Feasibility Assessment of Deep Well Injection to Assist in Management of Surface Water Releases from Lake Okeechobee to Estuaries

Prepared for:

South Florida Water Management District

Prepared by:

Water Resource Solutions
A Division of Entrix, Inc.

In Association with:

Boyle Engineering Corporation

Milian, Swain & Associates, Inc.

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FEASIBILITY ASSESSMENT OF DEEP WELL INJECTION TO ASSIST IN MANAGEMENT OF SURFACE WATER RELEASES FROM LAKE OKEECHOBEE TO ESTUARIES

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West Palm Beach, Florida

June 2007

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EXECUTIVE SUMMARY

Background

The Lake Okeechobee Estuary Recovery plan (LOER) is a response to the water resource needs, legislative directives, and demands of Florida citizens. LOER components include a comprehensive list of projects designed to improve water quality and the ecological health of Lake Okeechobee and to help restore the ecological health of Lake Okeechobee and the St. Lucie and Caloosahatchee River Estuaries.

Historically, there has often been a need to discharge water from Lake Okeechobee to the estuaries at volumes that exceed ecological targets. Biologists have established that safe or acceptable releases to the estuaries should range between about 450 and 2800 cubic feet per second (cfs). During a 1-in-5 wet year, the discharge to the Caloosahatchee River Estuary often exceeds 5000 cfs. In spite of new and proposed facilities that include reservoirs, surface water treatment areas and aquifer storage and recovery systems, it is still anticipated that releases to the estuaries can be potentially higher than the acceptable limits.

A deep injection well system can be used as an alternative discharge method to help reduce or eliminate excessive discharges to the estuaries. This technology also offers the opportunity to improve the quality of water in Lake Okeechobee. If the deep injection wells are located on upstream tributaries that carry high phosphorous concentrations, then they can be used to reduce the total daily phosphorous load entering the lake. The disposal of this water will help meet the target total maximum daily load (TMDL) for phosphorous.

Injection Well System Target Capacity

Use of deep injection wells to reduce discharges to the estuaries can be accomplished in several ways. The operational alternatives that control the design injection capacity fall into two primary categories, which are: 1) lake-level-based capacity targets and 2) instantaneous discharge based capacity targets.

Injection system design capacity, based on lake-level control, uses a selected discharge or injection volume and time of operation of the wells to reduce excess discharge to the estuaries. The degree to which injection wells might be operated in advance of the need to release water would control the number of wells required.

An instantaneous discharge rate based injection capacity system would skim off excess discharge whenever it might occur; however, the wells would not be operated during periods when the releases were not required. For this system, the injection rate would be reduced or stopped anytime the lake level began to drop below its maximum acceptable level.

The instantaneous discharge based operational program will require more wells than a lake level based operating plan and would not typically manage all excess discharges for a design year. If a 1-in-5 year discharge event is chosen, 20 wells (24-inch diameter) would reduce the volume of excess water discharged to the estuaries by about 27 percent. In order to eliminate 80 percent of the excess discharge to the estuaries using instantaneous discharge based program for a 1-in-5 discharge year, 60 wells would be required.

If injection wells are operated on a lake-level-based program, 20 wells could control the estuary discharge to within the ecologically acceptable range for a 1-in-5 year event, provided the wells can be operated continuously for a period of 3 months and injection would start at a lake level sufficiently below the maximum allowable level of the lake.

Permitting

Target injection zones would contain water with total dissolved solids (TDS) levels approaching that of seawater since the U.S. Environmental Protection Agency (EPA) and the Florida Department of Environmental Protection (FDEP) do not consider such aquifer zones as sources of drinking water. For purposes of the state and federal regulations, the TDS concentration of 10,000 mg/l represents the maximum concentration level for an aquifer classified as an "Underground Source of Drinking Water" (USDW). Injection wells would be designed to protect all aquifer zones classified as a USDW.

The FDEP was contacted and they have indicated they intend to classify injection wells for the LOER program as Class V injection wells. This classification would provide more flexibility than would exist if the wells were determined to be Class I wells, such as those used for injection of domestic wastewater. The wells constructed under this classification would meet the same stringent construction requirements as Class I injection wells to assure well integrity and provide protection of the aquifers containing drinking water, but certain regulatory policies regarding monitoring and construction protocol could be more flexible to meet the requirements of this program.

Pretreatment of the Surface Water

Injection of water into intervals that could allow its entry into a USDW would require that the water be treated to primary drinking water standards, and the costs for treatment would be substantial. Therefore, it is recommended that the LOER injection well program focus on injection only into zones below the USDW. The most economical method for utilizing the deep injection wells would minimize treatment requirements. In this case the primary concern of treatment would be removing only suspended solids that might cause plugging of the injection zone.

Target Injection Zone

The primary geologic zone of interest to receive the excess water is often referred to as the "boulder zone" of the Oldsmar formation. This interval is located approximately 2500 to 3500 feet below land surface (bls). The Boulder Zone is characterized by cavernous permeability, which makes it ideal for injection well operations. This zone has been extensively used for injection of municipal wastewater effluent in disposal wells in South Florida.

Cost and Benefits

The capital cost of a system of 20 injection wells with all associated facilities is estimated at $286,000,000, which is based on wells of 24-inch diameter.

There are a number of potential benefits associated with an injection well program. These benefits include:

- Reducing the hydraulic loading and nutrient loading to the Caloosahatchee and St. Lucie Estuaries,
- Reducing the hydraulic and nutrient loading to Lake Okeechobee from its tributaries,
- Improving water management capabilities of Lake Okeechobee by lowering the lake elevation at the initiation of the wet season.

Locating injection wells close to the downstream discharge structures of the C-43 and C-44 canals would allow these facilities to capture excess basin runoff in addition to Lake releases before discharges are made to the estuaries.

Recommended Injection Well Sites

The locations recommended for installation of injection well systems along with their ranking order are shown below:

1. C-40 below S-72
2. C-43 at Berry Groves Reservoir
3. C-44 St Lucie Canal
4. C-41 below S-71
5. Taylor Creek/Nubbin Slough (S-191)
6. S-154 Basin

Exploration wells should be drilled at each site before an injection well system would be built. There are several other sites that would also be appropriate, however it is recommended that the above sites should be explored first.

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Flow Rate	
1 CFS	1.98 acre-ft/day
1 MGD	1.54 CFS
1 MGD	3.06 acre-ft/day
Volume	
1 foot of Lake Okeechobee	445,000 acre-ft
1 inch of Lake Okeechobee	37,083 acre-ft
1 kaf	1000 acre-ft
1000 kaf /month	16.8 cfs
Injection Well Capacities	
1injection well (24" diameter)	30 CFS
1injection well (24" diameter)	18 MGD
1injection well (24" diameter)	59.5 acre-ft/day
20 injection wells (24" diameter)	36 kaf/month
60 injection wells (24" diameter)	107 kaf/month
90 injection wells (24" diameter)	160 kaf/month
1injection well (34" diameter)	70 CFS
1injection well (34" diameter)	46 MGD
1injection well (34" diameter)	141 acre-ft/day
20 injection wells (34" diameter)	85 kaf/month
60 injection wells (34" diameter)	254 kaf/month
90 injection wells (34" diameter)	380 kaf/month

SECTION 1
INTRODUCTION

1.1 Estuary Enhancement Using an Injection Well Alternative

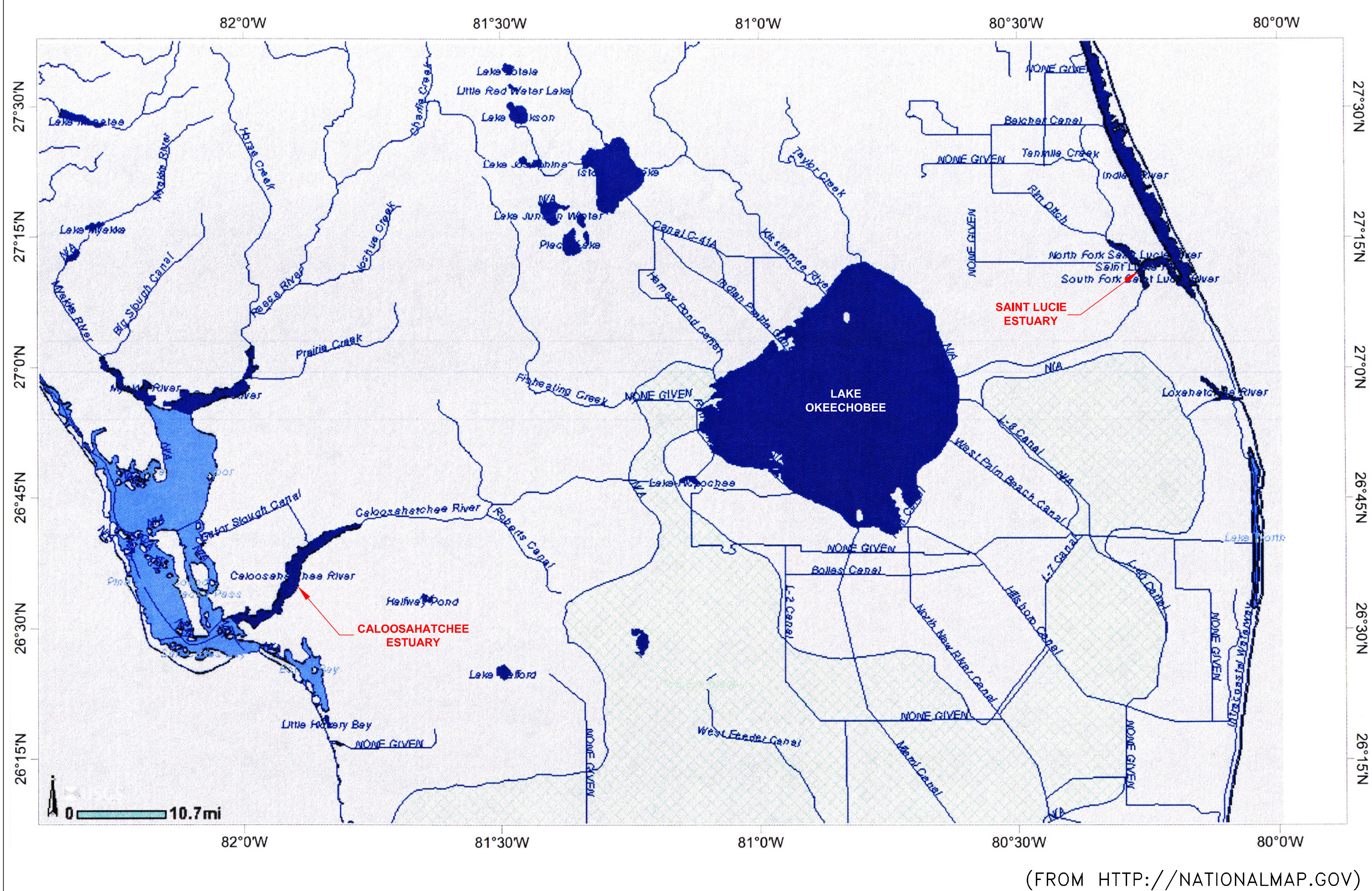
The Lake Okeechobee Watershed consists of approximately 5,400 square miles of agricultural, urban and natural areas. It extends from just south of Orlando, to Lake Okeechobee (the Lake) and includes basins bordering the lake to the east, west and south. The Lake is the largest lake in the southeastern United States and covers 668 square miles. It historically provided the headwaters for sheet flow south to the Everglades, and is currently a central component of the Central and Southern Florida Flood Control Project (C&SF Project). Lake waters flow south, east and west to the Everglades Protection Area, east to the St. Lucie River Estuary, and west to the Caloosahatchee River Estuary (Figure 1-1).

Agricultural and urban land uses in the watershed and the construction of the Central and Southern Florida Project have adversely the hydrology and water quality of Lake Okeechobee. These pressures along with increased hurricane activity in 2004 and 2005 have escalated the hydrologic and water quality problems within the Lake. These changes have resulted in adverse impacts not only to Lake Okeechobee, but also to in its receiving waters downstream, specifically the Caloosahatchee River Estuary to the west and the St. Lucie Estuary to the east.

The Lake Okeechobee Estuary Recovery plan (LOER) is a response to the water resource needs, legislative directives, and demands of Florida citizens. LOER components include a comprehensive list of projects designed to improve water quality in the Lake and its receiving water bodies. The plan has been developed to help restore the ecological health of Lake Okeechobee, and the St. Lucie and Caloosahatchee River Estuaries.

Historically, it has been necessary to release large volumes of water from the Lake during certain times of the year to prevent the water level of Lake Okeechobee from reaching elevations that could compromise human health and safety. The water released during these times flows into the estuaries where it is lost to tide. The discharges occur when water supply is plentiful and such timed releases are not considered a depletion of the water resource. However, the large volumes of water discharged can upset the ecological balance of the estuaries. Large volume discharges equate to large nutrient and sediment loads to the estuaries, increased bacteria levels, and disrupted salinity regimes.

The development of a new regulation schedule for Lake Okeechobee has several components that could potentially require a more rapid release of water from the Lake. During such periods, when it is impossible to store the excess water in above ground impoundments, an alternate method for disposal of the water is needed. Deep injection wells offer a better stormwater disposal alternative than discharging the excess volumes of water into the environmentally sensitive estuaries. Deep wells are generally used to safely dispose of large volumes of municipal wastewater. Application of deep injection well technology to the management of excess storm waters could offer a viable interim or



Water Resource Solutions	PROJECT NAME: LAKE OKEECHOBEE STUDY	DWG. NUMBER: 1161401rj1
	PROJECT NUMBER: 1161401	DATE: 05/18/07

FIGURE 1-1. MAP SHOWING THE LOCATIONS OF LAKE OKEECHOBEE, AND THE SAINT LUCIE AND THE CALOOSAHATCHEE ESTUARIES.

long term solution to the release of water from the Lake to tide.

The purpose of this study is to examine the feasibility of integrating deep injection well technology into the water management program for Lake Okeechobee and its estuaries. The investigation looks at the technical, environmental and regulatory issues associated with undertaking such a project.

1.2 Background of Injection Well Use in Florida

Deep injection wells serve a valuable purpose in Florida, by protecting the surface environment from large, localized discharges of wastewater. Injection wells have been used for disposal of both storm water and municipal wastewater for many years. The most common application of deep well injection in Florida is for disposal of municipal wastewater, whereby treated wastewater is injected into deep, underground and highly permeable rock formations that naturally contain saline water. The practice of deep well injection has been successfully applied for treated wastewater disposal at many locations throughout south Florida. The geologic formation that most commonly receives the injected water is the lowermost portion of the Floridan Aquifer System, between the depths of approximately 2,500 and 3,400 feet below land surface (bls). The formation at this depth is made up of limestone and dolostone containing highly transmissive solution channels. This zone is commonly referred to as the "Boulder Zone".

Deep wells that dispose of municipal wastewater are mostly termed Class I injection wells, and they must inject into deep aquifers that contain water with more than 10,000 mg/l total dissolved solids (TDS). Aquifers located above this depth that contain water having less than 10,000 mg/l TDS fall into a category termed by the United States Environmental Protection Agency (EPA) as an "Underground Source of Drinking Water" (USDW).

As of the end of 2006, there were 143 Class I deep injection wells operating within the State of Florida. An additional 28 new deep injection wells were under construction or in the permitting process (refer to Figure 1-2 for locations of Class I injection wells in south Florida in 2003). The total permitted injection capacity of Class I injection wells in Florida exceeds 1.5 billion gallons per day, and the average daily flow injected during the years 2000 through 2002 was approximately 410 million gallons per day (mgd). Figure 1-2 shows the location of the Class I injection wells in Florida as of the end of 2003.

The lower Floridan injection zone naturally contains highly brackish water with a salinity that is similar to seawater. Several hundred feet of confining layers separate this injection zone from the overlying, less brackish upper Floridan Aquifer. The aquifers that contain fresh water in south Florida lie within the Surficial and Intermediate Aquifer Systems, which are effectively separated from the Floridan Aquifer System by another

CLASS I INJECTION FACILITIES

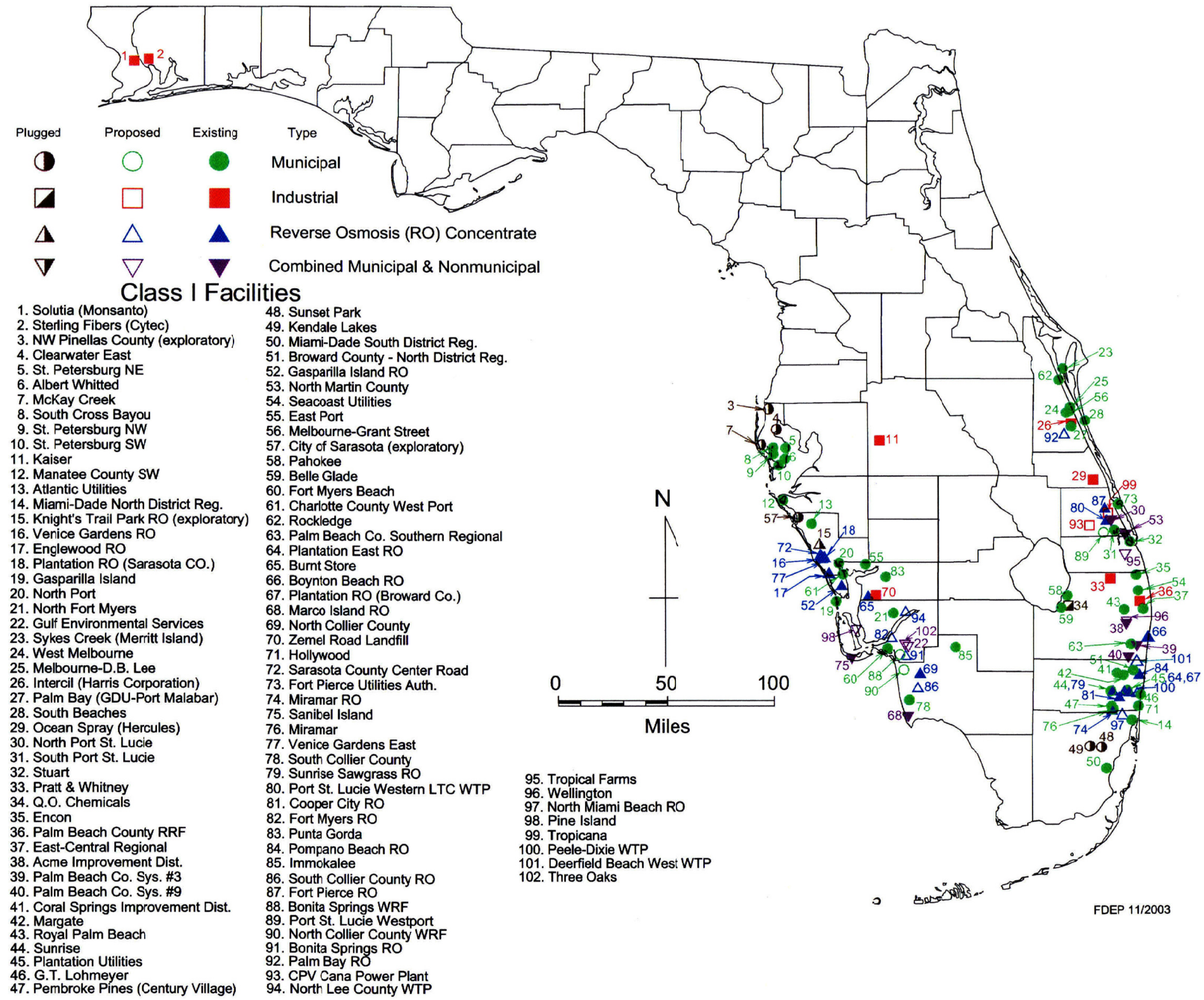


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FIGURE 1-2. LOCATION OF CLASS I INJECTION WELLS IN 2003. (FROM HTTP://WWW.DEP.STATE.FL.US/WATER/UIC/INDEX.HTM)

confining layer of low permeability clays and other formations that are 300 or more feet thick.

