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WATER SUPPLY NEEDS AND SOURCES ASSESSMENT ALTERNATIVE WATER SUPPLY STRATEGIES INVESTIGATION SURFACE WATER DATA ACQUISITION AND EVALUATION METHODOLOGY

by

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EXECUTIVE SUMMARY

St. Johns River Water Management District (SJRWMD) has determined that increased ground water withdrawals could adversely impact area water resources, especially wetland systems located near existing water supply wellfields. Because of these adverse impacts, SJRWMD has begun investigating the technical, environmental, and economic feasibility of alternative water supply strategies, including the development of additional surface water supplies.

This is the first of a series of technical memorandums (TMs) that addresses the feasibility of developing selected surface water sources to help meet future public supply needs. The major purpose of this TM is to review the water resources data available for the analysis and to develop a methodology for the quantitative evaluation. As part of the methodology development, the TM presents an overview of the factors affecting surface water supply development and discusses the types of facilities that may be required to develop a reliable municipal surface water supply.

The potential surface water sources included in this investigation are the St. Johns River, Haines Creek and the Palatlakaha Chain of Lakes. The St. Johns River will be evaluated as a potential source to meet a portion of the water supply needs in Volusia, Orange, St. Johns, Seminole, and northern Brevard counties. The Haines Creek/Palatlakaha Chain of Lakes hydrologic system will be evaluated as a potential source to meet water supply needs in Lake County.

Future surface water supply TMs will address withdrawal site selection and water availability and yield analysis. If surface water development is technically feasible, then costs associated with the surface water supply option will be estimated in future phases of the SJRWMD water supply planning process.

The following factors affect surface water supply development potential:

- Streamflow characteristics
- Minimum streamflow requirements and other withdrawal constraints
- Characteristics of the demands to be met
- Required system reliability

Unlike ground water, surface water sources can be highly variable in terms of both flow magnitude and water quality. To preserve the natural functions provided by streams, rivers and associated floodplains, a significant portion of the streamflow regime must be maintained. Therefore, only a small part of the resource will be available for water supply purposes.

The water supply demands to be met are often variable, and water demands usually are greatest during the dry season when streamflow rates are the lowest. For these reasons storage facilities often are required to reliably meet water supply demands.

Facilities required to develop a reliable municipal surface water supply within the SJRWMD may include a combination of the following components.

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

The objective of the surface water feasibility investigations is to define the relationship between reliable water supply yield and facility requirements for up to five selected candidate withdrawal points. This evaluation will be based, in large part, on existing streamflow and water quality records combined with well structured water supply systems simulation studies.

Streamflow and water quality records will provide the basis for the quantitative evaluation of surface water supply development potential. Streamflow records are the most important because these data will define the magnitude and variability of the potential source. The size of the water supply facilities will be controlled by streamflow characteristics, minimum flow regime, demand variability, and the required system reliability. Water quality characteristics will define treatment requirements and, therefore, will impact water supply development cost and economic feasibility.

Available records indicate that sufficient streamflow and water quality data are available to support this preliminary evaluation of surface water supply feasibility. There are seven U.S. Geological Survey (USGS) stream gauging stations with at least 10 years of daily streamflow records available within the Palatlakaha River/Haines Creek hydrologic system. There are six such stations located on the main stem of the St. Johns River. These streamflow records will provide an adequate basis for the water supply feasibility analysis.

The proposed evaluation methodology is based on continuous systems simulation studies. The water supply systems simulation is designed to simulate the long-term operation of a trial water supply system subject to a given set of monthly demands. The simulation will track the performance of the system as measured in terms of its reliability or ability to meet demands. The basic approach will be to define a number of trial water supply systems using appropriate components. Several sets of monthly demand arrays (small to large) also will be established. Each trial water supply system will be evaluated by the simulation relative to its ability to deliver the desired demands. The reliability of the trial system will be tracked for each demand array simulated. In this manner, relationships between facility size and water supply yield for the given system reliability, can be developed for each candidate raw water withdrawal point.

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INTRODUCTION

Municipal water supply within the St. Johns River Water Management District (SJRWMD) generally is provided for by high quality ground water. Several characteristics of SJRWMD's ground water resources make potable ground water the water supply source of choice. First, ground water is inherently reliable; an important attribute for municipal water supply. Second, treatment requirements and costs are often minimal because of the generally good-quality raw ground water. Third, if the resource is developed and managed properly, the quality of the raw ground water will not vary with time

To date, high quality, reliable, and inexpensive municipal ground water supplies have been developed within the SJRWMD. However, it is unlikely that all additional future municipal water supply needs can be provided by increased use of ground water resources without incurring unacceptable environmental impacts. Therefore, the SJRWMD has initiated investigations of the feasibility of alternative water supply strategies.

PROJECT BACKGROUND

The SJRWMD previously evaluated the potential impacts of increased ground water withdrawals through the year 2010 (Vergara, 1994). Based on this evaluation, SJRWMD has identified areas where water supply problems are now critical or will become critical in the future. Increases in ground water withdrawals could result in adverse impacts to area water resources. These adverse impacts include impacts to natural systems, ground water quality, and impacts to existing legal users.

Because of these existing and/or projected adverse impacts, SJRWMD is investigating the technical, environmental, and economic feasibility of alternative water supply strategies as a means of preventing the identified impacts. The SJRWMD-sponsored program includes investigations conducted by several consultants, including CH2M HILL, as well as other investigations being conducted by District staff.

Figure 1 illustrates the water supply options being considered for the SJRWMD. Major options available include increased supply, and demand reduction, and increased system storage to better manage existing supplies. For any area of critical concern, increased supply

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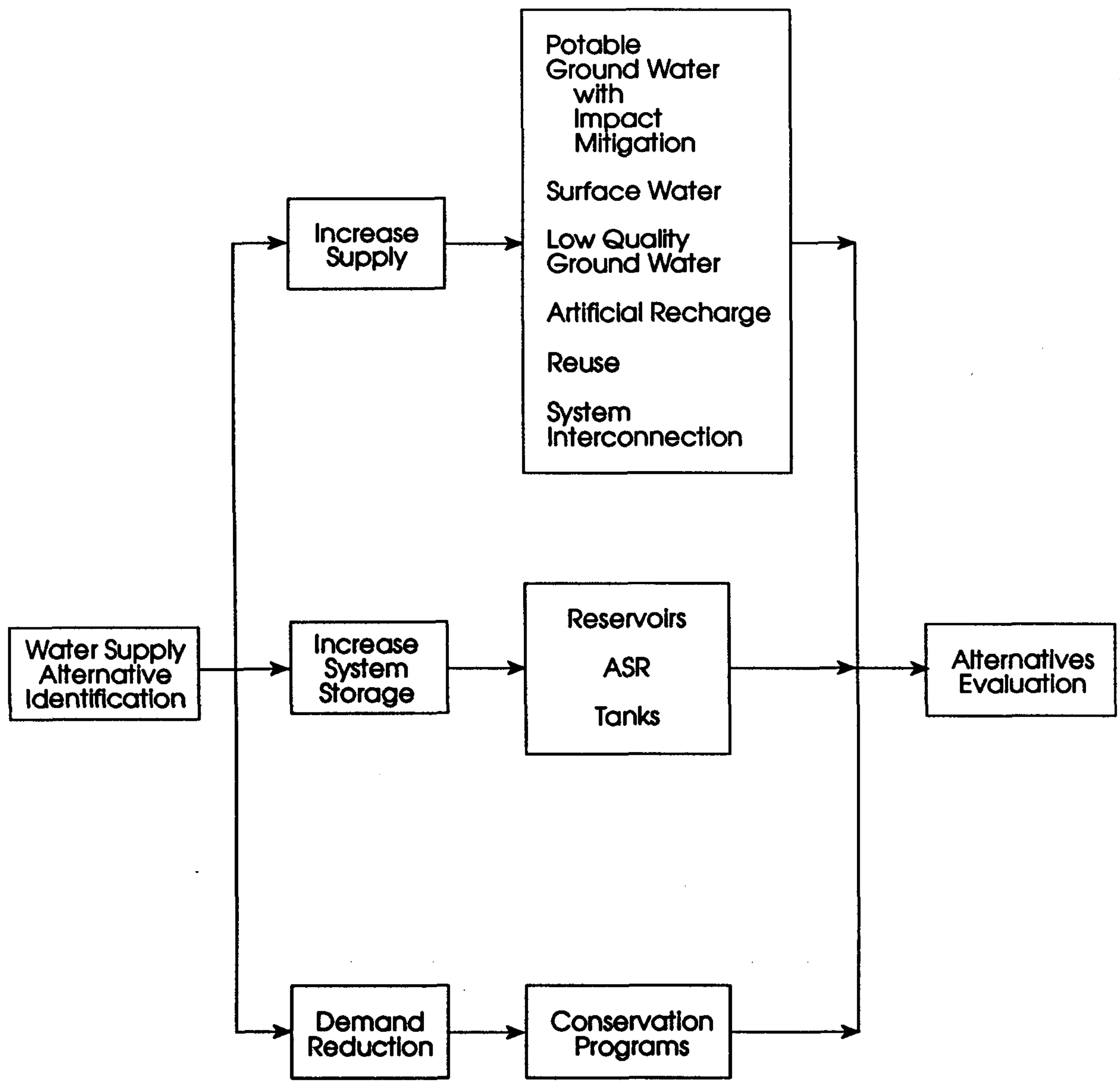


Figure 1. Water Supply Development Options for the SJRWMD.

options could include development of one or more of the following potential water supply sources:

- Potable ground water with mitigation of any adverse impacts
- Surface water
- Low quality ground water
- Artificial recharge
- Reuse of reclaimed water
- Water supply systems interconnections

Increased system storage could include the use of reservoirs, aquifer storage recovery facilities, or ground storage tanks. Demand reduction may be achieved by various water conservation initiatives. Some combination of increased supply, increased system storage, and demand reduction, in many cases, may provide the most environmentally acceptable and cost-effective future water supply systems.

This project is part of CH2M HILL's first phase of the required alternative strategies investigations. Included in the investigation are the following additional water supply sources or water management techniques, collectively referred to as "alternative water supply strategies."

- Surface water supply development
- Aquifer storage recovery (ASR)
- Development of lower-quality water sources
- Mitigation and avoidance of the impacts of ground water withdrawals

PURPOSE AND SCOPE

The purpose of the surface water feasibility investigations is to develop a preliminary evaluation of the quantities of water that may be developed from selected surface water sources to help meet future public demands. A preliminary evaluation of facilities requirements, as a function of the magnitude of the water supply developed, also will be addressed. If surface water is a reasonably feasible water supply alternative, then the cost of surface water supply development will be estimated in a future phase of this project.

Potential surface water sources included in this investigation are the St. Johns River, Haines Creek, and the Palatlakaha Chain of Lakes. The portions of the St. Johns River included are located above Crows Bluff (in Volusia County) and below Wolf Creek (in Brevard County) and in the vicinity of northern St. Johns County. The Haines Creek and Palatlakaha Chain of Lakes system, the headwaters of the Ocklawaha River, is located entirely in Lake County. These surface water bodies were chosen for evaluation because of their proximity to identified water resource caution areas, where projected future ground water withdrawals, if implemented, are expected to result in adverse impacts.

The St. Johns River will be evaluated as a potential source to meet a portion of the water supply needs in Volusia, Orange, Seminole, and northern Brevard counties, and in St. Johns County. The Haines Creek/Palatlakaha Chain of Lakes hydrologic system will be evaluated as a potential source to meet water supply needs in Lake County.

The surface water supply evaluation task is organized into the following three components, each of which will result in a technical memorandum documenting methods, assumptions, and results:

- Surface water data acquisition and development of the evaluation methodology
- Site selection
- Water availability and yield analysis.

