish 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 being considered for SJRWMD. 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.

SIMULATION OF CONTINUOUS WATER SUPPLY SYSTEMS

Direct calculation of requirements for surface water supply facilities for a given set of conditions is not possible because of the complexity of the system and the large number of interacting factors. Facility requirements must be determined on a trial-and-error basis using a structured, continuous simulation approach.

Overview and Application

The water supply systems simulation was designed to simulate the long-term operation of a trial water supply system subject to a given set of monthly demands and to track the performance of the system, as measured in terms of its reliability or ability to meet demands. The basic approach that was used defines a number of trial water supply systems using appropriate components, as defined in Figure 1. Several sets of monthly target yield arrays (small-to-large) were also established.

Each trial water supply system was then evaluated by the simulation relative to its ability to deliver the desired yields. The reliability of the trial system is tracked for each target yield array simulated. In this manner, relationships between facility size and water supply yield for the given system reliability, were developed. This is the basic approach used previously by CH2M HILL to evaluate surface water supply facilities requirements for the Peace River Water Supply System (CH2M HILL, 1985, 1987, 1993; Wycoff, 1985) and for the Florida Lower East Coast water supply planning project (CH2M HILL, 1994).

The procedure involves multiple, long-term simulations. In a given application, for each candidate withdrawal site, six trial water supply systems were identified and ten target yield arrays were defined. Sixty simulation runs were used to fully define facility requirements, yield, and reliability relationship. Some applications involved more than one complete iteration because the initially defined target yield levels proved to be inappropriate once initial results from the simulation were available.

The simulation uses a monthly time step, which is the appropriate level of detail for preliminary surface water supply planning purposes

(McMahon, 1992). The length of simulation varied, depending on the streamflow records used. In general, whole calendar years of monthly streamflow records were used.

Simulation Logic

The simulation was constructed around a flow distribution logic that defines how the water supply system will operate and provides criteria defining how a given monthly demand will be met, based on the monthly divertable streamflow, available facilities, and previously stored water. The flow distribution logic is defined as follows:

- Condition A. Monthly divertable river flow is greater than or equal to monthly target yield
  - Treat diverted flow and distribute to meet desired yield.
  - Treat and inject into the ASR system remaining divertable flow up to the available treatment capacity or ASR injection capacity, whichever is less.
  - Remaining divertable flow, if any, goes to the surface reservoir.
  - If the surface reservoir is full, potential divertable flow is lost from the water supply system (i.e., not diverted).
- Condition B. Monthly divertable flow is less than monthly target yield
  - Treat divertable flow, if any, and distribute.
  - Obtain remaining desired yield from the ASR system up to the maximum recovery rate or recoverable ASR volume, or both.
  - Obtain remaining desired yield, if any, from the surface reservoir, treat, and distribute.
  - If total desired yield cannot be met, a yield deficit occurs.

The above logic is applied to each time step in the simulation and the number of yield deficits is tracked. The total number of deficits divided by the total number of simulation time steps is equal to the water supply system deficit rate. One minus the deficit rate then equals system reliability.

SELECTED CANDIDATE WITHDRAWAL SITES

Initially, many sites were considered on the St. Johns River and the Haines Creek/Palatlakaha Chain of Lakes. The site selection process considered location of streamflow gauging stations, municipal water supply demand growth areas, and potential maximum surface water supply availability. Based on these criteria, the six candidate sites were chosen for this analysis.

Only one site from the Haines Creek/Palatlakaha Chain of Lakes watershed was selected. The chosen site is Lake Griffin in Lake County (Figure 2), which could potentially supply a portion of the future projected needs of northern Lake County. Lake Griffin receives the majority of its inflow from Haines Creek, and the water availability analysis is based on the Haines Creek gauging station, located near Lisbon Florida (U.S. Geologic Survey [USGS] Gauge No. 2238000). For the purpose of this feasibility analysis, withdrawals from Lake Griffin will only be allowed when Haines Creek flow rates are above the minimum streamflow requirements established for the Haines Creek gauge.

The following remaining five candidate withdrawal sites are all located on the main stem of the St. Johns River, as shown in 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
- St. Johns River above Jacksonville

USGS stream gauging records, including daily flow observations and periodic water quality data, are available at or near each of these sites. Streamflow and water quality characteristics for the Cocoa site are defined by USGS Station No. 2232400, located near Cocoa. The gauging station near Christmas Florida (2232500) is used for the Titusville site evaluation.

Data from the USGS De Land gauging station (2236000) are used to establish streamflow characteristics for both the De Land site and the Sanford site. For the Sanford site, which is located upstream from the De Land gauge, the observed streamflow values are multiplied by the previously established adjustment factor of 0.797 to account for the reduced streamflow expected at the upstream location (CH2M HILL, 1996b).

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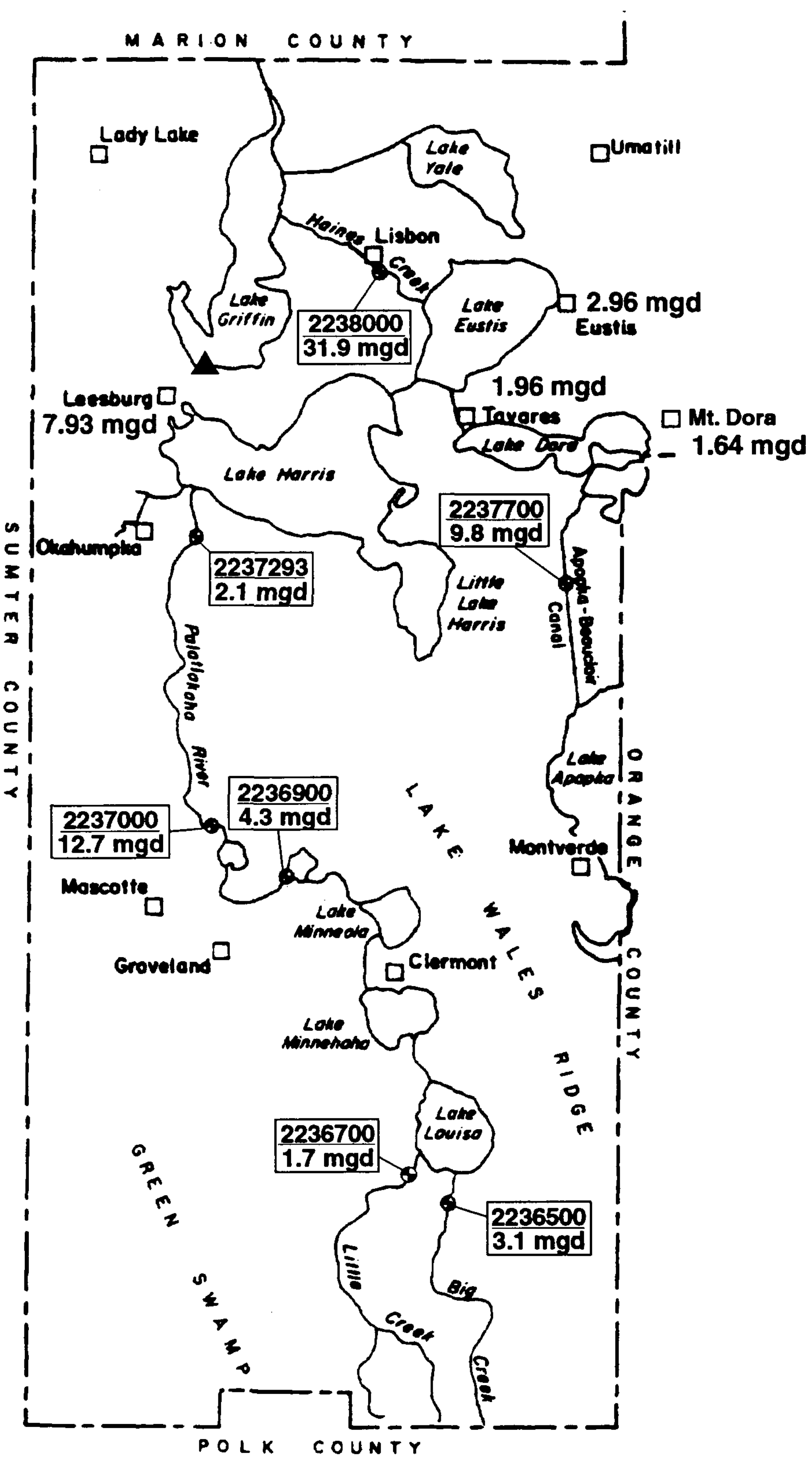


Figure 2. Location of the Candidate Surface Water Withdrawal Site in Lake County.

⊕	Stream gauging site
2236500 / 3.1 mgd	Gauging station number/approximate maximum developable surface water supply
7.93 mgd	Projected public water supply increase
▲	Withdrawal site

N

Approximate Scale in Miles

0 5 10

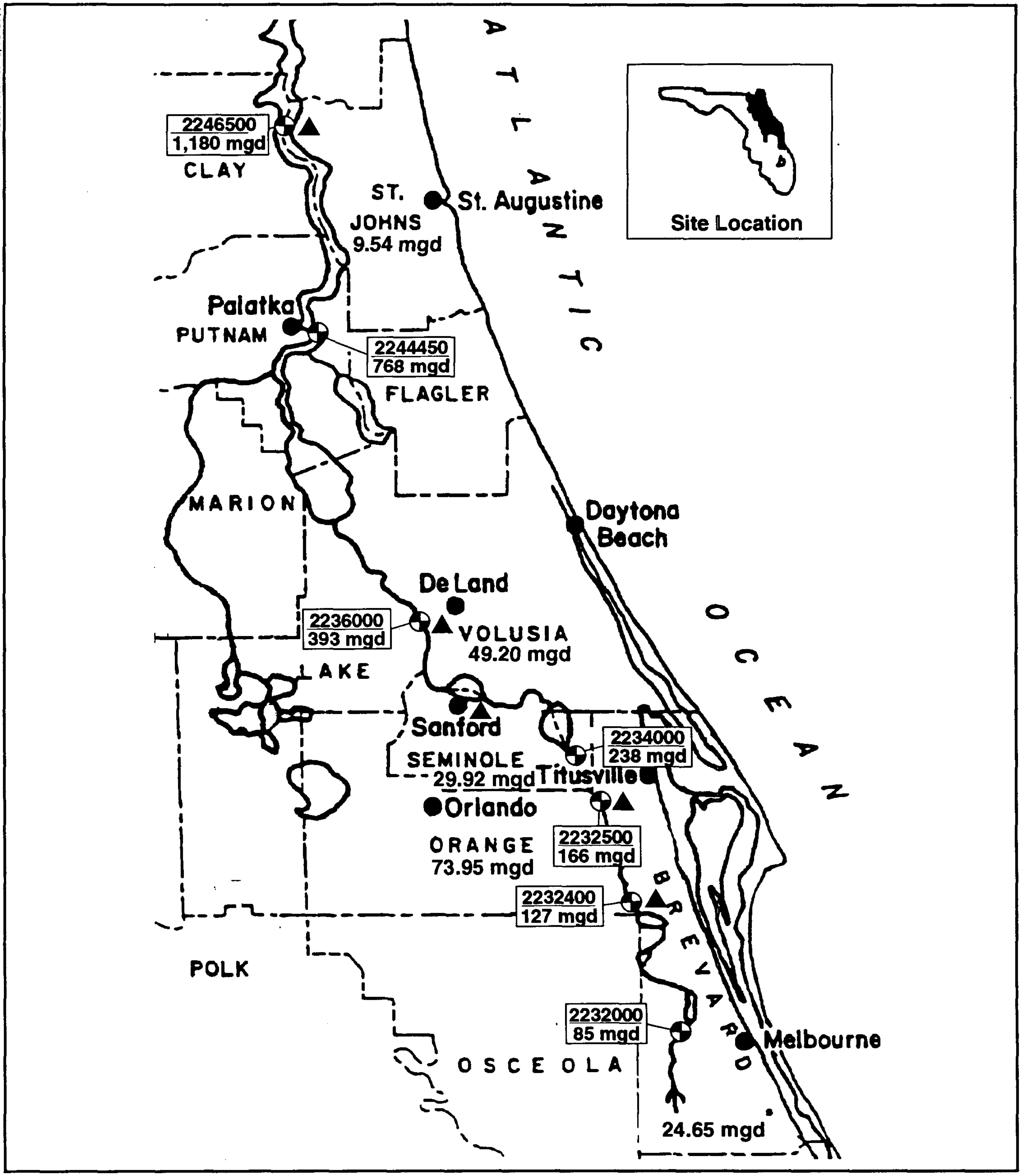


Figure 3. Locations of Candidate Surface Water Withdrawal Sites on the Main Stem of the St. Johns River.

Stream gauging site

2244450 768 mgd — Gauging station number/approximate maximum developable surface water supply

73.95 mgd — Projected public water supply increase

▲ Withdrawal site

Approximate Scale in Miles: 0 10 20

N

The final St. Johns River candidate withdrawal site is located in northern St. Johns County, just upstream of the City of Jacksonville. Streamflow and water quality records from the USGS station near Switzerland (2246500) are used to establish the characteristics of this site.

STREAMFLOW DURATION ANALYSIS

The streamflow duration analysis includes three major parts. First, individual flow duration curves were developed for each candidate withdrawal site. These curves, which are based on analysis of long-term USGS daily flow records, define streamflow magnitude and variability.

The previously developed minimum streamflow criteria were then applied to the flow duration curves to establish approximate minimum streamflow requirements and the maximum streamflow diversion rate considered in this feasibility analysis. Once these parameters were established, the effect of water supply withdrawal on each streamflow duration relationship was evaluated.

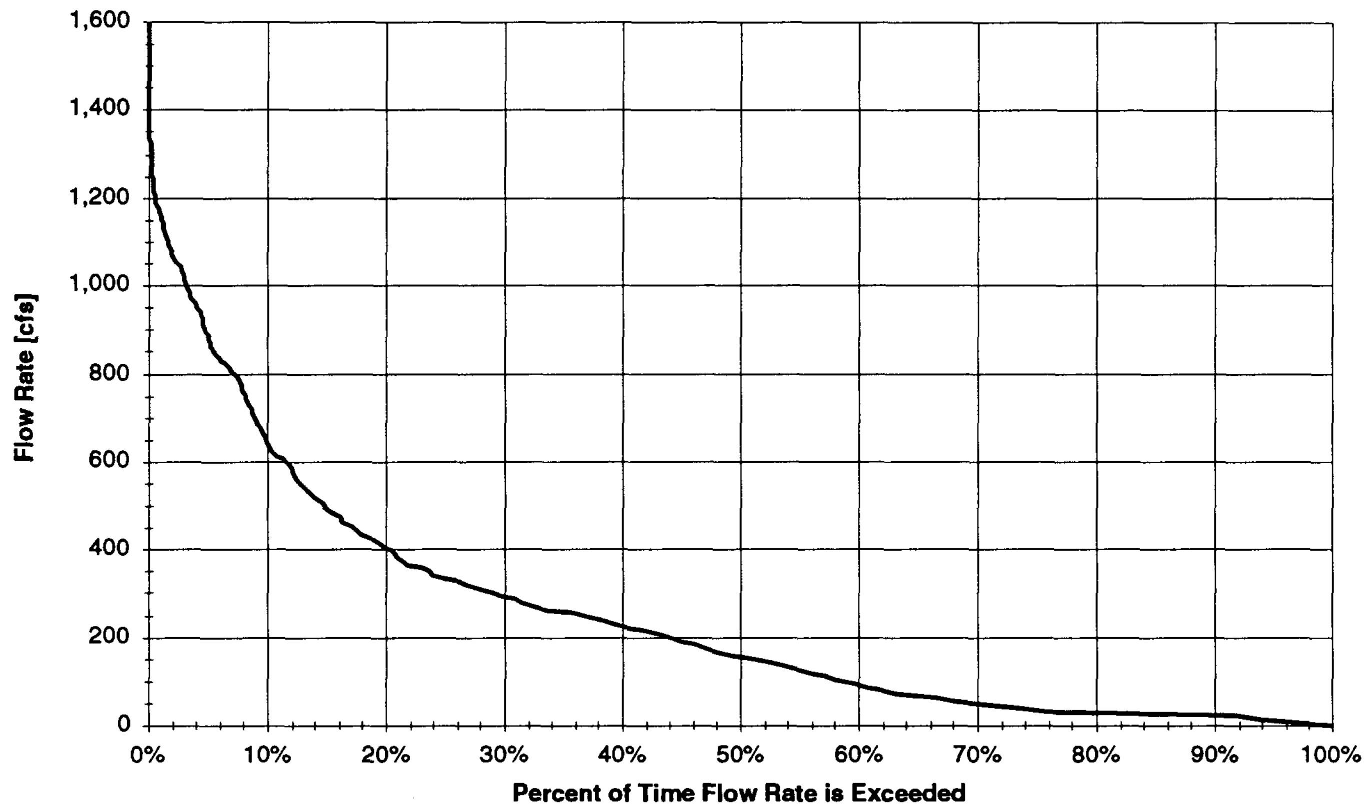
FLOW DURATION CURVES AND MINIMUM STREAMFLOW REQUIREMENTS

Haines Creek

Figure 4 presents the flow duration curve for Haines Creek near Lisbon Florida. During the 52-year period of record, Haines Creek flow has range from no flow to a daily maximum of 1,470 cubic feet per second (cfs), with a mean of 248 cfs. Periods of no streamflow are rare, occurring only about 0.7 percent of the time, or 2 to 3 days per year on the average.

Based on previously established minimum flow criteria, the minimum streamflow requirement for Haines Creek is 14 cfs. This flow rate is exceeded 94.3 percent of the time (0.95 * 0.993 = 0.943), which is also the maximum allowable diversion frequency. Again, using the previously established criteria, the maximum diversion rate considered in this analysis is 62 cfs (40 mgd), which is equal to 25 percent of the long- term observed mean flow rate.

SJRWMD plans to conduct a minimum flows and levels analysis for Lake Griffin. Once this analysis is complete, it is likely that a site-specific surface water diversion rule for Lake Griffin, based on lake stage, will be established. It is also likely that this rule will differ from the Haines Creek criteria used in this preliminary water supply feasibility analysis.



Mean Flow =	248 cfs
Minimum Flow =	14 cfs
Maximum Diversion Rate =	62 cfs
Maximum Diversion Frequency =	94.3%

Figure 4. Flow Duration Curve for Haines Creek near Lisbon, Florida.

Because of the uncertainty associated with the outcome of the planned minimum flows and levels analysis for Lake Griffin, it is possible that the estimated maximum water supply yield resulting from this preliminary water supply evaluation could be overstated. For this reason, an additional constraint could be placed on the Lake Griffin candidate withdrawal site when evaluated by the University of Florida decision model. The additional constraint would limit the maximum water supply considered to 50 percent of the theoretical maximum obtained by application of the streamflow diversion criteria established for this investigation.

The feasibility of developing a viable water supply from Lake Griffin should be re-evaluated once the planned Lake Griffin minimum flows and levels analysis is complete.

St. Johns River near Cocoa

Figure 5 presents the flow duration curve for the St. Johns River near Cocoa. Streamflow has ranged from 5.6 cfs to 10,700 cfs at this station. The long-term mean flow is 958 cfs. The maximum diversion frequency, based on these streamflow characteristics, is 95 percent. This flow frequency corresponds to a minimum streamflow requirement of 57 cfs, as determined from the flow frequency curve. Therefore, for the purpose of this analysis, water supply diversions will not be allowed when streamflow is less than 57 cfs and the maximum diversion rate to be considered is 239 cfs (154 mgd).