The Florida Department of Environmental Protection (FDEP) has comprehensive regulations that govern the injection well program. These regulations are similar to or more stringent than the Federal Regulations of the EPA. The goal of these regulations is to prevent injected fluids from migrating into an USDW. To date upward migration of injected fluid has been detected at eight Class I injection wells. While no potable aquifers have ever been impacted, some deep aquifer zones having TDS of less than the 10,000 mg/l level have been intruded by injected water. The impacted zones have been confined to Floridan Aquifer zones containing brackish water. The intrusion did not degrade or threaten any potable water sources, but rather the water entered zones containing brackish water. In one of these locations, the brackish zones that have been invaded now contain fresh water of desirable quality andit is currently proposed to recover the new fresh water to supplement reuse systems with a new irrigation water supply source.

1.3 Injection Well Applications for LOER Plan

When the ecology of Lake Okeechobee, or the integrity of the Herbert Hoover Dike surrounding it are threatened by high lake stages, discharges to tide become necessary. Biologists have established that lake levels in the range of 13.5-15.5 feet are favorable for the health of the lake. New reservoirs, storm water treatment areas (STAs) and the eventual application of aquifer storage and recovery, which are all presently part of the Comprehensive Everglades Restoration Plan (CERP), will soon help to provide additional storage for the excess water. However, in spite of these new facilities, there is still a need to discharge to the estuaries at volumes that exceed ecological targets. Deep injection wells can be used as an alternative to help reduce or eliminate excessive surface water discharges.

Operating similarly to the Class I wastewater disposal wells, injection wells developed for the LOER plan would dispose of stormwater that would otherwise be discharged to tidal waters in the estuaries. In addition, there also remains potential that a portion of the water injected for this purpose might later be recovered for use. Recovery might be accomplished either by pumping directly from the zones receiving the injected water or by capturing water from confined zones of the Lower Floridan Aquifer immediately above the receiving zones. The recovery method would be similar to the extraction system proposed for the previously mentioned Class I injection wells that have experienced vertical migration, which would provide yet another benefit to an injection well system.

In addition to reducing impacts on the estuaries, injection wells provide an opportunity to improve the quality of water in Lake Okeechobee. Locating deep injection wells on upstream tributaries that carry phosphorous at high concentrations can reduce the total daily load entering the lake and help meet the target total maximum daily load (TMDL). Nutrient reduction per unit resulting from injection well disposal of high phosphorous concentration water may, in certain locations, be more cost-effective than other alternatives.

There are a number of potential benefits to implementing an injection well program. These benefits include:

- Reducing the excess fresh water loading and nutrient loading to the Caloosahatchee and St. Lucie Estuaries
- Reducing the hydraulic and nutrient loading to Lake Okeechobee from its tributaries
- Improving water management capabilities of Lake Okeechobee by lowering the lake elevation at the initiation of the wet season
- Intercepting waters thereby reducing the need to backpump water high in nutrients from agricultural areas into the Lake

This study will address the degrees to which the deep well injection can help meet the goals of the LOER plan.

SECTION 2
PERMITTING CRITERIA AND REGULATORY ISSUES

The Florida Department of Environmental Protection (FDEP) regulates deep well injection under its Underground Injection Control (UIC) program. The UIC program is a permitting and enforcement activity that the federal Environmental Protection Agency has delegated to the FDEP. A comprehensive set of rules has been adopted to regulate underground injection. Under these rules, injection wells that are allowable in Florida fall into the following categories:

Class I	Wells used to inject municipal wastewater and/or by-product from desalinization facilities.
Class II	Wells used to inject water associated with the production of oil and gas or water used to enhance hydrocarbon recovery.
Class III	Wells which inject fluids for extraction of minerals.
Class V	Wells not included in the other well classes which inject nonhazardous aqueous solutions. There are several subgroups associated with this classification.

The topics of primary importance for permitting and regulatory issues related to implementing deep well injection as part of the LOER program include:

- Well classification options
- Monitoring requirements
- Area of review requirements for intermittent operations
- Injection rates and period of injection
- Aquifer pressure build-up
- Fluid/formation compatibility
- Potential treatment requirements
- Well design requirements

2.1 Well Classification Options

A variety of well classifications were initially considered applicable for the LOER program, including: Class I, and several categories of Class V wells.

2.1.1 Class I Wells

The Class I option was considered because the target injection zones are likely to contain water with total dissolved solids (TDS) levels approaching that of seawater and because these wells must meet the more stringent UIC injection well requirements. For purposes of the regulations, the TDS concentration of 10,000 mg/l represents the maximum concentration level for an aquifer classified as an “Underground Source of Drinking Water” (USDW). Class I wells must inject into aquifers below the USDW, whereas Class V wells can be permitted to inject below or into a USDW based on the purpose and quality of water. The Class I designation is used in Florida for municipal wastewater injection wells. The potential for using this classification was discussed with the FDEP and the prevailing opinion is that since the LOER injection wells are not intended to dispose of municipal waste, this would be an inappropriate classification. However, the more stringent construction criteria associated with Class I wells are considered appropriate for guiding the design of these injection wells.

2.1.2 Class V Wells

In accordance with discussions held with FDEP, three types of Class V wells are potentially appropriate for this project. These three types of wells include:

- Group 2 Aquifer Recharge - Saltwater Intrusion
- Group 6 Storm Water Wells - Wells used to drain storm water run-off or for lake level control
- Group 9 Experimental Technology - Other

Each of the above groups is considered viable based on the location of the well(s) and the specific purpose for selecting the location.

Group 2 Aquifer Recharge - Salt Water Intrusion

Since saltwater intrusion is an issue in certain areas within the region of this project, this classification could be useful at potential sites near the coastline where the movement of salt water threatens to cause significant reduction in the quality of feedwater to potable water treatment plants. This option would involve directly recharging the USDW with excess surface water and would be a suitable choice for siting injection wells at locations near the estuaries and the coast.

A second option within the Group 2 classification would be to locate these type wells at inland locations where brackish water aquifers are used as source water for reverse osmosis (R.O.) treatment plants. This option could also allow for discharge into USDW’s or aquifers immediately below the USDW. The reason for installing wells at such locations would be that any potential upward migration of this water would benefit the overlying brackish zones since the injected fresh water would reduce or eliminate upconing of highly saline water beneath a wellfield. The upconing of fresh water would improve the quality of the produced water and reduce the costs of R.O. treatment. However, migration into an unpermitted overlying USDW, no matter how beneficial, could be considered unacceptable from a regulatory perspective. The potential disadvantage of this would be a requirement to treat the water to meet higher disinfection standards before injection, which would add significant costs to an injection project.

Group 6 Storm Water Wells - Wells to drain storm water run-off or for lake level control

The Group 6 designation is the most logical designation for most of the wells that would be utilized for disposal of the water entering or exiting Lake Okeechobee due to storm events or for lake water level control. Wells under this designation could receive large volumes of water over a limited time period in order to drop lake levels at a rate commensurate with the need and ability to reduce discharge rates to the estuaries.

Wells under this designation could also be located in areas where nutrient loading in waters feeding into the lake are high. Wells located in these areas could be used for both nutrient and storm water run-off reduction.

Group 9 Experimental Technology - Other

A Group 9 designation might be utilized for this project. It is possible to request a special designation under this grouping; however, the need for an additional designation is not evident at this time.

Advantages of the Class V Designation

The primary advantage of selecting a Class V designation is that the FDEP has more flexibility regarding specific construction, operating, monitoring, and other permitting requirements. It may still be desirable to incorporate many of the stricter construction criteria for Class I wells; however, obtaining a variance from certain less important construction or monitoring details might be accomplished without requiring extensive formal action.

2.2 Monitoring Requirements

2.2.1 Injection Well Monitoring

FDEP monitoring requirements at each injection well will likely include maintaining a continuous record of the wellhead pressure, injection rate, and monitoring of the total injected volume. The required analysis for chemical parameters in the injected water usually involves some level of negotiation with the FDEP. The likely monitoring requirements include specific conductance, dissolved chloride, sulfate, TDS, fecal and total coliform, TKN, nitrate, nitrite, TOC, phosphorous, and total nitrogen. Periodic sampling for Cryptosporidium, Giardia, and other biological contaminants should also be anticipated. For a multi-well system these analyses might only be performed on water collected at a single sample point close to the intake or just downstream of the pretreatment system. Monitoring would typically be done monthly during extended periods of injection; however, since wells may only operate intermittently the sampling might only be required when injection is initiated.

2.2.2 Monitoring Well Locations

Monitoring requirements for the LOER injection well program should be designed to provide sufficient information to allow an understanding of what is occurring in the subsurface during injection while minimizing monitoring and well construction costs.

FDEP regulations related to Class I wells require that two zones be monitored above the injection zone and that these wells be located within 150 feet of the injection well. The purpose of these monitoring wells is to provide information concerning the possibility of vertical movement of injectate near the injection well. Basically, freshening of the monitor zone or the presence of certain tracer compounds is used to indicate upward movement of water towards an underground source of drinking water. This approach is reasonable when a limited number of injection wells are involved. However, for this project, it is possible that a large number of wells (10) could be installed at a single site. For a multiple well system, a single dual-zone monitoring well, strategically placed, would provide the necessary information required to identify any vertical migration from the injection zone. The primary monitoring well for vertical movement would likely be located within 150 feet of the centermost well in the wellfield.

In addition, for evaluation purposes, it is recommended that a monitoring well be located within the injection zone at a distance approaching 2000 feet from an injection well cluster. The purpose of this well would be to monitor pressure in the injection zone during operational phases and to identify when the injected plume passes the monitoring well. The data could be used to provide a more accurate picture of the injected plume size and thickness. For a pod of 5 to 10 wells, two local monitoring wells would be sufficient to meet operational monitoring needs. Figure 2-1 provides a representation as to how a two monitoring well system would provide the desired information.

For a large group of wells it may be valuable to install a regional monitoring well, completed in the injection zone, and located approximately 1 to 2 miles from the center of the injection site. This well would be utilized to evaluate the long term position of the injected water and aquifer pressure build-up at a distance. Ultimately, the number of monitoring wells is dependent on site-specific hydrogeologic conditions and negotiations with FDEP.

2.2.3 Monitoring Well Chemical Analyses

The parameters monitored should be limited to appropriate indicator parameters unless there is evidence of some issues of particular concern. It is recommended that specific conductivity, chlorides, and TDS form the basis of water quality analyses. Periodically, more detailed testing could be performed after water quality changes have occurred. The details for the more complete water quality analyses will need to be developed with the concurrence of the FDEP.

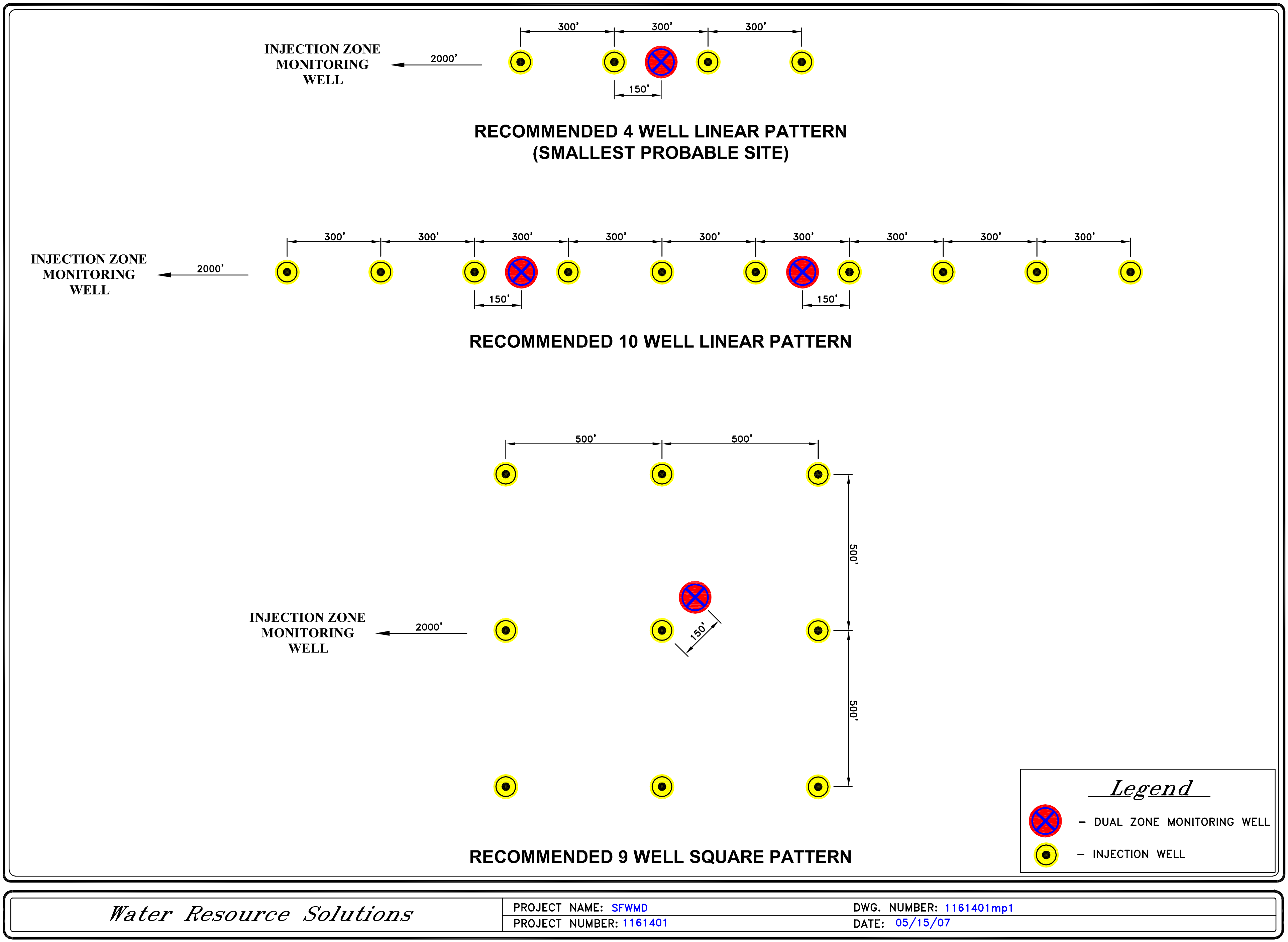

FIGURE 2–1. RECOMMENDED SITE INJECTION/MONITORING PATTERNS.

2.2.4 Monitoring Well Physical Analyses

The water level in the monitored zones should be recorded continuously immediately prior to, during, and after injection to determine the magnitude of water level changes associated with injection. No other physical parameter needs to be monitored.

2.3 Area of Review

The FDEP requires an area of review study (AOR) which documents existing and abandoned wells within a prescribed area surrounding an injection well. Of particular concern are borings that may have penetrated the confining units that would separate the injection interval from upper zones that are part of the USDW. The AOR also documents other subsurface features that may affect fluid movement in the subsurface such as faults or fractures.

A minimum area of review (AOR) for a Class V well is set at 1 mile by Florida Administrative Code (FAC) chapter 62-528.300(4)(a) and (b) for Class V wells. For Class I wells, the FDEP has recently required that the AOR be calculated based on ten additional years of injection at the maximum rate. Also, the AOR must be calculated using a minimum zone height of 200 feet and a porosity of 0.2. The extent of the plume is calculated based on the volume occupied by the injected water over the ten year period assumed to be stored within the pore spaces of the aquifer. Typically, this computation is made assuming continuous operation. For an injection rate of 36 MGD, this would result in a radius of 2.2 miles from the injection well. A collection of 10 injection wells pumping at the maximum rate of 36 MGD for 20 years would have a radius of approximately 10 miles. Since it is not intended that the wells would operate continuously, it is reasonable to request a modification of this methodology. For a Class V well, such a reduction in area of review is anticipated to be acceptable to FDEP.

It may be desirable to conduct a preliminary AOR prior to finalizing the injection capacity and number of wells for a given site. Once it is known if there are potential problem areas, the ultimate site capacity could be adjusted to fit the injection volume available.

2.4 Duration of Injection

From a regulatory perspective, several aspects of injection need to be evaluated concerning the time and duration of injection. Typically, the FDEP uses the maximum rate and a fixed time period (two permit renewal periods) to determine the anticipated long term area of review. This approach could be utilized to determine a limit for the useful life of an injection well. Since the AOR can be utilized to establish the maximum allowable amount of water that can be injected at a site without intersecting conduits that might allow injected water to move vertically into a USDW, the District should give some consideration to identifying the volume of water likely to be injected at a specific injection site over the life of the well. This value could then be used to establish an area of review that would serve the District over the injection life of the well and also help identify any potential long term injection issues associated with a given site.

Although the future is difficult to predict, continued five year permit approval for open-ended injection beyond 50 years may not be approved. Therefore, deep well disposal may only provide an interim solution until an alternate solution for diverting the water from the estuaries can be developed.

2.5 Injection Rates

The FDEP rules currently limit injection rates to 10 feet/second for normal periods and 12 feet/second during periods of emergency. However, the regulations provide for higher rates if "the applicant demonstrates higher velocities will not compromise the integrity or operation of the well". Table 2-1 provides the maximum injection rates currently allowed for a given casing inside diameter.

TABLE 2-1. MAXIMUM INJECTION RATES CURRENTLY ALLOWED FOR INSIDE CASING DIAMETER

Inside Casing Diameter (Inches)	Injection Rate @ 10 feet/Sec (MGD)	Injection Rate @ 12 feet/Sec (MGD)
23	18.6	22.4
25	22.0	26.4
29	29.7	35.6
33	46.0	55.3

2.6 Injection Pressure

The issue of concern regarding injection pressure is the potential that the subsurface fracture pressure threshold will be exceeded. The target injection interval is highly transmissive and therefore fracture pressures are not anticipated to be reached in the deep wells proposed for this site. A conservative fracture gradient to assume for Florida's "Boulder Zone" is estimated to be 0.55 psi/ft (Eaton, 1969). The following equation provides an estimate for the maximum allowable pressure based on this fracture pressure gradient for wells deeper than 1500 feet, which is estimated to represent the region where hydraulically induced fractures would rotate from horizontal to vertical:

I_p = 0.55 psi/ft X D - 0.445 psi/ft X D

Where:
I_p = Injection Pressure
D = Depth to base of casing
0.55 = Fracture gradient in psi/ft
0.445 = Hydrostatic Gradient

Based on the above equation, the minimum surface injection pressure required to generate and extend a fracture in the "Boulder Zone" is 263 psi for a well cased to 2500 feet and 315 psi for a well cased to a depth of 3000 feet.