This is the first technical memorandum (TM B.1.f) in a series discussing the feasibility of development of selected surface water sources to help meet future municipal water supply needs. The TM addresses background information and surface water resources data availability, and presents a methodology to be used in the quantitative evaluation of potential surface water yields and water supply facilities requirements. As part of the methodology development, this TM also presents an overview of the factors affecting surface water supply development and a discussion of the mix of facilities that may be required to develop a reliable municipal surface water supply.

METHODS

This TM was prepared by reviewing relevant literature, acquiring and reviewing available streamflow and water quality records, and developing the evaluation methodology. The surface water supply evaluation methodology is based on the results of the literature review, available data, and CH2M HILL experience in the preliminary evaluation of surface water supply potential in the State of Florida.

LITERATURE REVIEW

The purpose of the literature review is to locate relevant information that may be useful in evaluating surface water supply potential and facilities requirements for the stream segments of interest. Sources considered included reports published by SJRWMD; consultant reports, including in-house CH2M HILL reports, as well as reports prepared by other consultants; and technical reports prepared by State and Federal agencies.

Each document was initially screened for topics of potential interest to the quantification of surface water supply potential or facilities requirements. Documents with relevant content were then reviewed in greater detail. The following relevant topics were considered in the initial screening:

- Inventory of streamflow records
- Summary of streamflow characteristics
- Surface water quality data
- Surface water quality summaries or rating curves
- Monthly rainfall characteristics
- Monthly class-A pan evaporation data
- Environmental impacts of surface water withdrawal or streamflow reductions
- Minimum streamflow requirements or other withdrawal constraints
- Seasonal distribution of water demands
- Required reliability of water supply systems

A complete listing of all documents considered in the initial screening is provided in the Bibliography. Particularly relevant documents that provided key information are cited in the TM, where appropriate.

WATER RESOURCES DATA REVIEW

Water resources data of interest include long-term, continuous streamflow records and selected water quality data. Monitoring stations of interest include all stations located on the stream reaches that were previously selected for this evaluation.

Our water resources data searches consisted of several queries of environmental data bases supplied by EARTHINFO Inc., a commercial supplier that offers several current data bases on CD-ROM. Software included with each data base allows appropriate queries to be formulated and the data of interest located.

Two data bases were searched for this analysis. The first was the USGS Daily Values File. This file contains all USGS daily streamflow records available through 1994. The second data base, the U.S. Environmental Protection Agency (EPA) STORET Water Quality System, is a comprehensive water quality data base that contains information collected by a variety of sources. The current STORET data base contains all available water quality records through 1994, and it includes water quality data collected and provided by SJRWMD.

Details related to the data base searches and results are presented in a subsequent section of this TM.

DEVELOPMENT OF WATER SUPPLY EVALUATION METHODOLOGY

The development of the proposed water supply evaluation method is based on information identified in the literature search, available water resources data, and previous surface water supply planning experience. The method is designed to address all major issues impacting surface water supply availability and yield at the conceptual planning level. The objective is to estimate water supply facilities required as a function of the reliable water supply yield developed.

FACTORS AFFECTING SURFACE WATER SUPPLY DEVELOPMENT

It is important to understand the factors that impact the technical feasibility of surface water supply development before considering the available data and the evaluation methodology. These factors include the streamflow characteristics of the source, the minimum streamflow requirements of the source, the characteristics of the demand to be met, and the required reliability of the water supply system.

STREAMFLOW CHARACTERISTICS

Important streamflow characteristics, relative to water supply potential, are streamflow magnitude, flow variability, and water quality. Unlike ground water, surface water sources can be highly variable in terms of both flow magnitude and water quality. This inherent variability usually is more pronounced for small or medium-sized drainage basins than for large or very large basins. Generally, the greater the variability of the potential source, the more expensive it will be to develop a safe, dependable water supply.

Streamflow Magnitude

Streamflow magnitude defines the absolute volume of flow generated by a watershed. Overall flow magnitude is often measured as the mean annual flow of the watershed, sometimes referred to as watershed yield. Obviously, the greater the total watershed yield, the greater the potential for water supply development.

Streamflow Variability

Streamflow variability often is as important as (or more important than) watershed yield in defining the potential for economic water supply development. Streamflow variability can be measured in many ways. The most common is development of a flow duration curve that defines the relationships between flow rate and percentage of time (probability) that the given flow rate will be equaled or exceeded. The shape and range of the flow duration curve indicates the streamflow variability. Streams with relatively flat flow duration curves and limited flow range are less variable than streams with markedly S-shaped flow duration curves where observed flow rates vary over many orders of magnitude.

Figure 2 presents an example flow duration curve for the St. Johns River near DeLand, Florida, based on analysis of 60 years of daily flow records. The St. Johns River drainage area at DeLand is equal to 3,070 square miles, and the mean annual flow is equal to 3,043 cubic feet per second (cfs) or nearly 2 billion gallons per day. Observed daily flow rates range from a maximum of 17,100 cfs to a minimum of -3,020 cfs.

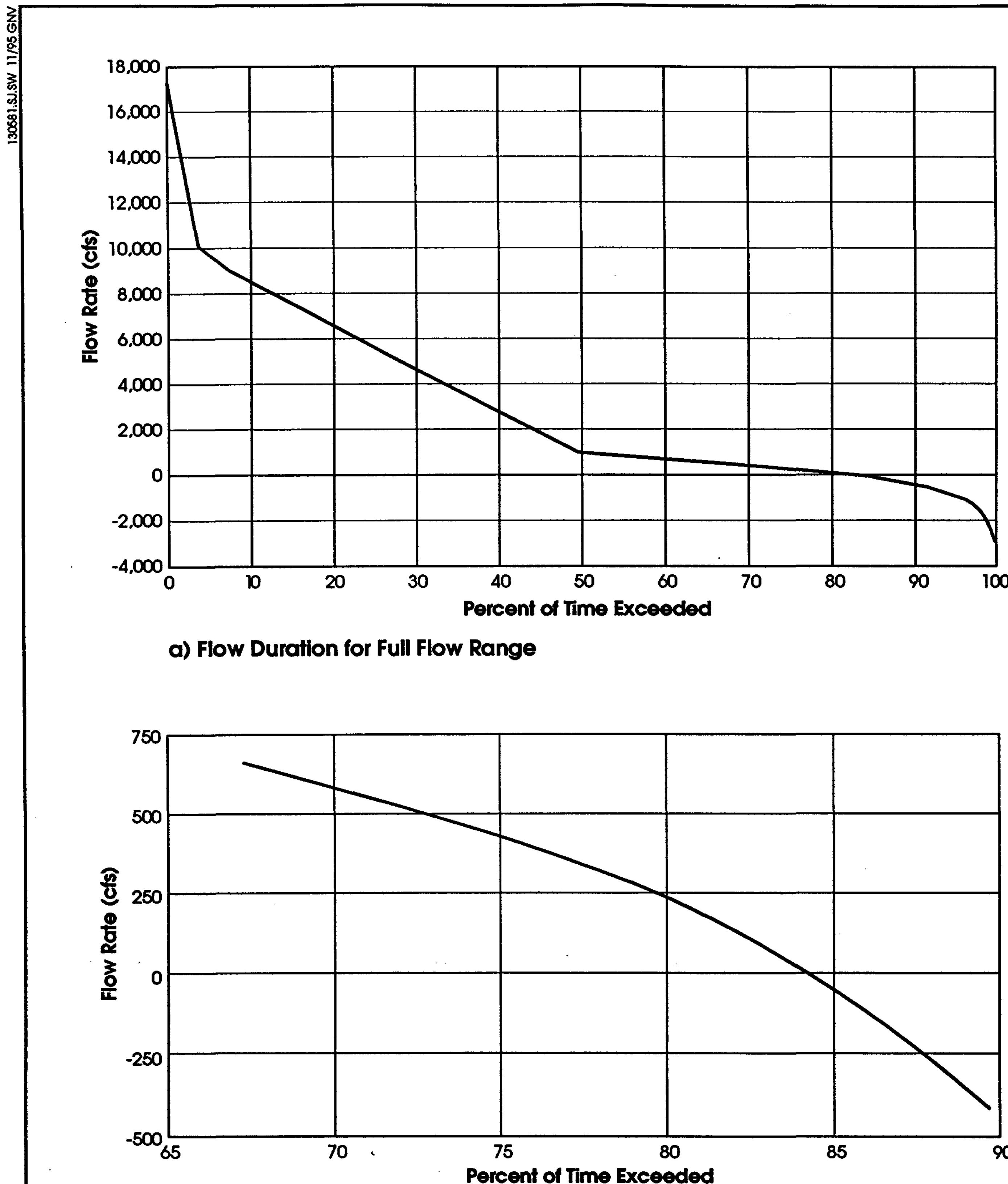
Negative or upstream flows, as shown on Figure 2, are a common characteristic for much of the middle and lower portions of the St. Johns River. In this case, flow rates are positive or in a downstream direction about 84 percent of the time. However, streamflow occurs in an upstream direction about 16 percent of the time. The observed negative flow is caused by tidal influence, wind, and upstream evaporation losses during drought conditions.

On small inland streams, flow duration curves could exhibit significant periods of zero flow during droughts. Streams with significant ground water or spring inflow are likely to produce some positive streamflow at all times regardless of the tributary area. The flow duration curve can provide both insight into the hydrology of a stream and a basis for the evaluation of relative water supply development potential.

Streamflow variability also can be measured seasonally. Seasonal flow statistics of interest include the mean monthly flow and the standard deviation of monthly flows. Comparison of the mean monthly flow rates yields insight related to the influence of the wet and dry seasons on the magnitude of streamflow. The standard deviation of monthly streamflow yields insight into the expected variation within each month of the year. Long-term continuous streamflow records are required to quantify both the magnitude and variability of streamflow.

Water Quality

Water quality is an important characteristic that will impact the economics of surface water supply development. The ideal source would meet all Class I water quality standards, and the quality would not vary with the flow rate or season. Unfortunately, such conditions are not likely to be encountered in actual applications. However, conventional and advanced water treatment technologies can be applied to raw water sources with a variety of poor water quality characteristics to produce a high quality finish water. Therefore, the quality of the source will affect the cost of treatment and economic feasibility of a given source, but is unlikely to control technical feasibility.



a) Flow Duration for Full Flow Range

b) Flow Duration for Low Flow Range

Figure 2. Flow Duration Curve for the St. Johns River near DeLand, Florida.

MINIMUM STREAMFLOW REQUIREMENTS

Streams, rivers, and associated lakes and floodplains provide a wide variety of natural functions as well as, in many cases, a variety of outdoor recreational opportunities. It is important that these functions be protected. In order to protect the natural systems, a significant portion of the streamflow regime must be maintained, and therefore will be unavailable for consumptive use. A major mission of SJRWMD is to establish minimum flows and levels, which will ensure that significant adverse environmental impacts do not result from permitted consumptive use including water supply withdrawals. Currently, SJRWMD is conducting an extensive multi-year program to establish the required minimum flows and levels for priority surface water bodies located within the district boundaries (SJRWMD, 1994).

SJRWMD Minimum Flows and Levels Project

The SJRWMD minimum flows and levels project goals include the establishment of minimum flows and levels for surface waters and minimum levels for ground waters to protect the water resources and water-dependent ecosystems from significant harm and to assure adequate water for non-consumptive uses. To accomplish these goals, the following multiple minimum flows and levels criteria have been established.

- Minimum infrequent high
- Minimum frequent high
- Minimum average
- Minimum frequent low
- Minimum infrequent low

To date, only two streams located in the greater Wekiva River system have been fully evaluated based on the above criteria (Hupalo, et al., 1994). These two streams, the Wekiva River and Black Water Creek, have very different hydrologic characteristics. The Wekiva River derives significant portions of its flow from ground water through spring discharge, and Black Water Creek derives most of its flow from surface runoff. The established minimum flows and their frequency of occurrence are summarized in Table 1.