St. Johns River near Titusville

The overall streamflow characteristics of the St. Johns River near Titusville, as illustrated in Figure 6, are similar to the characteristics near Cocoa. However, during the 61-year period of record, there were 5 days with no streamflow. The mean flow is 1,273 cfs and the maximum observed daily flow rate is 11,600 cfs. Based on our planning criteria, the minimum streamflow requirement is 70 cfs and flow can be withdrawn for water supply 95 percent of the time. The maximum diversion rate investigated is 318 cfs (206 mgd).

St. Johns River at Sanford

The flow duration curve for the Sanford (Lake Monroe) candidate withdrawal site is based on analysis of the flow records from the De Land gauge adjusted for the smaller tributary area. As previously discussed, the De Land gauging station daily flow data were

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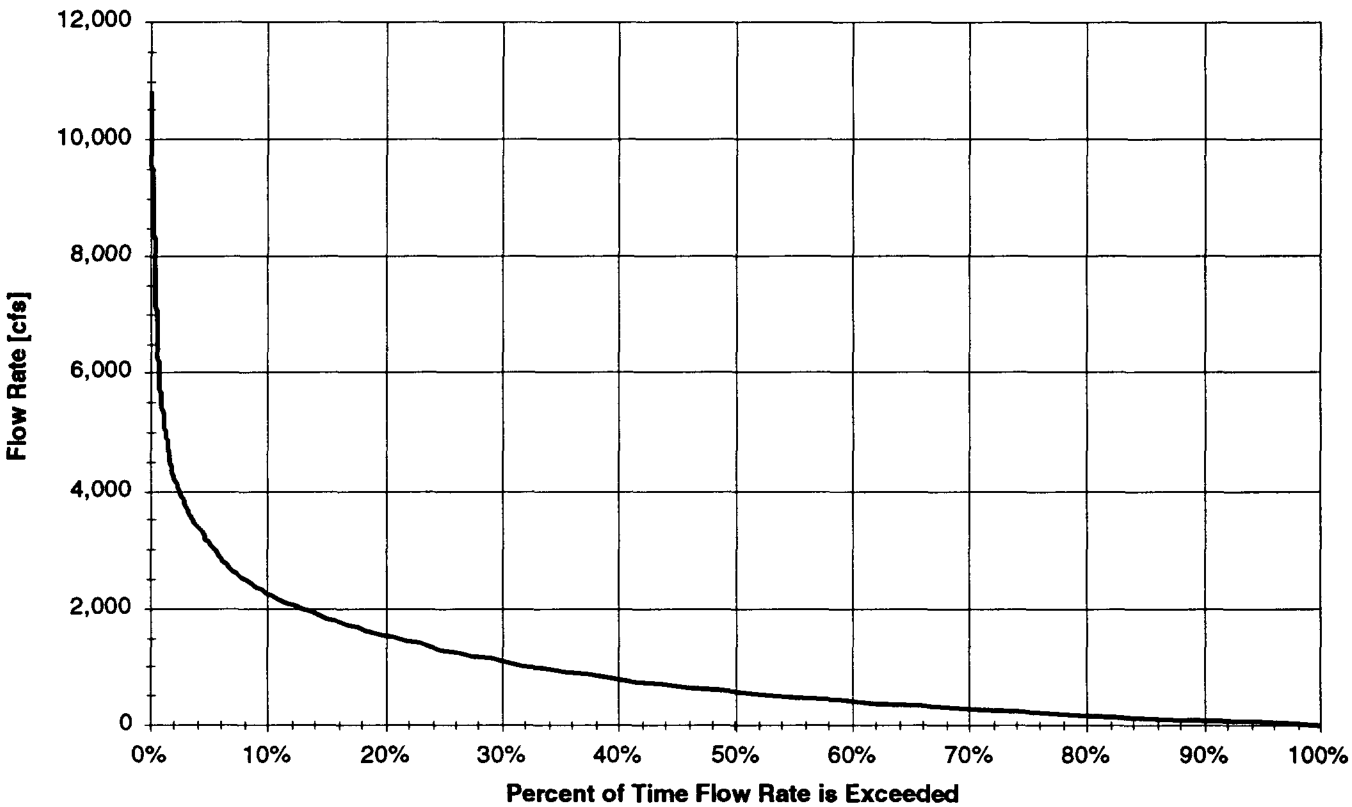

Mean Flow =	958 cfs
Minimum Flow =	57 cfs
Maximum Diversion Rate =	239 cfs
Maximum Diversion Frequency =	95.0%

Figure 5. Flow Duration Curve for the St. Johns River near Cocoa, Florida.

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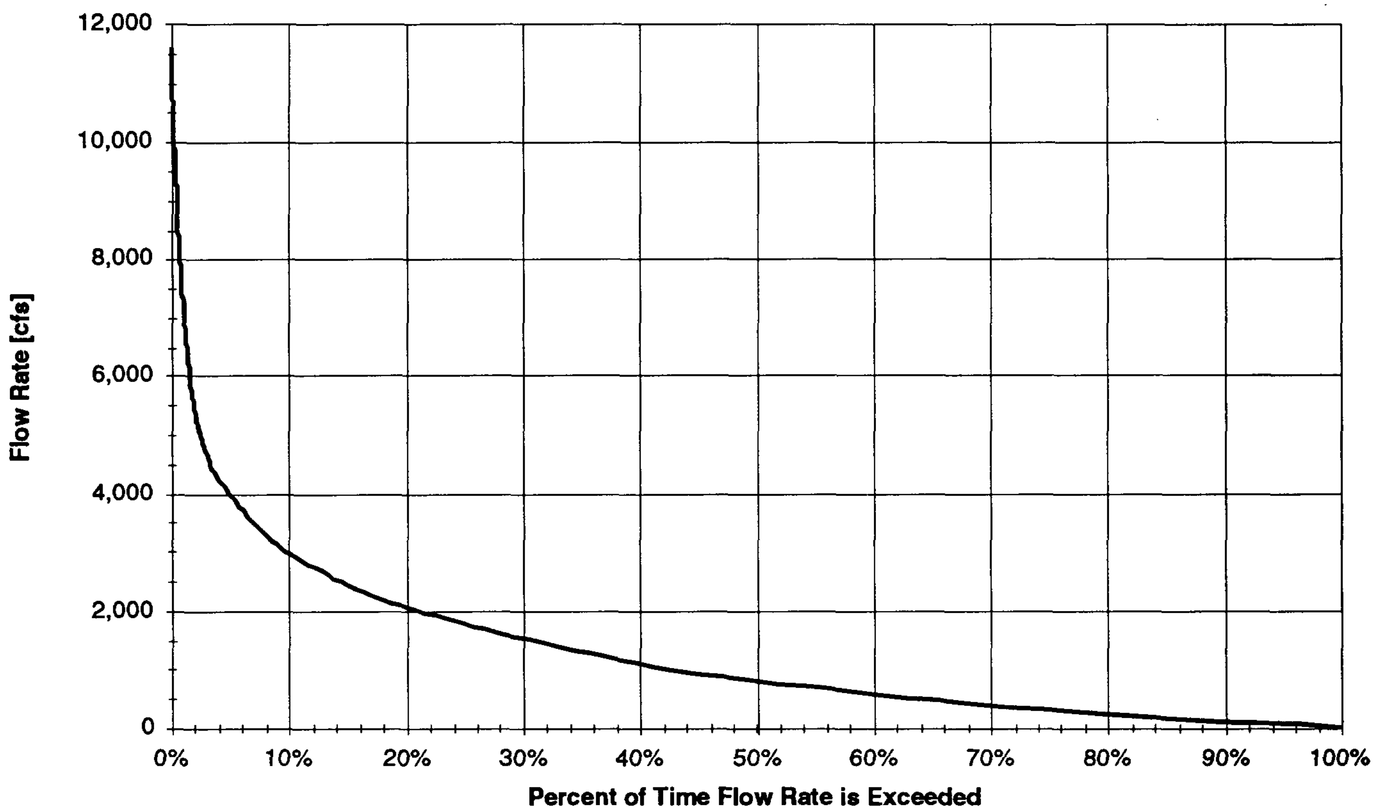


Mean Flow =	1,273 cfs
Minimum Flow =	70 cfs
Maximum Diversion Rate =	318 cfs
Maximum Diversion Frequency =	95.0%

Figure 6. Flow Duration Curve for the St. Johns River near Titusville (Christmas), Florida.

multiplied by an adjustment factor equal to 0.797. The characteristics of these adjusted data are illustrated in Figure 7.

As Figure 7 shows, the estimated streamflow characteristics for the Sanford site are somewhat different than those observed at the two previous upstream sites. At the Sanford site, significant negative or upstream flows are exhibited. Daily flow rates range from -2,966 cfs to 13,629 cfs, and the mean flow rate is 2,425 cfs. Although significant negative flow rates can occur, they only occur about 2.3 percent of the time.

Applying our planning criteria, the maximum diversion frequency for the Sanford site will be about 92.8 percent of the time and the corresponding minimum streamflow requirement is 571 cfs. The maximum stream diversion rate to be considered is 606 cfs (392 mgd).

St. Johns River near De Land

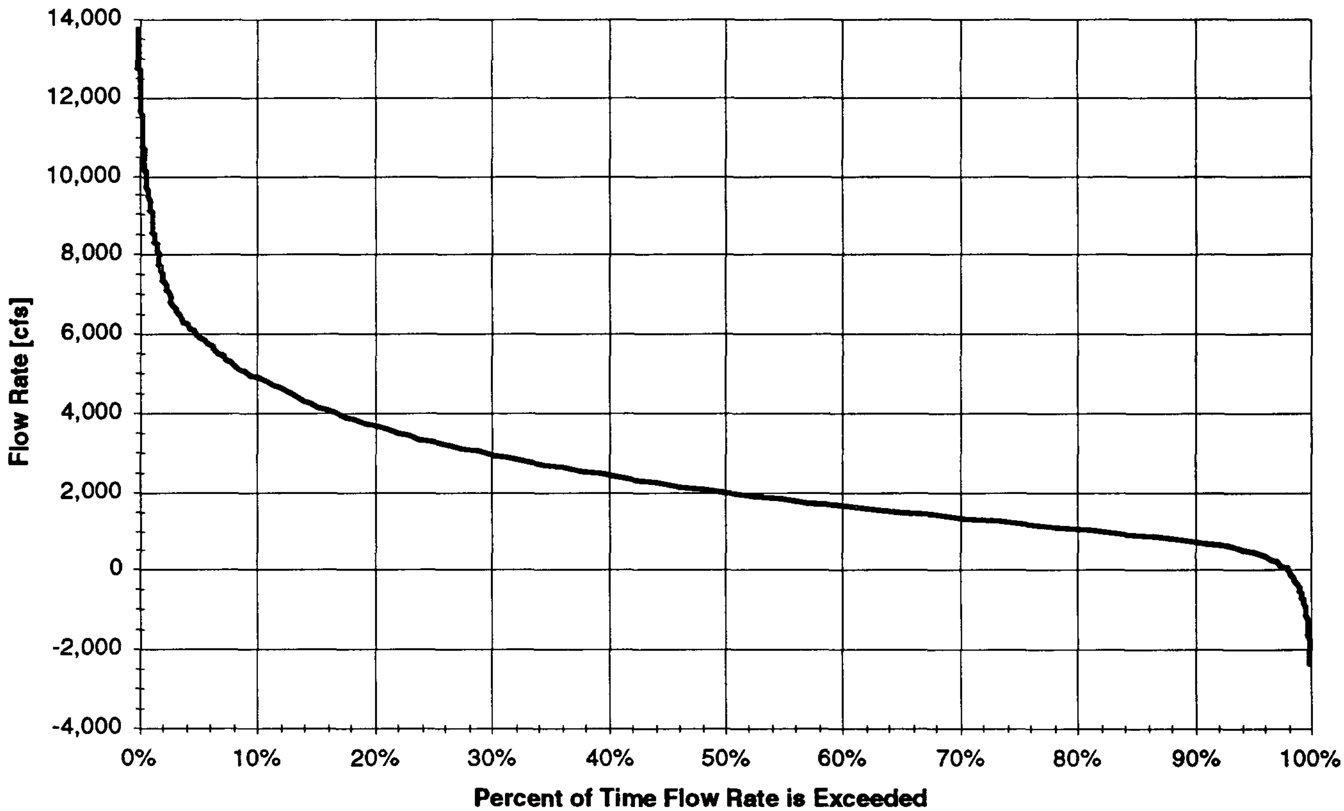
Figure 8 presents the flow duration curve for the De Land candidate withdrawal site. Since both the De Land and Sanford flow duration curves were derived from the same observed streamflow sequence, the shapes of these curves are the same. However, the magnitude of flow at De Land is larger than that at Sanford.

Daily flow rates range from -3, 030 cfs to 17,100 cfs and the mean flow rate is 3,043 cfs. Applying the streamflow diversion criteria for this investigation, the maximum diversion frequency for the De Land site will be about 92.8 percent of the time and the corresponding minimum streamflow requirement is 717 cfs. The maximum stream diversion rate to be considered is 761 cfs (492 mgd).

St. Johns River above Jacksonville

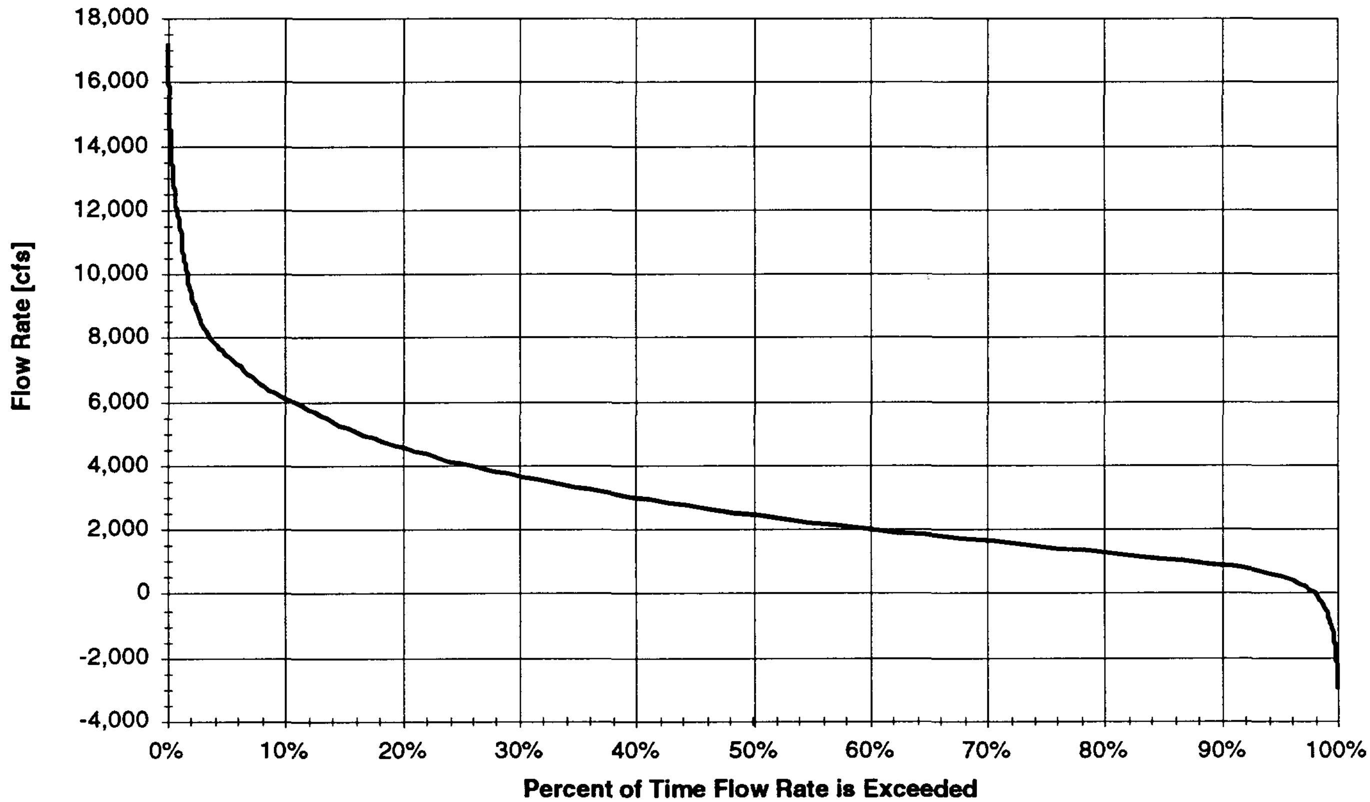
The final withdrawal site considered is the St. Johns River in northern St. Johns County, just upstream from Jacksonville. As can be seen in Figure 9, the streamflow variability at this site is large. Daily flow rates range from -202,000 cfs to 185,000 cfs, and negative or upstream flow occurs nearly 30 percent of the time. However, the net freshwater outflow is substantial. The mean flow equals 9,129 cfs.

Applying the streamflow diversion criteria for this investigation, the minimum streamflow requirement is 1,663 cfs and water supply withdrawal would be allowed 67.2 percent of the time. The maximum withdrawal rate considered here is 2,282 cfs (1,475 mgd).



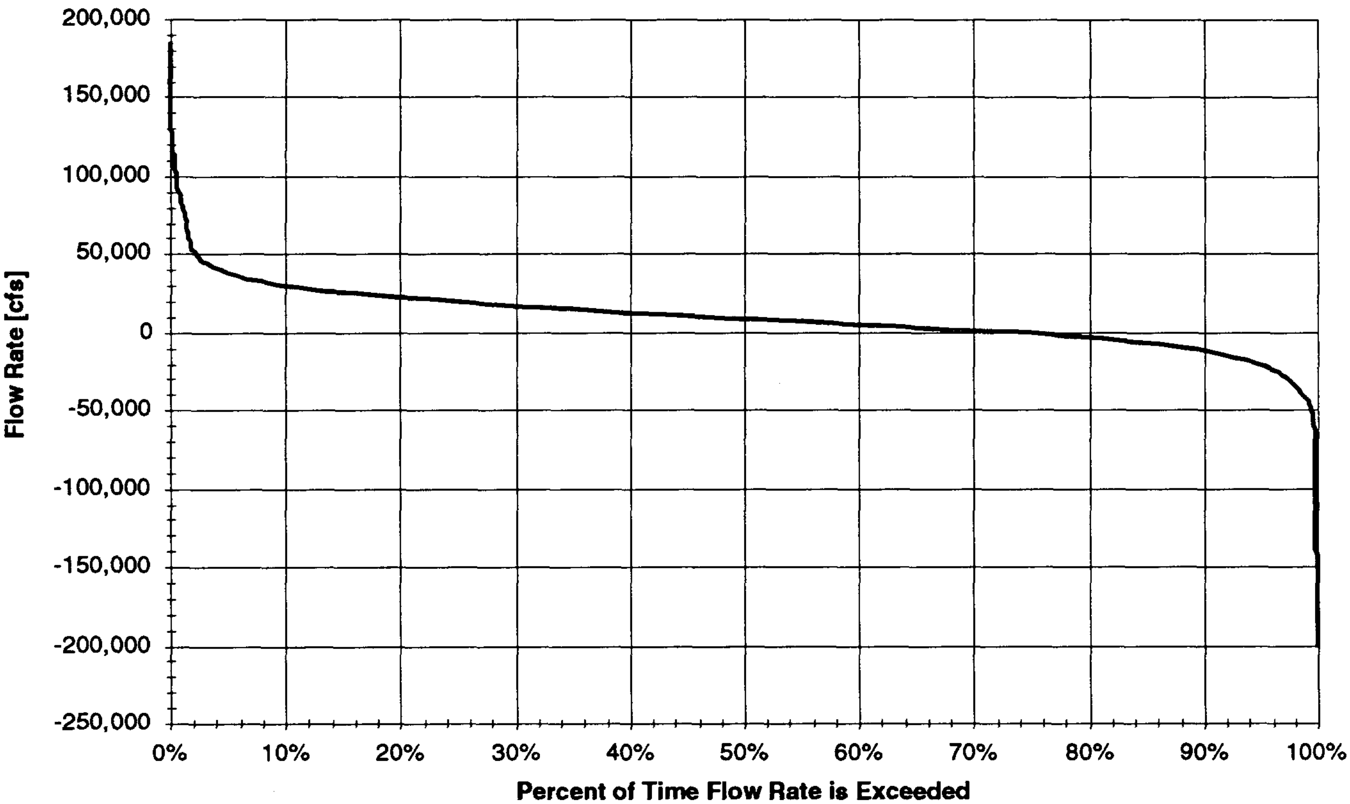
Mean Flow =	2,425 cfs
Minimum Flow =	571 cfs
Maximum Diversion Rate =	606 cfs
Maximum Diversion Frequency =	92.8%

Figure 7. Approximate Flow Duration Curve for the St. Johns River near Sanford, Florida.