Injection pressures that remain below 150 psi at the surface will not cause or extend a fracture within the "Boulder Zone". The 150 psi limit remains conservative, because it also does not include frictional pressure due to flow down the injection casing. Actual, formation pressure increases should be measured at the face of the formation and not at land surface if a true representation of the pressure build-up during injection is to be made. The typical injection pressure employed for this project is anticipated to be at least 200 psi below the fracture pressure of the formation, when measured at the borehole wall.

2.7 Fluid/Formation Compatibility

The compatibility between the water being injected into a formation and the formation matrix will need to be addressed during permitting. The primary concern of this issue is the potential for dissolution of the formation that might cause cavities and eventual erosion of the confining layers or potential for collapse of upper formations. The actual impact of dissolution in this case is anticipated to be small. The specific reaction of interest is:

$$\mathbf{CaCO_3 + H_2O \rightarrow Ca^{2+} + HCO_3^{-} + OH^{-}}$$

This reaction represents the dissolution of limestone. Calculations have been made to estimate the extent of dissolution that might occur after extended periods of injection. The water quality characteristics that were used for this analysis are within the range of data from several surface water samples that were collected as part of CERP studies related to the ASR pilot projects. The following water quality represents a breakdown of the water quality parameters of importance to this calculation:

pH	Hardness	Alkalinity	Bicarbonate	Calcium
7.5	120 mg/l	93 mg/l	93 mg/l	75 mg/l

An evaluation of the above data indicates that $CaCO_3$ is near or above saturation in the lake water. Thus, little if any significant dissolution of the formation matrix should be anticipated due to the injection of the water. The waters to be injected at the alternative locations for injection wells will differ from that used for this analysis. This evaluation will need to be done for each site based on site-specific water quality.

For Class V wells that would inject above the USDW, the potential for leaching and transport of trace metals would likely be an issue. This issue is the subject of developing policies that are currently being considered by the FDEP and the U.S. Environmental Projection Agency. Studies to address this issue could affect timing of implementation of an injection well project if injection were to take place into a USDW. This issue should be considered if evaluating injection into a USDW. For the LOER program, it is recommended that injection wells be designed to dispose of water below the USDW.

2.8 Potential Treatment Requirements

The most economical method for utilizing the deep injection wells will require minimizing treatment requirements. Injection of water into intervals that could allow its entry into a USDW would require that the water be treated to primary drinking water standards, and to meet high level disinfection criteria. The costs for conducting this level of treatment would be substantial. Therefore, it is recommended that LOER injection well program focus on injection only into zones below the USDW. In this case the primary concern of treatment would be removing only suspended solids that might cause plugging of the injection wells.

2.8.1 Filtration of Particulate Material

In general, injection of particulate material can plug injection wells. Typically, plugging is dependent on the size and the number of particles in the injected water. However, it is likely that if wells are constructed in the highly transmissive portions of the "Boulder Zone" which is known to contain large solution channels, no significant plugging due to fine particulate matter is likely. Therefore, minimal, if any, filtration or screening will likely be required. The issue of filtration is expected to be site-specific, based on formation properties and water quality. Filtration requirements may also vary seasonally due to variations in aquatic vegetation.

2.8.2 Disinfection

The level of disinfection that might be required, if any, would depend on the injection interval selected and the quality of the injected water. If the injection activity would appear to have the potential to cause upward migration into a USDW, then disinfection could be required. The types of biological units that may be found in the water such as coliform, giardia, crytosporidium, and others would also affect the treatment method used. Early discussions with the FDEP suggest that areas in the lake that may be exposed to high levels of Giardia, cryptosporidium, etc. should be avoided, to the extent possible, as source waters for injection. If the injection zones selected are shown to have suitable confinement, there should be no need for disinfection.

2.9 Regulatory Limitations Affecting Well Design

Regulatory limitations affect many components of well design; however, for the LOER program the regulations of primary importance are those that might limit the size of an injection well. A review of the FDEP regulations shows that there are only two limitations that could impact the size an injection well for the LOER program. These limitations are stated in FAC 62-528.410(4)(b) and FAC 62-528.410(5)(g).

The first limitation is the stated requirement that seamless casing must be utilized for the final casing. The largest common size casing meeting regulatory requirements is 24-inch casing. However that requirement may be bypassed if an applicant demonstrates "that the proposed material and thickness will not compromise the integrity or operation of the well." Since both seamless and longitudinally welded pipe meet the same API and ASTM standards and these pipe types appear to be used interchangeably, it is likely that longitudinally welded pipe may be utilized for the construction of Class V wells. A review of the literature available on the internet does not indicate that regulatory agencies such as the Department of Transportation (DOT) are indicating any corrosion issues associated with welded rather than seamless pipe. It is therefore expected that for Class V wells, the requirement to use seamless pipe can be deferred.

The second criteria of importance is making a demonstration that the cement grout between the final casing and the formation is sufficient, as required by FAC 62-528.410(5)(g). This requirement is somewhat more difficult to meet due to the physical limitations of the geophysical tools that are currently available to make this demonstration. Thus far, 26-inch pipe has been the largest pipe to have been authorized for use. The FDEP has raised concerns that cement bond logs for larger pipe may not provide sufficient resolution to confirm the presence of adequate cement bonding between the cement and the casing and the cement and the formation. Currently, Florida's largest injection well drilling contractor, Youngquist Brothers, Inc. is in the process of testing a modified cement bond log that is thought to be able to provide the resolution required by the FDEP. However, the sensitivity of the tool has not yet been established. This issue will require further discussions with the FDEP prior to approval to use casing larger than 26-inch.

SECTION 3
HYDROGEOLOGIC EVALUATION

3.1 Generalized Geologic History of the Lake Okeechobee Area

3.1.1 Structural Setting

The Lake Okeechobee area lies within the South Florida Basin, one of 18 subbasins recognized around the margin of the Gulf of Mexico (Mello and Karner, 1996). (Figure 3-1) The South Florida Basin is sometimes referred to as the Okeechobee Basin (Scott, 1997).

The Gulf of Mexico formed during the Triassic (250 to 200 million years ago) as the North American plate separated from Africa and South America and the North Atlantic Ocean formed. Thus, it is related to other, smaller Triassic-age rift basins along the North Atlantic margin of North America.

The South Florida Basin is characterized by a thick section of Mesozoic and Tertiary, predominantly carbonate, sedimentary rocks with an average thickness of about 17,000 feet (Figure 3-2). The Jurassic-age (200 to 140 mya) through Early Eocene-age (58 to 50 mya) rocks consist predominantly of interbedded sequences of carbonate and evaporite rocks. These are mainly limestones and anhydrites. This indicates consistent subsidence in the basin, closed circulation, and a lack of nearby clastic materials (i.e. quartz sands and noncarbonate clays) transported into the basin.

Toward the end of the early Eocene, plate tectonic activity to the south resulted in the opening of a connection between the Gulf of Mexico and the North Atlantic. This occurred as the Caribbean microplate progressively moved to the east relative to the North American plate and the Cuban island arc was obducted notheastward onto the edge of the North American plate. This is evidenced by duplex thrust faulting in the Cuban foreland (i.e. off the north coast of Cuba). Related vulcanism is present along the Caribbean microplate margin in southeast Cuba, Hispanola (Haiti and the Dominican Republic), Jamaica, and Puerto Rico.

In South Florida the tectonic stress related to the relative plate movements is manifested as a series of poorly defined west-northwest trending strike-slip faults and fracture zones, with a secondary northwest trend of small normal faults related to drag along the main stress related features and stress relaxation related to folding. The net effect of the resultant readjustment from the strike-slip faulting has been the progressive counterclockwise rotation of the Florida Platform, relative to a fixed arbitrary pivot point in north Florida, away from the Yucatan Platform as the Gulf of Mexico continued to open since the Early Eocene. One of these strike-slip fault zones commonly referenced in the geologic literature (Klitgord et al, 1984), known as the Florida-Bahamas Fracture Zone, occurs along the north side of the Lake.

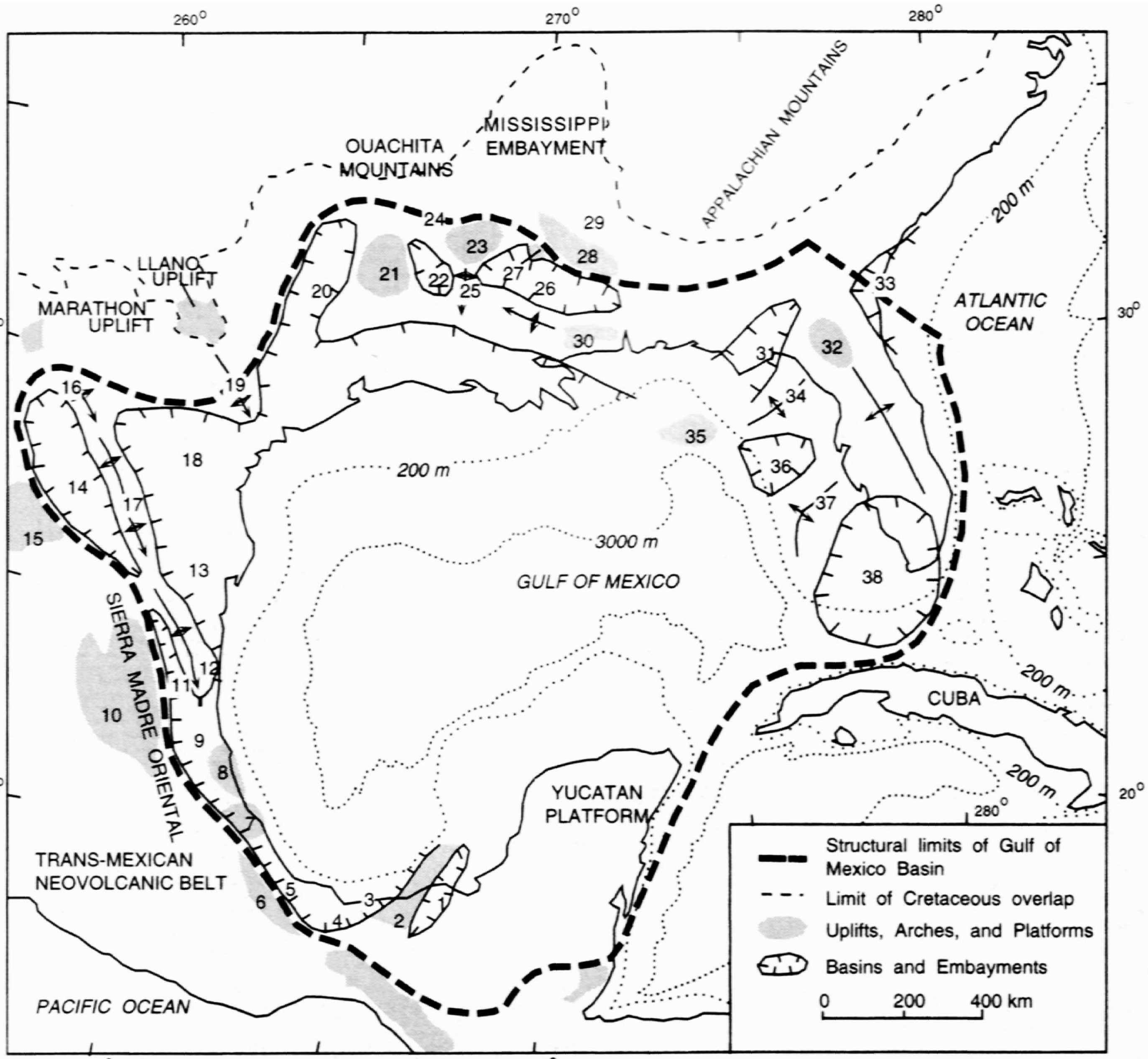

Figure 1—Generalized structural map of the Gulf of Mexico and the salt basins: 1 = Macuspana basin; 2 = Villahermosa uplift; 3 = Comalcaco basin; 4 = Isthmus saline basin; 5 = Veracruz basin; 6 = Córdoba platform; 7 = Santa Ana Massif; 8 = Tuxpan platform; 9 = Tampico-Misantla basin; 10 = Valles-San Luis Potosí platform; 11 = Magiscatzin basin; 12 = Tamaulipas arch; 13 = Burgos basin; 14 = Sabinas basin; 15 = Coahuila platform; 16 = El Burro uplift; 17 = Peyotes-Picachos arches; 18 = Rio Grande embayment; 19 = San Marcos arch; 20 = East Texas basin; 21 = Sabine uplift; 22 = North Louisiana salt basin; 23 = Monroe uplift; 24 = Desha basin; 25 = La Salle arch; 26 = Mississippi salt basin; 27 = Jackson dome; 28 = Central Mississippi deformed belt; 29 = Black Warrior basin; 30 = Wiggins uplift; 31 = Apalachiola embayment; 32 = Ocala uplift; 33 = Southeast Georgia embayment; 34 = Middle Ground arch; 35 = Southern platform; 36 = Tampa embayment; 37 = Sarasota arch; 38 = South Florida basin (modified from Salvador, 1991).

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FIGURE 3–1. MAP SHOWING LOCATION OF SOUTH FLORIDA BASIN WITHIN THE GULF OF MEXICO GEOLOGIC PROVINCE (FROM MELLO AND KARNER, 1996)

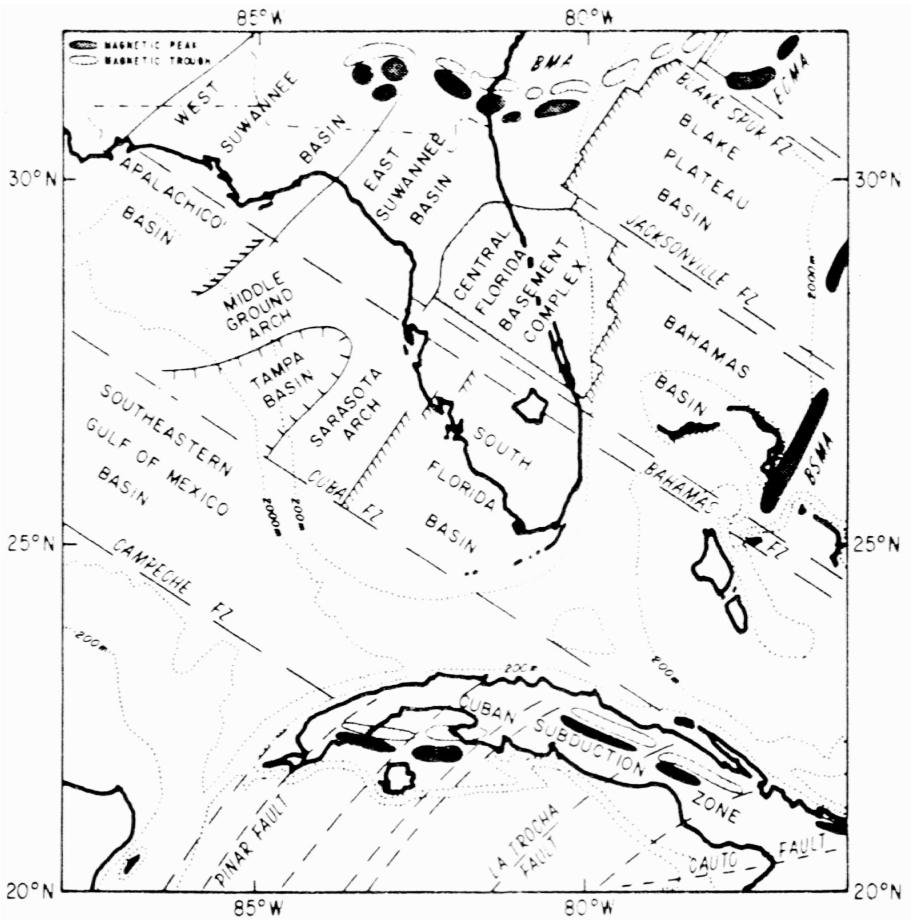

FIGURE 3-2A

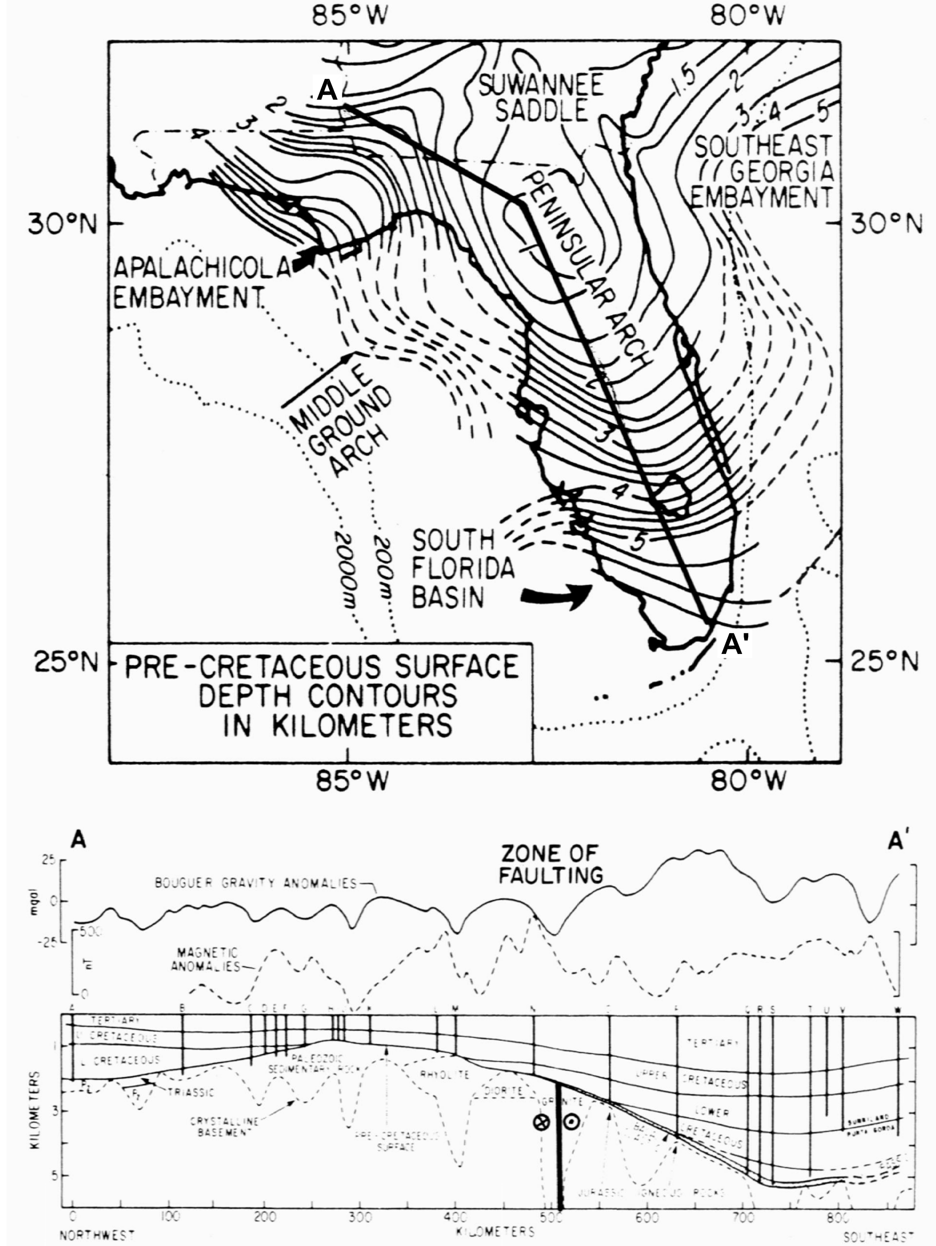

FIGURE 3-2B

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FIGURE 3-2. (A) MAP SHOWING MAJOR STRUCTUAL ELEMENTS OF THE FLORIDA-BAHAMAS PLATFORM AND CUBA ISLAND ARC (FROM KLITGORD ET AL, 1984)
(B) CROSS-SECTION THROUGH THE FLORIDA PENINSULA SHOWING MAGNETIC AND BOUGER GRAVITY ANOMALIES (FROM KLITGORD ET AL, 1984).