From a water supply planning standpoint, the high flow criteria (infrequent high and frequent high) are unlikely to present any real constraint on withdrawals. However, other criteria should be

Table 1. Occurrence Frequency of Minimum Flows Established for the Wekiva River and Black Water Creek (Hupalo, et al., 1994)

Flow Level	Flow Rate (cfs)	Percent of Time Flow Rate Exceeded
Wekiva River at SR 46		
Infrequent high	880	< 1%
Frequent high	410	9%
Minimum average	240	60%
Frequent low	200	88%
Infrequent low	120	> 99%
Station mean	286	34%
Black Water Creek at SR 44		
Infrequent high	340	1%
Frequent high	145	10%
Minimum average	33	60%
Frequent low	2.5	98%
Infrequent low	0	100%
Station mean	69	35%

considered in surface water supply planning. The most important of these is the minimum frequent low. This flow level represents the flow rate at which water withdrawal restrictions will be imposed. Therefore, for the purpose of preliminary water supply planning, it is probably prudent to assume that divertable flow will be unavailable when streamflow rates are less than this value. The minimum average flow rate is also likely to be important for some water supply planning purposes because this limit may define the total maximum volume of streamflow that may be diverted for water supply purposes.

Unfortunately, minimum flows and levels have not been established by the SJRWMD for the candidate surface water sources included in these investigations. Therefore, to develop a reasonable planning level rule governing water supply withdrawal, it will be necessary to use the results of the Wekiva River and Black Water Creek minimum flows analysis and other surface water withdrawal limits established elsewhere in the State. This general rule will be applied to selected candidate withdrawal points to establish estimated minimum streamflow requirements.

The Ocklawaha River Water Allocation Study

The Ocklawaha River Water Allocation Study (Hall, 1995) is another SJRWMD project of potential interest in establishing minimum streamflow requirements and resulting water supply withdrawal constraints. This project included an evaluation of the safe water supply yield of Rodman Reservoir. The limiting environmental factor considered was changes in reservoir water levels. In this analysis, constant withdrawals rates of 165, 250, and 330 cfs were investigated. These withdrawal rates correspond to about 10, 15, and 20 percent of the total reservoir outflow, respectively. A constant withdrawal rate of 165 cfs (107 million gallons per day [mgd]) was found to be environmentally acceptable; however, larger constant withdrawal rates would be unacceptable. It also was concluded that restoration of the Ocklawaha River (removal of Rodman Reservoir) may result in a greater portion of the watershed yield available for consumptive use without negative environmental impacts. Environmental impacts of variable withdrawal rates (higher rates at high stages, and lower rates at low stages) were not investigated.

Peace River Water Supply System

CH2M HILL has been involved with planning and designing the Peace River Regional Water Supply System for more than 10 years

(CH2M HILL, 1985, 1987 & 1993). The water supply source for this system is the Peace River, located upstream from Charlotte Harbor in DeSoto County, Florida. Because of the environmentally sensitive nature of the downstream estuary system, restrictive water supply withdrawal constraints were used in planning and evaluating this operational system. Water supply withdrawal is not allowed when the river flow (measured at Arcadia, Florida) is less than 100 cfs during March, April, and May, and 130 cfs in all other months. Based on the Peace River flow duration curve, these flow rates are exceeded 95 and 94 percent of the time, respectively.

Stage Discharge Relationships

In many natural stream systems, water levels (stage) and stream discharge are closely related. Often discharge is estimated directly from observed stage using a stage discharge relationship, also known as a flow rating curve. However, the stream slopes under consideration in this investigation are extremely mild and the relationship between stage and discharge is not well defined.

Consider, for example, the St. Johns River near DeLand. As previously discussed and illustrated on Figure 2, streamflow occasionally occurs in an upstream direction. This reverse flow phenomena is caused by many factors including the extremely mild gradient of the river, wind, and tidal influence at the river mouth. The DeLand gauge is located approximately 142 miles from the mouth of the river. However, mean river stage is only about 1.2 feet above mean sea level. Therefore, the average hydraulic gradient is less than one foot per hundred miles. This extremely mild gradient produces a complex hydraulic regime, which results in river stage influenced by many factors in addition to river flow rate.

Because of the poorly defined relationship between river stage and flow rate, flow is measured at DeLand using a stage recorder to establish river cross-sectional area and an electromagnetic current meter to establish flow direction and velocity. Measured water levels at DeLand have varied from about 6 feet above mean sea level to about 0.7 feet below mean sea level. At mean river flow (3,043 cfs), stages between 0.3 and 2.3 feet above mean sea level can be expected. Given the weak relationship between river stage and flow rate under normal flow conditions, it would be difficult to accurately measure the impact of water supply withdrawal on river stages. However, if withdrawals are limited to a reasonably small portion of the total annual river yield, the impact on stage frequency should be negligible. This is because stage frequency is controlled by many factors in addition to streamflow rate, and a small change in the river flow regime will cause a considerably smaller change in the river stage regime.

Maximum Diversion Rate

In addition to the minimum streamflow rate below which diversion should not be allowed, a maximum allowable diversion rate also must be established to fully define minimum streamflow requirements. The lower limit protects the resource during low flow periods, and the upper limit ensures that the overall streamflow regime is not significantly impacted.

Withdrawals of 10 percent or less of the natural watershed yield generally should not result in any measurable adverse environmental impact. Withdrawals ranging from 20 to 50 percent will likely cause measurable impacts but could be acceptable, depending on the characteristics of the hydrologic system and in-stream habitats. For example, the Tennant Method as reported by McMahon (1992) suggests that the optimum streamflow for fish, wildlife, recreation, and related environmental resources ranges from 60 to 100 percent of the mean annual discharge and that excellent to outstanding conditions could be maintained at 30 percent (dry season) to 60 percent (wet season) of the mean annual discharge. These criteria are based on long-term observations in Montana, Nebraska, and Wyoming. Therefore, the criteria are not directly applicable to Florida conditions, but do provide an order-of-magnitude guidance.

For the purpose of this preliminary assessment of surface water supply potential, a reasonable yet fairly conservative maximum diversion rate should be established. Based primarily on general guidance provided by the Tennant criteria discussed above, a maximum allowable diversion rate equal to 25 percent of the mean annual flow appears to be a reasonable, yet conservative, value. It should be noted, however, that if the maximum diversion rate is limited to this value, then the total annual volumetric withdrawal would be somewhat less because actual diversion rates will be less than the maximum rate during moderate- to low-streamflow conditions.

Consider, for example, the St. Johns River near DeLand. If the maximum allowable diversion rate is limited to 25 percent of the mean annual flow (3,043 cfs), then the maximum allowable diversion rate would be equal to 761 cfs. If it is further assumed that no diversion would be allowed when reverse flow occurs, then the maximum allowable diversion schedule would be summarized as follows.

Allowable Diversion Rate	Frequency (Percent of Time)
0 cfs	16
1 to 760 cfs	22
761 cfs	62

Based on this diversion schedule, the maximum long-term average diversion rate would be about 555 cfs or approximatly 18 percent of the total watershed yield.

Summary and Proposed General Diversion Rule

Considering the minimum streamflow determinations discussed above, established minimum flows tend to occur within a rather narrow range of the flow duration curve. Table 2 summarizes minimum streamflow requirements, which are expressed in terms of frequency of exceedance and range from 88 percent for the Wekiva River to 100 percent for Rodman Reservoir. The remaining three minimum streamflow determinations range from 94 to 98 percent.

The minimum streamflow determined for both the Wekiva River and the Rodman Reservoir may be viewed as somewhat unique cases. The Wekiva River is unique because it is such a highly valued natural resource with much of the streamflow derived from spring discharge; and Rodman Reservoir is unique because it is a controlled stream with an existing man-made, on-line reservoir. Neither situation occurs within the watershed systems under consideration in this preliminary evaluation.

If high and low values are not considered, the average previously established exceedance frequency for minimum streamflow requirements is 95.7 percent. For this preliminary evaluation of surface water supply potential, we propose to establish the minimum streamflow requirement as the flow rate exceeded 95 percent of the time, for flow rates greater than zero. For example, if a given stream produced flow 100 percent of the time, the minimum streamflow requirement would equal the 95 percentile flow rate. However, if another stream produced positive flow only 90 percent of the time, then the minimum streamflow requirement would equal the 85.5 percentile flow (0.95*0.90).

Table 2. Established Minimum Streamflow Requirements Expressed in Terms of Flow Frequency

Stream / Location	Minimum Streamflow Expressed as Frequency of Exceedance
Wekiva River at SR 46	88%
Black Water Creek at SR 44	98%
Peace River at Arcadia (March - May)	95%
Peace River at Arcadia (June - February)	94%
Rodman Reservoir	100%

In addition to establishing minimum streamflow requirements, a reasonable maximum withdrawal limit must be established to protect the resource. These constraints on consumptive use must be described in terms of a diversion rule, which defines the quantity of streamflow that may be diverted for water supply purpose as a function of flow in the stream. Applying this diversion rule to an observed streamflow sequence will define the divertable or available streamflow array.

For the surface water supply feasibility investigation, we propose that the maximum instantaneous withdrawal rate be limited to a value equal to 25 percent of the mean annual flow rate. Total long-term volumetric withdrawals considered would be limited to values less than 25 percent of the total watershed yield because there will be times when no withdrawal is allowed and other times when divertable streamflow is less than the maximum diversion capacity. As part of this investigation, we will evaluate stream diversion rates less than the maximum value, but diversion rates greater than 25 percent of the mean annual flow rate will not be considered.

DEMAND CHARACTERISTICS

In ground water development applications, demand characteristics of importance include the mean demand (i.e., average daily demand [ADD]) and the maximum demand (i.e., maximum daily demand [MDD]). The ADD will define the long-term aquifer impacts, and the MDD will define the required peak water supply facilities capacities. These characteristics are also important in the evaluation of surface water supplies. However, in addition to the ADD and MDD, the seasonal characteristics of the demands are also important in surface water supply applications.

Municipal demands tend to be highest during the dry season, when streamflow is lowest; and lowest during the wet season, when streamflow is highest. In many parts of Florida, demands from the seasonal or tourist population also are maximized in the dry season and minimized in the wet season. Therefore, it will be important to establish representative seasonal demand variations to be expected within the SJRWMD planning area.