Mean Flow = 3,043 cfs
Minimum Flow = 717 cfs
Maximum Diversion Rate = 761 cfs
Maximum Diversion Frequency = 92.8%

Figure 8. Flow Duration Curve for the St. Johns River near De Land, Florida.



Mean Flow =	9,129 cfs
Minimum Flow =	1,663 cfs
Maximum Diversion Rate =	2,282 cfs
Maximum Diversion Frequency =	67.2%

Figure 9. Flow Duration Curve for the St. Johns River above Jacksonville, Florida.

The extremely large daily flow range and frequent upstream flow are caused by strong tidal influences at this downstream location. These tidal influences would make development of a municipal water supply difficult because of the large volume and significant duration of seawater inflow. Because water supply withdrawals can only occur during a certain time period, the facilities required for water supply development would be relatively large compared with the amount of water that would be gained. In addition, the raw water quality will be extremely variable because of tidal mixing, resulting in difficult and expensive treatment requirements.

Also, the available streamflow records at this site are of poor quality. Again, this is because of the tidal influences, which make flow measurement difficult. Large incoming and outgoing tidal flows occur daily, and the differences in these flow volumes is the net daily outflow or river flow.

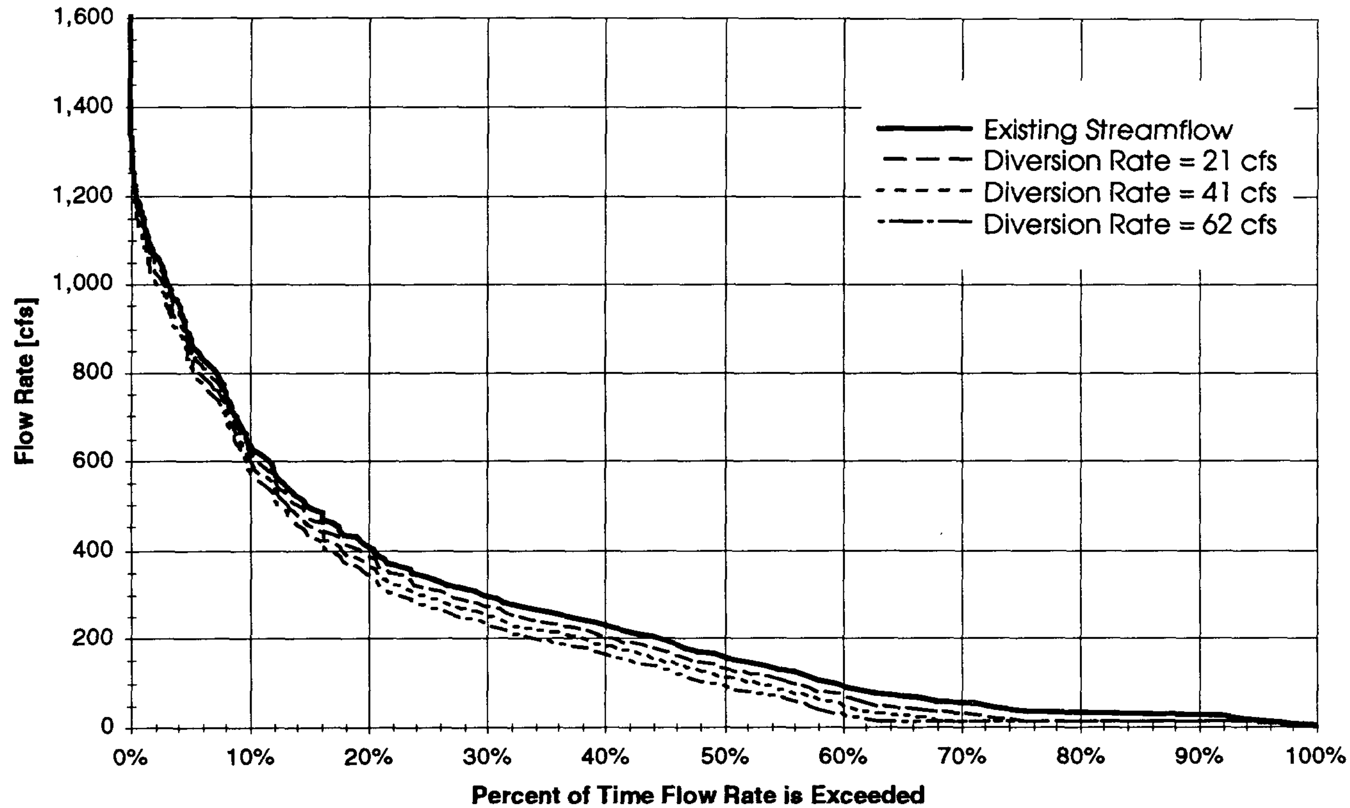
EFFECT OF WATER SUPPLY WITHDRAWAL ON FLOW DURATION RELATIONSHIPS

If a significant surface water supply were developed at any of the candidate withdrawal sites, the streamflow duration relationship would be modified. An analysis was conducted to quantify the maximum effects that could result from these withdrawals at each of the six sites.

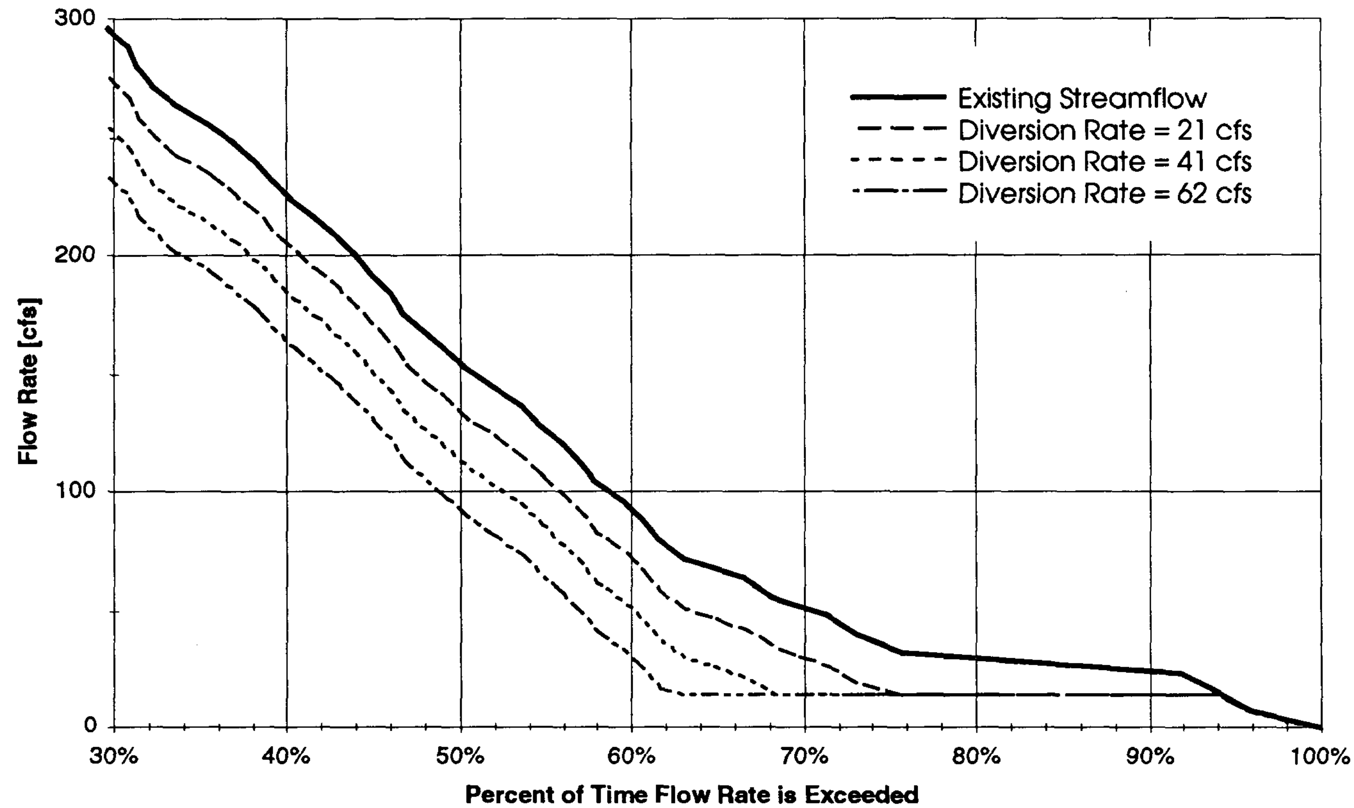
In each case, the effect of withdrawal at the maximum rate considered, as well as withdrawals at 1/3 and 2/3 of the maximum, were evaluated. Modified flow duration curves, one for each withdrawal rate, were developed and are shown in Figures 10 through 15. These figures also demonstrate the effect of withdrawal on the entire streamflow regime and on the normal to low-flow regime.

The effect of water supply withdrawal using the previously established withdrawal criteria are similar for each site. In the upper portions of Figures 10 through 15, the effects relative to the entire streamflow regime are shown. In most cases, when the entire streamflow regime is considered, the effects on the flow duration curve appear to be relatively minor.

However, the effects on the flow duration relationship are more apparent in the bottom portions of Figures 10 through 15, which illustrate only the low and moderate flow regime. Under these conditions, water supply development tends to flatten the flow duration curve. At flow rates less than the minimum withdrawal rate,



a) Entire Streamflow Regime



b) Moderate and Low Streamflow Regime

Figure 10. Maximum Effect of Water Supply Withdrawal on Flow Duration Curve for Haines Creek at Lisbon, Florida.

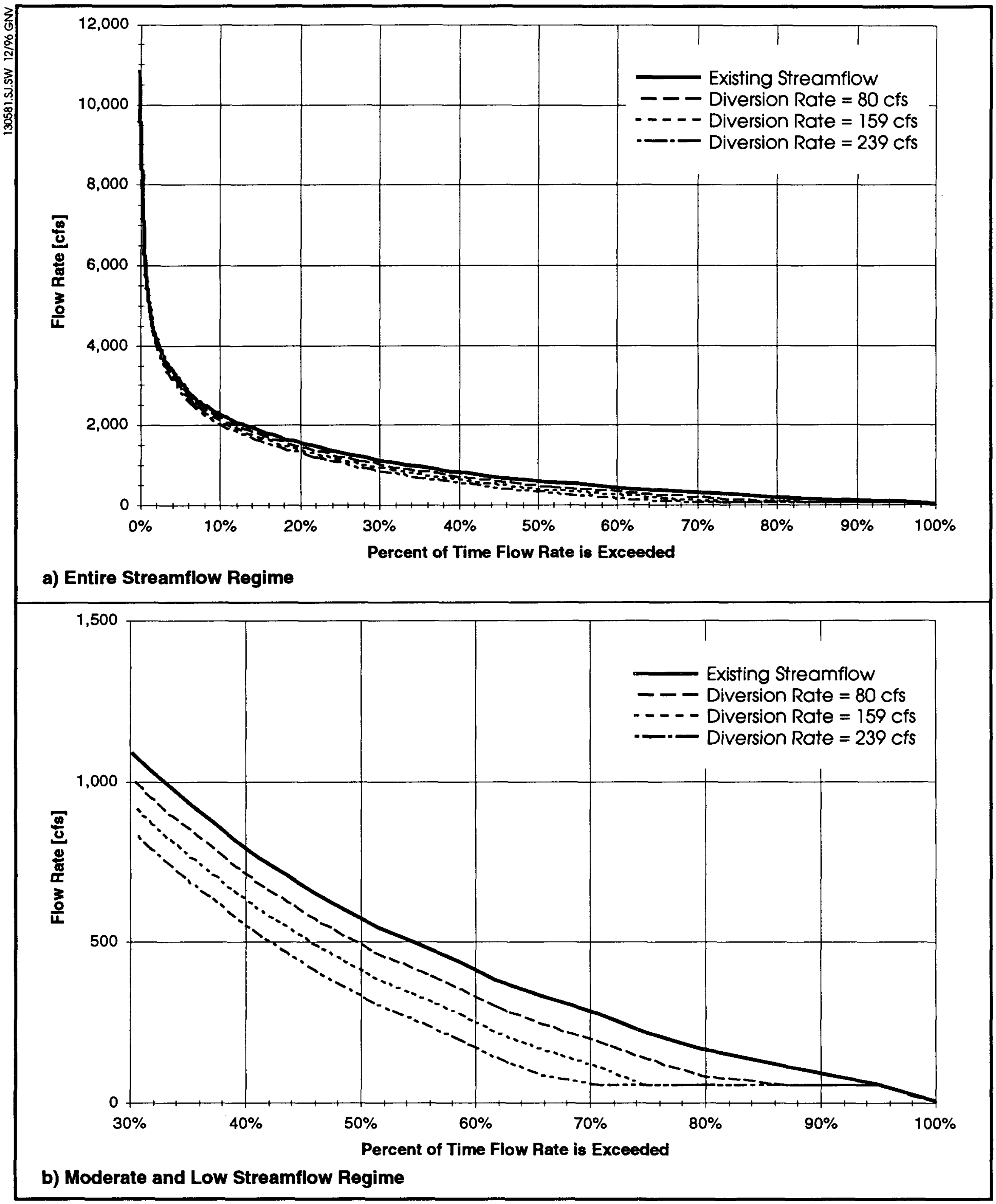


Figure 11. Maximum Effect of Water Supply Withdrawal on Flow Duration Curve for the St. Johns River near Cocoa, Florida.