Notwithstanding the presence of fractures and faults, the main expression of tectonic stress in South Florida is folding. These tend to be relatively broad, large scale features. Conversely, faulting tends to be localized and of the “thin skinned” type, wherein more competent (i.e. harder, more compacted and lithified units) tend to react to stress brittly, whereas less competent units (e.g. clays, anyhdrites, chalky or poorly lithified limestones) tend to react more plasticly. In this type setting, faulting or fracturing of a competent rock unit, such as a dolomite or well lithified limestone, would tend to be vertically constrained within that unit if it is bounded above and below by less competent rock units.

Periods of tectonic stress in South Florida that are relevant to this investigation occurred in the Late Eocene (approximately 41 to 38 mya), Late Oligocene (approximately 33 to 25 mya), and Mid Miocene (approximately 18 to 11 mya).

3.1.2 Stratigraphy

The Jurassic through Early Eocene age rocks are about 14,000 feet thick and consist predominantly of interbedded sequences of carbonate and evaporite rocks. These are mainly limestones and anhydrites. Rock units of interest to this study include the Late Paleocene-age (approximately 62 to 55 mya) Cedar Keys formation, the Early Eocene-age (approximately 53 to 47 mya) Oldsmar formation, the Middle Eocene-age (approximately 47 to 43 mya) Avon Park formation, and the Late Eocene-age (approximately 40 to 38 mya) Ocala formation (Figure 3-3).

The Cedar Keys formation consists of interbedded limestones and anhydrites. The unconformably overlying Oldsmar formation consists of limestones and dolomites, with minor lignite and anhydrite locally (SFWMD, 2004). The Avon Park formation conformably overlies the Oldsmar and consists of interbedded limestones and dolomites, with minor lignite. The Ocala formation unconformably overlies the Avon Park and unconformably underlies the overlying younger rocks. The Ocala consists mainly of chalky limestones.

Unconformities, representing periods of significant erosion, occur at the end of both the Eocene and Oligocene. These are related to global drops in sea level (Haq et. al, 1987) and locally also likely represent, as detailed above, periods of more intense tectonic activity. During these periods of relative sea level decline, fresher meteoric waters moved along the vertical pathways formed by the fracture trends resulting in significant diagenesis in the Oldsmar formation, in some areas causing pervasive dolotimization of the limestones and dissolution of the anhydrite beds. Removal of the anhydrite beds resulted in extensive cavernous porosity in the Oldsmar formation. The volume reduction caused by conversion of limestone to dolomite also resulted in creation of significant permeability.

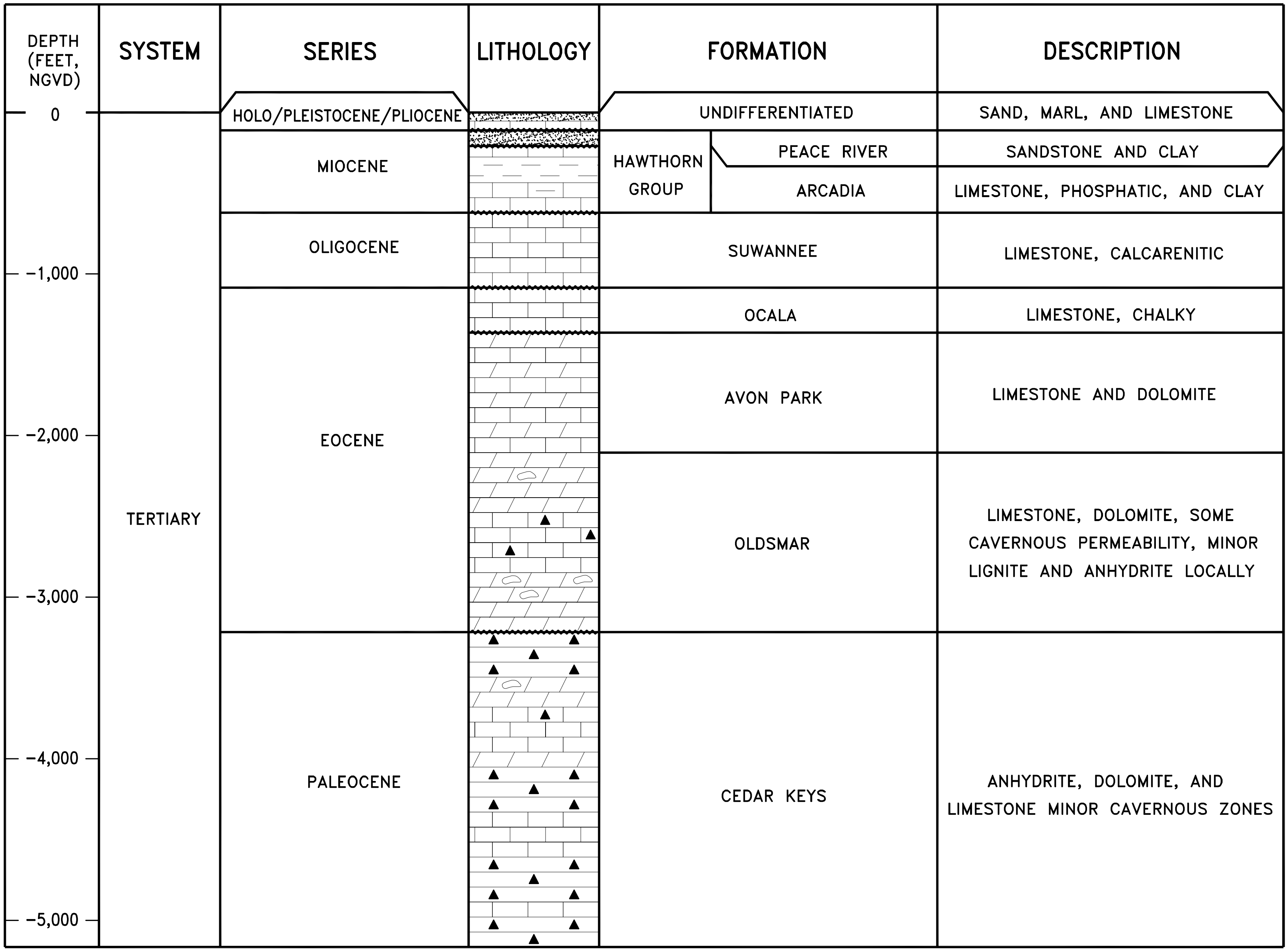

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FIGURE 3–3. GENERALIZED STRATIGRAPHIC COLUMN FOR THE LAKE OKEECHOBEE AREA (MODIFIED FROM RANDAZZO, 1997).

Intervals of cavernous porosity, particularly in the Oldsmar formation, are commonly referred to as “boulder zones”. This is because when drillers of early petroleum exploration wells in South Florida encountered these zones of cavernous porosity, drilling conditions (i.e. very slow progress, loss of circulation of drilling fluids, sticking of drill pipe, and hole caving) were similar to those encountered when drilling in boulder fields in mountainous areas. These tough drilling conditions in South Florida are often caused by roof collapse in caverns in the Boulder Zone when penetrated by a drill bit. The Boulder Zone of the Oldsmar formation is the principal zone used for injection of municipal wastewater in disposal wells in South Florida. Most of those wells are located in the heavily populated areas along the east and west coasts of South Florida. Figure 3-4 shows the area where the Boulder Zone has been considered to be generally present in Florida.

3.2 Implications for Boulder Zone Development in the Lake Okeechobee Area

Approximately two dozen petroleum test wells have been drilled around Lake Okeechobee. Several hundred more have been drilled in the productive Early Cretaceous-age Sunniland formation that trends southwest of the Lake. Information gained from analyses of the lithologic logs, geophysical logs, drilling histories, drill time logs, and casing records from these wells indicates that the Boulder Zone of the Oldsmar formation is present in the Lake Okeechobee area. Figure 3-5 shows the penetration depths of inventoried wells in the study area.

Native groundwater quality in the Oldsmar formation throughout South Florida is saline, similar to seawater quality. At all locations where a suitably permeable formations are encountered, the native water quality should be appropriate for deep well disposal. The transmissivity of the Boulder Zone is highly variable. It is related to the thickness and lateral extent of the cavernous zones and the related intensity of fracturing. In areas near the Lake, the transmissivity of the Oldsmar formation cannot be confidently estimated without testing.

3.3 Preliminary Evaluation of Available Data

In order to provide a preliminary evaluation of the available subsurface data, and more particularly to better define the distribution of high permeability zones in areas around Lake Okeechobee, four cross-sections were constructed. The locations of the cross-sections are shown on the map provided as Figure 3-6. The cross-sections are provided as Figures 3-7 through 3-10. In general, the available lithologic and geophysical log information is not complete enough to provide a detailed evaluation of the potential for high rate subsurface disposal of excess surface water flows in areas that have not been explored for this purpose. However, some general conclusions can be made. These are:

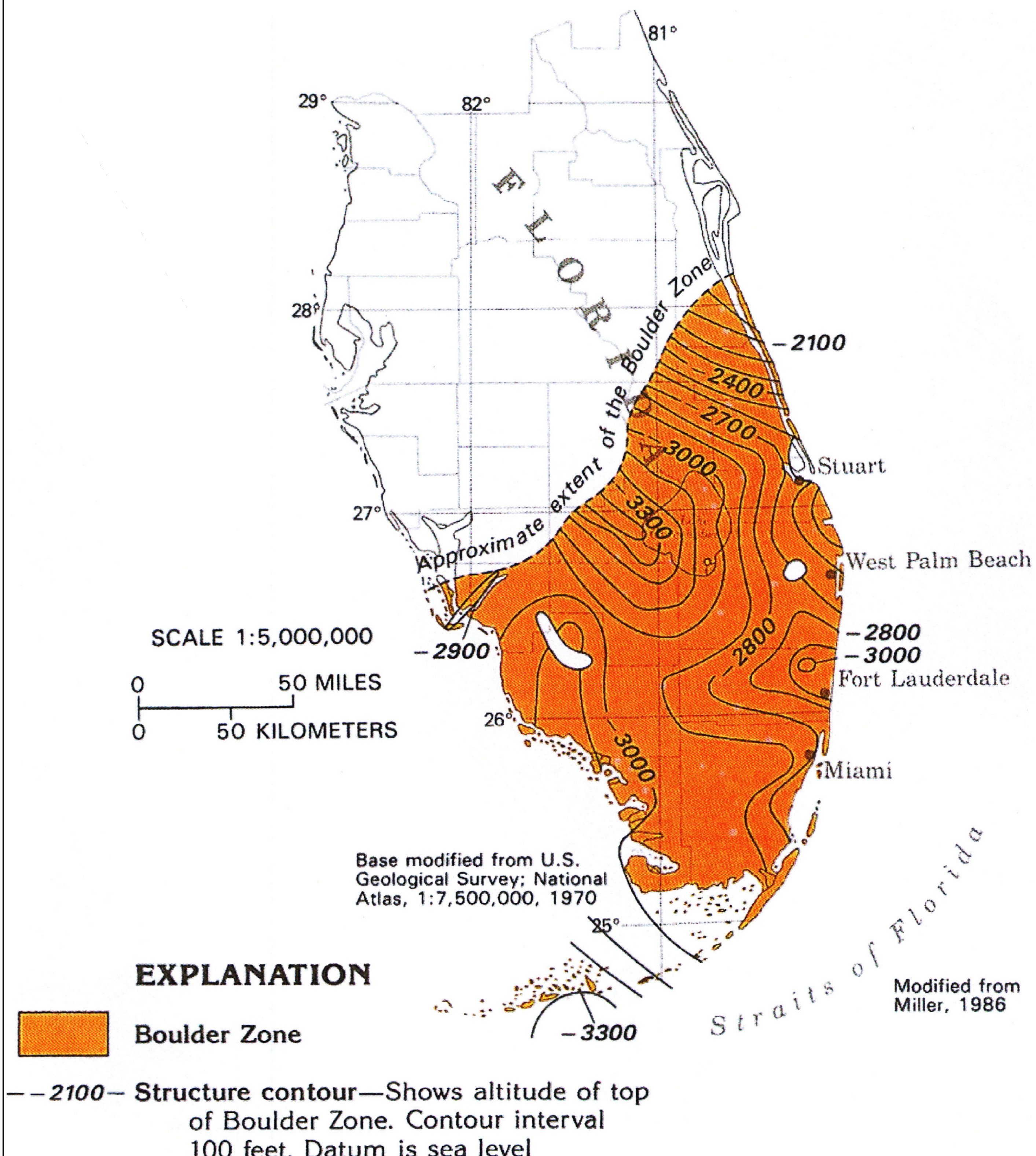

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FIGURE 3-4. GENERAL LOCATION OF BOULDER ZONE (FROM http://capp.water.usgs.gov/gwa/ch-g/G-text.html).

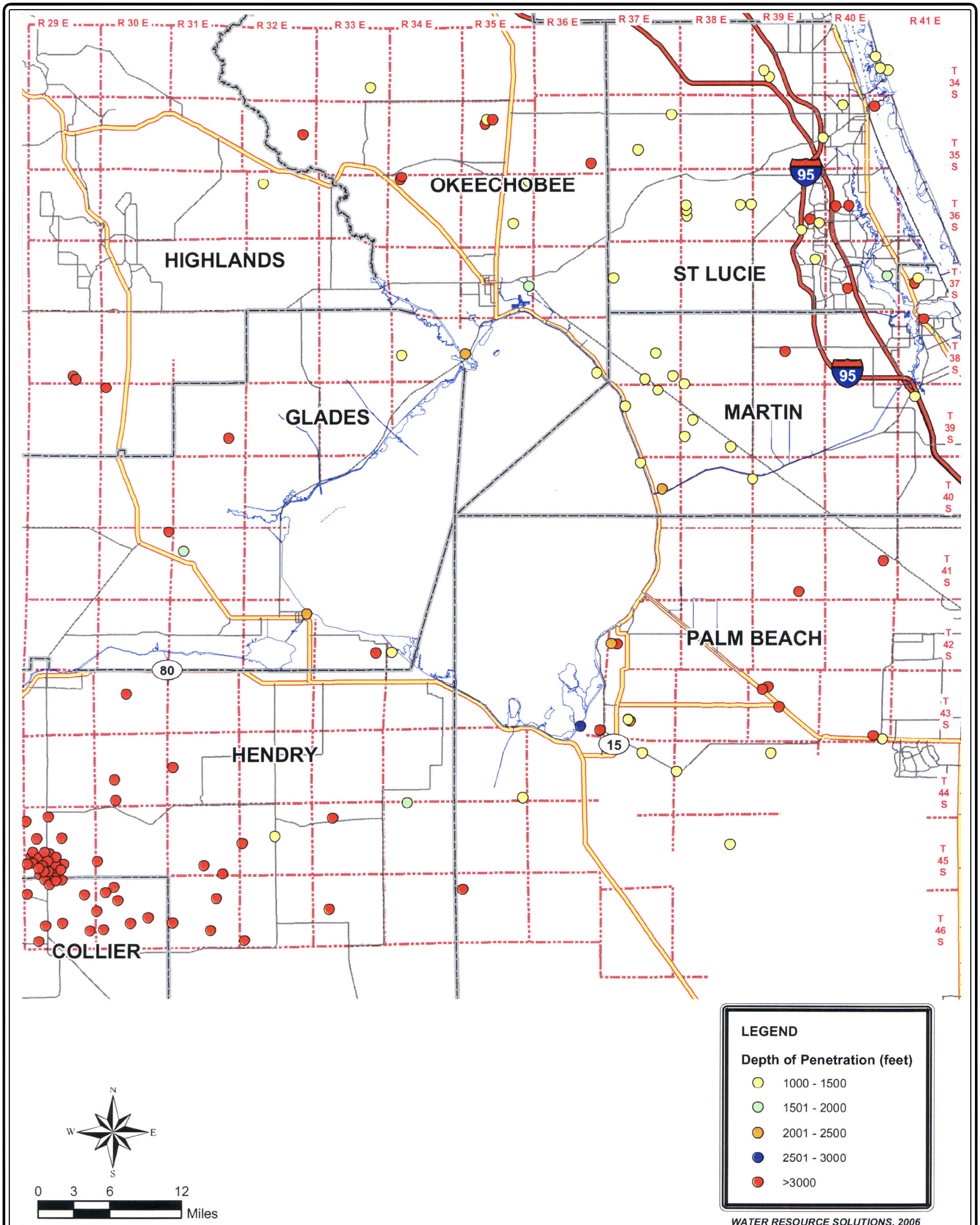

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FIGURE 3–5. DEPTH OF PENETRATION MAP FOR INVENTORIED WELLS.

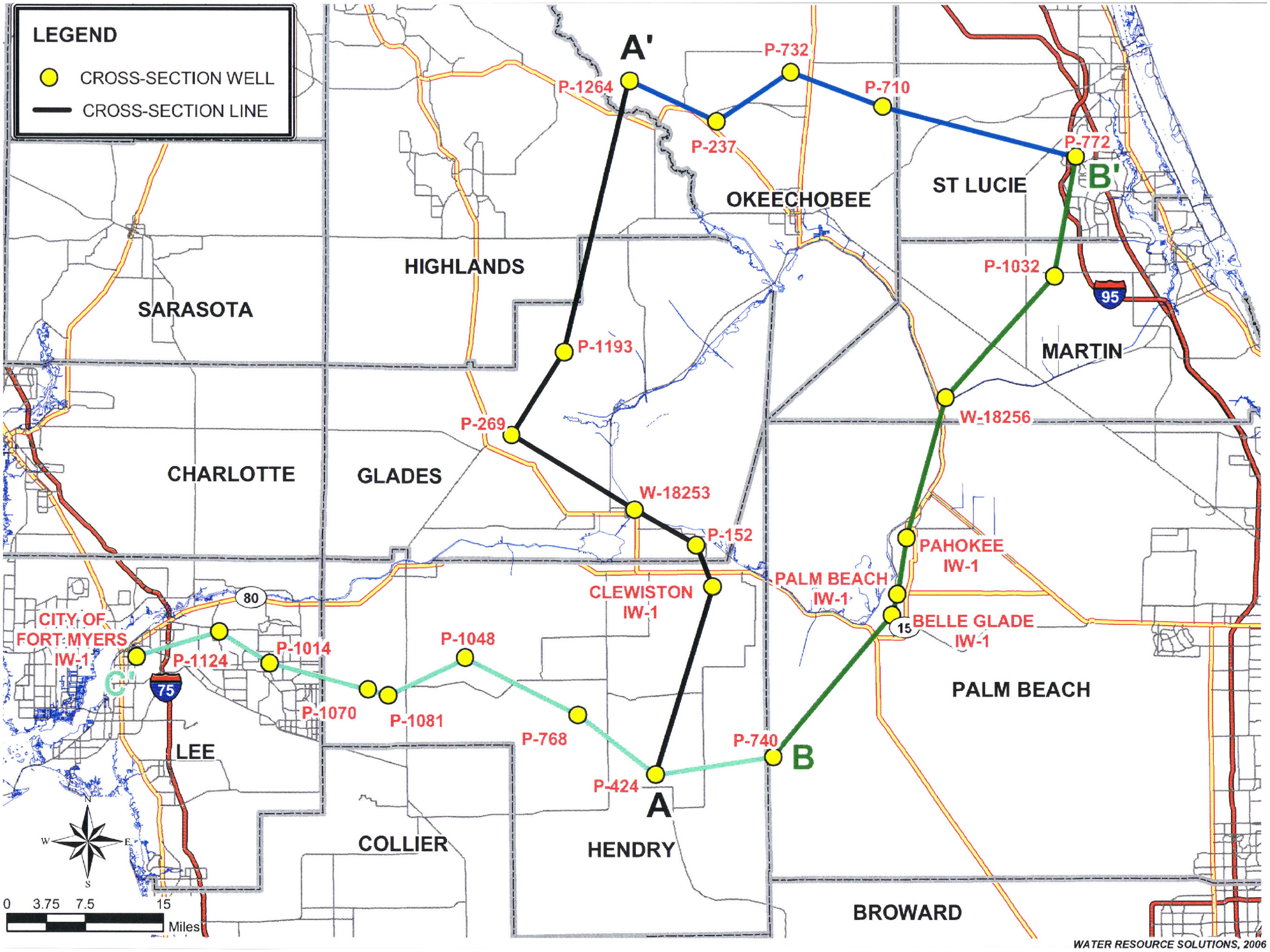

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FIGURE 3–6. MAP SHOWING LINES OF CROSS–SECTION.