MDD is often expressed as a ratio to the ADD. Typical values range from about 1.3 to nearly 2.0. A similar convention is often used to express the seasonal water supply demand characteristics, where the average monthly demand is expressed as a ratio to the ADD. Figure 3

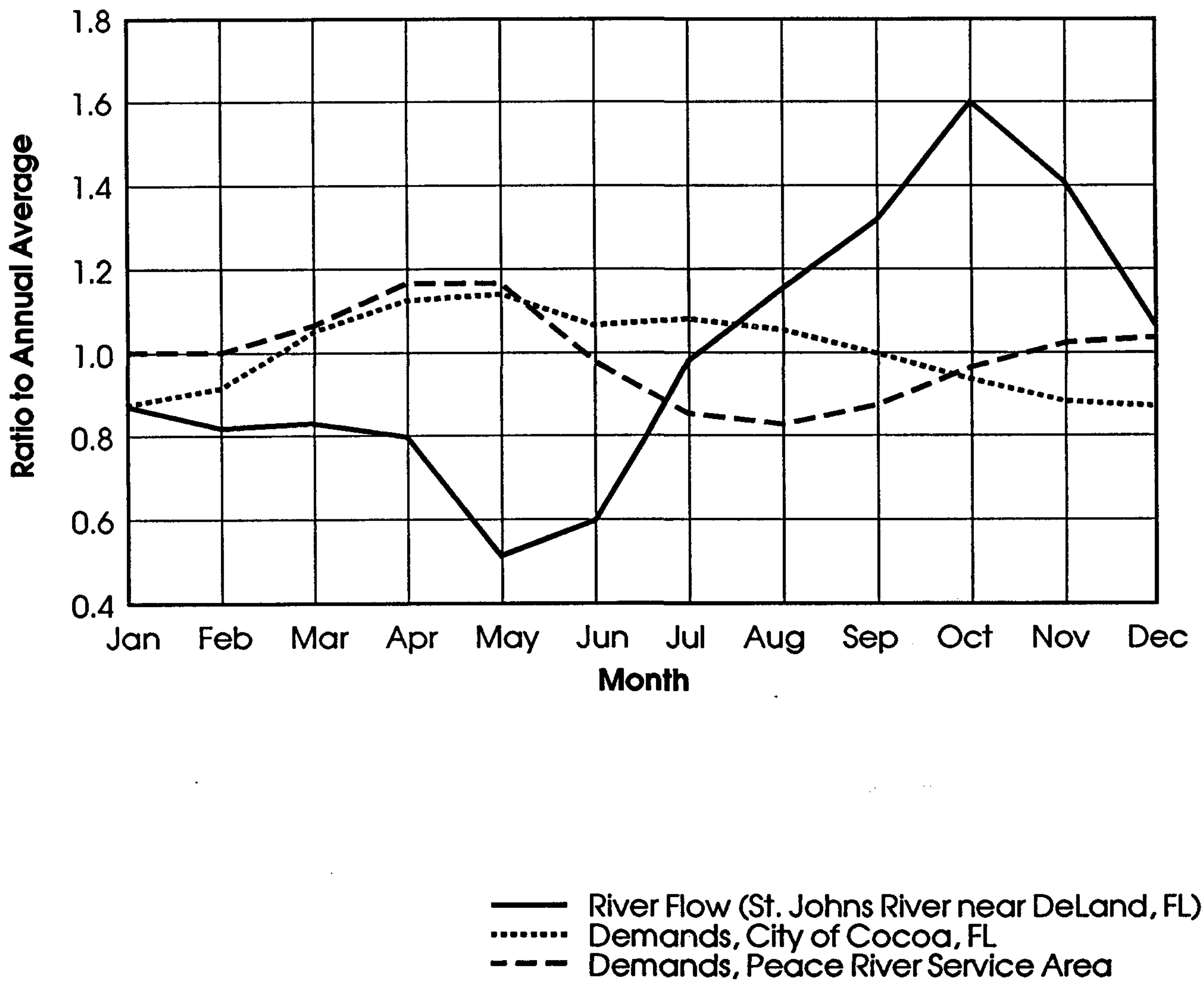


Figure 3. Typical Monthly River Flow and Water Supply Demand Ratios.

presents typical seasonal distributions for municipal water supply demands used in previous surface water supply planning projects for the City of Cocoa, Florida (CH2M HILL, 1995), and for the Peace River Regional Water Supply System (CH2M HILL, 1993). This figure also shows the seasonal distribution of streamflow for the St. Johns River near DeLand, Florida. As shown in Figure 3, seasonal demands peak in May for both the City of Cocoa and the Peace River service area, when streamflow is at its seasonal low. In both cases, demands are near average in October when seasonal streamflow is at a maximum. Monthly demand ratios for these typical municipal water supply systems vary from about 87 to 118 percent of the ADD.

REQUIRED SYSTEM RELIABILITY

Another important factor affecting both the technical and economic feasibility of a surface water supply system is the required reliability of the water supply system. Higher system reliability requirements generally mean larger facilities (storage facilities, in particular) resulting in a more costly water supply system. Municipal water supply systems must be highly reliable; however, system reliability can be defined and quantified in several ways. It is important to set appropriate reliability goals before site-specific feasibility evaluations are conducted.

For the purpose of this analysis, a deficiency is defined as the inability to supply all the water required at the desired quality. A water supply system deficiency that results in no water being delivered (system failure) is rare and unacceptable. Water supply deficiency usually means either imposing water use restrictions; delivering water that, although safe, may not meet all primary drinking water standards; or a combination of both.

Reliability is defined as the percentage of time that the water supply system is able to meet the full demand at the desired quality. Therefore, deficiency is defined as not meeting the full demand or not providing the desired quality. Such condition would result in water use restrictions until the water supply system is again able to meet all quantitative and qualitative criteria.

SURFACE WATER SUPPLY FACILITIES

Facilities required to develop a safe and reliable surface water supply will include a combination of the following components.

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

Under favorable conditions, including a high volume source and limited water supply needs, it may be possible to develop the required water supply system with only a river diversion structure and a water treatment plant. However, usually some type of storage must be added to the facilities mix to provide the required system reliability. That is, raw water will be available for diversion in quantities adequate to meet current demands for only a portion of the time. Storage facilities, including either raw water storage reservoirs or ASR systems, can be used to store available water 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 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 constructing a dam across the stream and flooding a portion of the upstream valley, thereby creating the required water supply storage. Off-line reservoirs are constructed adjacent to the free flowing stream and 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 reservoir area and the depth to which water can be impounded.

Both types of reservoirs will receive additional inflow from direct rainfall and will incur water losses through lake evaporation. Under certain conditions, additional water also could be lost by seepage.

For an on-line reservoir, the capacity of the river diversion structure (Qd) will match the capacity of the water treatment plant (Qt). For an off-line reservoir, the capacity of the river diversion structure must be greater than the capacity of the water treatment plant (Qd > Qt). This will allow the reservoir to be filled during high flow for use when the allowable divertable flow is less than the demand.

In Florida, construction of on-line reservoirs is very difficult because stream valleys typically are wide and favorable dam sites are rare. Also, constructing on-line reservoirs will greatly impact the natural flow regime of the stream and often will flood productive adjacent wetlands. Off-line reservoirs do not interfere with the natural streamflow regime and, therefore, are less disruptive environmentally than on-line reservoirs. However, off-line reservoirs would likely be located on or near the floodplain and also may impact wetlands. Environmental concerns for constructing off-line reservoirs, although less than for on-line reservoirs, would still be substantial. For this preliminary analysis of surface water supply potential, only off-line reservoirs will be considered, and priority will be given to water supply development options, which minimize the need of any raw water storage reservoir.

WATER TREATMENT PLANT

The water treatment plant provides safe potable finished water that meets all necessary drinking water standards. If the raw water is of reasonably high quality, then only conventional treatment is necessary. For surface water sources, this usually consists of some type of clarification and filtration with disinfection. In current practice, disinfection often is provided by ozone treatment. If the raw water is of poor quality, including a high total dissolved solids (TDS) content, then membrane treatment may be needed. In some cases, pre-treatment may be provided by a raw water off-line storage reservoir.

The quality characteristics of the raw water will define treatment requirements and, in part, treatment costs. However, treatment capacity (Qt) requirements will be defined by the demands to be met and the amount and type of storage to be provided. If no finished water storage is provided (e.g., by an ASR system), then the treatment plant must be sized to meet MDD (Qt = MDD). On the other hand, if finished water storage is provided, the treatment plant can be somewhat smaller because peak demands can be met from finished water storage.

AQUIFER STORAGE RECOVERY (ASR) SYSTEMS

ASR systems generally can be used to store both raw water and treated finished water (Pyne, 1995). In raw water applications, the ASR system could replace the off-line raw water storage reservoir discussed above. However, in most water supply applications implemented to date, ASR has been used to provide finished water storage. 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 systems inject 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 that prevent all of the water injected from ultimately being recovered and used. As water is injected some injected water mixes with native ground water. Depending upon 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. TDS concentration is usually the parameter that controls the acceptability of the recovered mixture in Florida drinking water applications.

If the ASR system is developed and operated properly, the mixing characteristics of the storage aquifer and water quality of the native ground water are not usually as restrictive in the application of ASR as it may first appear. Even if the native ground water quality is poor and considerable initial mixing occurs, a viable ASR system usually can still be developed by investing an initial volume of treated water in the development of a buffer between the native ground water and treated injected water. If it is maintained, the buffer will allow good recovery efficiencies.

Storing raw surface water can be more difficult than storing treated water because of a more variable water quality and greater possibility of clogging well screens or encountering other operational problems. Such systems also are more difficult to permit and there is not nearly as much operational experience available. For these reasons, only finished water ASR systems will be considered in this preliminary evaluation of surface water supply potential.

Another potential advantage of finished water ASR is the possibility of reducing the maximum required treatment plant capacity. The water treatment plant may not need to be sized to meet MDD because peak demands can be met with a combination of direct treatment and recovery from the ASR system. Under ideal circumstances, the plant capacity could be sized to meet only the ADD; however, such ideal circumstances are unlikely. In most cases, the required treatment plant size with a treated water ASR system will be greater than the ADD, but less than the MDD. Also, if the ASR recover capacity is equal to the MDD, peak demands could be met even if no water is available for treatment during the peak demand period.

GENERAL SURFACE WATER SUPPLY SYSTEM APPLICABLE TO SJRWMD

Based on the above discussion and evaluation of various surface water supply facilities, Figure 4 presents a general system for evaluating potential surface water sources in this project. The general system consists of a raw water diversion structure and pumping station that delivers water to an off-line raw water storage reservoir. Water from the off-line reservoir feeds the water treatment plant. If the raw water reservoir is not necessary, then the raw water is routed directly to the water treatment plant. Treated water can then be used to meet current demands or, if excess is available, it can be stored in the ASR system. If insufficient water is available for treatment, then water is recovered from the ASR system to meet current demands.

The minimum system considered will consist of the diversion facilities, the water treatment plant, and finished water ASR. Off-line reservoirs will be considered if additional storage is necessary to provide the necessary raw water yield and to keep the treatment plant operating efficiently. Off-line reservoirs are likely to require significant land areas; therefore, primary storage will be provide by finished water ASR when practical.