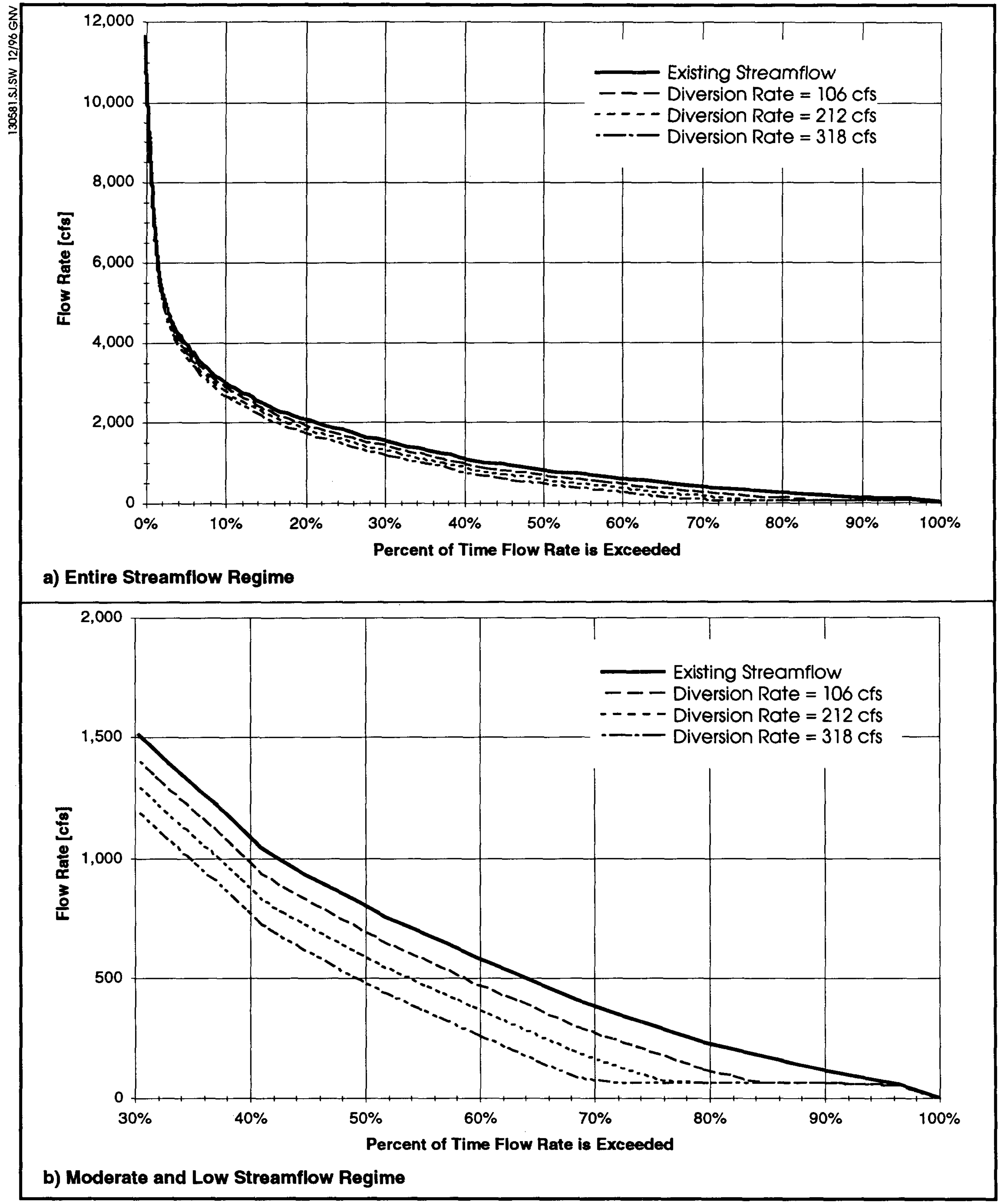
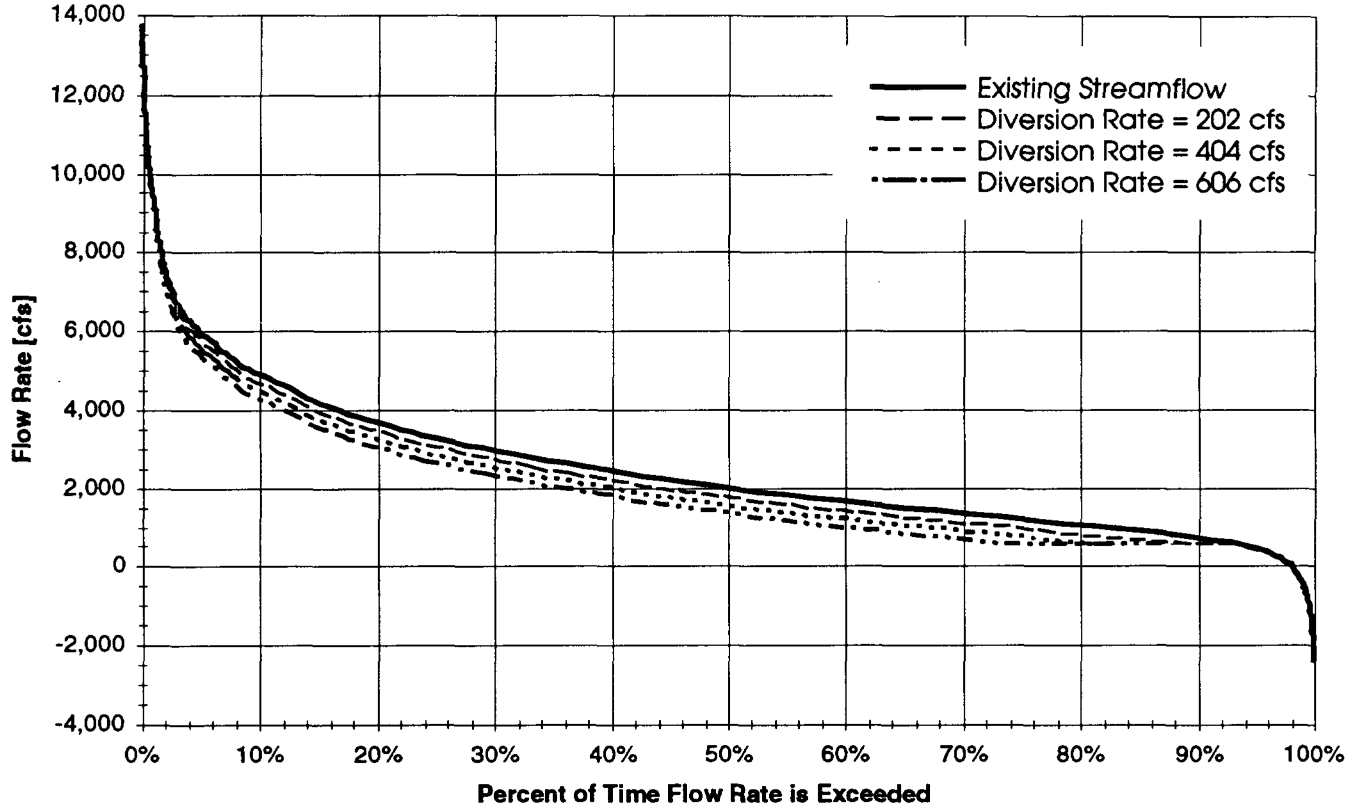
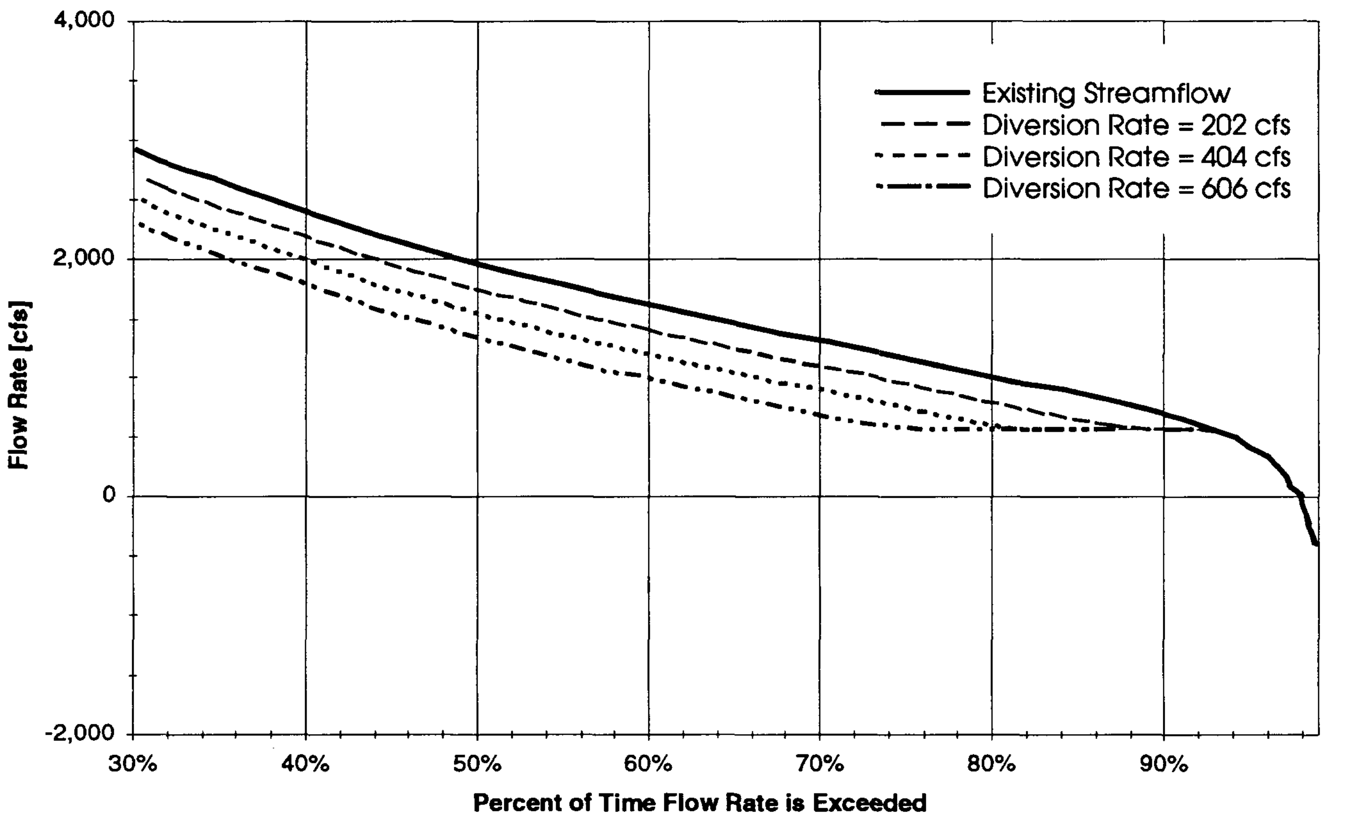


Figure 12. Maximum Effect of Water Supply Withdrawal on Flow Duration Curve for the St. Johns River near Titusville (Christmas), Florida.



a) Entire Streamflow Regime



b) Moderate and Low Streamflow Regime

Figure 13. Maximum Effect of Water Supply Withdrawal on Flow Duration Curve for the St. Johns River at Sanford, Florida.

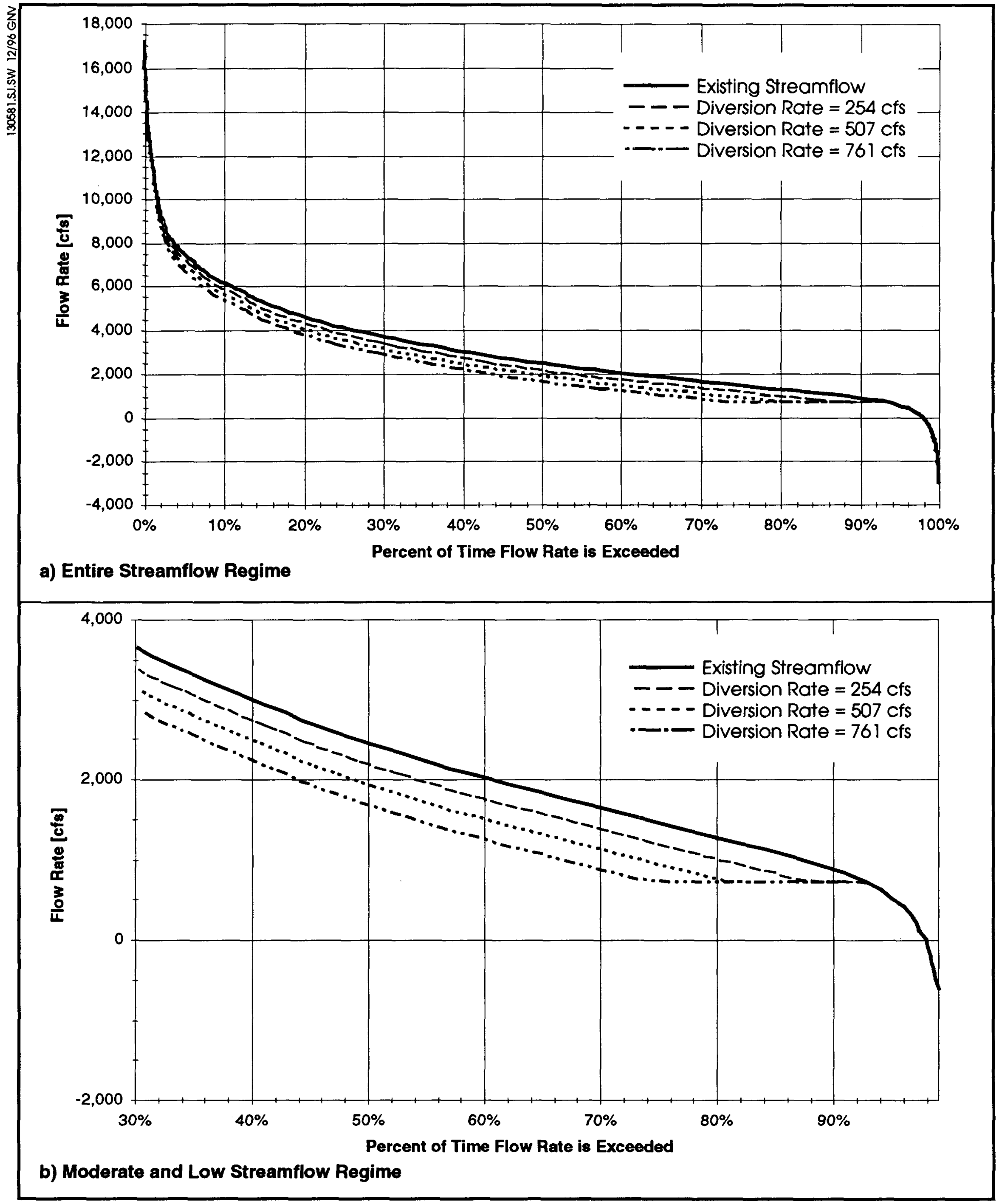


Figure 14. Maximum Effect of Water Supply Withdrawal on Flow Duration Curve for the St. Johns River at De Land, Florida.

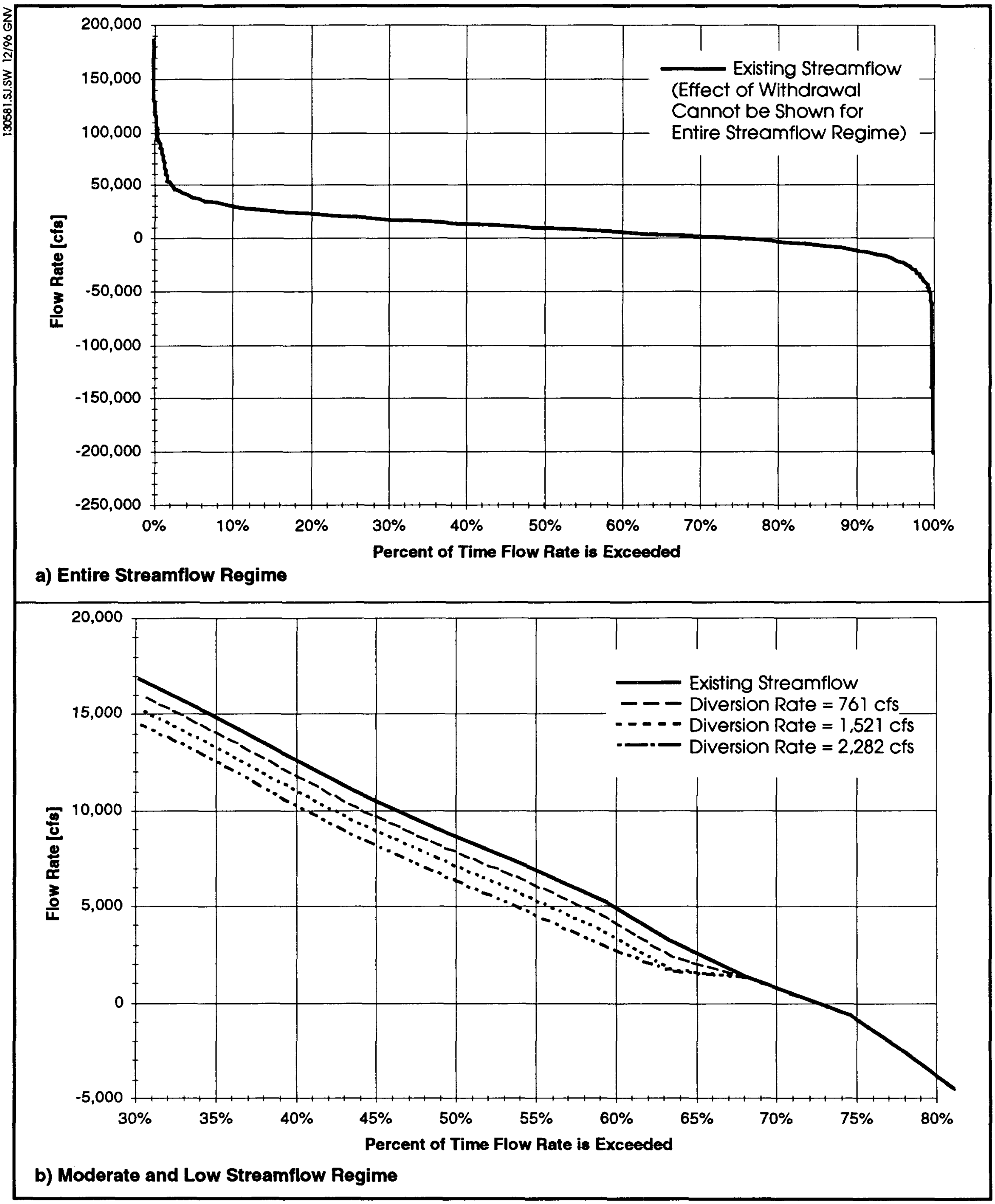


Figure 15. Maximum Effect of Water Supply Withdrawal on Flow Duration Curve for the St. Johns River above Jacksonville, Florida.

the flow duration relationship would be unchanged as diversion would not be allowed. However, the duration of time at or near the low-flow value may increase noticeably.

This flattening effect appears to be more pronounced for the candidate withdrawal sites with the smallest total streamflow magnitude; for example, at the Haines Creek site (Figure 10) and St. Johns River site near Cocoa (Figure 11). The apparent effect on the Haines Creek flow regime is only theoretical if the water supply withdrawal is located in Lake Griffin, as envisioned. The creek itself would not be affected because the water would actually be withdrawn from the downstream lake.

POTENTIAL YIELD ANALYSIS

The purpose of the potential yield analysis is to develop a quantitative relationship between installed river diversion capacity and the maximum long-term water supply that could be developed. The potential yield analysis establishes the maximum theoretical water supply yield for each diversion capacity investigated. This is a necessary intermediate step between the flow duration analysis and determination of water supply facility requirements because it establishes the upper limit of the developable water supply and provides insight into the magnitude of the facilities required to develop each site.

Potential yield is a function of the minimum streamflow criteria, the maximum installed water supply diversion capacity, and the streamflow variability. For each withdrawal site, the minimum streamflow has been determined by applying the established streamflow diversion criteria, and streamflow variability is defined by the observed streamflow records. Therefore, the only remaining variable is the installed diversion capacity. For each diversion capacity analyzed, the potential yield is calculated for each observed daily streamflow. These individual daily potential yield values are then averaged over the period of record to establish the overall potential yield for that diversion capacity. The process is repeated for a number of diversion capacities to establish a relationship between installed diversion capacity and total divertable flow or potential yield.

For example, consider the St. Johns River near Cocoa, which has a minimum streamflow requirement of 57 cfs (about 37 mgd), with an installed river diversion capacity of 50 mgd. If the streamflow on a given day is 30 mgd, which is less than the minimum streamflow requirement, then the allowed diversion for that day is zero. If, however, the daily streamflow is equal to 60 mgd, then the allowable diversion is 23 mgd (60 mgd minus 37 mgd). If the daily streamflow is large, say 300 mgd, then the withdrawal that day is limited by the diversion capacity and would be equal to 50 mgd. The divertable amount of water is calculated on a daily basis for the entire period of streamflow record to establish the long-term potential yield for each maximum diversion capacity considered.

The potential yield curve for each candidate withdrawal site is a function of streamflow magnitude and variability and the minimum streamflow criteria applied. Potential yield curves are both site-specific and applicable only for a given set of minimum flow criteria. Thus, the potential yield analysis presented here applies only to the previously established minimum streamflow requirements. If these criteria change, then the potential yield curves, subsequent facility requirements, and water supply development costs will also change.

The potential yield curves for each of the six candidate withdrawal sites are illustrated in Figures 16 through 21. In each case, the installed river diversion capacity, in mgd, is plotted on the x-axis and the potential yield, in mgd, is shown on the y-axis. An empirical equation was fit to each potential yield curve, and each of these equations is shown on the figures. The equations may be used to obtain an estimate of the potential yield for any diversion rate up to the maximum.

The maximum diversion rate considered and the resulting maximum potential yield are also shown on Figures 16 through 21. For example, on Figure 16, which shows the potential yield relationship for Haines Creek, the maximum diversion rate investigated is 40 mgd and the resulting maximum potential yield is 30 mgd, or about 75 percent of the diversion capacity. Because the maximum diversion rate is 25 percent of the mean streamflow, the maximum potential yield in this case is equal to about 18.8 percent ($0.75 \times 0.25 = 0.188$) of the total streamflow. Table 1 summarizes the maximum potential yield of each candidate withdrawal site as a function of the mean annual streamflow.

Table 1 also provides some insight into the relative water supply development potential of each candidate withdrawal site. The yield ratio, which is defined as the potential yield divided by the installed diversion capacity (PY/Qd), illustrates the relative scale of facilities required at each site. In general, a site with a larger yield ratio will require smaller facilities relative to the water supply developed. Based on a comparison of the yield ratio, the most attractive sites would be the St. Johns river at Sanford or the St. Johns River near De Land. The yield ratio at these locations is equal to 84 percent, which represents an efficient use of constructed water supply facilities.

The least desirable location would be the St. Johns River near Jacksonville, with a yield ratio of just 64 percent. This low-yield ratio is a direct result of the significant tidal influences that restrict the time period during which flow could be withdrawn from the river. Therefore, facilities at this site would have to be proportionately larger to meet a given target yield.