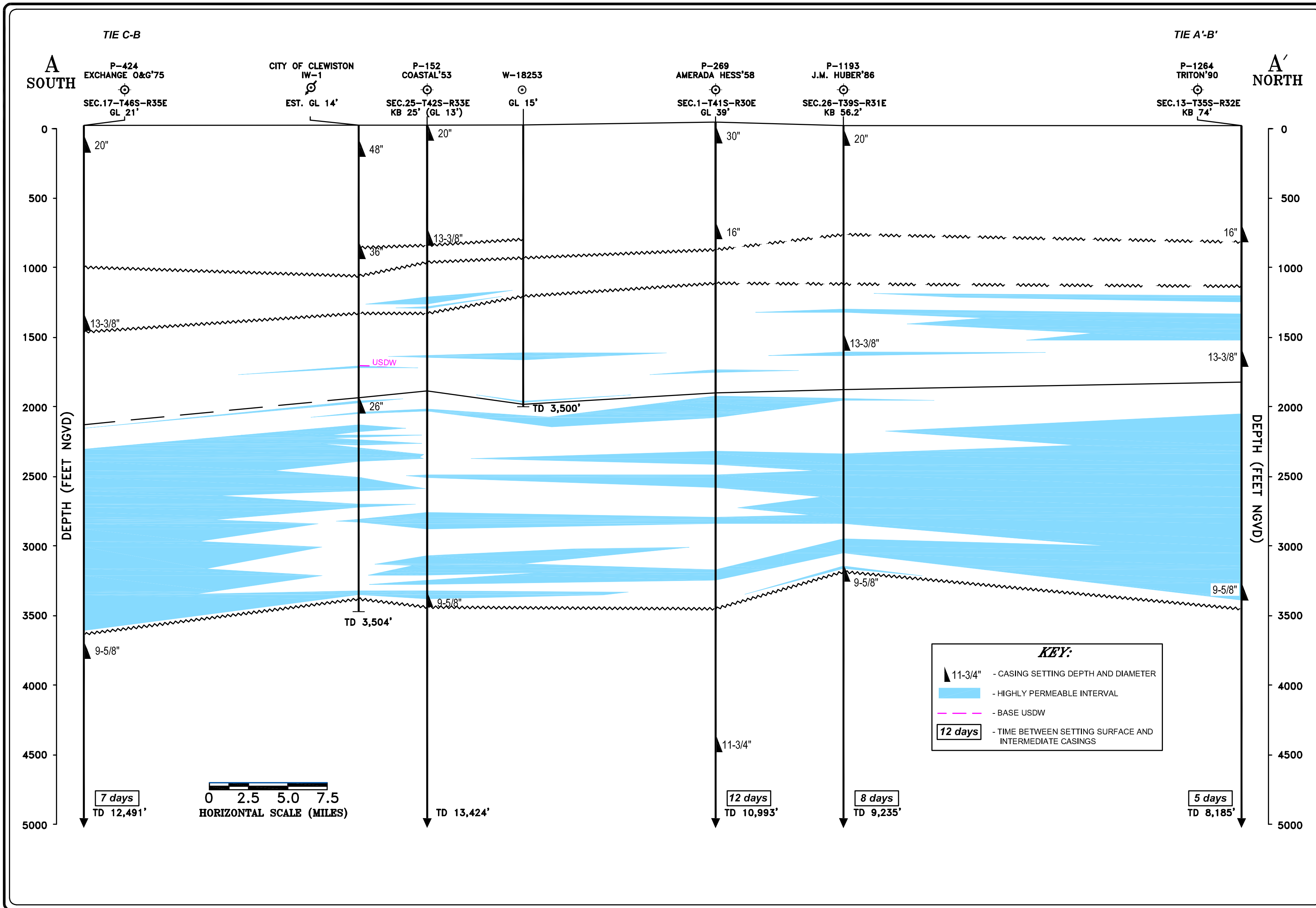

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FIGURE 3-7. CROSS-SECTION A-A'.

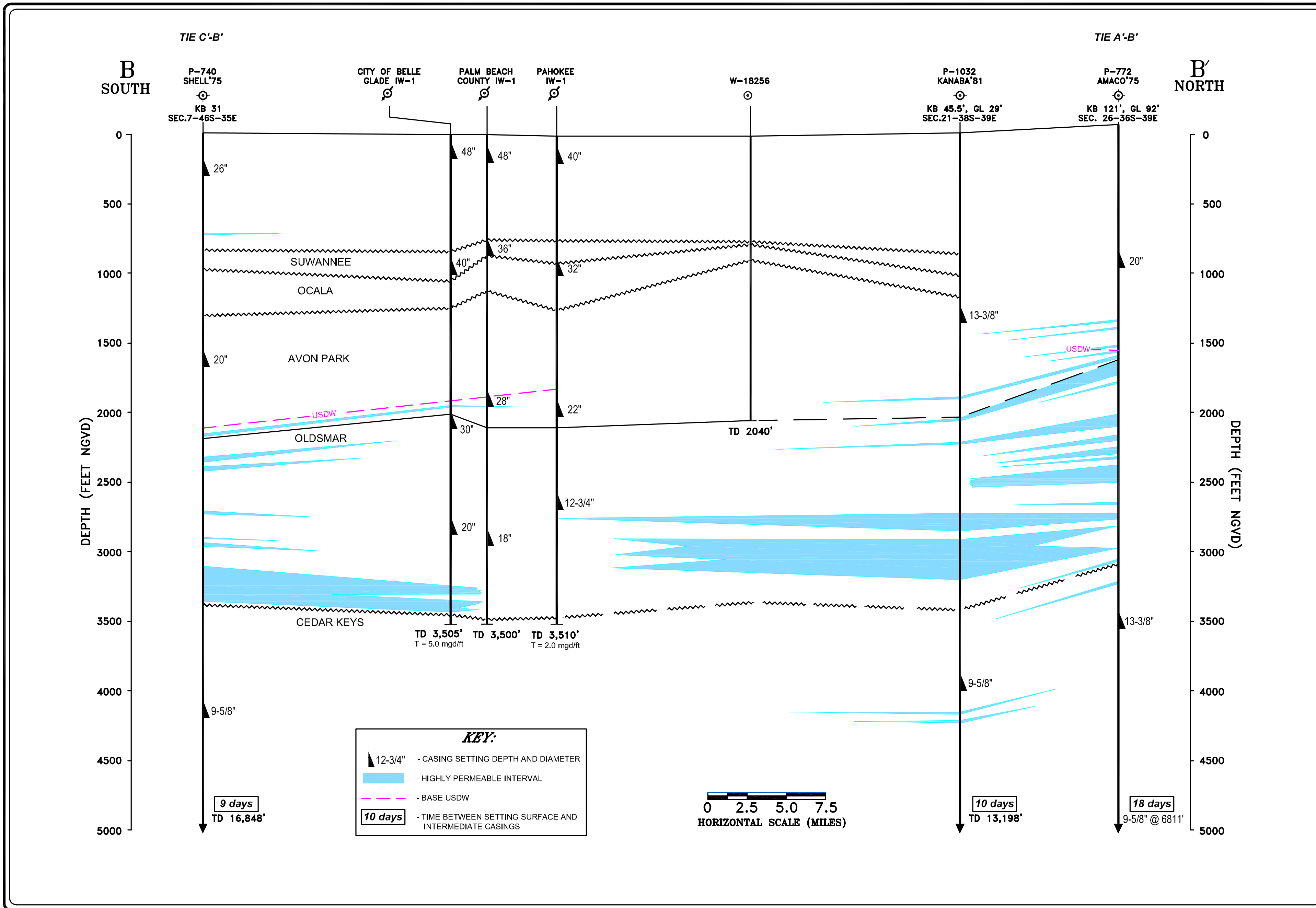

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FIGURE 3-8. CROSS-SECTION B-B'.

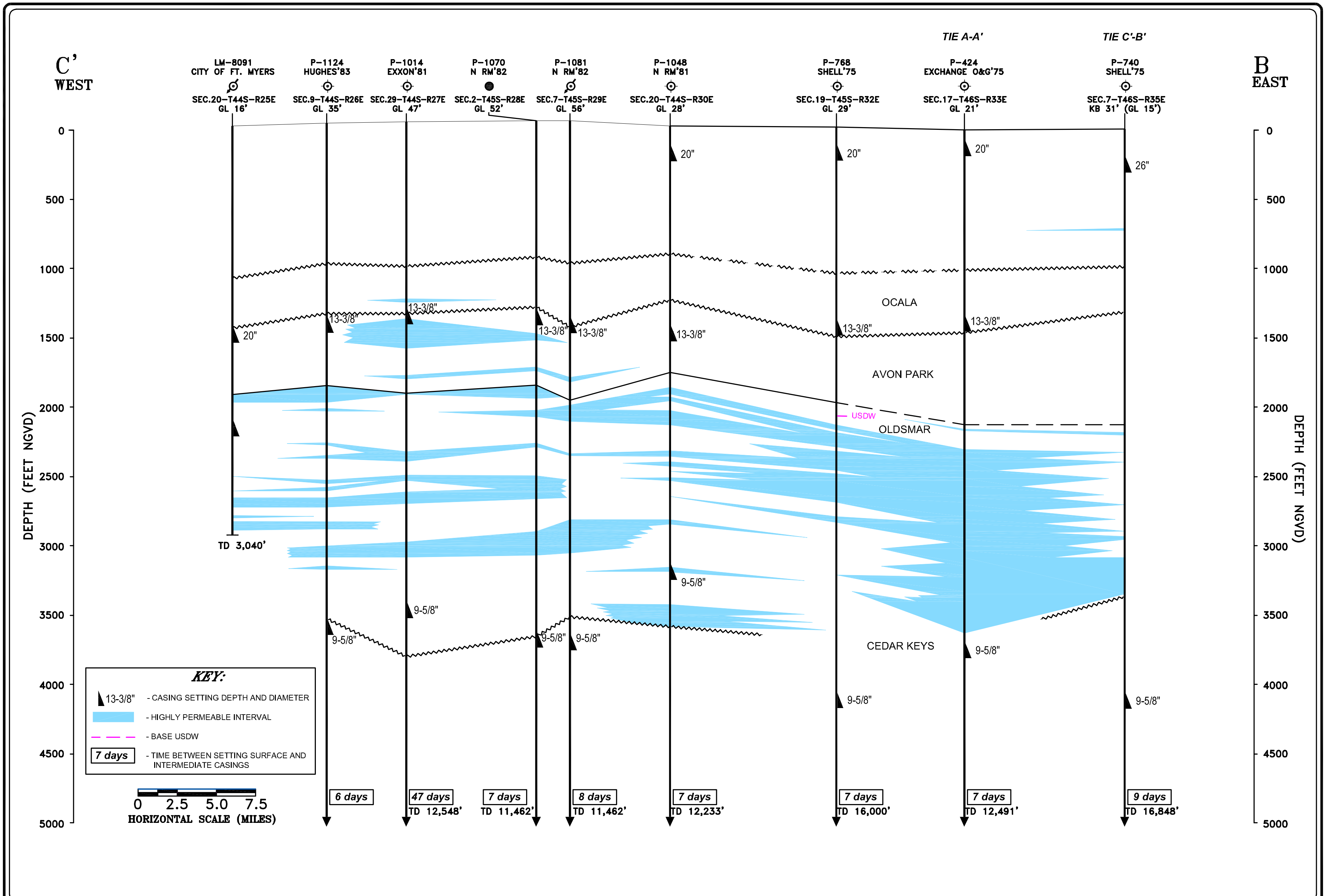

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FIGURE 3-9. CROSS-SECTION C-B'.

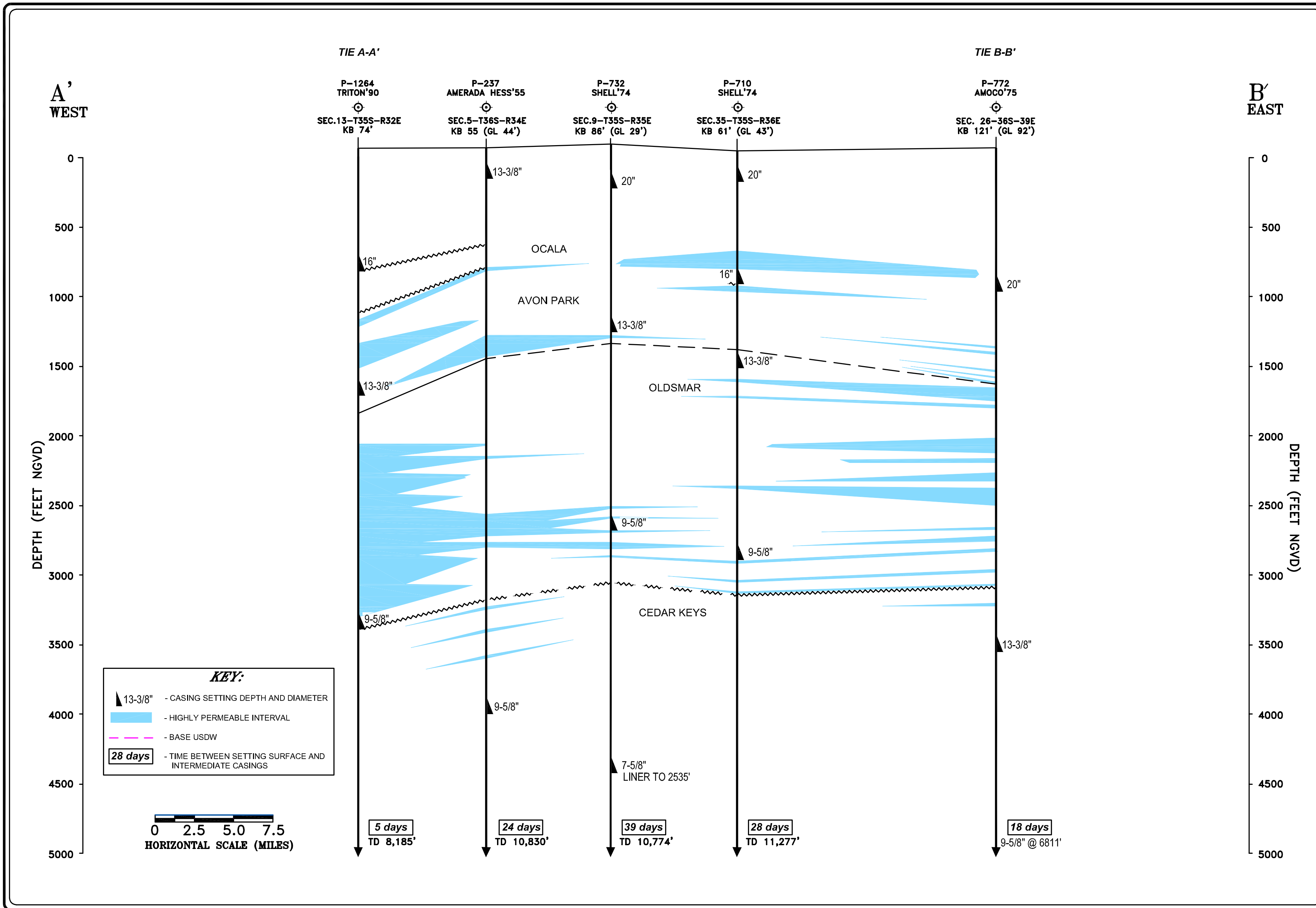

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FIGURE 3-10. CROSS-SECTION A'-B'.

- The most extensive high permeability zones in the Oldsmar formation, the formation typically used in municipal disposal wells in South Florida, occur on the west and south sides of Lake Okechobee. In these areas the high permeability zones appear to be stratigraphically controlled and related to movement of fresher high-magnesium-content groundwater, initially along fractures and then laterally, probably during the Late Oligocene (Randazzo, 1997), causing dissolution of bedded anhydrites and diagenesis of limestones to dolomites, resulting in a rock volume reduction and corresponding increase in void space.

- High permeability zones also occur in the Avon Park and Ocala formations on the west side of the Lake and become better developed in the Avon Park to the north.

- North of Lake Okeechobee, high permeability zones are present in the Eocene-age Ocala, Avon Park, and Oldsmar formations, as well as in the upper part of the underlying Paleocene-age Cedar Keys formation. The Eocene section is closer to the surface here than other areas around the Lake to the south. High permeability zones throughout the Eocene section may be indicative of some high angle fracturing and faulting in this area. This is an area of difficult drilling, as evidenced by the much longer times generally required for drilling between surface and intermediate casing depths in petroleum test wells. The potential for upward migration of low density injected fluids (i.e. surface water) may be greater in this area compared to others areas around the Lake to the south.

- In the central portion of the area east of the Lake, high permeability zones are less evident. Yet transmissivity values obtained from evaluation of tests in municipal injection wells (i.e. Pahokee, Belle Glade and western Palm Beach County) range up to 5,000,000 gallons per day per foot, which is a high value. More information is needed before it can be concluded that this area offers similar disposal capacity to that of the south and western areas using the Oldsmar formation.

3.4 Use of the Oldsmar Formation as a Disposal Zone

In areas west and south of the Lake, overlying confinement above the Boulder Zone of the Oldsmar does not appear to be problematic, considering the extensive thickness of low permeability limestones present in the upper part of the Oldsmar formation and the overlying Avon Park formation. Also, there is a relatively high likelihood of encountering favorable conditions for high capacity injection wells in these areas.

However, because of the general paucity of core, packer test, and pumping test data, test well drilling and aquifer testing should be conducted before investing the considerable financial resources that would be required to install large diameter injection wells into the Boulder Zone in the areas distant from the coastal areas.

The areas north and east of the Lake have a lower likelihood of encountering favorable conditions for high capacity injection wells, based on the limited available data.

3.5 Other Potential Disposal Zones

Cavernous porosity related to fracturing and subsequent dolomitization is sometimes present in thin intervals in the Avon Park and Ocala formations. It is likely that native water quality in these shallower zones is less saline than in the underlying Oldsmar formation and would generally be expected to be less than the 10,000 milligram per liter total dissolved solids regulatory classification for a potentially useable source of underground drinking water.