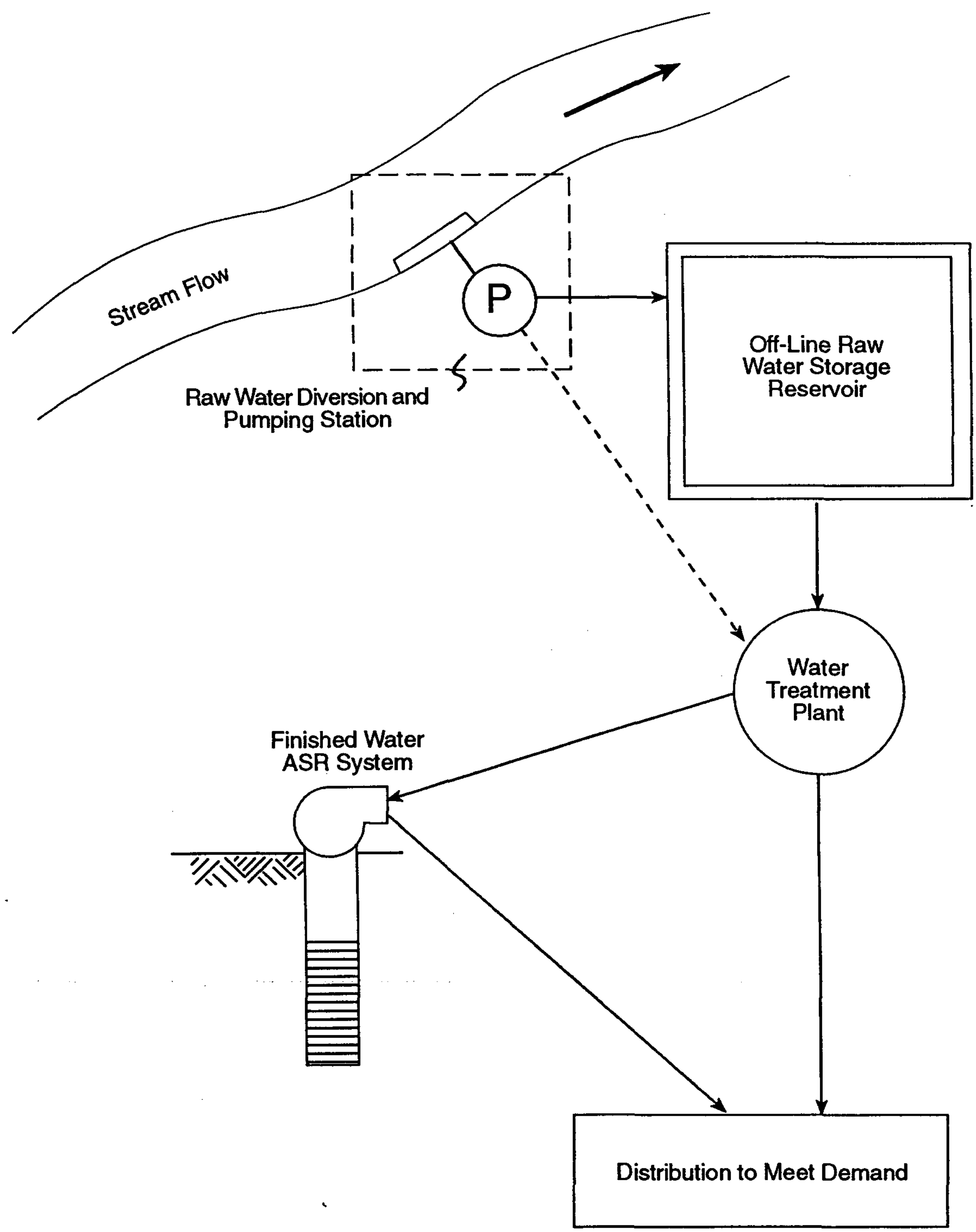


Figure 4. Facilities Required to Develop Reliable Surface Water Supply to Meet Urban Demands.

STREAMFLOW AND WATER QUALITY RECORDS

Streamflow and water quality records will provide the basis for the quantitative evaluation of surface water supply development potential. Streamflow records define the magnitude and variability of the potential source and are the most important data required. These characteristics, along with the variability of the demands to be met and the required system reliability, will control the size of the required water supply facilities. Water quality characteristics will define treatment requirements and, therefore, will impact water supply development cost and economic feasibility.

STREAMFLOW RECORDS

Streamflow records must be continuous, relatively complete, and long term to be of value in this investigation. The USGS Daily Values File was searched to identify gauging stations with daily streamflow data located on the stream reaches of interest. Twelve candidate stations were identified within the Haines Creek and Palatlakaha River system (Upper Ocklawaha Watershed in Lake County, Florida); and 8 candidate stations were identified on the main stem of the St. Johns River. Only stream gauges with more than 10 years of record are considered because long-term watershed yield and streamflow variability is important.

Palatlakaha River and Haines Creek System

Figure 5 shows the location of the seven USGS stream gauging stations within the Palatlakaha River and Haines Creek hydrologic system with at least 10 years of daily streamflow record. Table 3 lists the summary characteristics of each gauging station, including the USGS gauging station number, station name, number of years of daily streamflow data available, watershed drainage area in square miles, mean annual flow or watershed yield in cfs, and unit watershed yield in cfs per square mile of tributary area.

As shown in Figure 5, the gauging stations are well distributed within this portion of the planning area. The tributary areas are fairly small and the watershed yields are highly variable (see Table 3). Haines Creek at Lisbon, Florida (USGS station number 2238000), the most

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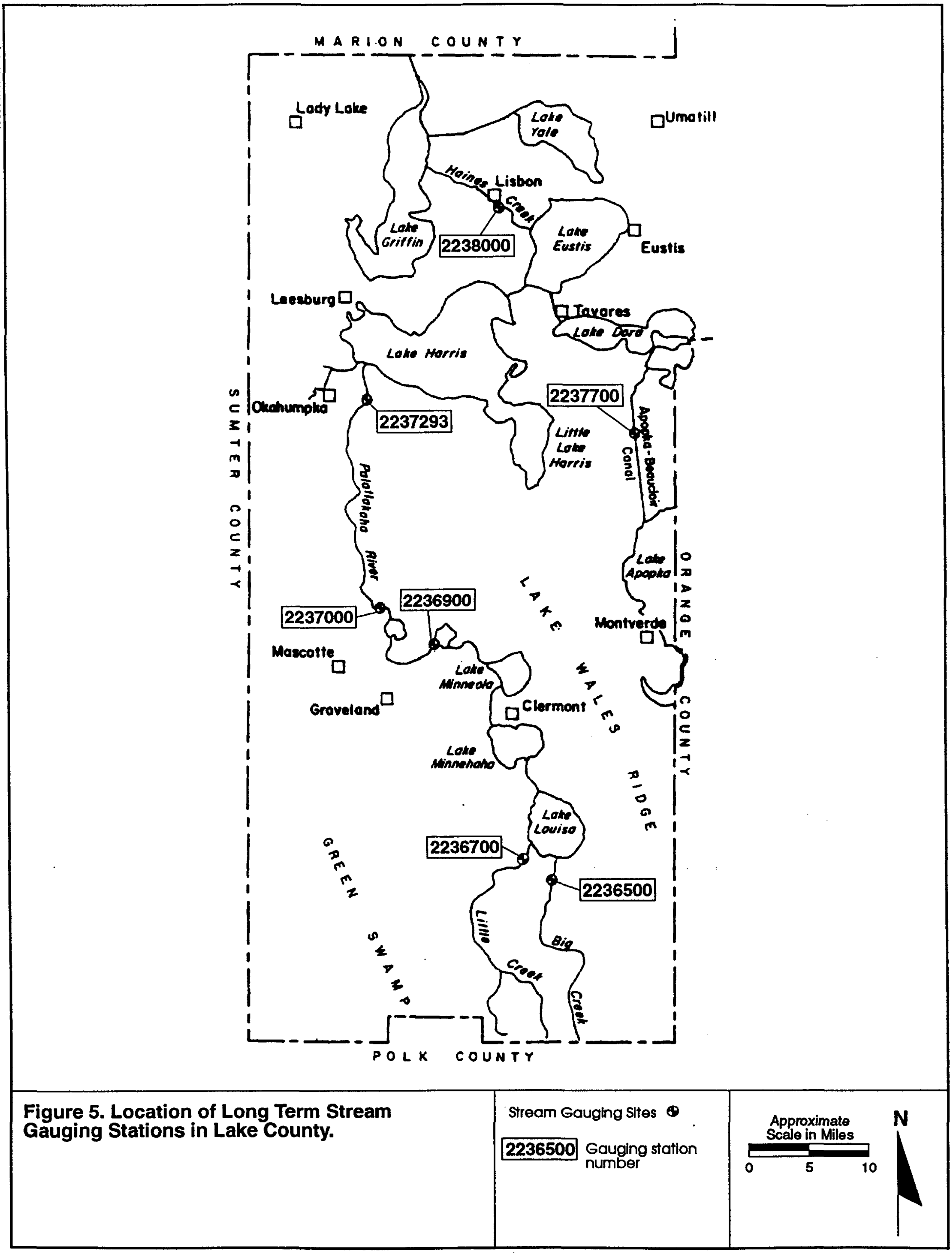

Figure 5. Location of Long Term Stream Gauging Stations in Lake County.

Table 3. Stream Gauging Stations Located in the Ocklawaha River Hydrologic Unit and Lake County Florida with 10 or More Years of Daily Streamflow Records

USGS Station Number	Station Name	Number of Years of Record	Drainage Area (Square Miles)	Mean Annual Flow (cfs)	Unit Yield (cfs/sq. mi.)
2236500	Big Creek near Clermont, FL	35	68	24	0.353
2236700	Little Creek near Clermont, FL	15	14.7	13	0.884
2236900	Palatlakaha River at Cherry Lake Outlet near Groveland, FL	32	165	33	0.200
2237000	Palatlakaha River near Mascotte, FL	16	182	98	0.538
2237293	Palatlakaha River at Structure M-1, near Okahumpka, FL	23	221	16	0.072
2237700	Apoka-Beauclair Canal near Astatula, FL	32	184	76	0.413
2238000	Haines Creek at Lisbon, FL	43	648	247	0.381

downstream station, provides the greatest watershed yield at 247 cfs (160 mgd), which is more than 2.5 times greater than the next largest measured yield.

The unit yields also are highly variable, ranging from 0.072 cfs per square mile to 0.884 cfs per square mile. The lower unit yield indicates considerable surface water losses either through seepage into the ground water aquifer, or substantial evaporation losses through the many lakes and wetlands within this hydrologic system.

St. Johns River

Figure 6 shows the location of the six USGS stream gauging stations on the main stem of the St. Johns River with at least 10 years of daily streamflow record. Characteristics of each gauging station are summarized in Table 4.

The hydrologic characteristics of the St. Johns River are very different from the characteristics of the Palatlakaha and Haines Creek system. First, the watershed tributary areas are much larger. The smallest gauged tributary, (St. Johns River near Melbourne, Florida) at 968 square miles, is about 50 percent larger than Haines Creek at Lisbon, Florida. The watershed yield at 660 cfs (427 mgd) is more than 2.5 times greater than the maximum Haines Creek yield. Maximum gauged yield on the St. Johns River, within the planning area, is measured at Palatka; it is 5,945 cfs or about 3.8 billion gallons per day.

As shown in Table 4, the unit yield of the St. Johns River watershed is nearly uniform compared to the highly variable unit yields observed in the Palatlakaha River/Haines Creek watershed. Unit yields range from 0.682 to 0.991 cfs per square mile. There is a general trend toward increased unit yield in a downstream direction. This is likely caused by somewhat greater ground water inflow in the middle portion of the river as compared to the upper portions of the river.

WATER QUALITY RECORDS

The STORET data base for the State of Florida was searched to identify stream stations with potentially useful water quality data. STORET, a comprehensive water quality data base, contains information collected by numerous sources including the USGS, the EPA, the SJRWMD, and cities and counties, as well as several other state and federal agencies. STORET contains water quality data on all types of water bodies, including aquifers, streams, rivers, lakes and estuaries. It also contains