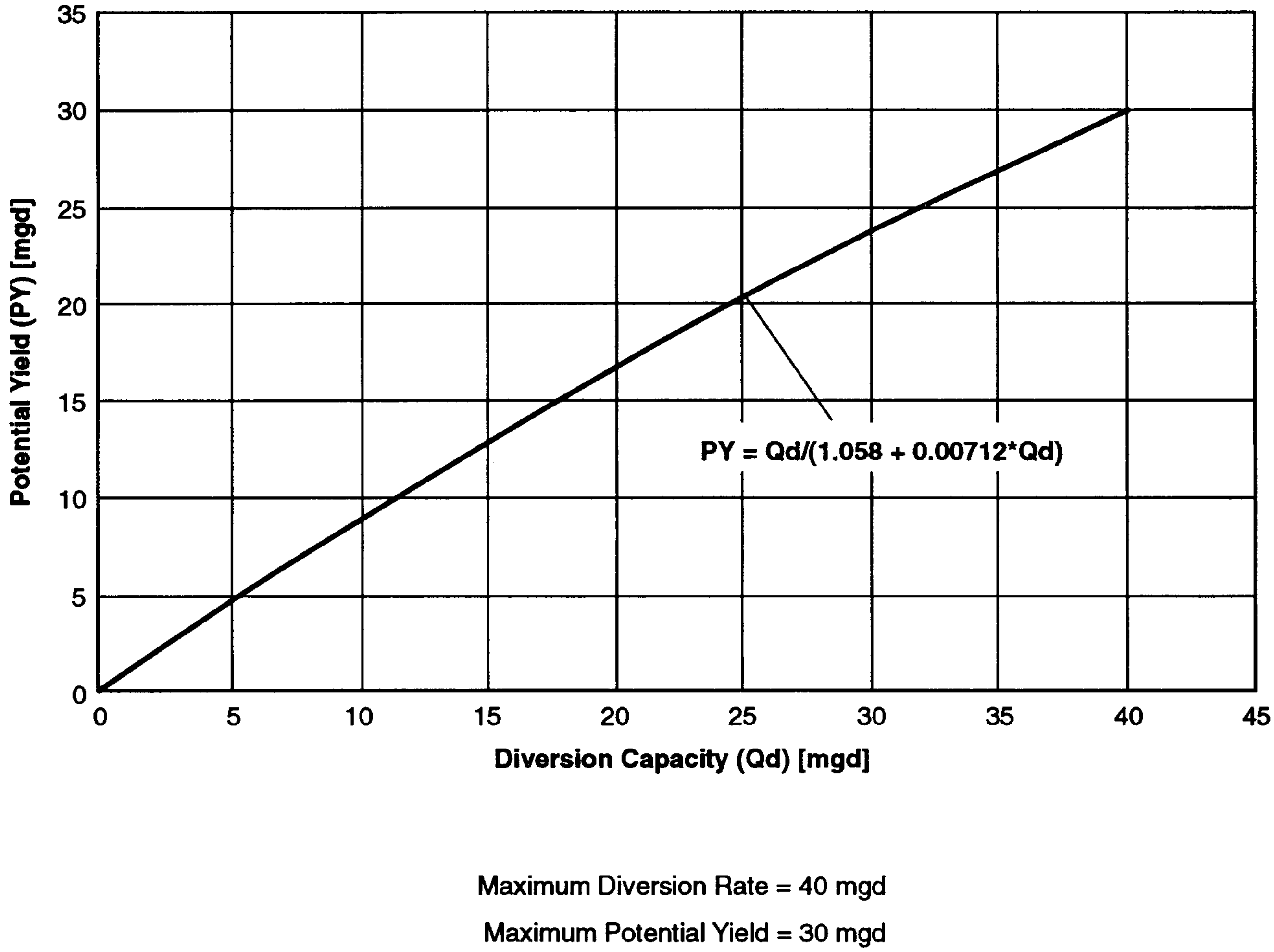
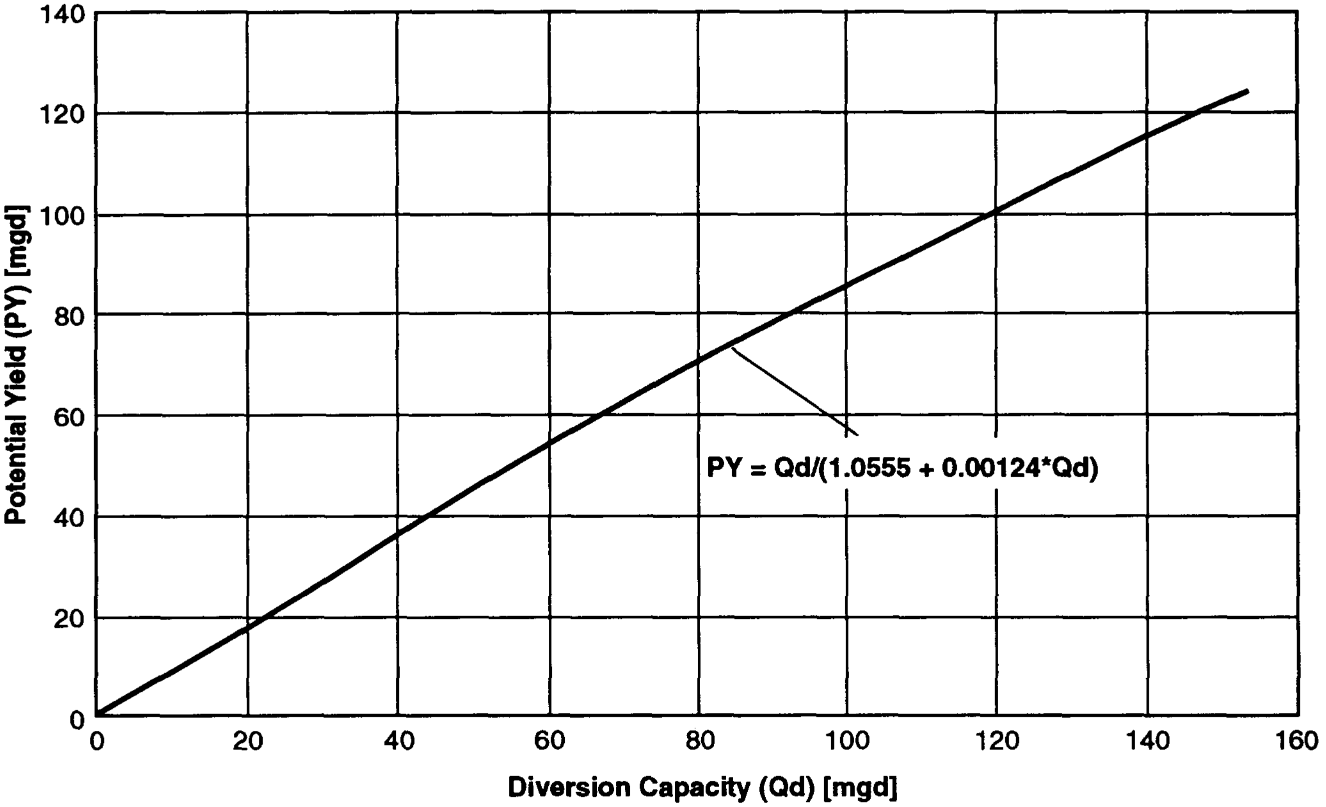


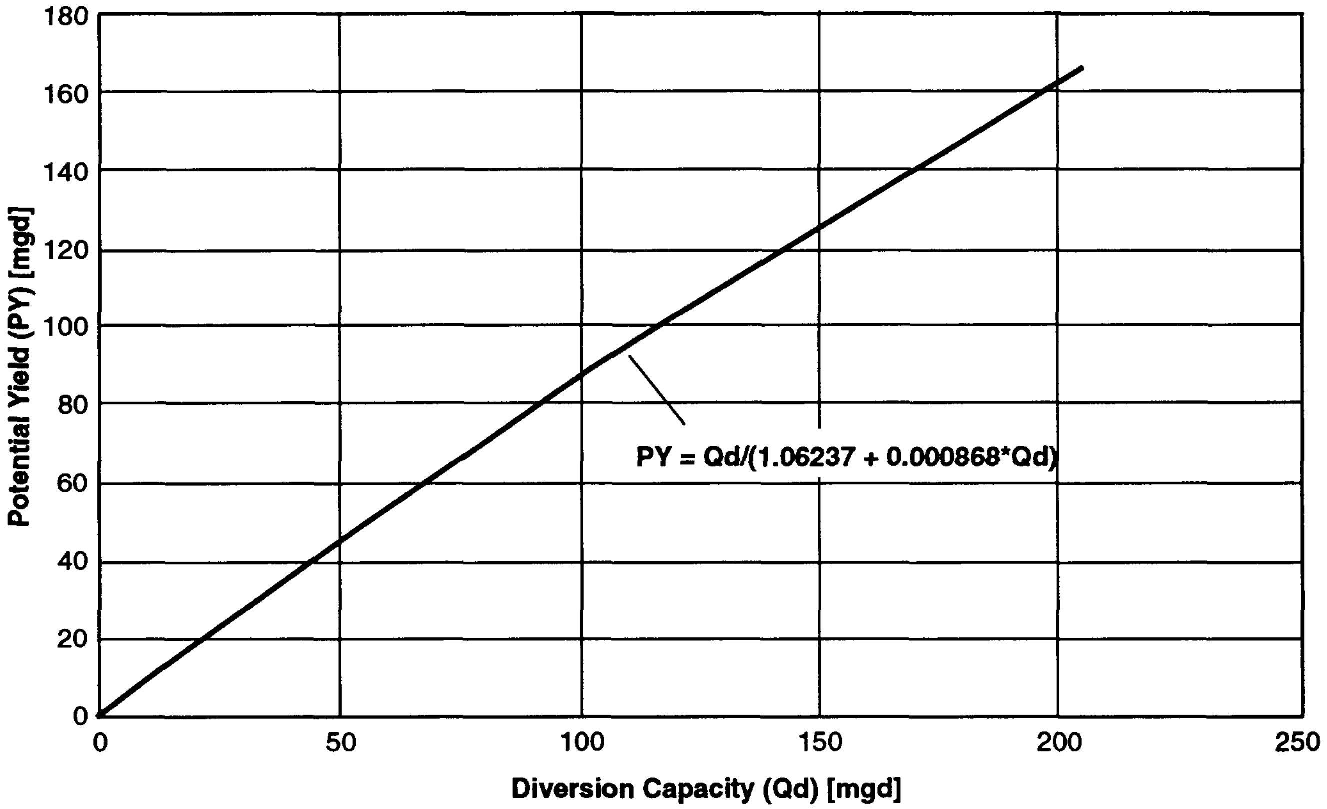
Figure 16. Potential Yield Curve for Haines Creek at Lisbon, Florida.



Maximum Diversion Rate = 154 mgd

Maximum Potential Yield = 124 mgd

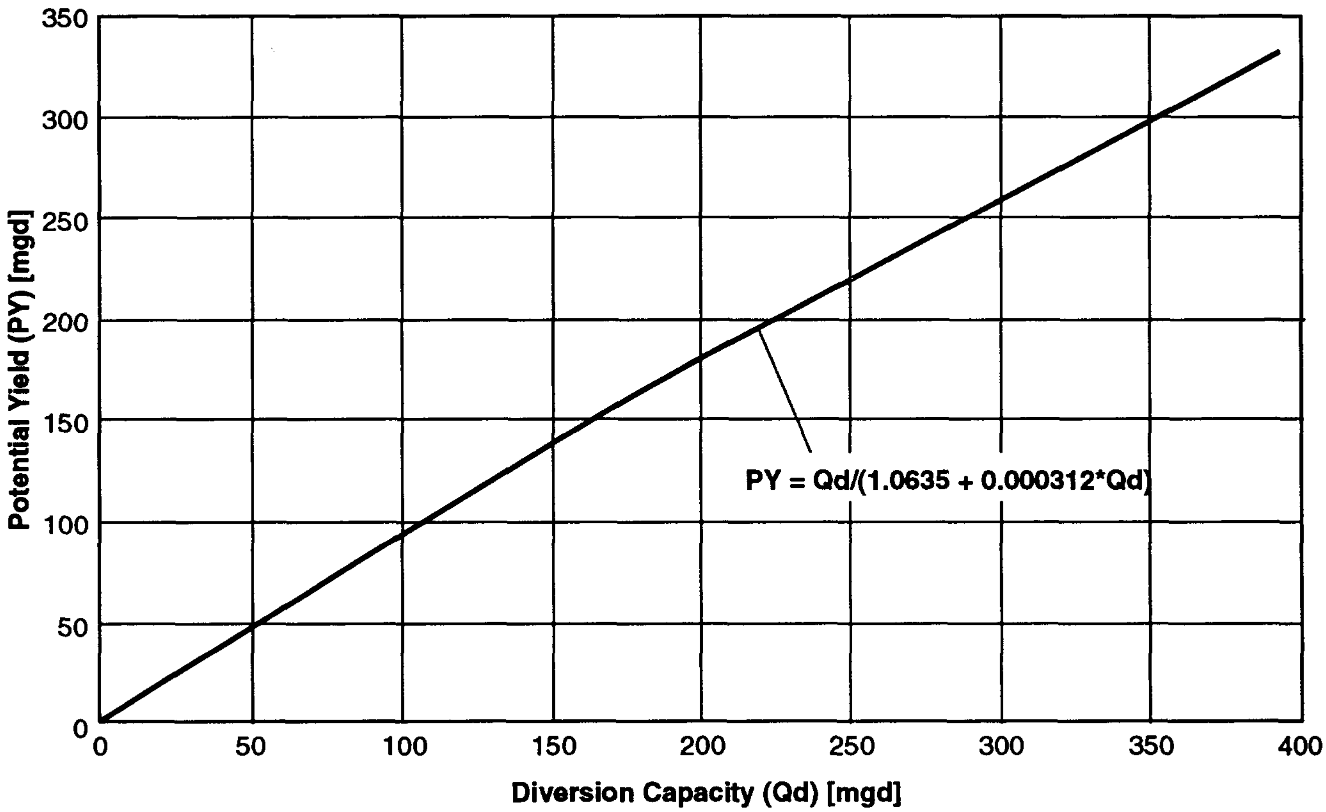
Figure 17. Potential Yield Curve for St. Johns River near Cocoa, Florida.



Maximum Diversion Rate = 206 mgd

Maximum Potential Yield = 166 mgd

Figure 18. Potential Yield Curve for St. Johns River near Titusville (Christmas), Florida.



Maximum Diversion Rate = 392 mgd

Maximum Potential Yield = 331 mgd

Figure 19. Potential Yield Curve for St. Johns River at Sanford, Florida.

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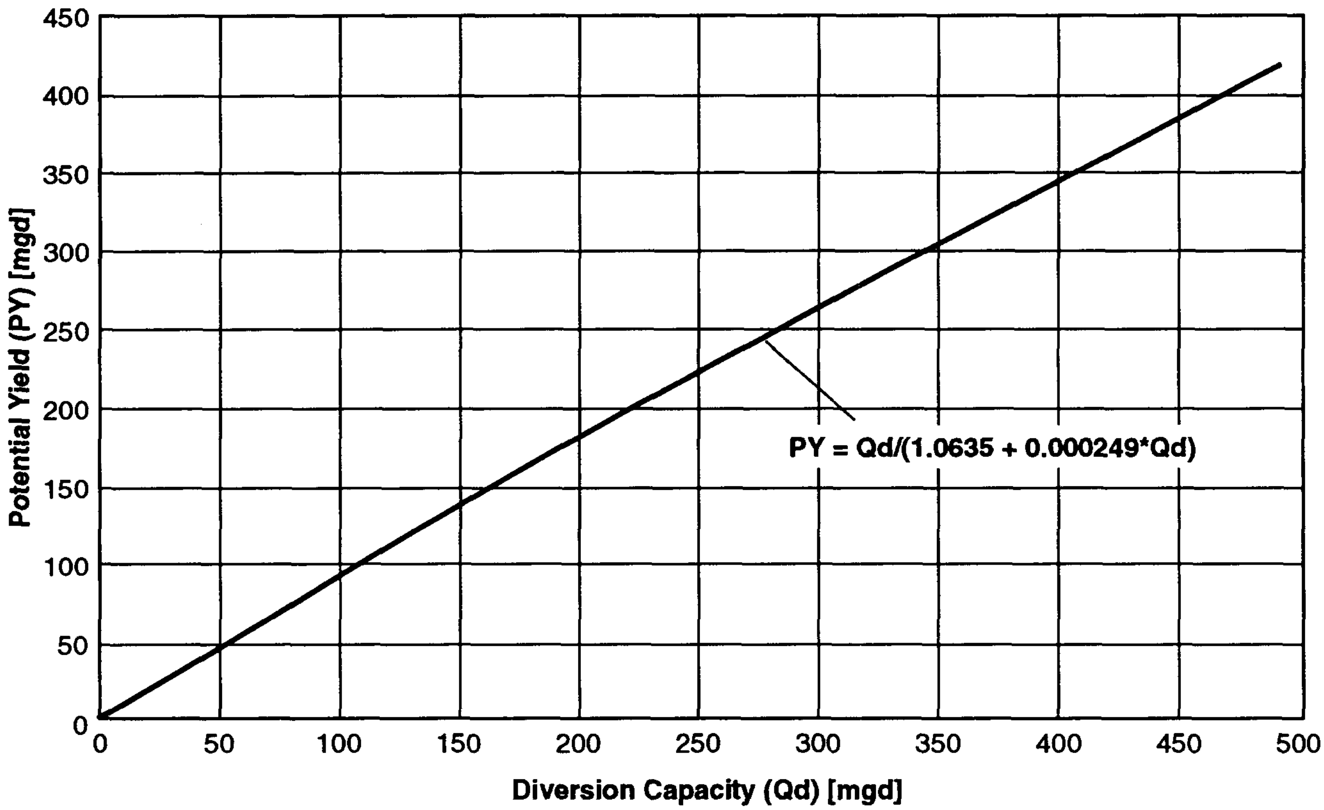
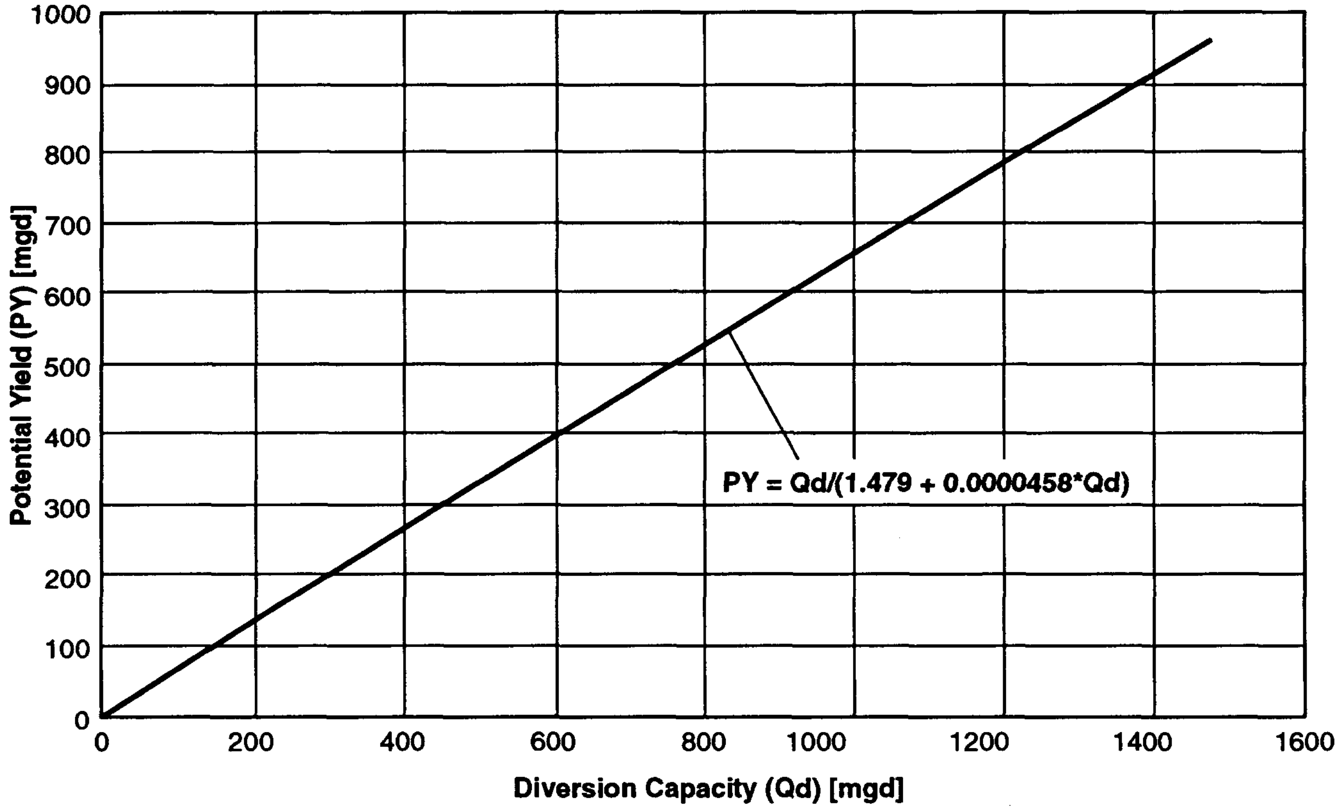


Maximum Diversion Rate = 492 mgd

Maximum Potential Yield = 415 mgd

Figure 20. Potential Yield Curve for St. Johns River near De Land, Florida.