3.6 Pressures Induced by Injection

Development of a multi-well system ("cluster") of injection wells will need to be based on hydrogeologic criteria that affect flow rate and pressure buildup in the subsurface. Injection of water causes a rise in aquifer pressure, and this affects the flow rate of the injection well and also that of other wells completed in the same hydrogeologic interval operating in the area. It is reasonable to anticipate that any site to be considered for injection well use will incorporate multiple wells. The number of wells that may fit on a site will depend on the hydraulic properties of the injection zone and the property size and configuration.

The most important hydraulic property for this evaluation is the transmissivity of the receiving formation, as this will impact well spacing and injection rate. Based on the data available from numerous injection wells operating in south Florida, the range of transmissivity that might be expected from suitable injection zones is about 300,000 ft^2/day to 1,000,000 ft^2/day. In areas where transmissivity is at the low end of the range, single well capacities might be limited to about 15 mgd (27 cfs), and spacing between wells might need to be more than 600 feet. For areas that have high transmissivity, the injection rate could reach 35 mgd (55 cfs), depending on well diameter, and spacing could be less than 300 feet. A wide range of possibilities exist for well capacity and spacing, and the size of an available property will affect the total disposal capacity of the site.

A computer model was used to evaluate the range of well capacity and spacing alternatives. The model was used to determine the injection pressure for various alternatives, depending on the range of aquifer parameters. It provides information that can be used to generate a conceptual design of the injection facilities for a given site.

For this evaluation, it is assumed that a site will be suitable for 4 to 10 injection wells and that the wells are oriented in a linear fashion. The above described range of transmissivity was used for wells injecting between 15 mgd and 35 mgd. Several model runs were made to evaluate the injection pressure within the aquifer system. The parameters used in the model runs are summarized in Table 3-1. The results of 8 different model runs are shown in Figure 3-11 though Figure 3-14.

Table 3-1. Eight Model Scenarios used to Evaluate Injection Pressure within the Aquifer System

	Model Scenario1	Model Scenario2	Model Scenario 3	Model Scenario 4	Model Scenario 5	Model Scenario 6	Model Scenario 7	Model Scenario 8
Transmissivity ($ft^{2/}d$)	300000	300000	300000	300000	1000000	1000000	1000000	1000000
Leakance (day^{-1})	2.00E-04	2.00E-04	2.00E-04	2.00E-04	2.00E-04	2.00E-04	2.00E-04	2.00E-04
Storage	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03
Injection Rate (MGD)	15	35	15	35	15	35	15	35
No. of Wells	4	4	4	4	10	10	10	10
Well Spacing (ft)	300	300	500	500	300	300	500	500

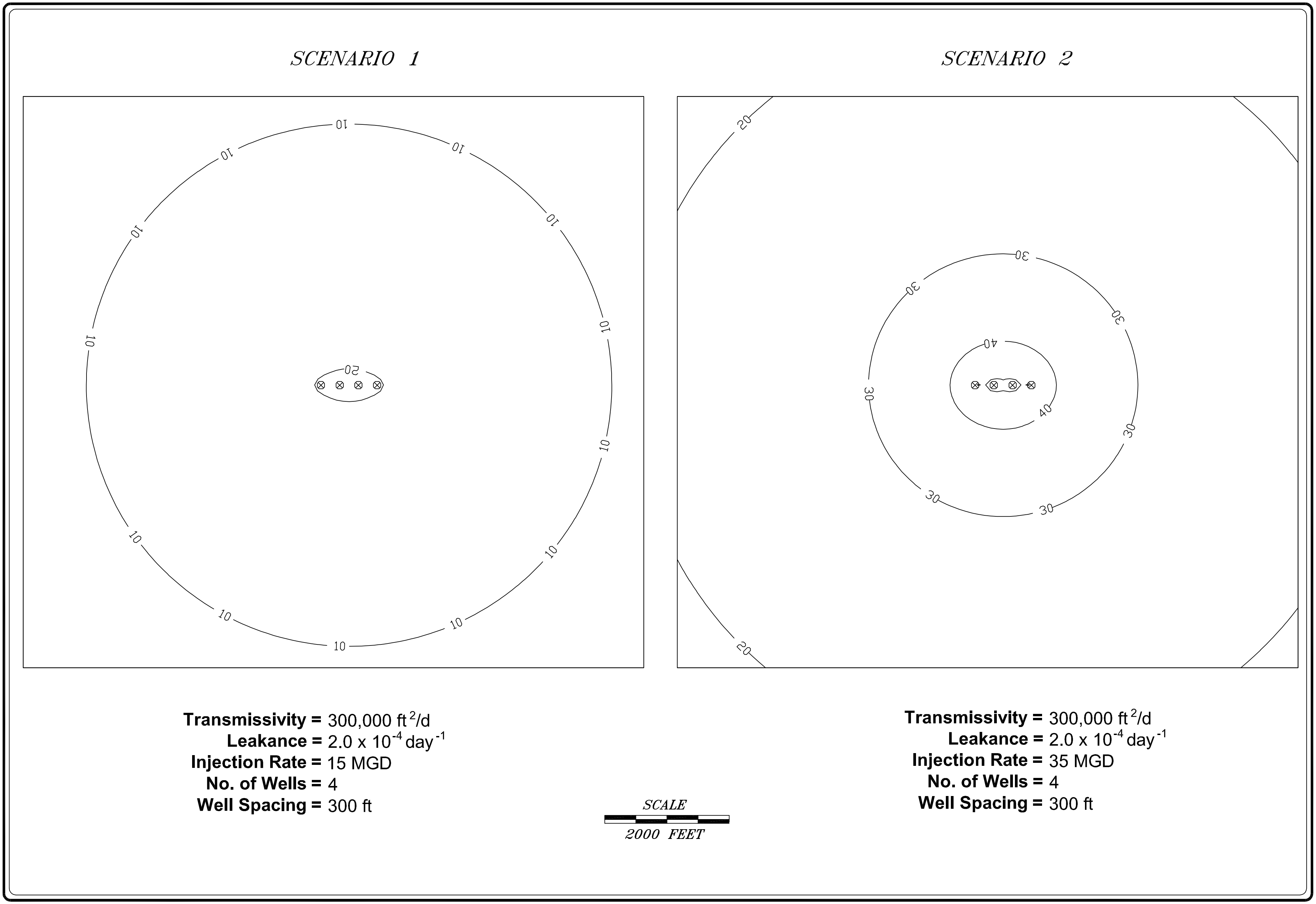

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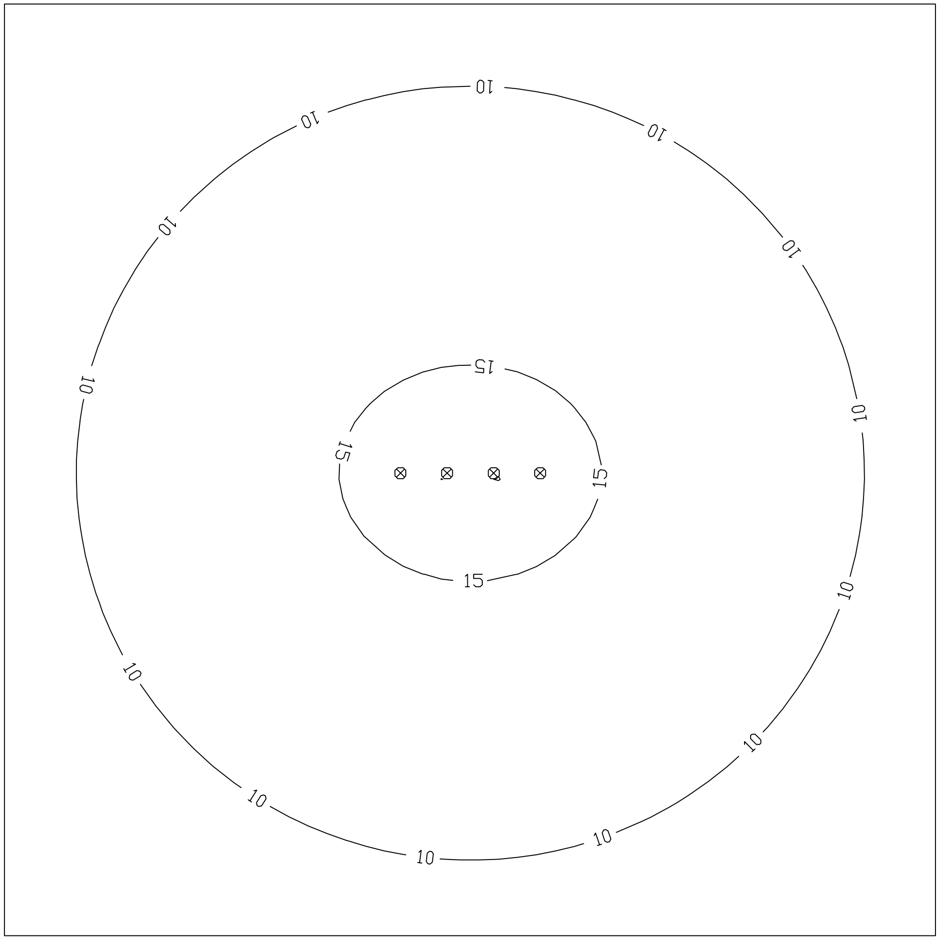
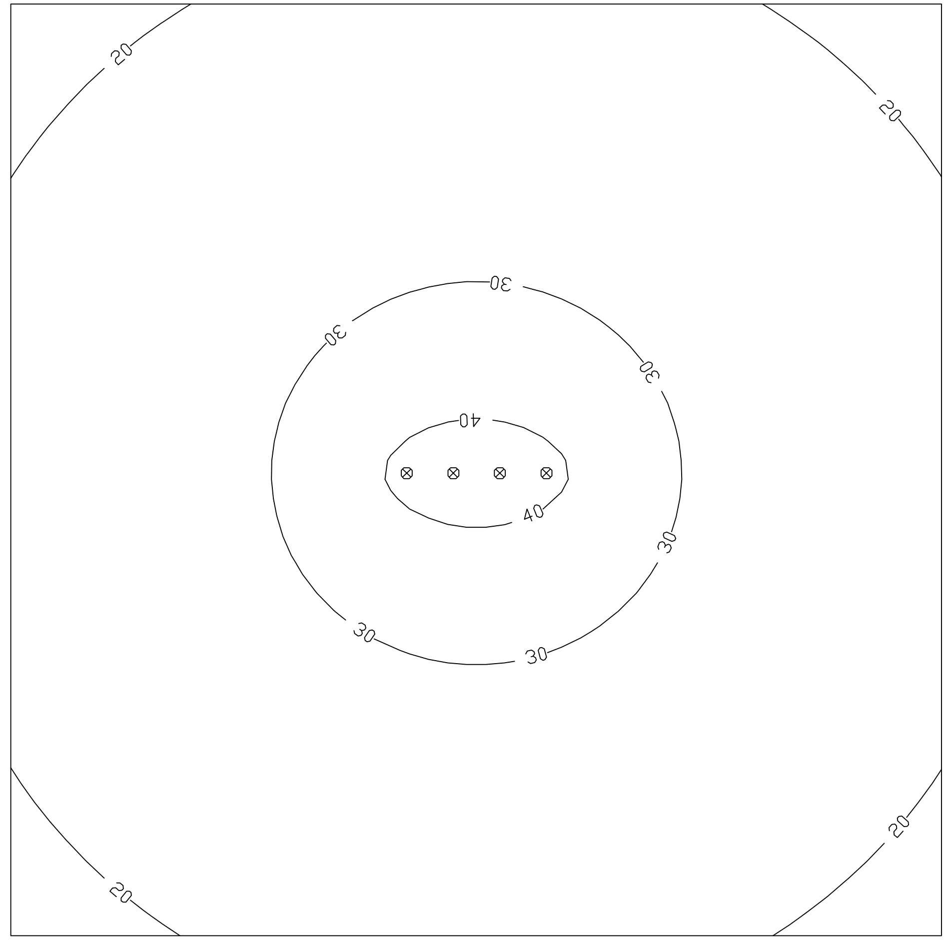
FIGURE 3–11. INJECTION PRESSURE CONTOURS IN FEET WITHIN THE AQUIFER SYSTEM FOR MODEL SCENARIOS 1 AND 2.

SCENARIO 3



Transmissivity = 300,000 ft^2/d
Leakance = 2.0×10^{-4} day^{-1}
Injection Rate = 15 MGD
No. of Wells = 4
Well Spacing = 500 ft

SCENARIO 4



Transmissivity = 300,000 ft^2/d
Leakance = 2.0×10^{-4} day^{-1}
Injection Rate = 35 MGD
No. of Wells = 4
Well Spacing = 500 ft

SCALE
2000 FEET

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FIGURE 3–12. INJECTION PRESSURE CONTOURS IN FEET WITHIN THE AQUIFER SYSTEM FOR MODEL SCENARIOS 3 AND 4.

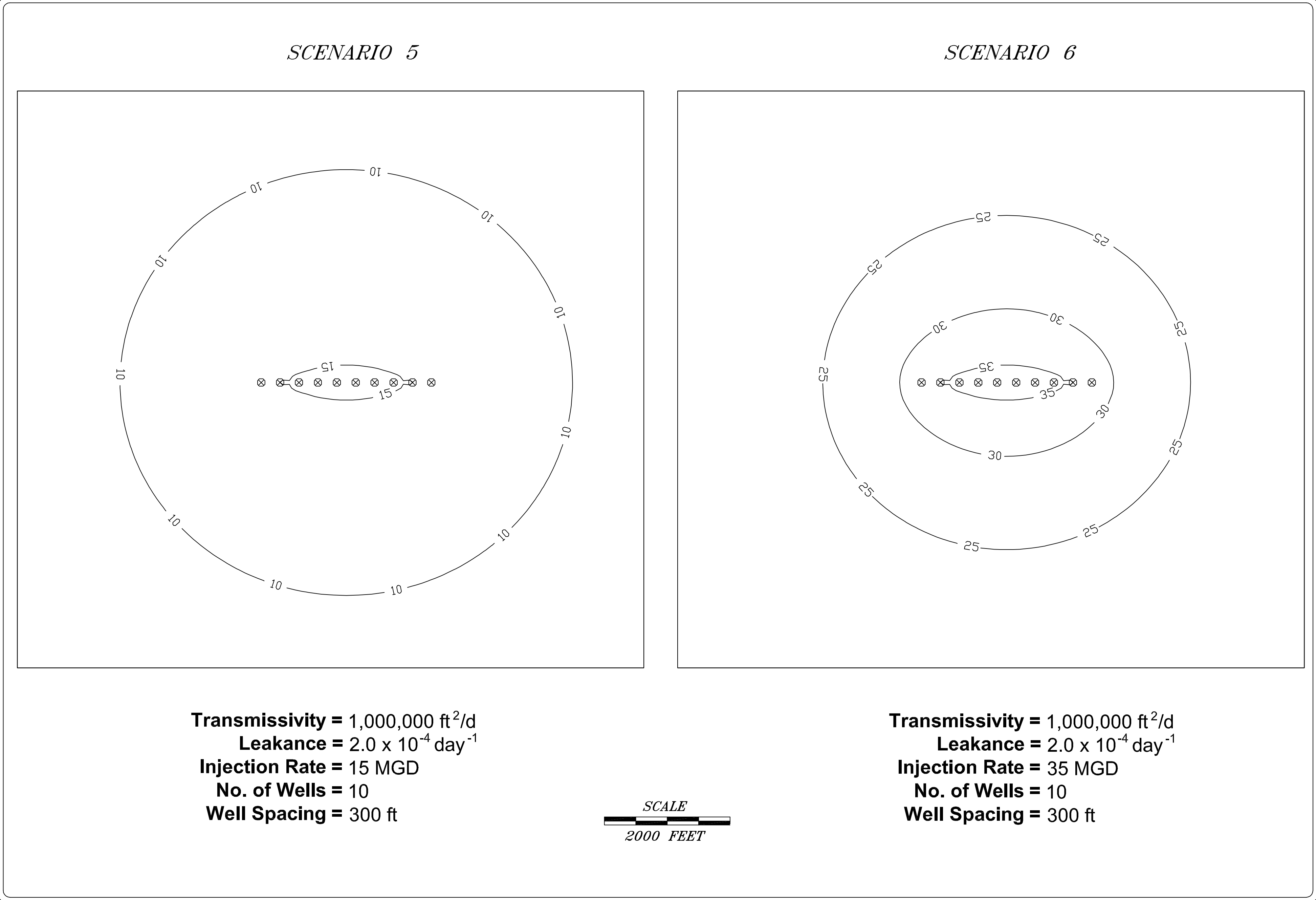

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FIGURE 3–13. INJECTION PRESSURE CONTOURS IN FEET WITHIN THE AQUIFER SYSTEM FOR MODEL SCENARIOS 5 AND 6.

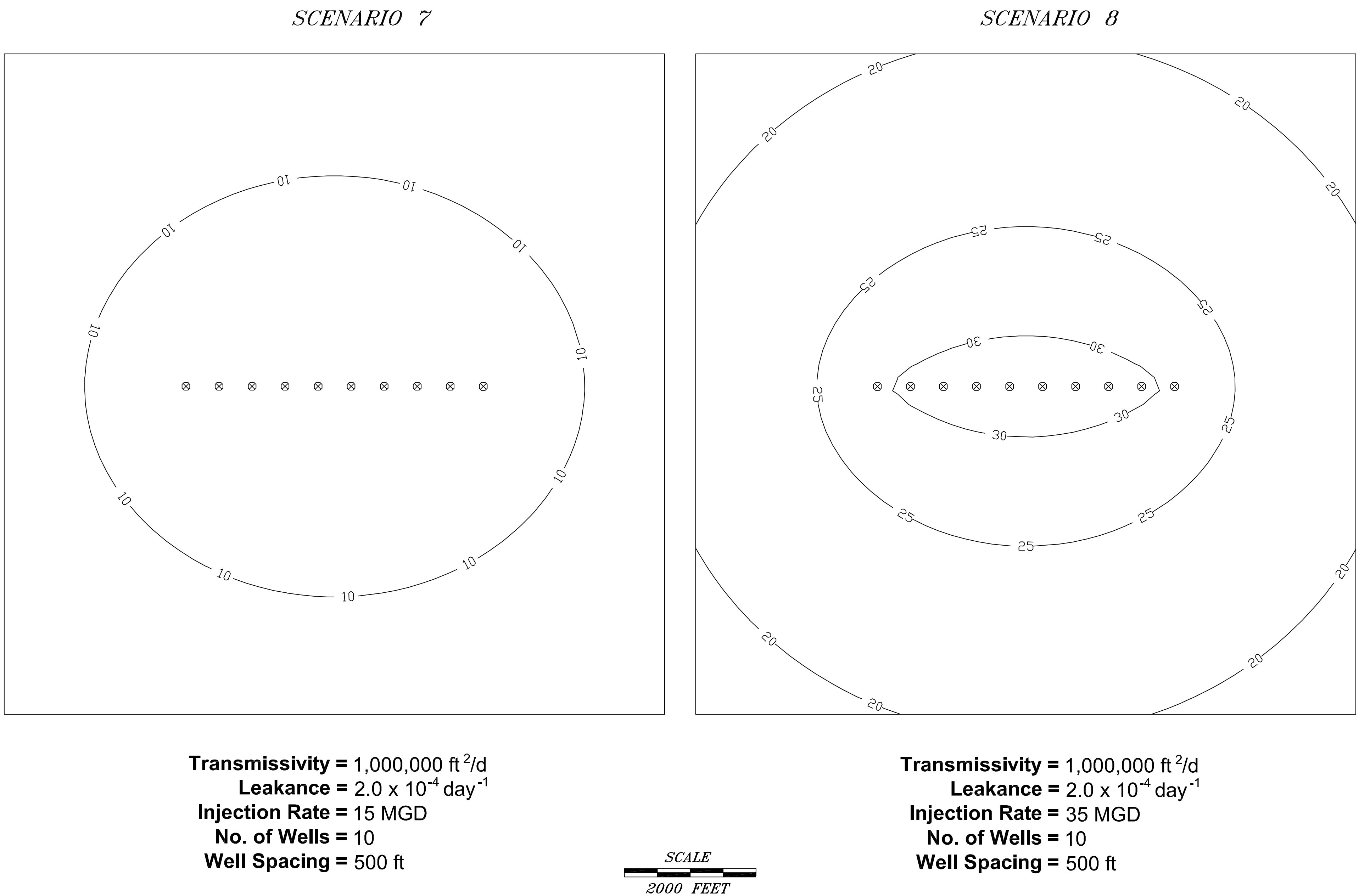

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FIGURE 3–14. INJECTION PRESSURE CONTOURS IN FEET WITHIN THE AQUIFER SYSTEM FOR MODEL SCENARIOS 7 AND 8.