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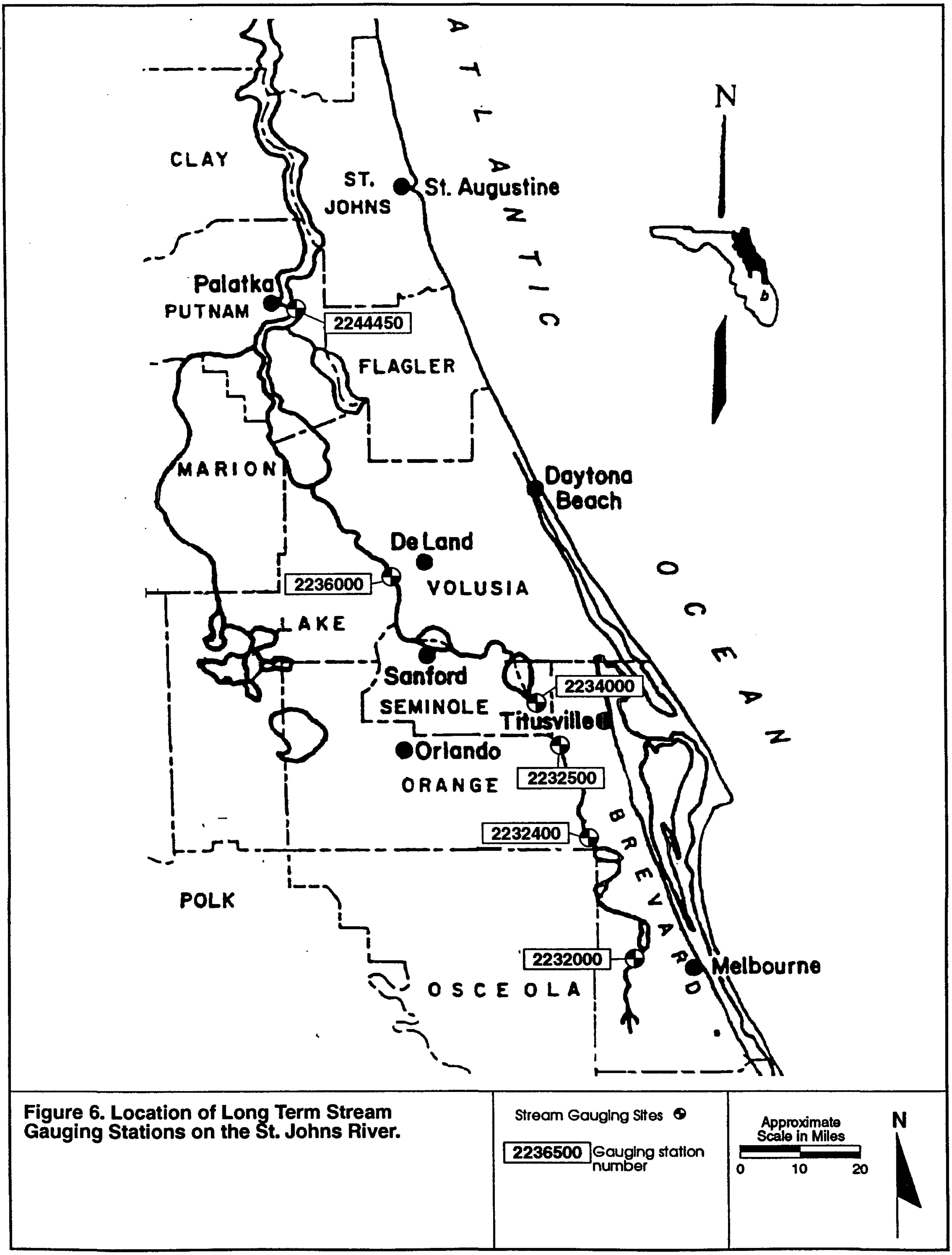

Figure 6. Location of Long Term Stream Gauging Stations on the St. Johns River.

Table 4. Stream Gauging Stations Located on the Main Stem of the St. Johns River with 10 or More Years of Daily Streamflow Record

USGS Station Number	Station Name	Number of Years of Record	Drainage Area (sq. mi.)	Mean Annual Flow (cfs)	Unit Yield (cfs/sq. mi.)
2232000	St. Johns River near Melbourne, FL	55	968	660	0.682
2232400	St. Johns River near Cocoa, FL	41	1,331	986	0.741
2232500	St. Johns River near Christmas, FL	61	1,539	1,281	0.832
2234000	St. Johns River above Lake Harney near Geneva, FL	11	2,043	1,844	0.903
2236000	St. Johns River near DeLand, Fl	60	3,070	3,043	0.991
2244450	St. Johns River at Palatka, FL	14	7,094	5,945	0.838

data on pollutant sources, including wastewater treatment plant discharges, compliance monitoring stations, and hazardous waste sites.

To be useful to this analysis, water quality data must be representative of the streamflow at or near the point of withdrawal. Also, data should be representative of the water quality associated with the long-term streamflow records previously identified.

Only certain water quality parameters are useful in this preliminary analysis. The following parameters of interest to this investigation are those that most often impact treatability and treatment requirements:

- Temperature (maximum and minimum)
- Total suspended solids
- Turbidity
- Color
- Total dissolved solids
- Chlorides
- Specific conductance
- Total organic carbon
- Chlorophyll-a
- pH
- Alkalinity
- Hardness
- Nitrate
- Ammonia

Because of both numerous data contributors and types of data contained on the STORET data base, locating information useful for a specific purpose can be difficult. To assist in data location, STORET contains a significant amount of station identification and location information. Unfortunately, these data are not always complete. Initial trial searches of the data base found that a station location described by North latitude and West longitude, together with a key word search of the station name, provided the most useful initial screen.

Palatlakaha River and Haines Creek System

Considering the Palatlakaha River/Haines Creek system, station name key words considered included Ocklawaha, Palatlakaha, Haines, Apopka-Beauclair, River, Creek, Lake, and Canal. Identified would be a water quality monitoring station with a station name containing any of the above key words located within the designated latitude and longitude polygon. This search identified of 238 stations, most of which are not of interest in surface water supply planning for a variety of reasons. Some are well sites, others are wastewater discharge or compliance monitoring stations, and others are located on tributary systems. Our interest is in main stem in-stream water quality stations located at or near the previously identified seven long-term streamflow stations. Given these considerations, 19 identified water quality stations were selected for further queries.

St. Johns River

Considering the St. Johns River station name, the key words considered included St. Johns as well as the names of major in-stream lakes, such as Washington, Winder, Poinsett, Puzzle, Harney, Monroe and George. This search identified 95 stations that contain any of the above key words and that are located within the designated latitude and longitude polygons. Again, our interest is in main stem in-stream water quality stations located at or near the previously identified six long-term streamflow stations. Given these considerations, 32 of the 95 identified St. Johns River water quality monitoring stations were selected for further queries.

Water Quality Data Summary

Table 5 presents a summary of the water quality records identified from the STORET searches and screens. Included are the station number, station name, and the number of observations for each water quality parameter of interest. The water quality parameter codes listed on the table are the data codes used in the STORET data base. The legend at the bottom of the table defines the parameter and measurement units associated with each code. Some data are available for all the parameters of interest except for chlorophyll-a.

There appears to be adequate water quality records available to provide reasonable characterization of the raw water quality at any candidate withdrawal point within the surface water planning area. The water quality monitoring stations shown in **bold type** on Table 5 are also streamflow gauging stations listed in Tables 3 and 4. In the Upper Ocklawaha River basin, five of the seven streamflow stations also have associated water quality data. The only streamflow stations without some corresponding water quality data are the two upstream

Table 5. Summary of Water Quality Data at Selected Stations

Basin Name	Station Number	Station Location	Number of Observations by Water Quality Parameter Code: 10	76	80	94	95	400	403	410	515	530	619	620	680	900	940	Total
	111950	Haines Cr Inlet To Lake Griffin	5	0	3	0	5	5	0	3	0	0	0	0	0	3	5	29
	1202A1	Apopka Beauclair Canal	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	9
	1214B1	Haines Creek	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	11
	20020045	Palatkalaha R Hwy 50 L Hiawatha	10	0	9	0	5	9	10	10	5	5	9	4	0	0	7	83
	20020324	Palatlakaha (River) at 48 Bridge & Palatlakaha R Mid At Hwy 48	49	4	15	41	17	45	16	21	4	15	22	4	0	0	50	303
	20020337	Apopka-Beauclair Canal atHwy 448 Bridge & Beauclair Canal At Sr #448 Midst	34	0	1	28	9	31	8	13	2	2	23	2	0	0	35	188
	20020449	Palatlakaha R. Between Minneola And Cherry Lks	6	4	6	6	5	6	6	6	0	6	1	0	0	0	6	58
Upper Oklawaha River	2236852	09E Lake Minneola Nr Clermont FL	1	1	2	0	2	2	0	2	0	0	1	2	1	2	2	18
	2236880	Cherry Lake Nr Groveland, FL	5	1	4	0	6	4	0	5	0	0	1	4	1	7	7	45
	2236900	**Palatlakaha R At Cherry Lk Out Nr Groveland, FL**	**95**	**4**	**8**	**0**	**66**	**10**	**0**	**10**	**0**	**0**	**4**	**4**	**10**	**0**	**0**	**211**
	2236901	Palatlakaha R Bl Spwy At Ch Lk Out Nr Grv., FL	76	0	4	0	65	4	0	4	0	0	0	0	0	4	4	161
	2237000	**Palatlakaha River Nr Mascotte, FL**	**159**	**4**	**10**	**0**	**76**	**11**	**0**	**11**	**0**	**0**	**4**	**4**	**9**	**11**	**11**	**310**
	2237293	**Palatlakaha R At Struct M-1, Nr Okahumpka, FL**	**92**	**5**	**16**	**0**	**52**	**19**	**0**	**17**	**0**	**0**	**10**	**10**	**2**	**17**	**17**	**257**
	2237700	**Apopka-Beauclair Canal Nr Astatula, FL**	**152**	**48**	**65**	**0**	**131**	**55**	**42**	**22**	**0**	**0**	**48**	**21**	**52**	**20**	**61**	**717**
	2237701	Apopka-Beauclair Canal Bl Dam Nr Astatula, FL	23	0	0	23	0	23	0	4	0	0	15	0	0	0	24	112
	2238000	**Haines Creek At Lisbon, FL**	**83**	**0**	**22**	**0**	**72**	**22**	**0**	**21**	**0**	**0**	**4**	**4**	**8**	**21**	**21**	**278**
	2238001	Haines Creek Below Burrell Dam At Lisbon, FL	64	0	3	0	58	3	0	3	0	0	0	0	0	3	3	137
	Subtotal		854	71	168	98	569	249	82	152	11	28	142	79	83	88	253	2,927
	121001	Lake George	4	0	0	2	4	4	0	4	0	0	4	0	0	0	0	22
	121002	Lake George	7	0	0	4	7	7	0	7	0	0	7	0	0	0	0	39
	121003	Lake George	5	0	0	2	5	5	0	5	0	0	5	0	0	0	0	27
	121004	Lake George	6	0	0	4	6	6	0	6	0	0	6	0	0	0	0	34
	121005	Lake George	18	0	0	4	6	8	0	6	0	0	8	0	2	0	0	52
	123101	Lake Monroe	7	0	0	4	7	7	0	7	0	0	7	0	0	0	0	39
	123102	Lake Monroe	6	0	0	4	6	6	0	6	0	0	6	0	0	0	0	34
	123103	Lake Monroe	6	0	0	4	6	6	0	6	0	0	6	0	0	0	0	34
	123401	Lake Poinsett	4	0	0	3	5	5	0	5	0	0	4	0	0	0	0	26
	123402	Lake Poinsett	5	0	0	3	5	5	0	5	0	0	5	0	0	0	0	28
	20010482	St Johns River At Lake Harney	6	6	6	6	5	3	3	5	0	0	1	0	0	0	5	46
	20010660	St Johns R Near Lk Washington Control Structure	5	5	5	4	3	2	2	5	0	5	1	0	0	0	5	42
	2231800	St. Johns R Crest Gage 3 Nr Melbourne, FL	2	0	5	0	5	5	0	5	0	0	0	0	0	5	5	32
	2232000	**St. Johns River Near Melbourne FL**	**115**	**12**	**83**	**0**	**120**	**112**	**7**	**83**	**0**	**0**	**42**	**41**	**34**	**71**	**76**	**796**
St. Johns River	2232100	Lake Washington Near Eau Gallie, FL	65	4	19	0	42	19	0	20	2	1	2	7	5	20	20	226
	2232254	09E Lake Winder Near Bonaventure, FL	7	0	9	0	12	12	0	12	0	0	1	0	1	9	9	72
	2232260	St. Johns River Crest Gage No.7 Nr Cocoa, FL	1	0	4	0	4	4	0	4	0	0	0	0	0	4	4	25
	2232300	Lake Poinsett Near Cocoa, FL	13	0	8	0	13	12	0	10	0	0	1	3	4	7	7	78
	2232400	**St. Johns River Nr Cocoa, FL**	**293**	**5**	**341**	**0**	**466**	**379**	**7**	**294**	**0**	**0**	**41**	**45**	**39**	**328**	**334**	**2,572**
	2232430	St. Johns R Crest Gage No.8 Nr Christmas, FL	2	0	2	0	3	3	0	3	0	0	0	0	0	2	0	15
	2232500	**St. Johns River Nr Christmas, FL**	**109**	**17**	**96**	**0**	**145**	**125**	**3**	**95**	**0**	**9**	**32**	**45**	**6**	**92**	**96**	**870**
	2232700	St. Johns R Crest Gage No.9 Nr Christmas, FL	3	0	7	0	7	7	0	7	0	0	0	0	0	7	7	45
	2234000	**St. Johns River Above Lake Harney Nr Geneva, FL**	**182**	**19**	**78**	**0**	**133**	**122**	**9**	**71**	**0**	**8**	**54**	**52**	**31**	**61**	**68**	**888**
	2234010	St. Johns River At Osceola, FL	7	2	7	0	7	5	4	1	0	0	4	0	4	3	7	51
	2234440	St Johns R Above L Monroe Nr Sanford FL	2	0	0	0	6	4	0	4	0	0	0	0	0	5	6	27
	2234499	Lake Monroe Nr Sanford, FL	25	0	0	0	2	0	0	0	0	0	0	0	0	0	0	27
	2234500	St. Johns River Nr Sanford, FL	17	0	14	0	16	13	0	13	0	0	0	0	0	14	15	102
	2236000	**St. Johns River Nr Deland, FL**	**154**	**45**	**129**	**0**	**188**	**183**	**39**	**154**	**0**	**0**	**55**	**39**	**18**	**134**	**168**	**1,306**
	2236210	Lake George Nr Salt Springs, FL	37	0	1	0	1	1	0	1	0	0	0	0	0	1	1	43
	2244450	**St. Johns River At Palatka, FL**	**79**	**32**	**36**	**0**	**78**	**79**	**13**	**51**	**0**	**0**	**65**	**59**	**36**	**70**	**71**	**669**
	32208	St. Johns River, Osteen Bridge	13	0	0	0	14	12	0	13	0	0	8	13	0	0	7	80
	40106	St. Johns River, S.R. 46 Bridge	31	0	0	0	31	29	0	19	0	0	23	30	0	0	5	168
	Subtotal		1,236	147	850	44	1,358	1,190	87	927	2	23	388	334	180	833	916	8,515
Total			2,090	218	1,018	142	1,927	1,439	169	1,079	13	51	530	413	263	921	1,169	11,442