Maximum Diversion Rate = 1,475 mgd

Maximum Potential Yield = 953 mgd

Figure 21. Potential Yield Curve for St. Johns River above Jacksonville, Florida.

Table 1. Maximum Potential Yield for the Six Candidate Surface Water Withdrawal Sites

Withdrawal Site	Maximum Diversion Rate [Qd] (mgd)	Maximum Potential Yield [PY] (mgd)	Yield Ratio PY/Qd as percentage	Maximum Potential Yield as a Percentage of Mean Streamflow
Haines Creek (Lake Griffin)	40	30	75	18.8
St. Johns River near Cocoa	154	124	81	20.1
St. Johns River near Titusville	206	166	81	20.1
St. Johns River at Sanford (Lake Monroe)	392	331	84	21.1
St. Johns River near De Land	492	415	84	21.1
St. Johns River above Jacksonville	1,475	953	64	16.2

SURFACE WATER SUPPLY FACILITY REQUIREMENTS

Facility requirements for each candidate withdrawal site were determined by simulating the water supply systems and evaluating the treatment requirements, based on analysis of available water quality data. The first step in this process is to establish the initial target yield array and the trial facility components array to be evaluated. Both of these arrays are based on the potential yield curve of the withdrawal site.

For example, consider the St. Johns River near Cocoa, with an estimated maximum potential yield of 124 mgd (Figure 17). As previously discussed, the maximum reliable yield will probably be somewhat less than this value. Therefore, the trial average daily yield investigated was limited to 120 mgd or less. The trial average daily yield array was established on equal increments of from 12 to 120 mgd. Initial target yields for each of the six candidate withdrawal site were selected in a similar manner.

TRIAL FACILITY COMPONENTS

The trial facility components were also selected on the basis of the potential yield curve and selected interrelationships among the components. Major surface water supply system facilities, which are identified in Figure 1, include a raw water diversion structure, a raw water off-line storage reservoir, a water treatment plant, and a treated water ASR system.

Raw Water Diversion and Pumping Station

Again, considering the St. Johns River near Cocoa, the maximum diversion capacity considered is equal to 154 mgd, as illustrated in Figure 17. The maximum diversion rate was divided into six elements (ranging from 25.7 mgd to 154 mgd) to define the diversion capacity of the six trial water supply systems. The sizes of the remaining components are then based on the diversion capacity to define reasonably balanced trial water supply systems.

Off-line Raw Water Storage Reservoir

The purpose of the off-line raw water storage reservoir is primarily to provide operational flexibility. Because streamflow cannot be diverted for at least 5 percent of the time, the raw water storage allows the plant to continue operation while withdrawals are not allowed. Because shutting down and starting up a water treatment plant is a significant task, the frequency of shut-down and start-up should be minimized. For the purpose of this preliminary facilities analysis, the off-line storage reservoir is sized to provide 5 days of storage, based on the installed diversion capacity. During periods when streamflow withdrawals are not allowed, plant operations would probably be reduced to approximately 20 percent of plant capacity, but would not be shut down completely. Thus, the off-line reservoir would allow the plant to operate at this reduced rate for at least 25 days before it would be necessary to completely cease operations.

An off-line raw water storage reservoir would also provide other functions and operational flexibility. For example, if a contaminant is spilled in the river, the raw water intake could be closed while the contaminated flow moves downstream, without interrupting plant operations. In addition, the raw water storage reservoir would provided some sedimentation and mixing of the raw water prior to entering the treatment facilities.

The off-line storage reservoir may be difficult to site and permit, given that these reservoirs will probably be located near the river withdrawal site and, therefore, within or adjacent to floodplains or wetlands, or both. The need for the off-line reservoir is driven in part by the assumed minimum streamflow criteria, which would not allow water supply diversion for at least 5 percent of the time during low streamflow periods. If the streamflow diversion criteria were relaxed to allow reduced diversion during low-flow periods (say 20 percent of treatment capacity), then the need for the off-line reservoir would be reduced and, possibly, could be eliminated. To a large extent, the environmental trade-off is whether it is better to allow some reduced diversion at all times and avoid floodplain or wetland encroachment, or fully protect the riverine system during low-flow periods. This trade-off will likely be answered on a case-by-case basis if surface water supply proves to be a technically and economically feasible water supply option.

An off-line storage reservoir may not be necessary at the Lake Griffin site, which is itself a large reservoir. If some water supply withdrawal were allowed on a continuous basis, it may be possible to develop a viable water supply without constructing a separate off-line raw water storage reservoir. The same general reasoning also applies along the main stem of the St. Johns River. Because of its mild slopes, the St. Johns River system is very much like a system of interconnected lakes. Again, if some continuous diversion were allowed, the off-line reservoir component may be unnecessary.

The only currently operational municipal surface water supply on the St. Johns River is located on Lake Washington and serves the City of Melbourne, Florida. This system does not include an off-line raw water reservoir. However, the City of Melbourne also uses ground water as a source of supply. Therefore, the overall reliability of the water supply system does not depend on surface water alone. A stand-alone surface water supply system located on the Peace River in southwest Florida does incorporate an off-line raw water reservoir. Therefore, examples of each application exist. The final decision for a given site should be based on detailed engineering alternatives and environmental systems analysis.

For the purpose of this preliminary feasibility analysis, the off-line raw water reservoir is included because a reservoir will be necessary to meet the minimum streamflow criteria established for this investigation. However, the cost of the off-line reservoirs will be tracked separately so that alternatives that do not include this component can be evaluated by SJRWMD if desired.

Water Treatment Plant

The conventional water treatment plant capacity is set equal to 95 percent of the raw water diversion capacity. The small difference between the diversion capacity and treatment capacity allows some capability to refill the off-line reservoir, while at the same time operating the water treatment plant at full capacity.

If desalting is required, it is assumed that RO treatment will be provided following conventional surface water treatment. The required RO treatment capacity will vary with each candidate withdrawal site, depending on water quality characteristics (including variability) of the raw water. In each case, the RO treatment capacity is expressed as a percentage of the conventional treatment capacity (from 0 to 100 percent). Where desalting is required, a split-stream treatment system will be provided because the degree of desalting required could vary significantly with river flow or other factors. When surface water supply sources have variable raw water quality, this type of operational flexibility is essential to successful development.

Treated Water ASR System

The ASR system consists of a wellfield into which excess treated water is injected for ultimate withdrawal and distribution as needed. Volumetrically, the ASR storage capacity is considered unlimited. However, the hydraulic capacity of the ASR wellfield determines the rate at which water can be injected and recovered. In general, the required recovery rate will control the size of the ASR facilities.

For the purpose of the facility requirements simulation, ASR injection or recovery capacity should not limit the reliability of the water supply system. That is, sufficient ASR facilities will be constructed to maximize the reliability of the water treatment plant, which is the facilities component with the greatest cost. Therefore, ASR injection capacity was set equal to treatment plant capacity, and ASR recovery capacity was set equal to 1.5 times the potential yield for the corresponding diversion capacity. By doing so, ASR capacity will not limit the reliability of the simulated water supply systems.

Once treatment plant capacity and a corresponding net reliable yield are determined after the simulation and treatment requirements analysis, the required ASR capacity can be computed directly, based on these values. The injection capacity will be equal to the maximum amount available for injection, which is equal to the treatment plant capacity minus the minimum monthly demand. On the other hand, the maximum recovery rate is based on delivering the maximum demand with the treatment plant shut down. Therefore, based on a maximum day demand equal to 1.5 times the ADD, the ASR withdrawal rate will also be equal to 1.5 times the ADD. In this way, the ability to meet peak demands is fully satisfied by the ASR system. The ability to meet long-term demands and fill the ASR storage area must be met by upstream diversion and treatment components.

FACILITY REQUIREMENTS SIMULATION RESULTS

The simulation results indicate that reliable gross water supply yields approaching the potential yield can be developed for most candidate withdrawal sites. In general, the gross reliable yield is equal to about 95 percent of the potential yield. This is true for all sites except the St. Johns River near Jacksonville, where adverse hydrologic characteristics result in a gross reliable yield of only 72 to 78 percent of the potential yield.

If there were not appreciable wastewater generated by the water treatment process, then the gross reliable yield would equal the net reliable yield. Net reliable yield, as used in this application, is the water actually delivered to the distribution system, while gross reliable yield is the water diverted from the stream and processed by the water supply facilities. Gross reliable yield is identified by application of the water supply systems simulation.

For conventional surface water treatment systems, volumetric losses are generally in the range of 2 to 8 percent of the total raw water inflow. The volume of wastewater generated will vary with the characteristics of the sludge produced and the dewatering system provided to treat the sludge. For the purpose of this preliminary feasibility analysis, a loss of 5 percent is assumed. This means that the volume of treated water produced by the conventional treatment components is assumed to be equal to 95 percent of the total raw water volume diverted for treatment.

For that portion of the diverted flow requiring desalting using RO technology, volumetric losses can be more significant. The waste residual, which is the concentrate produced in the desalting process, ranges from about 15 percent of the flow treated by the RO component to more than 50 percent, depending on the quality of the raw water.

Therefore, the gross reliable yield identified by application of the long-term water supply systems simulation must be adjusted, based on treatment requirements and raw water quality variability considerations to establish net reliable yield. Thus, net reliable yield, water quality characteristics, and treatability are interrelated.

WATER QUALITY AND TREATMENT REQUIREMENTS

Table 2 presents a summary of the water quality characteristics for previously selected parameters for five USGS gauging stations of interest to this investigation. The summary provided includes the average, standard deviation, maximum value, minimum value, and number of observations for each parameter for each gauge.

Each candidate withdrawal site corresponds directly to a gauging station, with the exception of the St. Johns River at Sanford. The St. Johns River near Titusville is the nearest upstream station to Sanford and is considered to be most representative. Therefore, water quality data for Titusville is also used to characterize expected water quality at Sanford.

Table 2. Water Quality Characteristics at Candidate Withdrawal Points

	Water Temperature (deg C)	Turbidity (JTU)	Color (PT-CO)	pH	Alkalinity (mg/L $CaCO_3$)	Ammonia (mg/L NH_3)	Nitrate (mg/L NO_3-N)	Total Organic Carbon (mg/L)	Hardness (mg/L $CaCO_3$)	Chloride (mg/L)
Haines Creek at Lisbon FL (2238000)										
Average	23.7	18	36	7.3	101.5	0.0070	0.0075	18.5	16.1	24
Standard Deviation	5.3	15	40	0.5	10.7	0.0082	0.0150	8.1	6.6	5
Maximum	32.3	45	150	8.7	134	0.016	0.03	34	25	40
Minimum	11.0	5	5	6.7	77	0	0	0	2	17
Number of Observations	86	7	26	25	25	5	4	12	21	25
St. Johns River near Cocoa (2232400)										
Average	23.4	5	107	7.1	36.7	0.0030	0.0642	22.2	76.9	127
Standard Deviation	5.9	3	46	0.4	17.0	0.0063	0.2110	8.3	81.1	135
Maximum	80	20	420	9.2	115	0.03	1.4	49	570	960
Minimum	8.5	1	3	5.1	13	0	0	0.1	8	18
Number of Observations	293	39	341	379	294	37	45	39	325	334
St. Johns River near Christmas* (2232500)										
Average	23.4	7	119	7.0	45.2	0.0052	0.1098	20.2	154.2	280
Standard Deviation	7.7	4	80	0.4	22.6	0.0174	0.2867	5.0	134.8	245
Maximum	79	12	700	8.2	120	0.09	1.8	26	672	1150
Minimum	6.5	1	35	5.8	17	0	0	12	21	37
Number of Observations	109	11	96	125	95	26	45	6	90	96
St. Johns River near De Land (2236000)										
Average	24.1	6	98	7.3	61.8	0.0028	0.1890	20.7	124.9154	241
Standard Deviation	6.7	3	67	0.5	22.0	0.0046	0.2604	9.4	48.13225	86
Maximum	81	10	500	8.7	133	0.024	1.1	46	312	570
Minimum	10.5	1	12	6.2	2	0	0	6.5	46	0
Number of Observations	159	11	134	188	159	51	39	23	130	173
St. Johns River at Jacksonville (2246500)										
Average	22.17787	9	76	7.3	68.6	0.0019	0.2208	12.2	1316.173	3551
Standard Deviation	5.244494	4	55	0.4	17.0	0.0021	0.0968	6.4	1088.345	3164
Maximum	31	20	400	8.2	98	0.008	0.4	21	3300	11000
Minimum	11.5	1	12	6.6	33	0	0.01	0	52	71
Number of Observations	122	45	60	73	47	13	39	11	52	104

JTU = Jackson Turbidity Units.
PT-CO = Platinum Cobalt Units.
*Assumed to be applicable at Titusville and Sanford withdrawal sites.

For this preliminary feasibility investigation, the available water quality parameter of most concern is the chloride concentration reported in the last column of Table 2. The magnitude and variability of the chloride concentration will define in large part the degree of RO treatment required. This, in turn, will impact the net reliable yield and, eventually, the cost of developing the candidate water supply source.

The only truly fresh water source is Haines Creek. The maximum observed chloride concentration is 40 milligrams per liter (mg/L), well within the drinking water standard (DWS) of 250 mg/L. Development of this site would require only conventional surface water treatment consisting primarily of coagulation/sedimentation (clarification), filtration, and disinfection using ozone and chloramines.

Periodically, all the St. Johns River candidate withdrawal sites exceed the DWS for chlorides. Thus, each site would require desalting of at least part of the flow for part of the time. In each case, a split-stream treatment system is envisioned. In a split-stream treatment system, only a portion of the total flow would receive RO treatment on an as-needed basis. All flow would receive conventional treatment, similar to that required for the Haines Creek source. When the inflow exceeds 90 percent of the DWS for chlorides (0.9*250=225), then a portion of the inflow would also receive RO treatment so that the product water does not exceed 225 mg/L. Product water is the treated water that actually enters the distribution system and is delivered to the consumer.

As can be seen in Table 2, chloride concentration generally increases in a downstream direction. Mean chloride concentration ranges from 127 mg/L near Cocoa to more than 3,500 mg/L above Jacksonville. However, the water quality at De Land is slightly better and much less variable than the water quality near Titusville, probably because of the influence of the Wekiva River, which contributes significant high quality flow between theses two stations. Because both Titusville and Sanford are upstream of the Wekiva River, the Titusville data were selected as most representative of conditions at Sanford.

Using the water quality summaries in Table 2, conceptual treatment requirements for each candidate withdrawal site were established and are reported in Table 3. All the sites will require conventional surface water treatment, including chemical-aided sedimentation, filtration, and disinfection. In addition, all of the St. Johns River candidate withdrawal sites will require varying degrees of RO treatment. For the purpose of this preliminary feasibility analysis, RO treatment is

Table 3. 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%)
St. Johns River near Jacksonville	✓	✓				✓ (100%)	✓ (55%)

[a]All water treatment systems will require sludge thickening and dewatering facilities, finish water transfer pumping, ground storage tankage, disinfection (ozone) and miscellaneous facilities including 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

grouped into the following four major classifications, which are based on maximum expected chloride concentration:

- **Slightly brackish.** This classification applies when the maximum chloride concentration is less than 500 mg/L. For this application, the RO removal efficiency (salt rejection) is anticipated to be 90 percent and the concentrate volume is anticipated to be about 15 percent of the treated inflow.
- **Moderately brackish.** This classification applies when the maximum chloride concentration is greater than 500 mg/L, but less than 1,000 mg/L. RO removal efficiency is expected to be about 90 percent and the concentrate volume will be about 20 percent of the treated inflow.
- **Highly brackish.** This classification applies when the maximum chloride concentration is greater than 1,000 mg/L, but less than 5,000 mg/L. Expected RO removal efficiency is about 90 percent and concentrate volume is about 30 percent of the treated inflow.
- **Saline.** This classification applies when the maximum chloride concentration is greater than 5,000 mg/L. The expected RO removal efficiency is greater than 98.5 percent and the concentrate volume is about 55 percent of the treated inflow.

These classifications are conceptual only; actual RO removal efficiencies and concentrate volumes may vary considerably with additional planning and preliminary design analysis. However, these values are considered appropriate for the purpose of initial feasibility evaluation and cost estimating.

As can be seen from Table 3, the St. Johns River near Cocoa is slightly brackish. Most of the time, raw water will be well within the DWS for chloride. However, the maximum chloride concentration of the diverted flow is expected to be about 400 mg/L. Flow with the highest chloride concentration (up to 570 mg/L) is associated with low river flow and will not be diverted, based on the previously established diversion rule. Therefore, under worst-case operating conditions, only about 50 percent of the diverted flow would require desalting.

Under average or normal operating conditions, most flow would not require desalting. Over the long-term, only about 2 to 3 percent of the diverted flow would become waste concentrate, and the maximum concentrated flow rate would equal approximately 7.5 percent of the conventional treatment capacity. The net reliable yield is estimated to be about 98 percent of the gross reliable yield.