The aquifer pressures indicated range from about 18 ft (7.8 psi) to 50 ft (21.7 psi) for a system of 4 wells operating in aquifer system having the lower transmissivity from 15 ft (6.5 psi) to 35 ft (15.2 psi) for a system of 10 wells operating in an injection zone with a transmissivity at the high end of the range.

In addition to the pressure shown, additional injection pressure is needed to overcome friction losses within the injection tubing and the effect of buoyancy of fresh water. The friction loss is estimated to be about 19 psi (45 feet), and the effect of buoyancy adds approximately 30 psi, depending on the elevation of the water surface at the site intake.

Injection pressures at land surface between the range of about 55 and 70 psi are within a range practical for injection well applications. The pressure increase within the receiving formation is not a concern with regard to causing any undesirable hydrogeologic or environmental impact. These pressures are well below the theoretical values that could cause fracturing of the formations between the depths of 1,000 to 3,000 feet below land surface.

SECTION 4
INJECTION CAPACITY TARGET FOR THE LOER PROGRAM

4.1 Assumptions for Evaluating Injection System Capacity Alternatives

Alternative targets for the injection well program are presented in this section to focus on how much deep well injection capacity might be needed to achieve a range of results. For purposes of the LOER program, injection capacity is effective at locations upstream of either the estuaries or the lake itself. Reduction of inflows in any upstream area would reduce the need to release water to the estuaries. The actual site selection for wells and the advantages of each site are discussed in detail later in this report.

Water is released from Lake Okeechobee to meet needs for both water supply and to maintain the ecological health of the estuaries. Water is also released to manage the level of the lake surface. Estuary releases that are considered safe or acceptable have been quantified by biologists at the SFWMD to range between 450 and 2,800 cfs for the Caloosahatchee Estuary and between 300 and 2,000 cfs for the St. Lucie Estuary (Neidrauer, 2006). This section addresses releases beyond the acceptable amounts, and those releases are termed herein as "excess'' releases or excess discharges from Lake Okeechobee. In addition to discharges that enter the estuaries from Lake Okeechobee, there is also a significant amount of basin runoff from both the Caloosahatchee River and the St. Lucie River basins. The excess discharges used in the following analyses include the basin discharges along with the releases from Lake Okeechobee. This report deals with releases that have been quantified or modeled at the last downstream structure before the estuary.

4.2 Operational Programs and System Capacity Targets

Use of deep injection wells to reduce discharges to the estuaries can be accomplished in several ways. The selected operational program and schedule for operating the wells would essentially control the number of wells needed to obtain the desired results. The operational alternatives that control the design injection capacity or number of wells needed fall into two primary categories, which are: 1) instantaneous discharge based capacity targets and 2) lake-level-based capacity targets.

4.2.1 Instantaneous Discharge-Based Capacity Targets

Instantaneous discharge-based injection capacity relates to design for meeting excess discharges on an instantaneous basis. This system would capture excess discharge whenever it might occur; however, the wells would not be operated during periods that releases would not otherwise be occurring. An injection system for this type of operation requires more injection wells than other options, because it would be based on peak discharges for whatever statistical criteria or return period is chosen for the design event. This type of system would not involve injection of water in anticipation of the need to release water at a later time. This operational program would not result in the injection of water that could otherwise be stored.

As an example of a flow rate based capacity injection well system, consider a situation where the S-79 structure is discharging at 3,000 cfs. If the acceptable release is 1,000 cfs, then the design injection capacity would be 2,000 cfs, which constitutes the excess discharge. For this system, the injection rate would be reduced or stopped anytime the lake level began to drop below its maximum acceptable level or the estuary discharge dropped below 1,000 cfs.

4.2.2 Lake Level Based Capacity Targets

Injection system capacity based on lake-level control targets uses a selected discharge/injection volume and time of operation of the injection wells to limit excess discharge to the estuaries. This type of operational system would take advantage of some designated amount of lake storage in determining when to start and stop injection operations. Such a system would put injection wells into operation in advance of the need to release water to the estuaries, and it would involve injection during periods of rising water level in anticipation of a future need to release water to the estuaries. Such an operation would seek to minimize unnecessary injections of water which may have been better stored in the Lake for subsequent use. A set of criteria would be developed regarding what conditions might initiate injection, and what conditions would cause injection to cease.

The degree to which injection wells might be operated in advance of the need to release water would control the number of wells required. An injection system design based on an operational lake-level control program reduces the number of injection wells required as the difference between the elevation for initiating injection and the maximum lake level (before discharge) increases.

4.3 Data Used for Analysis

Data that were used in this study include daily discharges and ecological targets to the Caloosahatchee and St. Lucie estuaries, and simulated stages of lake Okeechobee for a 36-year period from 1965 to 2000.

Discharge data through S-79 (Caloosahatchee Estuary), and S-80+SLTRIB (St. Lucie Estuary) were compiled from results generated by the Lake Okeechobee Regulation Schedule Study, South Florida Water Management Model (LORSS-SFWMM). Numerous versions of the model were evaluated; however this report uses the latest simulation results of the model at the time of this study (February, 2007) namely *LORS-alt1bS2-a17.25-LOWSM-TSPmod3-L8-113006*,obtained from the website: http://hpm.saj.usace.army.mil/loweb/sfwmm.

Ecological targets of discharge to the Caloosahatchee and St. Lucie estuaries from 1965 to 2000 were provided by Peter Doering of the SFWMD. These targets are time varying and constitute daily "healthy" discharge to the estuaries during the period of interest. For the analyses presented in this section, the excess discharge to the estuaries is calculated as the discharge in excess of 2,800 cfs for the Caloosahatchee Estuary and, in excess of 2,000 cfs for the St. Lucie Estuary. A discussion of excess discharges calculated based on ecological targets is provided in Appendix A.

4.4 Capacity of Injection Wells

It is anticipated that injection wells would range in diameter from 24 to 34 inches with capacities ranging from 30 cfs (18 MGD) to 70 cfs (46 MGD) respectively. The well diameter in this study is conservatively selected to be 24 inches, with a capacity of 30 cfs (18 MGD).

The following sections analyzes the effects of three injection well systems in reducing flow to the estuaries. These systems include a 20 well injection well system, a 60 well injection well system, and a 90 well injection well system.

4.5 Target Injection Well Capacity Based on Instantaneous Discharge

4.5.1 Analysis Summary

The analysis used to determine the injection well capacity to control instantaneous discharges is presented in Appendix A. The objectives of the analyses presented in Appendix A are to: 1) estimate how injection well systems consisting of 20, 60 and 90 wells can reduce the number of days that target discharges are exceeded, 2) calculate return periods of high discharge events to the Caloosahatchee Estuary, 3) calculate return periods of rate of lake level rise during wet season, and 4) estimate the injection capacity needed to control discharges that are likely to occur during 1-in10, 1-in-5 and average discharge years. For ease of review, only the results are presented in this section.

4.5.2 Effects of Injection Wells in Reducing the Period of Excess Discharge

Table 4-1 tabulates the period of time when discharge to the Caloosahatchee Estuary (S-79) was above 2,800 cfs and discharge to the St. Lucie Estuary including its tributaries (S-80+SLTRIB) was above 2,000 cfs based on 36 years of data. The effects of wells in reducing the number of excess discharge days are also provided in Table 4-1.

The results indicate that a 20 well system can reduce the number of excess discharge days by 20 percent, a 60 well system can reduce the number of excess discharge days by 53 percent and a 90 well system can reduce the number of excess discharge days by percent for the CE. And for SLE, a 20 well system can reduce the number of excess discharge days by 77 percent a 60 well system can reduce the number of excess discharge days by 88 percent and a 90 well system can reduce the number of excess discharge days by 90 percent.

Table 4-1. Effects of Wells in Reducing the Period of Excess Discharge
(Data Time Period: 1965 -2000)

	No. of Months of Excess Discharge						
	O Wells	20 Wells	Percentage Reduction	60 Wells	Reduction in Discharge	90 Wells	Percentage Reduction
Caloosahatchee Estuary (S-79)	82	66	20%	39	53%	28	65%
St. Lucie Estuary (S-80 + SLTRIB)	11	3	77%	1.4	88%	1.2	90%

4.5.3 Effects of Injection Wells in Reducing the Excess Discharge Volume

Table 4-2 shows the volume of excessive discharge to the Caloosahatchee Estuary for typical 1-in-10, 1-in-5 and average discharge years. Also provided in the table are: 1) the number of 24-inch injection wells (18 MGD capacity) needed to totally eliminate excess discharges during the selected years and 2) the percentage reduction in excess discharge volume accomplished by using a 20, 40 or 90 well system. The analysis assumes that the wells are in operation only when the discharge exceeds the estuary target of 2800 cfs.

Table 4-2. Effects of Wells in Reducing the Excess Discharge Volume to the CE

Discharge Year	Model Year	No. of Months of Excess Discharge	Volume of Excess Discharge (1000 acre-ft)	No. of 24" wells needed to eliminate all excess discharge	Reduction in Excess Discharge Volume Using Injection Wells		
					20 Wells	60 Wells	90 Wells
1-in-10	1983	3	781	146	13%	41%	61%
1-in-5	1994	4	534	75	27%	80%	100%
Average	1992	1	76	43	47%	100%	100%

The results indicate that to totally eliminate excess flow for a 1-in-10 discharge year event, 146 injection wells are required. However, depending on the return period selected, significant reductions in excess discharge can result from utilizing a lesser number of wells. It is relevant to note that if 34-inch wells are used instead of 24-inch wells, the number of wells will be reduced by 40%.

4.6 Target Injection Capacity Based on Lake Levels

4.6.1 Background

For lake levels between 14 and 18 ft NGVD, 1 foot of lake level equals a volume of about 445,000 acre feet of water (source: http://spatial1.sfwmd.gov/losac/sfwmd.asp). The lake level data indicate that the stages have varied between 8.71 ft NGVD (June 24, 1974) and 17.33 ft NGVD (October 26, 1995). Data also indicate that the lake typically tends to rise starting late May or early June and continues to rise until late October or mid November. After this time, the lake level generally starts to recede and continues to recede until the beginning of the next water year. Therefore the most critical months to manage lake levels fall between June and November. Based on the data, it is observed that there are primarily two criteria instrumental in managing lake levels: 1) understanding the rate of lake level rise and 2) estimating the number of wet months remaining when lake approaches a desired level (eg. 15 ft NGVD).

4.6.2 Using Injection Wells to Reduce the Lake Elevation

The expected lake level rise from June through November (5 months) for a 1-in-10, 1-in-5 and average rainfall years are provided in Table 4-3. The drop in final lake level accomplished by utilizing an injection well system of 20, 60 or 90 wells is also provided in the table. It is assumed that when injection wells are in operation, discharge to the Caloosahatchee Estuary is maintained at 2800 cfs, and discharge to the St. Lucie Estuary is maintained at 0 cfs. No water is released to the SLE from the Lake because the tributary located downstream of the S-80 structure, SLTRIB, is assumed to feed the estuary with healthy range of discharges. The calculations pertaining to Table 4-3, and graphical presentations showing the drop in lake level when wells are in operation, are provided in Appendix A.

Results indicate that depending on the duration of operation during 1-in-10 year wet season, 20 wells can lower the final lake level between 0.41 and 1.6 feet, 60 wells can lower the lake level between 0.58 and 2.3 feet, and 90 wells can lower the final lake level between 0.72 and 2.8 feet.

4.7 Discussion

The decision on which event should be the design target for an injection well system is a subject for the SFWMD Governing Board, however it is suggested that a system designed for the average year or the 1-in-5 year event would offer a significant advantage to the estuary system. Designing an injection well system for a 1-in-5 year event and an average year will have the capability to manage discharge events that are likely to occur in 8 out of 10 years.

Table 4-4 summarizes the discharge volume accommodated by injection wells for an average year and 1-in-5 year, for both instantaneous discharge based operation plan and lake-level based operational plan. A system using a lake level based control program is recommended for the LOER program, because regardless of the number of wells, it is the most flexible and effective at protecting the estuaries.

Table 4-3 Summary of the effects of operating 20, 60 and 90 wells on lake levels.

Probability of Occurrence (Years)	Expected Rise in Lake Level from June through November (ft)	No. of Wells	No. of Months of Operation	Final Drop in Lake Level (ft)	Discharge to the estuaries while wells are operating(cfs)
1-in-10	4.75	20	1	0.41	2800 cfs to CE and 0 cfs to SLE
			2	0.81	
			3	1.20	
			4	1.60	
		60	1	0.58	2800 cfs to CE and 0 cfs to SLE
			2	1.17	
			3	1.70	
			4	2.30	
		90	1	0.72	2800 cfs to CE and 0 cfs to SLE
			2	1.43	
			3	2.10	
			4	2.80	
1-in-5	3	20	1	0.36	2800 cfs to CE and 0 cfs to SLE
			2	0.72	
			3	1.00	
			4	1.40	
		60	1	0.62	2800 cfs to CE and 0 cfs to SLE
			2	1.25	
			3	1.80	
			4	2.50	
		90	1	0.82	2800 cfs to CE and 0 cfs to SLE
			2	1.65	
			3	2.50	
			4	3.30	
Average (1-in-2)	2	20	1	0.54	2800 cfs to CE and 0 cfs to SLE
			2	1.00	
			3	1.60	
			4	2.10	
		60	1	0.94	2800 cfs to CE and 0 cfs to SLE
			2	1.90	
			3	2.80	
			4	3.70	
		90	1	1.23	2800 cfs to CE and 0 cfs to SLE
			2	2.50	
			3	3.70	
			4	4.90	

Table 4-4 Summary of excess discharge volume and lake level reduction accommodated by injection wells for an instantaneous discharge based operating plan and a lake-level based operating plan.

		Average Model Year (acre-ft)	1 in 5 Model Year (acre-ft)	Number of Wells	No. of Months Wells are Online	Reduction in Excess Discharge
Instantaneous Discharge Operating Plan [A]	Discharge Volume Accommodated by Injection Wells (acre-ft)	35,700		20	1	47%
		107,100		60	1	100%
		160,650		90	1	100%
			142,800	20	4	27%
			428,400	60	4	80%
			642,600	90	4	100%
						Decline in Final Lake Level (ft)
Lake Level Operating Plan [B]	Discharge Volume Accommodated by Injection Wells (acre-ft)	35,700		20	1	0.54
		107,100		60	1	0.94
		160,650		90	1	1.23
			71,400	20	2	0.72
			214,200	60	2	1.3
			321,300	90	2	1.7
			107,100	20	3	1.0
			321,300	60	3	1.8
			481,950	90	3	2.5

Note for Table 4-4:

A: For instantaneous discharge based operating plan, only the discharges to the Caloosahatchee estuary is analyzed. The discharges to the St. Lucie estuary (S-80) is one-fourth the discharge to the Caloosahatchee estuary (S-79) (Refer to Appendix A). Therefore, it is reasonable to assume that the number of wells needed to manage the discharge to the St. Lucie side is one-fourth the number of wells on the Caloosahatchee side, and the total number of wells needed to effect the result is multiplied by 1.25 that shown in the table.

B: For Lake-Level based operating plan, 2,800 cfs is released to the Caloosahatchee estuary and 0 cfs to the St. Lucie estuary when the injection wells are in operation.

SECTION 5
DEEP INJECTION WELL SITE SELECTION

This section outlines the approach and methodology used for selecting the deep well injection sites within the Lake Okeechobee Watershed. Locations have been recommended and ranked based on their ability to meet primary criteria that are required for each well facility location. Next, each location was subjected to ecological benefit tests to evaluate its overall effectiveness at reducing excess discharges to the estuaries and providing other environmentally beneficial functions such as assisting upstream tributaries in meeting TMDL targets. Sites were also evaluated based on potential operational benefits from a water management perspective. Certain sites have the flexibility to dispose of excess surface water from multiple basins, function as a tool for managing Lake stages, and enhance reservoir and Stormwater Treatment Area (STA) functionality, while still serving their primary purpose of reducing excess estuary discharge. Finally, hydrogeologic confidence was considered given the hydraulic conditions known beneath the watershed basins.