Note: Water quality parameter codes:

- 10 = Temperature, water (deg. C)
- 76 = Turbidity (NTU)
- 80 = Color (Platinum-Cobalt Units)
- 94 = Specific Conductance, Field (microsiemens per centimeter at 25º C)
- 95 = Specific Conductance (microsiemens per centimeter at 25º C)
- 400 = pH (Standard Units)
- 403 = pH, Lab (Standard Units)
- 410 = Alkalinity, Water, Whole, Field, FET (mg/l as CaCO3)
- 515 = Solids, Residue on Evaporation at 105º C, Dissolved (mg/l)
- 530 = Solids, Residue at 105º C, Suspended (mg/l)
- 619 = Ammonia Un-Ionized (mg/l as N)
- 620 = Nitrogen, Nitrate, Total (mg/l as N)
- 680 = Carbon, Organic, Total (mg/l as C)
- 900 = Hardness, Total (mg/l as CaCO3)
- 940 = Chloride, Water, Dissolved (mg/l as Cl)

stations (Big Creek and Little Creek near Clermont, Florida). These small watersheds have very little potential for water supply development.

There is considerable water quality data available for the main stem of the St. Johns River. In this case, all stream gauging stations have some associated water quality records available.

PROPOSED SURFACE WATER SUPPLY EVALUATION METHODOLOGY

The objective of this surface water supply evaluation is to determine, on a preliminary feasibility level, the type and size of water supply facilities required to develop a potential surface water source for public supply. The facility requirements will be described as a function of the magnitude of the dependable yield developed, given reasonable estimates of minimum streamflow requirements and other withdrawal constraints. Facility requirements will be estimated for a variety of target yields, from a relatively small yield to the largest potential yield considered reasonably feasible.

Facility requirements will depend on the following major factors:

- Streamflow characteristics including magnitude and variability
- Minimum streamflow requirements and other withdrawal constraints
- Demand characteristics including magnitude and seasonal distribution
- Required system reliability

Because of the complex interrelationships among these major factors, direct calculation of facilities requirements for a given set of conditions is not possible. Facility requirements must be determined on a trial-and-error basis using a structured continuous simulation approach.

OVERVIEW OF CONTINUOUS WATER SUPPLY SYSTEM SIMULATION

The water supply systems simulation is 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 will be to define a number of trial water supply systems using appropriate components defined in Figure 4. Several sets of monthly demand arrays (small to large) also will be established. Each trial water supply system will be evaluated by the simulation relative to its ability to deliver the desired demands. The reliability of the trial system will be tracked for each demand array simulated. In this manner, relationships can be developed between facility size and water supply yield for the given system reliability. This is the basic approach used previously by CH2M HILL to evaluate the 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. For example, if in a given application, 6 trial water supply systems are identified and 10 demand arrays are defined, 60 simulation runs would be required to fully define the facilities requirements, yield, and reliability relationship. It is likely that some applications will involve more than one complete iteration because the initially defined water supply facilities, or demand levels, may be inappropriate once initial simulation results are known.

The simulation will occur on a monthly time step, which is the appropriate level of detail for preliminary surface water supply planning purposes (McMahon, 1992). The length of simulation will depend upon the streamflow records used. Record length available varies from 11 to 61 years depending on the exact withdrawal points chosen for analysis.

Facilities Considered

Trial water supply systems will be defined based on the components previously discussed and illustrated on Figure 4. Raw water cannot be withdrawn at all times because of minimum streamflow requirements. Therefore, some storage components will be required to develop a reliable water supply system. The minimum facility requirements will include a raw water diversion and pumping station, a water treatment plant, and a finished water ASR system. Because siting the off-line raw water storage reservoirs is likely to be problematic and expensive, we will attempt to meet trial demands with these components only. However, if necessary to provide the required system reliability or operational flexibility, a raw water storage reservoir will be included.

Simulation Logic

The simulation will be constructed around a flow distribution logic that defines how the system will operate and provides criteria that defines how monthly demands will be met based on the monthly divertable streamflow, available facilities, and previously stored water. Considering the most general case, which includes an off-line raw water storage reservoir as well as a finished water ASR system, the flow distribution logic is defined as follows.

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

The above logic is applied to each time step in the simulation and the number of deficiencies is tracked. The total number of deficiencies divided by the total number of simulation time steps is equal to the water supply system deficiency rate. The system reliability is equal to one minus the deficiency rate.

WITHDRAWAL SITE SELECTION

The initial step in the surface water supply evaluation will be to select up to five sites for feasibility analysis. The withdrawal site selection will be the subject of TM B.1.h, *Surface Water Withdrawal Sites*. The sites will be selected after consulting with SJRWMD staff and should be based on matching potential withdrawal sites with urban demand centers. The stream gauging stations to be used in the analysis will be chosen based on the location of the selected withdrawal sites.

Based on our proposed minimum streamflow criteria and maximum allowable diversion rate, it is unlikely that more than about 15 to 20 percent of the total watershed yield will be available for consumptive use. Therefore, water supply development potential in the Palatlakaha River/Haines Creek system is fairly modest. The maximum gauged mean annual flow from this system is 247 cfs. Based on an approximate maximum developable yield of 20 percent of the total yield, the upper limit on water supply from this system will be about 32 mgd.

Potential yield from the St. Johns River will be much greater. Based on the same assumptions, the upper limit for maximum water supply yield from the St. Johns River could be as much as 768 mgd, based on the mean annual river flow observed at Palatka. Therefore, it is likely that the majority of the five candidate withdrawal sites will be located on the St. Johns River. The withdrawal site selection process is described by the following major steps.

- Plot projected public supply demand increases by county on a planning area base map. Counties considered in the surface water analysis include Brevard, Lake, Orange, St. Johns, Seminole, and Volusia.
- Plot approximate maximum developable surface water supply for each stream gauging station listed in Tables 3 and 4 on a similar base map. Maximum developable yield will be calculated as 20 percent of total annual streamflow.
- By visual inspection of the relative geographic location of demand centers and the magnitude of the potential surface water yield, develop a list of candidate withdrawal points.
- Meet with SJRWMD staff to review the mapped demand and source data, and select the five most appropriate sites to be included in the subsequent water availability and yield analysis.

DEVELOPMENT OF REPRESENTATIVE TOTAL STREAMFLOW ARRAY

Once the candidate withdrawal sites are identified a representative streamflow array must be established in order to develop the necessary water supply system simulation studies. If the withdrawal site coincides with 1 of the 13 stream gauging locations then the observed record may be used directly. However, it is likely that one or more of the chosen withdrawal sites will be located between existing gauging station locations. In this case, one of the stations must be chosen and the observed streamflow records adjusted to represent estimated hydrologic conditions at the desired withdrawal point.

In general, the nearest gauge should be used and the daily streamflow values adjusted by multiplying the observed flows by the ratio of the drainage area at the withdrawal point to the drainage area at the gauging station. However, the length of record also should be considered. If the choice is between a station with 11 years of record and a station with 60 years of record, then the longer record should be chosen and adjusted based on the drainage area ratio.

DEVELOPMENT OF MINIMUM FLOW REQUIREMENTS AND AVAILABLE STREAMFLOW ARRAY

Once established, the representative daily streamflow array will be used to develop a flow duration curve for the withdrawal point. Minimum flow requirements will be estimated using the minimum streamflow estimation criteria previously discussed. The minimum flow requirement will be equal to the positive flow rate exceeded 95 percent of the time.

For example, consider the flow duration curve for the St. Johns River near DeLand as illustrated in Figure 2. Positive (downstream) flow occurs 84 percent of the time; therefore, the frequency of the minimum flow would be equal to 95 percent of 84 percent, or 80 percent. The flow rate that was exceeded 80 percent of the time is equal to 236 cfs. This value would become the estimated minimum streamflow requirement for the purpose of the preliminary water supply feasibility analysis.

Once the minimum streamflow requirement is established, this value will be subtracted for all observed (or adjusted) daily streamflow values and all negative values will be set equal to zero. The result will be the available streamflow array. This represents the flow sequence available for diversion, which is subject to a maximum diversion rate constraint.

Daily available flow will be summed for each month in the period of record to develop the available monthly streamflow array. This is the array that will be used in the water supply system's simulation study.

POTENTIAL YIELD ANALYSIS

Potential yield is defined as the water supply yield that could be developed if adequate storage and treatment facilities are provided. It is a function of the available streamflow discussed above and the installed river diversion capacity. Development of a potential yield curve is illustrated on Figure 7. For each diversion rate (q_1, q_2, etc.) up to the maximum allowable, the volume of flow that could be diverted is calculated for each monthly time step. The sum of these values, expressed as the average annual divertable flow, is the potential yield of the stream for a given installed diversion capacity.

The maximum diversion rate proposed for consideration in this analysis is equal to 25 percent of the total watershed yield. Considering the St. Johns River near DeLand, the total watershed yield is equal to 3,043 cfs. In this case, the maximum river diversion rate considered would be 761 cfs or about 492 mgd. Potential yield will always be less than the diversion rate.

The potential yield curve (Figure 7) accounts for the streamflow magnitude and variability, the minimum streamflow requirements, and installed diversion capacity. It provides insight into the scale of facilities (storage and treatment) required to adequately develop the source and will be used to establish trial water supply systems as well as the range of demands to be used in the simulation studies.