The next three sites (Titusville, Sanford, and De Land) are similar. Each is considered moderately brackish, with maximum raw water chlorides greater than 500 mg/L, but less than 1,000 mg/L. The split-stream treatment described previously for the Cocoa site would also apply to these sites. The estimated required RO capacity ranges from 63 to 67 percent of the conventional treatment capacity and the maximum concentrate flow would be on the order of 13 percent of the total conventional treatment capacity. Net reliable water supply yield for these three sites will be about 94 to 95 percent of the gross yield, with only 5 to 6 percent of the diverted flow becoming waste concentrate.

The final candidate withdrawal site, the St. Johns River near Jacksonville, has poor water quality characteristics. Net outflow at this point can be relatively good quality fresh water, or it can be sea water or a mixture of the two. Chlorides have ranged from 71 mg/L to 11,000 mg/L. Chloride concentrations can also be high at any flow rate. Sea water will flow upstream during incoming tides and be part of the outflow on the outgoing tide. The Jacksonville site is considered saline, because the diverted raw water will often exceed 5,000 mg/l chlorides, and would require construction of sea water RO facilities. Over the long term the reliable net yield would be about 65 percent of the reliable gross yield. That is, about 35 percent of the total diverted flow would become waste concentrate.

Given the very poor hydrologic and water quality characteristics of this site and the expensive and relatively under-used facilities required to develop the potential water supply, this site is not considered a feasible surface water supply alternative and should not be evaluated in future phases of the SJRWMD alternative water supply investigations.

These adverse hydraulic and water quality conditions apply only to the downstream portion of the main stem of the St. Johns River. It is possible that tributaries to the lower St. Johns River could be developed as viable water supply sources if the withdrawal sites are located above tidal influence or behind constructed salinity barriers. Candidate watersheds may include Black Creek in Clay County or Deep Creek in St. Johns County. Evaluation of these hydrologic systems would be hampered, however, by a lack of basic long-term streamflow and water quality data.

RELIABLE NET YIELD AND FACILITY REQUIREMENTS

The results of the long-term systems simulation and the water quality and treatment requirements analysis were used 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 that yield, are reported in Table 4.

There are six reliable yield estimates and six water supply systems defined for each of the candidate water withdrawal sites. For example, at the Lake Griffin site, reliable yields of up to 28 mgd could be developed. Facilities required to develop the maximum 28-mgd yield include a 40-mgd water diversion structure, a 38-mgd conventional water treatment plant, and a 42-mgd ASR system. An off-line raw water reservoir with a 200-million-gallon (MG) capacity would also be needed. This water supply system will fully meet the desired monthly demand at least 98.3 percent of the time.

As previously discussed, the planned minimum flow and levels analysis for Lake Griffin may further restrict the reliable net yield available from this candidate withdrawal point. Therefore, to provide a relatively conservative estimate of Lake Griffin water supply potential, the maximum net reliable yield to be evaluated in the University of Florida decision model will be limited to 50 percent of the maximum net reliable yield estimated in this analysis, or 14 mgd (0.5 x 28).

If Lake Griffin appears to be a desirable water supply source, as determined by application of the University of Florida decision model, then it may be necessary to re-evaluate Lake Griffin facility requirements and costs. This re-evaluation would be based on a new diversion rule established after the planned minimum flows and levels analysis is complete.

The St. Johns River sites would require additional facilities. The maximum reliable net yield for the St. Johns River at Sanford is about 279 mgd. To fully develop this yield, substantial facilities would be required including a 392-mgd river diversion structure, a 2-billion-gallon off-line storage reservoir, a 372-mgd conventional water treatment plant, a 223-mgd RO treatment facility, a 419-mgd ASR system, and a 45-mgd concentrate disposal system.

The data reported in Table 4 can be used to estimate the approximate facility requirements for any desired yield at any of the candidate withdrawal sites by linear interpolation. Figures 22 through 27 illustrate the relationship between net reliable yield and required facilities for each of the six candidate withdrawal sites.

Table 4. 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
f) St. Johns River above Jacksonville					
75.1	245.8	233.5	221.8	112.6	122.0
152.1	491.7	467.1	443.8	228.1	244.1
229.1	737.5	700.6	665.6	343.8	366.1
302.7	983.3	934.1	887.4	454.0	488.1
381.0	1,229.2	1,167.7	1,109.4	571.5	610.1
418.9	1,475.0	1,401.3	1,331.2	628.3	732.2

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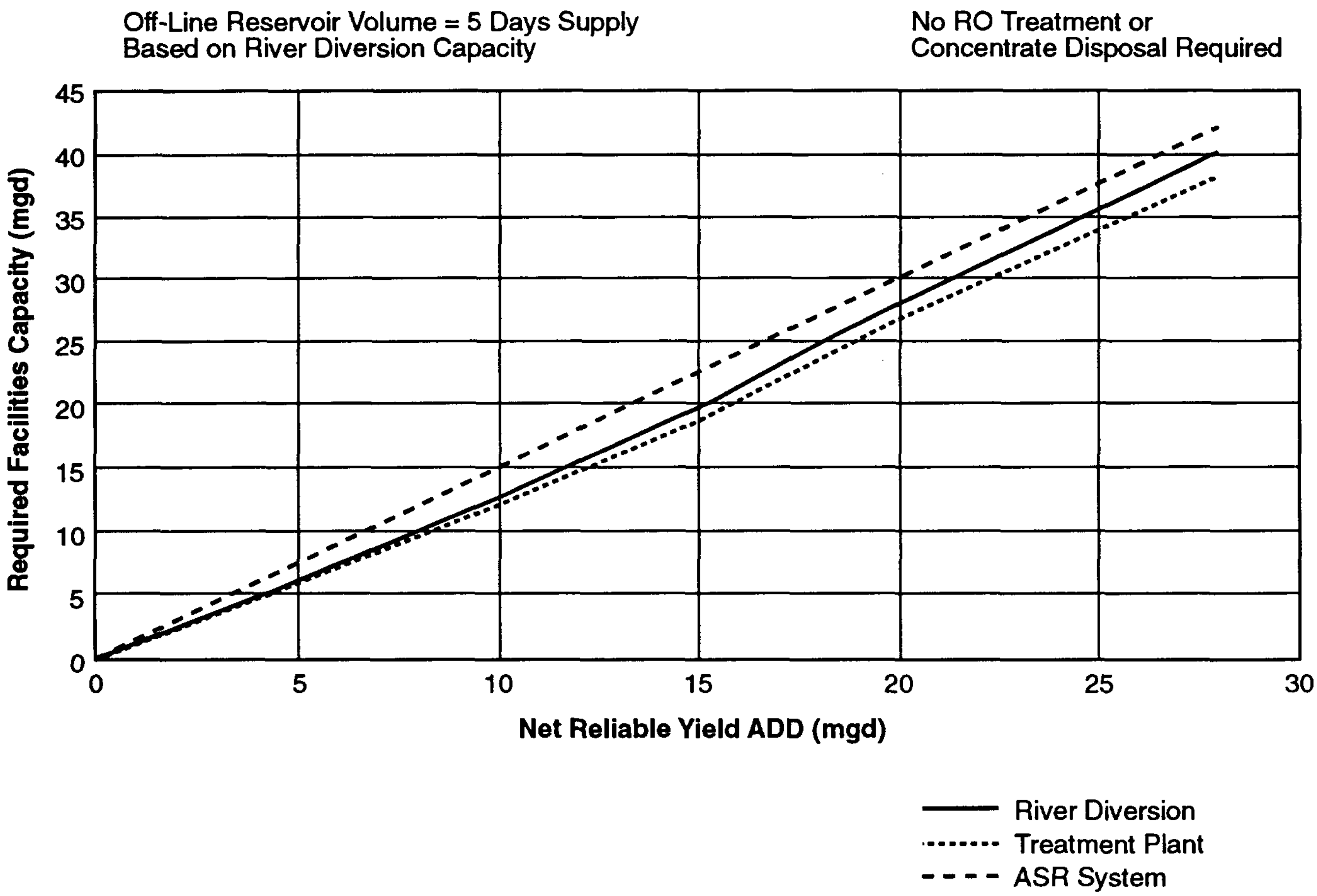

Figure 22. Surface Water Facility Requirements for Lake Griffin (Haines Creek).

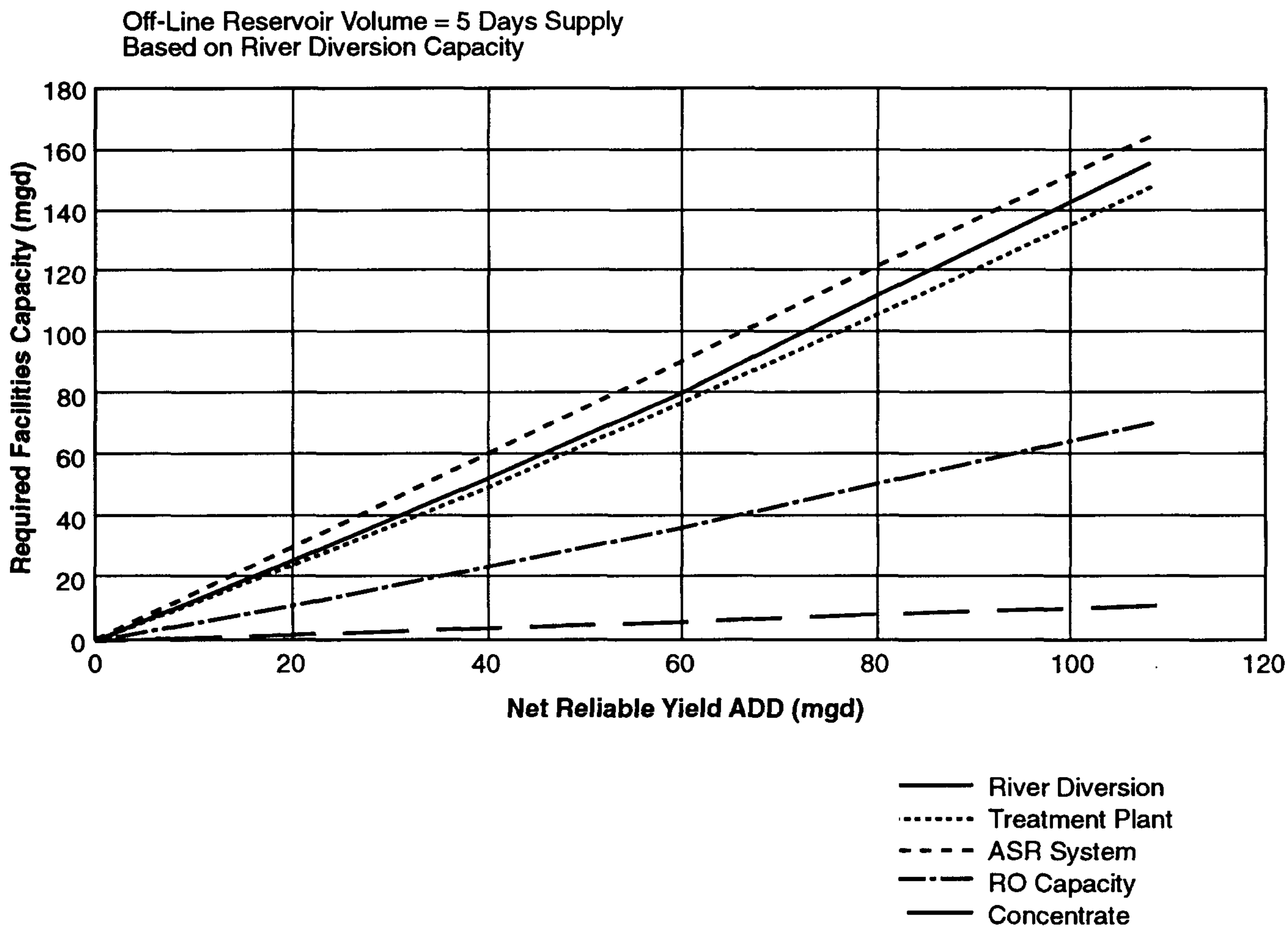

Figure 23. Surface Water Facility Requirements for St. Johns River near Cocoa.

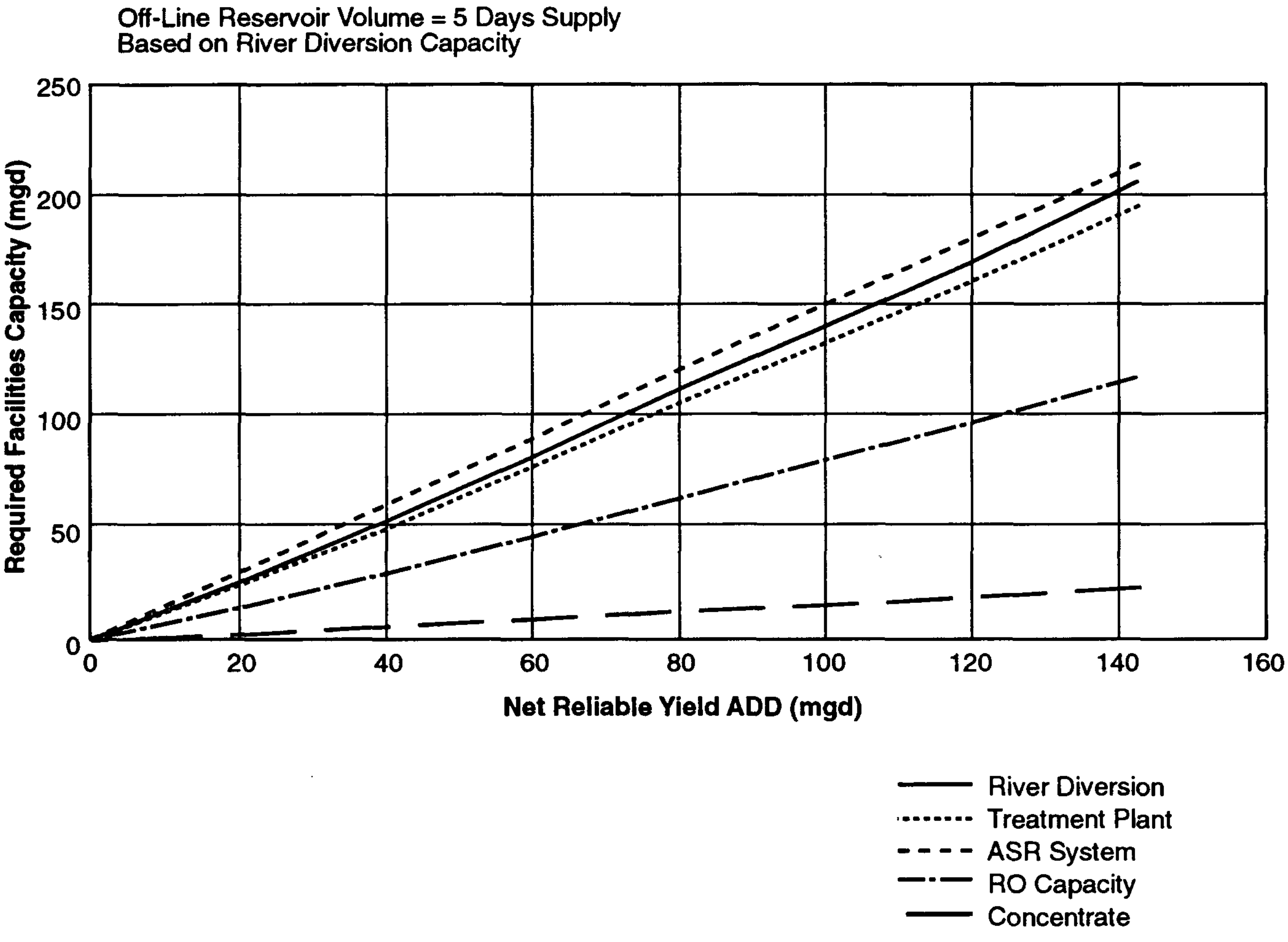

Figure 24. Surface Water Facility Requirements for St. Johns River near Titusville.

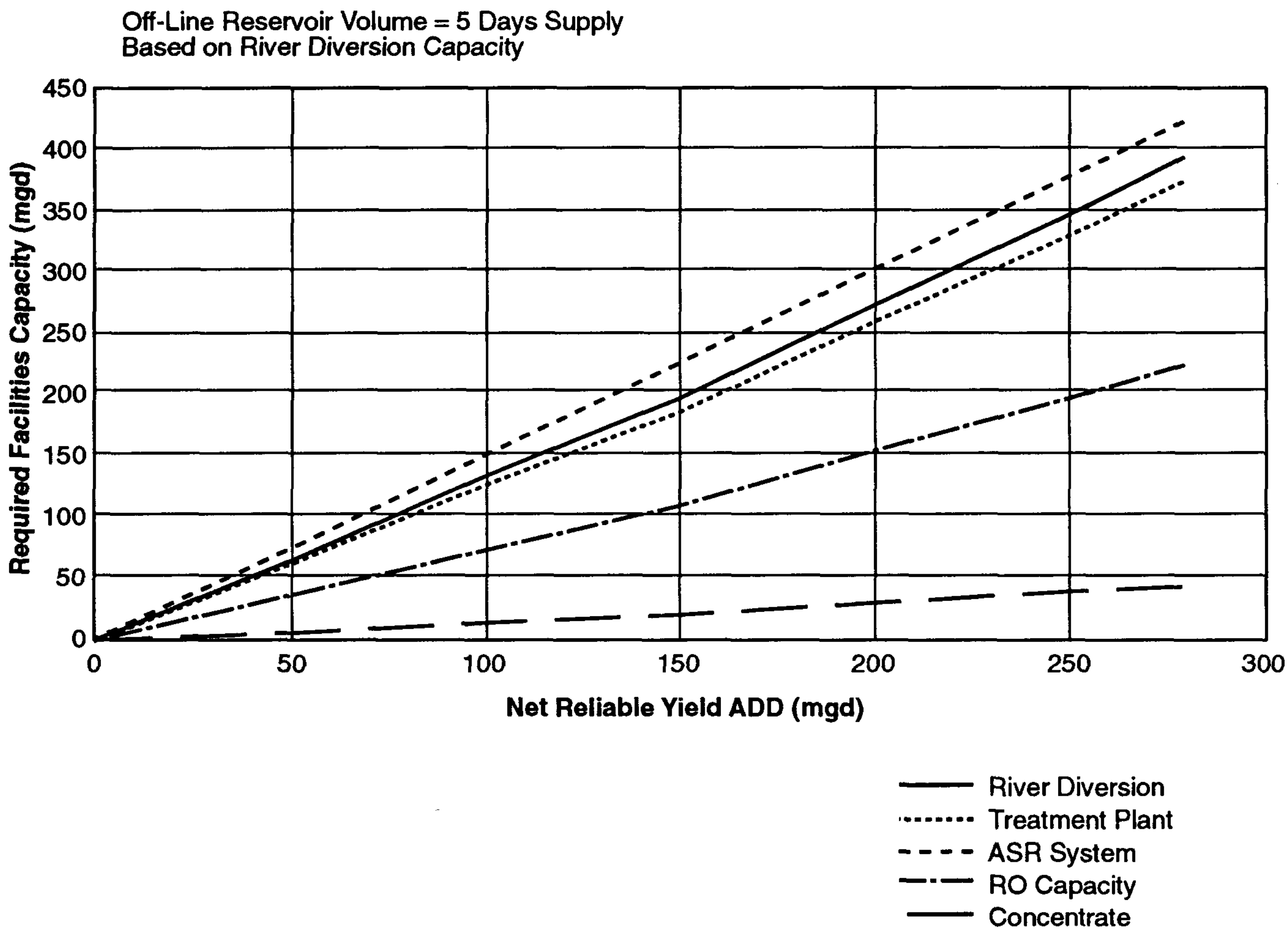

Figure 25. Surface Water Facility Requirements for St. Johns River at Sanford.

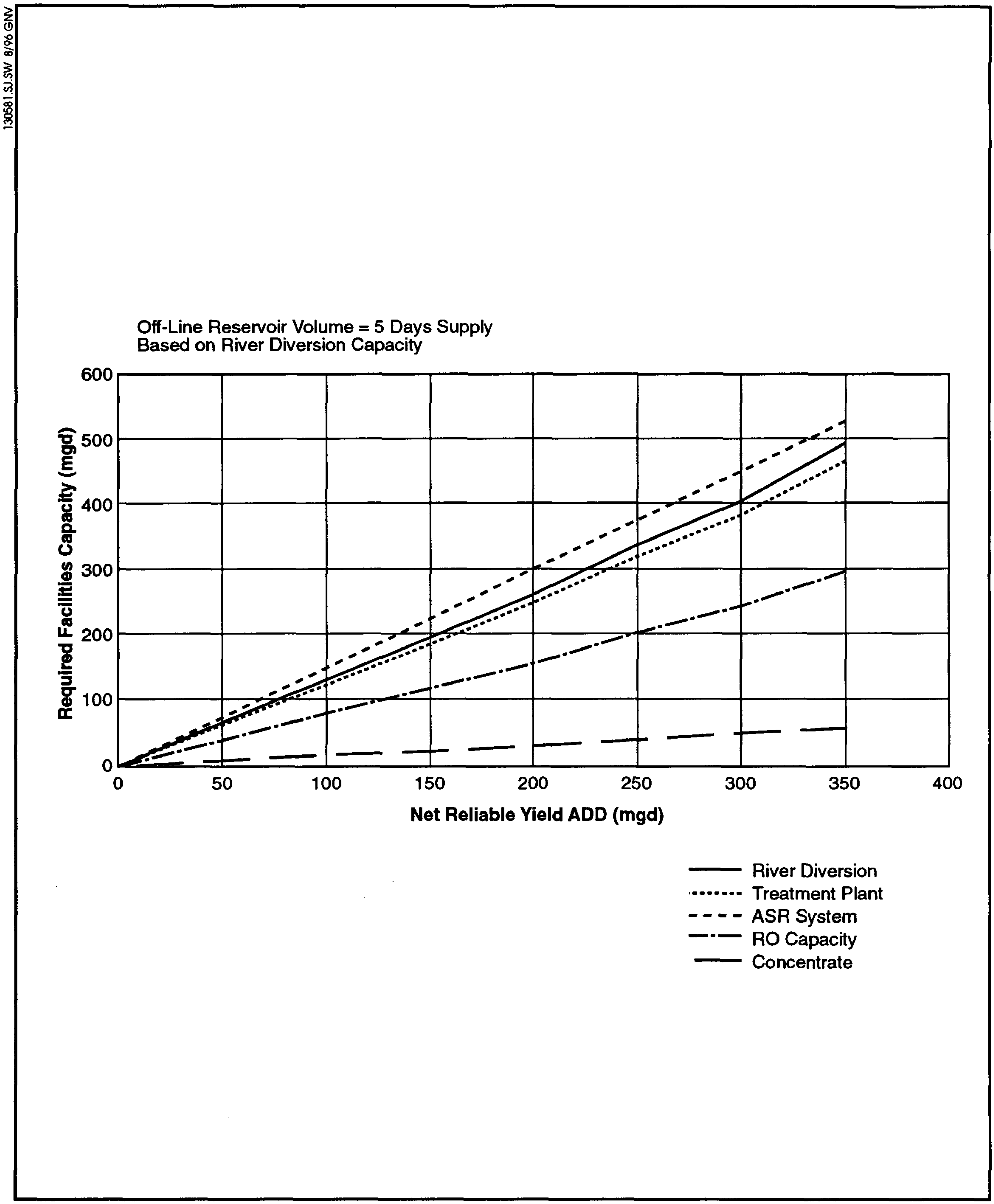

Figure 26. Surface Water Facility Requirements for St. Johns River near De Land.

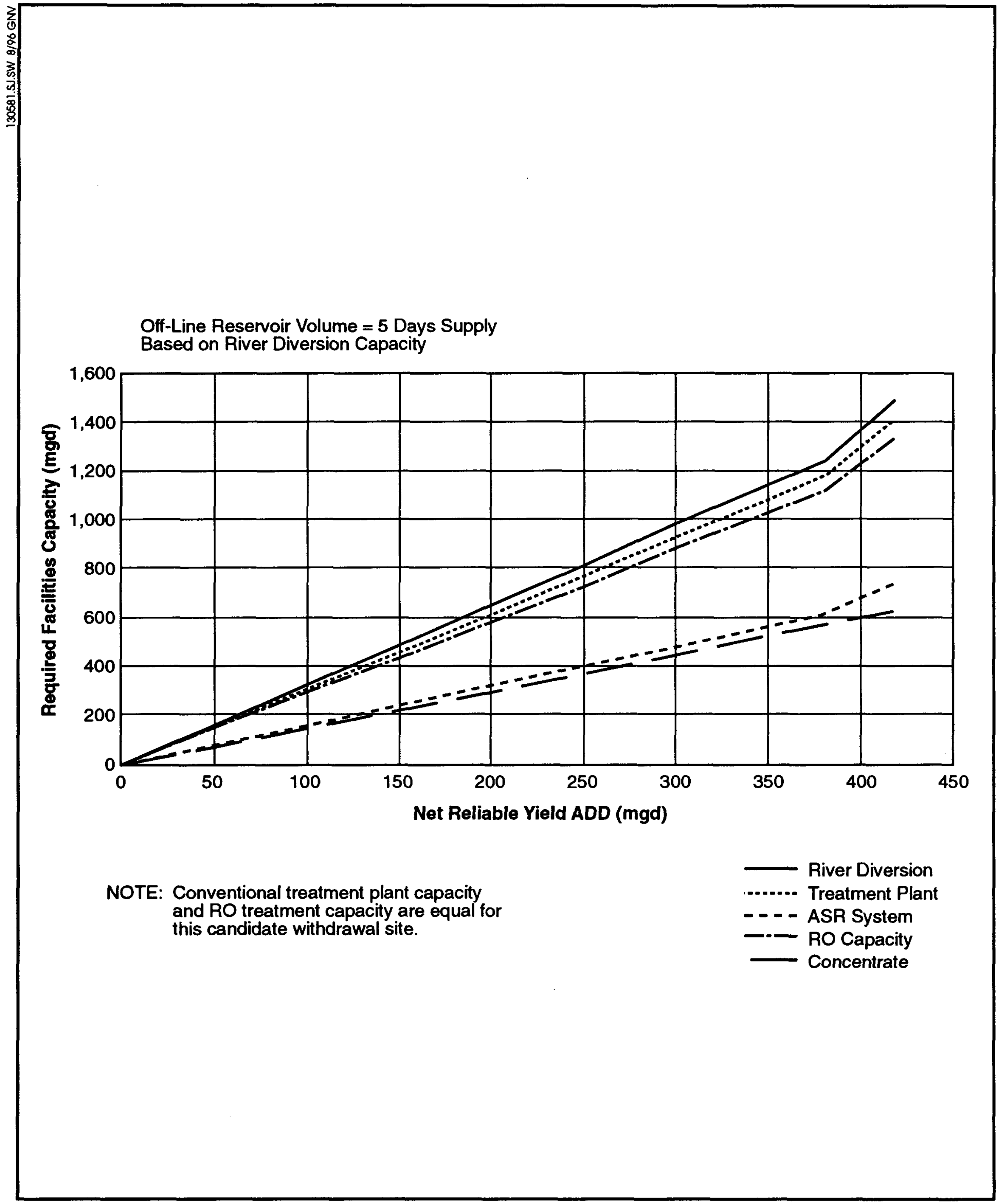

Figure 27. Surface Water Facility Requirements for St. Johns River above Jacksonville.

PROPOSED COST ESTIMATION PROCEDURE

The surface water supply cost estimates will include development of a complete array of planning-level cost estimates for six different size facilities at five different candidate withdrawal sites. Cost functions for each withdrawal site (net reliable yield [ADD] vs. cost) will also be developed and a TM will be produced to report the methods used and results obtained.

SITES CONSIDERED

All candidate surface water withdrawal sites, with the exception of the St. Johns River above Jacksonville, will be included in the cost estimating phase of the investigation. As discussed previously, the Jacksonville site does not provide a practical alternative for municipal water supply development.

COST PARAMETERS AND CRITERIA

Cost parameters to be considered have been previously established by the project team and include the following:

- Construction cost
- Non-construction capital cost
- Land cost
- Land acquisition cost
- Total capital cost
- Operation and maintenance (O&M)
- 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 investigations. These previously established criteria will be used to develop the required cost estimates for the surface water facilities.

CONSTRUCTION AND O&M COST COMPONENTS

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

- River diversion structure
  - intake structure
  - bar screen
  - pumping station
  - raw water transmission to off-line reservoir
- Off-line raw water reservoir
  - perimeter levee
  - emergency spillway
  - site preparation
- 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 membranes
  - chemical addition
  - concentrate disposal system (deep wells)
- ASR system
  - wells
  - pumps
  - piping and I&C

Applicable cost curves will be identified in the literature. Where necessary, cost curves or unit costs for individual items (e.g., filtration) or major systems (e.g., conventional surface water treatment) will be developed. Using the identified or developed construction and O&M

cost curves, a spreadsheet application will be developed. This spreadsheet will be used to develop the required cost estimates for six different water supply yields at the five candidate withdrawal sites. The facility capacities to be used in the cost estimating procedure are presented in Table 4, parts a through e.

LAND COSTS

Land requirements will be estimated for the off-line raw water storage reservoir, the water treatment plant, and ASR wellfield. Total land costs, including the cost of acquisition, will then be estimated, based on the estimated total land requirement for each of the 30 facilities considered.

OTHER COST ESTIMATES

Other cost parameters, including total capital cost, equivalent annual cost, set-up cost, and unit cost, will be estimated, based on the construction, land, and O&M costs computed for each facility. These cost estimates will be included in the cost estimating spreadsheet and will be developed in accordance with the cost estimating guidelines and economic criteria established for the SJRWMD alternative water supply investigations.

COST FUNCTIONS

The cost analysis will result in the development of estimated costs for each of the eight cost parameters for six different water supply systems at each of the five candidate water supply withdrawal sites. These individual cost estimates will be used to develop cost equations for each cost parameter applicable to the individual withdrawal sites. The resulting cost equation will likely have the following general form:

$$COST_{(p,l)} = a_{(p,l)} + b_{(p,l)} * RNY^{c(p,l)}$$

Where:

$COST_{(p,l)}$ = estimated cost of parameter p, at withdrawal site location l, in total dollars or dollars per year, depending on the units of the cost parameter.

RNY = reliable net water supply yield in mgd. This is also the ADD delivered to distribution.

$a_{(p,l)}$ $b_{(p,l)}$ and $c_{(p,l)}$ are best fit parameters for each equation as determined by regression analysis.

To provide added flexibility, the costs associated with the off-line raw water reservoir will be considered separately from the other water supply system components, including the river diversion structure, the water treatment plant, and the ASR system. Surface water supply system costs with and without the reservoir component may then be evaluated if desired.

These equations may be used to estimate any cost parameter for any desired water supply yield, within the range investigated, for each candidate withdrawal site. These equations will be used in the University of Florida Decision Model to define the cost characteristics of the surface water supply alternative.

TECHNICAL MEMORANDUM

A TM reporting the methods and results of the surface water supply cost estimating and cost equation development will be prepared.

SUMMARY AND RECOMMENDATIONS

SUMMARY

This preliminary surface water availability and yield analysis addresses the municipal water supply development potential of six previously selected candidate surface water supply withdrawal sites (CH2M HILL, 1996b). The locations of the six sites are as follows:

- 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
- St. Johns River above Jacksonville

In evaluating these sites, similar analyses were conducted that included the following elements:

- Development of flow duration curves
- Determination of minimum streamflow requirements and maximum water supply withdrawal rate
- Evaluation of the effect of water supply withdrawal on the flow duration relationship
- Evaluation of the potential water supply yield as a function of maximum installed withdrawal capacity
- Determination of streamflow water quality characteristics and water treatment requirements
- Estimation of the type and size of water supply facilities required as a function of the total reliable water supply yield developed

Flow Duration Analysis

There were two primary objectives for the streamflow duration analysis. First, the flow duration curves for each candidate withdrawal site were established to determine the frequency of allowable water supply diversion, the minimum streamflow requirements, and the maximum diversion rate to be investigated.

For this project, minimum streamflow requirements are defined as the positive streamflow rate observed 95 percent of the time. Using this rate, at least 5 percent of the time (during low-flow periods) water supply withdrawal will not be allowed. In addition, the maximum withdrawal rate considered is equal to 25 percent of the long- term average flow rate. Lesser withdrawal rates are also considered.

These minimum streamflow and maximum diversion rate criteria, as well as the source evaluation methodologies in this TM, were previously established for the purpose of this preliminary feasibility analysis (CH2M HILL, 1996a). If these criteria change, then all facility requirements reported in this TM will also change. This is because surface water facility requirements are a direct function of the allowed diversion criteria; thus, the results reported in this TM are valid only for the previously selected diversion criteria.

Once the withdrawal parameters were established, the maximum effect on the flow duration relationship for each candidate withdrawal site was investigated. From this effort, it was determined that there are little noticeable effects if the entire streamflow regime is considered. However, if only the normal and low-flow portions of the streamflow regime are considered, the water supply withdrawal effects are more apparent. The water supply withdrawal tends to flatten the flow duration curve at moderate flow rates. At flow rates less than the minimum withdrawal rate, the flow duration relationship would be unchanged because water supply diversion would not be allowed.

Potential Yield Analysis

The objective of the potential yield analysis is to establish a relationship between the installed river diversion capacity and the maximum long-term volume of water that may be withdrawn for water supply. This parameter is termed potential yield because it represents the maximum possible water supply yield, if sufficient storage and treatment facilities are constructed to fully use the diverted flow and assuming there is no waste in the treatment process.

The maximum potential yield for the Lake Griffin site is approximately 75 percent of the maximum diversion capacity. For the four upstream St. Johns River sites (Cocoa to De Land), the maximum potential yield ranges from 81 to 84 percent of the installed maximum diversion capacity. For the downstream St. Johns River site (above Jacksonville), the maximum potential yield is only 64 percent of the maximum installed diversion capacity.

Surface Water Supply Facility Requirements

Facilities required to develop the surface water supply at each candidate withdrawal site were determined by a combination of facilities simulation and water quality and treatability analyses. In each case, required facilities included the following:

- River diversion structure
- Off-line raw water storage reservoir
- Water treatment plant
- ASR system

The simulation analysis estimates the gross reliable yield, which could be developed for each site for a selected array of facility sizes. The water quality and treatability analysis established the treatment processes needed in the water treatment plant component of the water supply system. Also, the analysis provides a preliminary quantitative estimate of the wastewater volume produced. These volumetric losses include losses associated with conventional surface water treatment, as well as the waste concentrate produced by the required desalting. The total volumetric loss must be subtracted from the system gross yield to obtain the net reliable yield, which is the final estimate required. The net reliable yield is defined as the average daily demand that can be reliably delivered to the distribution system by the surface water supply facilities.

The results of the water availability and yield analysis are summarized in Table 5. Lake Griffin is the only true freshwater site among the candidate withdrawal sites considered. Desalting will not be required at this site and a waste concentrate stream will not be produced. Therefore, the estimated maximum reliable yield for the Lake Griffin withdrawal site, 28 mgd, is nearly equal to the maximum potential yield of 30 mgd.

The planned SJRWMD minimum flow and levels analysis for Lake Griffin may further restrict the reliable net yield. Therefore, to provide a relatively conservative estimate of Lake Griffin water supply potential, the maximum net reliable yield, to be evaluated by the University of Florida decision model, will be limited to 50 percent of the maximum net reliable yield estimate in this analysis, or 14 mgd (0.5 x 28).

Table 5. Water Supply Availability and Yield Analysis Results Summary

Candidate Water Supply Withdrawal Site	Average Annual Streamflow cfs (mgd)	Maximum Diversion Rate (mgd)	Maximum Potential Yield (mgd)	Maximum Reliable Yield (mgd)
Lake Griffin (Haines Creek)	248 (160)	40	30	28[a]
St. Johns River near Cocoa	958 (619)	154	124	108
St. Johns River near Titusville	1,273 (823)	206	166	143
St. Johns River at Sanford	2,425 (1,568)	392	331	279
St. Johns River near De Land	3,043 (1,967)	492	415	351
St. Johns River above Jacksonville	9,129 (5,901)	1,475	953	419

Note: The maximum yield values for the St. Johns River sites are not independent. These values represent cumulative amounts for the candidate withdrawal site and all upstream sites. For example if a 100-mgd reliable water supply were developed near Titusville the maximum reliable yield at De Land would be reduced by 100 mgd from 351 mgd to 251 mgd.

[a]Maximum reliable yield for Lake Griffin considered in the University of Florida decision model will be limited to 70 percent of this value or 19.6 mgd.

The four upstream St. Johns River candidate withdrawal sites (Cocoa to De Land) are similar to each other. The worst-case water quality diverted for use at these sites is classified as either slightly or moderately brackish. Under many flow conditions, desalting will not be required. However, some desalting would be required for some of the diverted flow. Also, a waste concentrate would be produced, reducing the net reliable yield to about 108 mgd to 351 mgd, or about 85 percent of the maximum potential yield. Concentrate volume would be on the order of 5 percent of the total diverted flow.

The final candidate withdrawal site, the St. Johns River above Jacksonville, has poor water quality characteristics because of significant tidal mixing. The worst-case water quality at this site is saline or near seawater conditions, with observed chloride concentrations of more than 10,000 mg/L. This water would require extensive desalting, generating a large amount of concentrate. The estimated maximum reliable yield that could be developed at this location is only 44 percent of the maximum potential yield. About 35 percent of the diverted flow would become waste concentrate.

These adverse hydraulic and water quality conditions apply only to the downstream portion of the main stem of the St. Johns River. It is possible that tributaries to the lower St. Johns River could be developed as viable water supply sources if the withdrawal sites are located above tidal influence or behind constructed salinity barriers. Candidate watersheds may include Black Creek in Clay County or Deep Creek in St. Johns County. Evaluation of these hydrologic systems would be hampered, however, by a lack of basic long-term streamflow and water quality data.

RECOMMENDATIONS

It is recommended that five of the six candidate surface water withdrawal sites be considered further in the cost estimating phase of these investigations. These sites are as follows:

- 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

Because of its poor hydrologic and water quality characteristics, the sixth candidate withdrawal site, the St. Johns River above Jacksonville, should not be considered further. The results of this analysis indicate that this site is not a viable municipal surface water supply source. Thus, it is unlikely that this site would prove to be an economically viable municipal water supply source under any foreseeable set of withdrawal criteria or other operating conditions.

The cost estimating procedure recommended in this TM should be approved and applied to the five remaining candidate withdrawal sites.

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