FLOW DURATION ANALYSIS

The potential impact of water supply withdrawal on the flow duration relationship also will be developed. Flow duration curves for three potential withdrawal levels will be developed and presented as part of the surface water supply feasibility evaluation. These curves will be based on installed diversion capacities equal to the maximum investigated (25 percent of the mean annual discharge rate), two-thirds of the maximum rate, and one-third of the maximum rate. In this manner, the potential impact of surface water supply withdrawals on the existing flow duration relationship will be quantified.

DOMESTIC WATER SUPPLY DEMAND CHARACTERISTICS

The water supply simulation is demand driven. Therefore, it is important that the characteristics of the demand to be met, including seasonal distribution and maximum day requirements, are reasonably representative of domestic water use patterns within the planning area. Demand ratios will be used to establish the required characteristics. These ratios will describe the demand characteristics as a function of the ADD.

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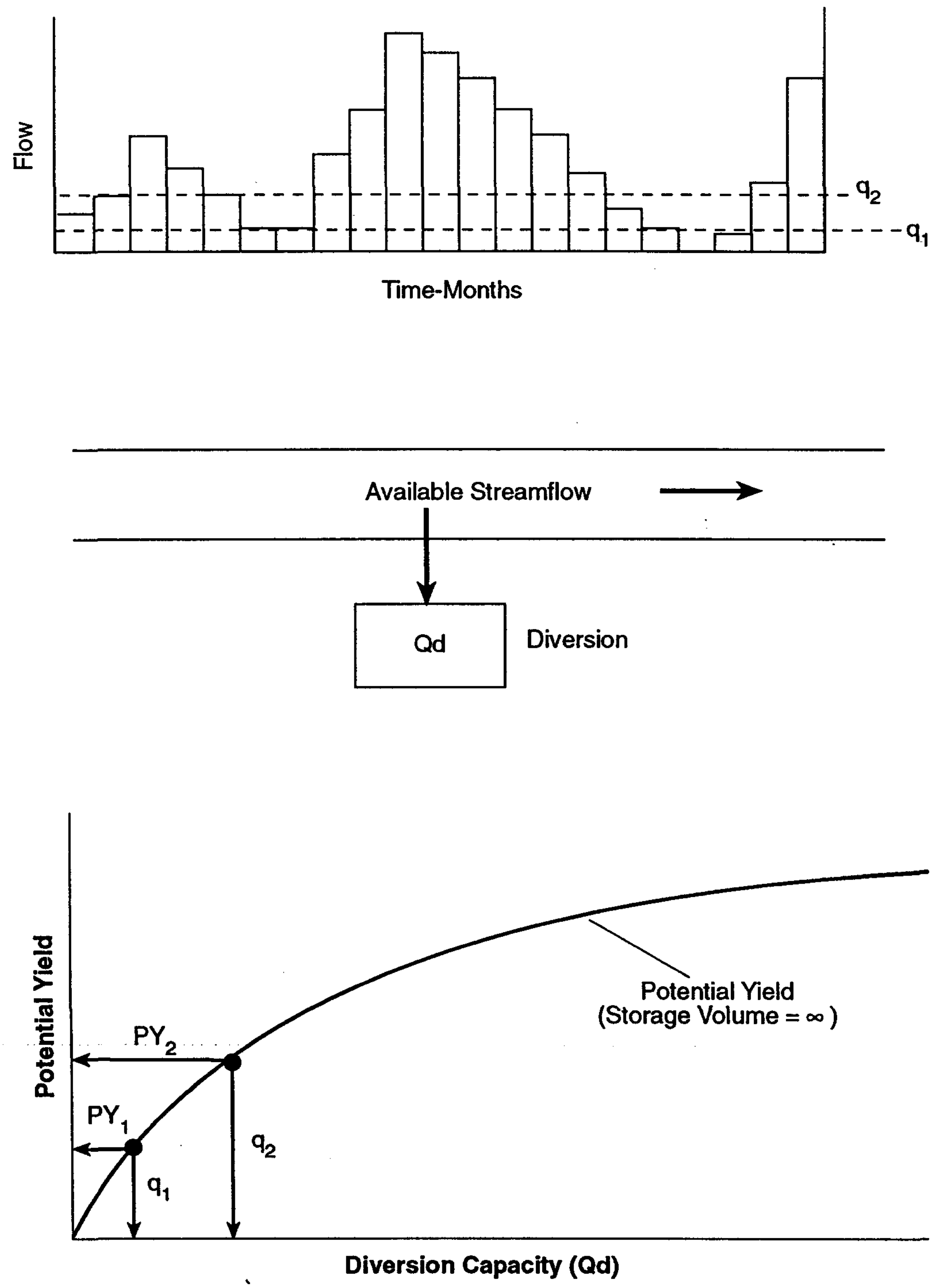

Figure 7. Potential Yield Depends on Availiable Streamflow and Diversion Capacity.

Based on our recent water supply planning experience for the City of Cocoa, Florida (CH2M HILL, 1995), the maximum day to average day ratio will be set equal to 1.5 (MDD/ADD = 1.5). Monthly demand ratios will be as follows:

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

Defining maximum day demand and monthly demand variability as a function of ADD is appropriate for preliminary surface water supply feasibility planning. More sophisticated methodologies for describing demand variations (e.g., techniques based on rainfall or seasonal population variations) are site specific and require a considerable amount of concurrent rainfall and water use data. Such techniques may be applicable to advanced facilities planning or design studies. However, the less complex demand ratio approach will provide a reasonable representation of domestic water use patterns within the planning area.

WATER SUPPLY SYSTEM RELIABILITY REQUIREMENTS

Domestic water supply systems must be highly reliable. That is, these systems must be able to supply the desired quantity and quality of water for a high percentage of the time. However, in most cases, a system deficiency means providing only a portion of the demand or providing water that does not fully meet all desired quality criteria. For example, with an ASR system, the option to provide some water will always be available. However, the TDS concentration (or other constituent) of the product water may exceed the desired primary drinking water standard, depending on the quality of the native ground water present in the ASR storage zone. In any case, a system deficiency is likely to mean implementation of water use restrictions rather than a complete lack of supply, or system failure.

The presence of other sources is another factor that could impact the desired reliability of a given surface water supply system. For example, if a utility produces water from both a ground water supply and a surface water supply, it may be feasible to accept a higher degree of risk than if the total supply were developed from the surface water source.

For the purpose of this preliminary feasibility analysis the acceptable level of risk and corresponding system reliability requirements are a matter of professional judgment. We propose that the target reliability equal 98.3 percent, which is an average of one monthly deficiency occurrence every five years (reliability = 1.0 - 1/60).

FACILITIES REQUIREMENTS SIMULATION

Once the analysis described above is complete, target demands will be established and the trial water supply systems defined. The simulation studies will consist of a complete, period-of-record simulation of each combination of target demand and trial facilities. The simulation output will be the overall system reliability. Based on these results, a relationship will be established between desired yield and water supply facility requirements. This will be the final product of the Phase I surface water supply development feasibility analysis.

Ten target demands will be defined by inspecting the potential yield curve. The maximum potential yield, associated with the maximum diversion rate, will be divided into 10 equal increments to establish ADD values to be used in the simulations. Appropriate demand ratios will be applied to the ADD values to fully define the monthly demand characteristics input to the simulations.

Six initial trial water supply systems then will be defined for evaluation. As previously discussed these systems will include a diversion structure, water treatment plant, and ASR system. A raw water off-line storage reservoir will be used only if necessary to develop the required reliability. Each of these water supply systems will be described in the simulation by their maximum capacity.

Certain initial conditions must be defined to perform the simulation. It will be assumed that a volume of water equal to two months of target demand has been initially injected into the ASR system. Initial ASR recovery efficiency will be assumed to be equal to 70 percent unless a better site specific estimate can be developed. Initial ASR recovery efficiency must be evaluated on a case-by-case basis and will depend on characteristics of the storage aquifer near the withdrawal point.

If an off-line raw water storage reservoir is included in the mix of facilities, then it will be assumed to be full at the beginning of the simulation period. Monthly reservoir volume will be adjusted based on expected direct rainfall input and evaporation losses. Seepage losses will not be considered.

SUMMARY AND RECOMMENDATIONS

Surface water is one of several potential water supply sources being evaluated by the SJRWMD. This TM is the first of a series that addresses the feasibility of developing selected surface water sources to help meet future public supply needs. The TM addresses background information and surface water resources data availability; and it also presents the methodology and major assumptions to be used in the quantitative evaluation of potential surface water yields and water supply facilities requirements. As part of the methodology development, the TM also presents an overview of the factors affecting surface water supply development and a discussion of the mix of facilities that may be required to develop a reliable municipal surface water supply.

SUMMARY

The following factors affect surface water supply development potential:

- Streamflow characteristics (including magnitude and variability)
- Minimum streamflow requirements and other withdrawal constraints
- Characteristics of the demands to be met (including magnitude, seasonal variability and daily maximum)
- Required system reliability

Water storage will likely be required to develop a dependable water supply system because streamflow is highly variable and withdrawal during low flow periods will be restricted. Water supply systems considered in this preliminary feasibility evaluation will include a combination of the following components.

- Raw water diversion structure and pumping station
- Off-line raw water storage reservoir
- Water treatment plant
- ASR system

The minimum water supply system considered will consist of the diversion facilities, the water treatment plant, and finished water ASR. If additional storage is necessary to provide the necessary yield or to keep the treatment plant operating efficiently, then off-line raw water reservoirs will be considered. Off-line reservoirs are likely to require significant land areas; therefore, primary storage will be provide by the finished water ASR system, when practical.

There are sufficient streamflow and water quality records available to support this preliminary evaluation of surface water supply feasibility. Long-term streamflow records will provide the basis of the quantitative feasibility analysis. There are seven USGS stream gauging stations within the Palatlakaha River/Haines Creek hydrologic system with at least 10 years of daily streamflow records available. There are six such stations located on the main stem of the St. Johns River. These streamflow records can provide a basis for the water supply feasibility analysis.

The proposed water supply evaluation methodology is based on continuous simulation of trial water supply systems. A structured simulation study will be conducted for each potential withdrawal point. The simulation studies will establish the relationship between reliable water supply yield and facility requirements. These relationships will be based on certain system operational logic and assumptions related to the minimum streamflow requirements, demand characteristics, and required system reliability.

RECOMMENDATIONS

We recommend approval of the proposed surface water supply evaluation methodology. The methodology includes the basic continuous systems simulation approach and water supply system operational logic previously presented; as well as principal assumptions regarding minimum streamflow requirements and available streamflow, water supply demand characteristics, and system reliability requirements.

Minimum Streamflow Requirements and Available Streamflow

For the purpose of this preliminary feasibility analysis, it is recommended that minimum streamflow requirements be estimated based on an analysis of the withdrawal point flow duration curve. Minimum streamflow requirements will be equal to the positive flow rate exceeded 95 percent of the time. When streamflow rates are less than this value, withdrawal will not be allowed.

The maximum monthly stream diversion capacity to be considered in this feasibility analysis will be equal to 25 percent of the estimated mean annual streamflow at the withdrawal point. This means that the allowable monthly withdrawal rate will never exceed 25 percent of the long-term average streamflow rate.

Domestic Water Supply Demand Characteristic

For the purpose of this preliminary feasibility analysis, it is recommended that seasonal and maximum day water supply demand characteristics be based on these characteristics as previously measured for the City of Cocoa, Florida (CH2M HILL, 1995). These demand characteristics should be reasonable representations of conditions likely to be encountered within the surface water supply planning area.

Water Supply System Reliability

For the purpose of this preliminary feasibility analysis, it is recommended that the water supply system reliability target equal 98.3 percent, which is an average of one monthly deficiency every five years. A water supply system deficiency is an inability to meet all demands at the desired product water quality but does not necessarily imply that no water would be available for distribution.

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