Primary Assumptions:

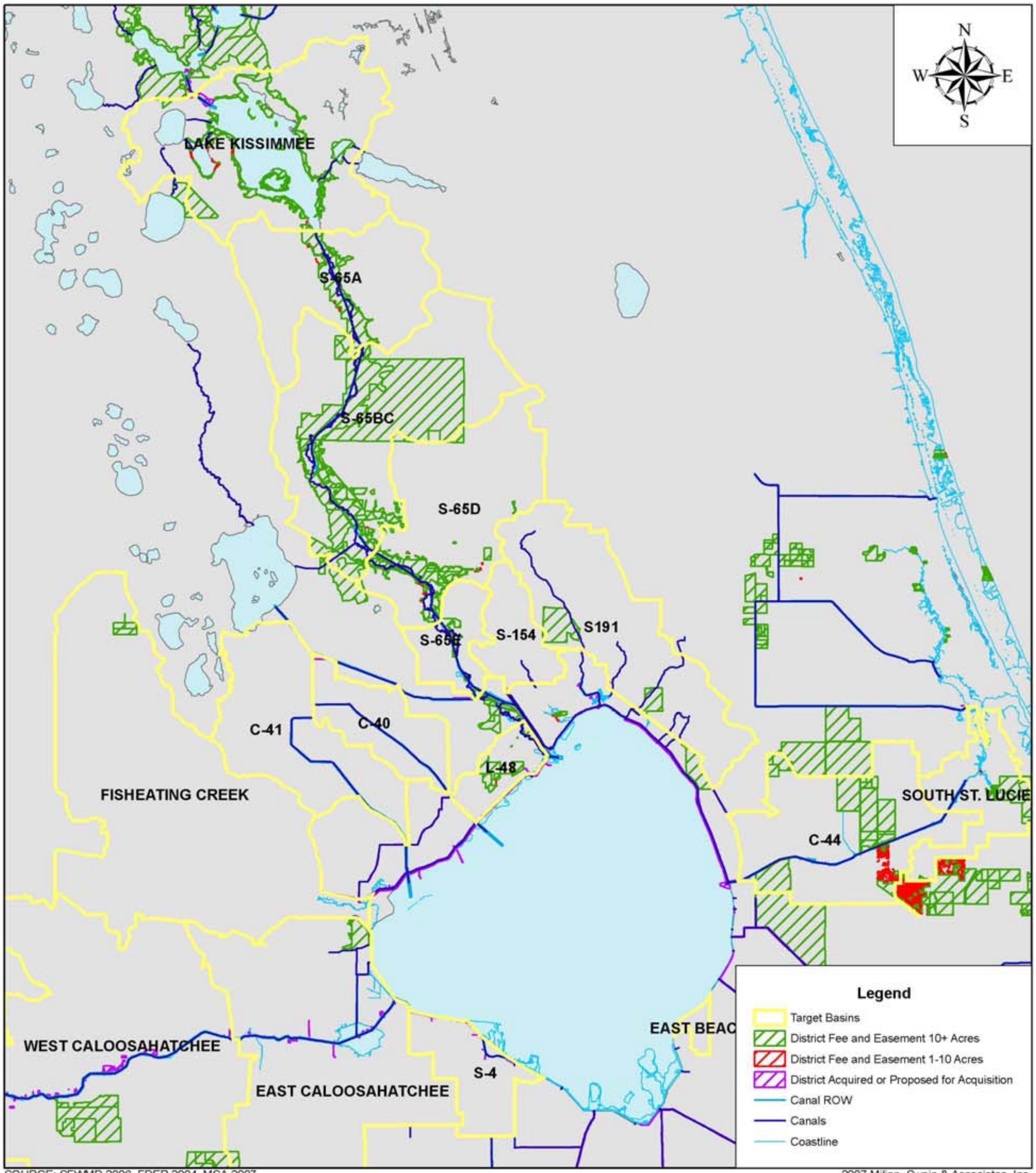
Injection well site selection was performed based on a list of criteria. Each site will ultimately need to meet the following list of criteria to be considered a candidate for injection well facilities:

1. The site is located on District-owned property, unless otherwise noted.
2. Site has adequate size to accommodate the number of wells and facilities needed to meet injection targets for the site.
3. Hydrogeologic conditions within the injection zone will be appropriate for the injection targets anticipated for the site as confirmed by performing test well investigations.

The Lake Okeechobee Watershed and its basins are shown in Figure 5-1 along with District-owned properties and easements.

Tests Evaluating Ecological Benefits:

The locations within the Lake Okeechobee Watershed that met the primary assumption criteria were subjected to an ecological benefit evaluation. Sites both upstream and downstream of the lake were considered. Although all locations have the ability to help manage flows to the estuaries and manage lake levels, the upstream locations have an added operational benefit by reducing discharge from tributaries into the Lake to help meet TMDL targets. The primary TMDL target relates to phosphorous load and for evaluations of alternative sites, the value of a site increases with concentration of phosphorous in the basin runoff. For purposes of this section, sites are given a TMDL benefit only if the concentration of phosphorous in the runoff is above 200 mg/l.



SOURCE: SFWMD 2006, FDEP 2004, MSA 2007

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SCALE 1:750,000

20 10 0 20 Miles

20 10 0 20 Kilometers

Figure 5-1 Lake Okeechobee Deep Injection Well Siting Potential Target Basins

Individual sites are further evaluated according to these criteria and comparatively ranked in Section 7.

Downstream Location Benefits:

Siting deep well injection facilities anywhere downstream of the Lake would attenuate discharges to the estuaries and allow for these facilities to assist in managing Lake levels. Injection wells downstream of the Lake would operate during peak discharges, but could also operate in an anticipatory mode, assisting water managers with another tool to meet regulation schedule levels.

Siting injection wells close to the downstream discharge structures of the C-43 and C-44 canals would allow these facilities to capture additional basin runoff, in addition to Lake releases, before discharges are made. Since estuary discharges during the rainy season contain both regulatory Lake releases along with contributions from watersheds along the C-43 and C-44 canals, the most efficient and ecologically beneficial locations to stage deep well injection facilities near the most downstream structures, (S-80 and S-79). Locating injection well facilities near these structures would allow for maximum operational flexibility and efficiency.

Advantages: Peak discharge attenuation, Lake Okeechobee water level management tool, and capture of additional downstream basin discharge.

Disadvantages: No TMDL benefit.

Upstream Benefits:

The benefit to locating injection well facilities upstream of, or along the Lake, is that the system could be operated not only as a means to reduce estuary discharge, but also to help prevent nutrient loads to the Lake. This double functionality would provide benefits to the estuaries and assist the upstream basins in meeting their TMDL targets. Phosphate reduction evaluations are summarized in Section 7.

Upstream stations that are located to assist basins in achieving TMDL targets are not always co-located with the structures that discharge directly to the Lake. Therefore for upstream benefits to be maximized, a direct hydraulic connection to Lake Okeechobee must be maintained in order for these sites to reduce peak discharge and help manage lake levels.

Advantages: TMDL benefit, Peak discharge attenuation & Lake Okeechobee Regulation Schedule management tool (if hydraulic connection to the Lake is established).

Disadvantages: No capture of additional flows generated downstream of Lake Okeechobee.

Tests Evaluating Operational Benefits:

Siting deep injection wells with existing or planned District infrastructure can result in operational benefits and enhancements to the Lake Okeechobee Regulation Schedule, reservoirs, and STAs. The following section provides information on how each benefit is achieved.

Lake Okeechobee Regulation Schedule Management Benefits:

Both upstream and downstream deep well injection facility sites have the potential to regulate the stage within Lake Okeechobee. Therefore, these facilities can be used as a tool to assist water managers in maintaining the Lake Okeechobee Regulation Schedule. However, in order for upstream sites to be able to operate in this manner, a direct hydraulic connection to the lake must be maintained.

Advantages: Peak discharge attenuation & Lake Okeechobee Regulation Schedule management tool.

Disadvantages: No capture of additional downstream basin flows, TMDL benefit not assumed.

Reservoir Benefits:

The District is planning to utilize multiple locations within the Lake Okeechobee watershed in order to meet future water supply demands. Co-locating deep injection wells with these reservoirs could potentially enhance the operational flexibility of these reservoirs.

Injection wells could be used to dispose of lower quality water that may be in the reservoir if water managers expected higher quality water to be released or generated upstream. This would allow for improved water quality conditions within the reservoir, and potentially increase the uses for the water. The wells could also operate to drain a reservoir for certain conditions to improve the ecology of the reservoir. Injection wells could dispose of water in excess of the reservoir's capacity such as following a heavy rainfall event.

Sites co-located with downstream reservoirs would have the added potential to dispose of additional basin contributions if the reservoirs are located downstream on the C-43 and C-44 Canals, near the S-79 and S-80 Structures. These sites would also be able to attenuate peak discharges and assist in regulation schedule management.

Sites co-located with upstream reservoirs would also be able to attenuate peak discharges and assist in regulation schedule management if a hydraulic connection to the lake existed.

Advantages: Manage water quality in reservoirs, discharge waters in excess of reservoir capacity, capture of additional downstream basin discharge, capture of additional downstream basin discharge (if located near S-79 or S-80), Peak discharge attenuation & Lake Okeechobee Regulation Schedule management tool (if hydraulic connection to Lake).

Disadvantages: TMDL benefit not assumed.

Stormwater Treatment Area Benefits:

Stormwater Treatment Areas are being installed within the Lake Okeechobee Watershed to treat stormwater runoff, enhancing downstream water quality. The STAs are primarily designed for phosphorus removal, but also effectively remove nitrogen, total suspended solids, and other contaminants. The effectiveness of these systems is directly related to water depth and hydraulic loading rate. Therefore, if the optimal states of either are exceeded, the STA will not operate as it was designed. Therefore, STAs are by-passed during extremely wet periods, and untreated water is discharged into the same areas that the STAs were designed to improve. Co-location of deep well injection sites with STAs would eliminate the need for STA by-pass, as the water could be disposed through deep well injection.

Sites co-located with downstream STAs would have the added potential to dispose of by-pass water if the STAs are located downstream on the C-43 and C-44 Canals, near the S-79 and S-80 Structures. These sites would also be able to attenuate peak discharges and assist in regulation schedule management.

Sites co-located with upstream STAs would also be able to attenuate peak discharges and assist in regulation schedule management if a hydraulic connection to the lake existed.

Advantages: Manage water quality in reservoirs, discharge waters in excess of reservoir capacity, capture of additional downstream basin discharge, capture of additional downstream basin discharge (if located near S-79 or S-80), Peak discharge attenuation & Lake Okeechobee Regulation Schedule management tool (if hydraulic connection to Lake exists).

Disadvantages: TMDL benefit not assumed.

Multiple Basin Benefits:

Locating injection well facilities at the intersections of multiple major canals and control structures can result in major benefits to operational flexibility. In addition to potential TMDL and Lake stage management benefits, some upstream locations have the potential to serve as a means to dispose of excess stormwater from multiple basins. Further investigations would be needed to investigate the existing infrastructure's capacity to convey appropriate loads to the injection well facility in order the meet injection well targets for each basin.

Advantages: The ability to service peak discharge needs of multiple upstream basins with a single facility

Disadvantages: Existing infrastructure conditions may limit reaching injection well targets.

Hydrogeologic Confidence

The presence of appropriate hydrogeologic conditions for development of injection wells is less certain in areas north and immediately east of the Lake Okeechobee. Most of the areas considered for locating injection wells have little existing data regarding hydrogeologic conditions of the Boulder Zone or its confining layers. Generally the confidence level increases toward the coastal areas and southward. For this reason sites are mostly ranked as uncertain with respect to this criterion. A location that might have more favorable data would be considered to provide higher confidence with respect to hydrogeologic conditions.

Recommended Sites for Injection Facilities

Potential target basins considered for injection wells include the Lake Kissimmee, S-65 A-E, S-154, S-191, L-48, C-40, C-41, Fisheating Creek, East and West Caloosahatchee, C-44, S-4, and East Beach Basins. Figure 5-1 contains a map of these target basins, District owned land tracts greater than 10 acres in size, District owned land tracts less than 10 acres in size, land tracts that are proposed for District acquisition, and canal right of way boundaries. These datasets were used to identify areas with sufficient available land and hydraulic connectivity required for siting deep well injection facilities. Together with the ecological and operational benefit tests and the hydrologic confidence criteria, this data was used to generate and rank a list of recommended deep well injection site locations. Table 5-1 presents a summary of potential benefits associated with each of the higher ranked locations. Figures 5-2 thorough 5-7 identify the six recommended locations for further investigation in the form of test well drilling.

TABLE 5.1 RECOMMENDED DEEP WELL INJECTION LOCATIONS WITH CORRESPONDING BENEFITS AND RANKING

Basin	Upstream / Downstream of Lake Okeechobee	Higher Hydrogeologic Confidence	Ecological Benefit		Operational Benefits			Final Rank of Site	Test Well Drilling Order
			Estuaries	TMDL	Regulation Schedule Management	Reservoir & STA Co-location	Multiple Basin Benefit		
*[1]C-40	Upstream		X	X	X		X	1	1
*C-43 West Caloosahatchee	Downstream	X	X		X	X		2	2
* C-44	Downstream	X	X		X	X		3	5
*[1]C-41	Upstream		X	X	X		X	4	3
*[1]S-191	Upstream		X	X		X		5	4
*[1]S-154	Upstream		X	X	X			6	6
Fisheating Creek	Upstream		X	X	X			—	
S-65E	Upstream		X		X		X	—	
L-48	Upstream		X		X			—	
*[1]South S-191	Upstream		X	X		X		—	

*Deep well injection facility recommended for this basin
[1] Phosphate TMDL reduction ranking was used in selection (See Section 8)

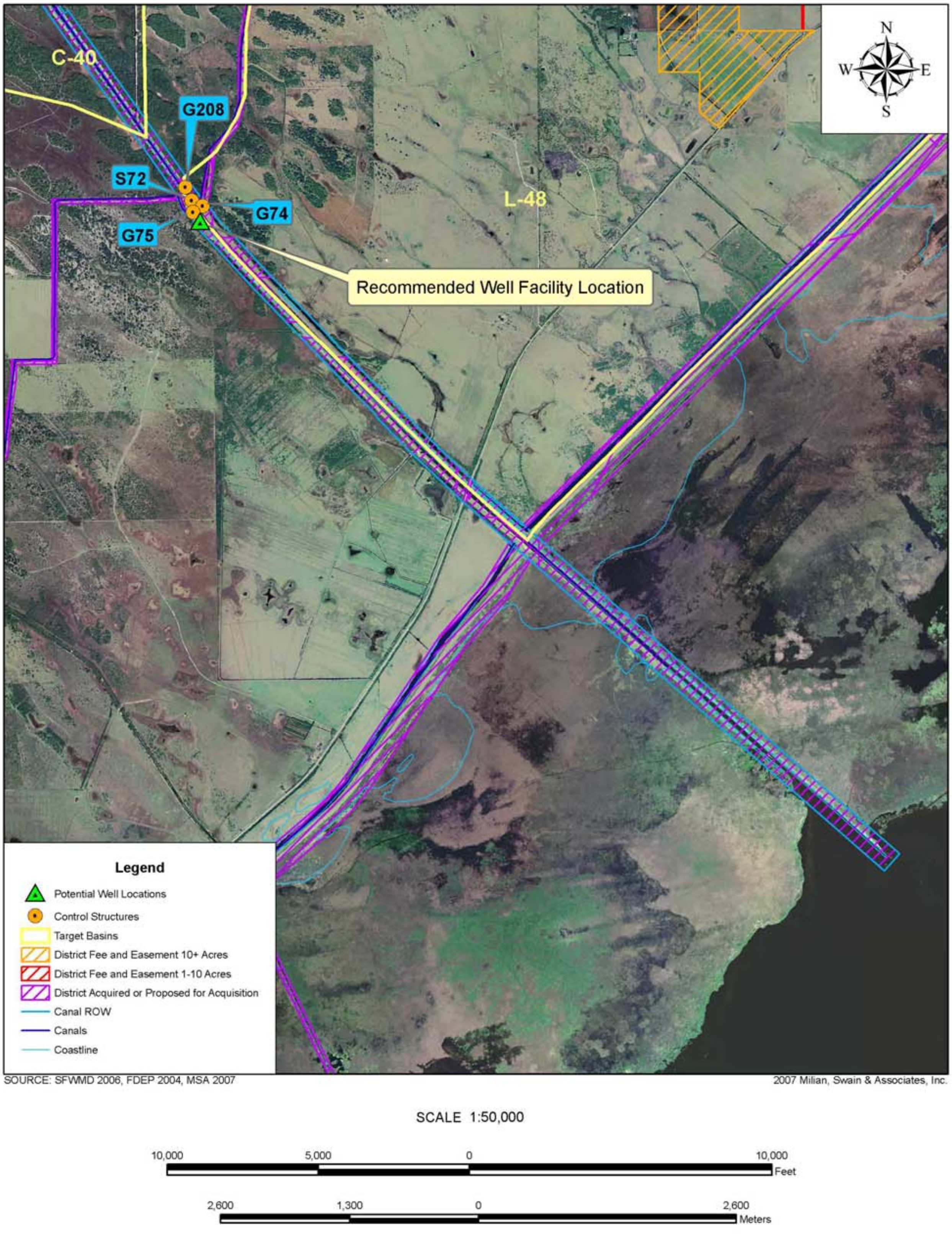

Figure 5-2 C-40 Basin Potential Injection Well Facility Locations

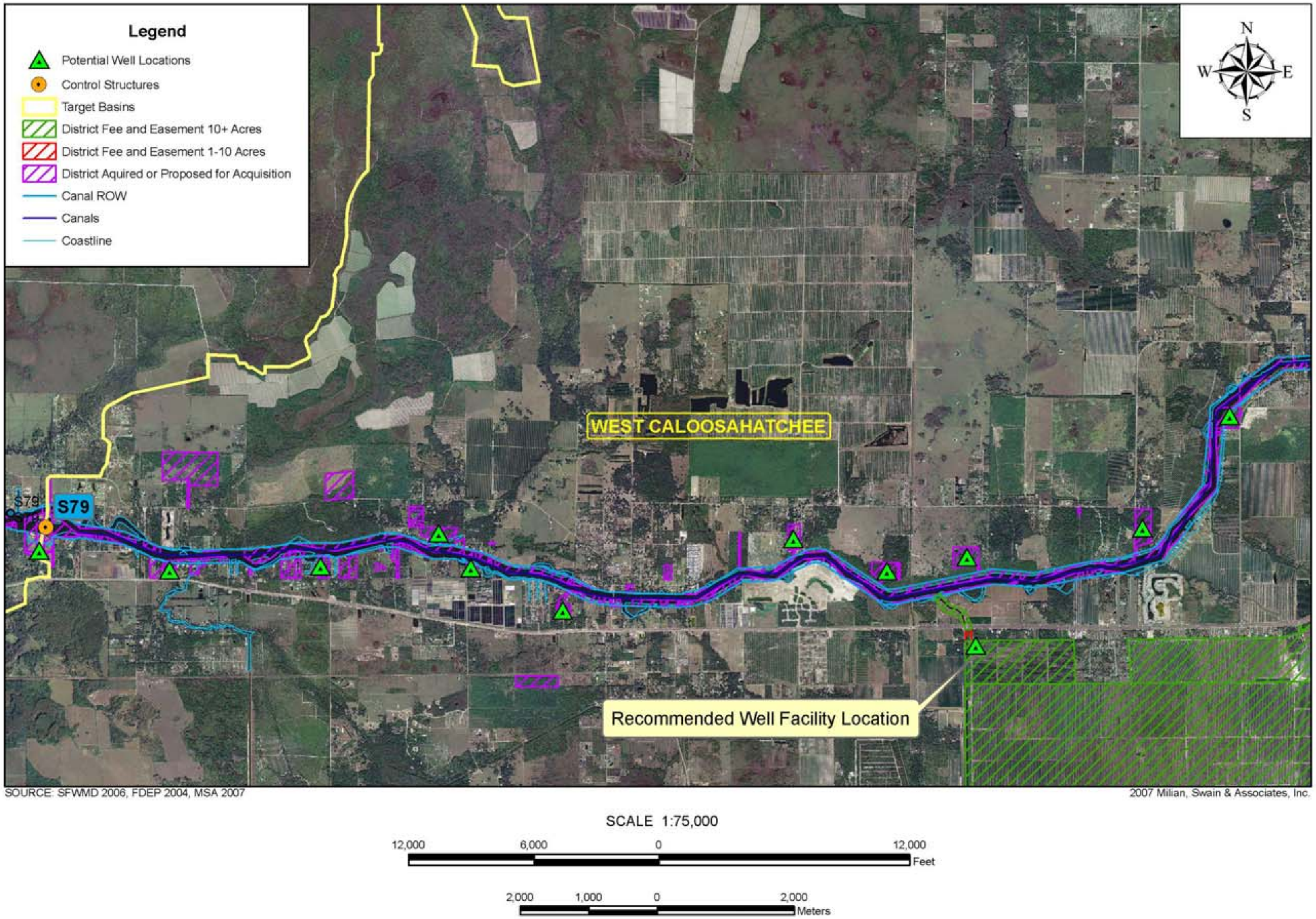

Figure 5-3 West Caloosahatchee Basin
Potential Injection Well Facility Locations

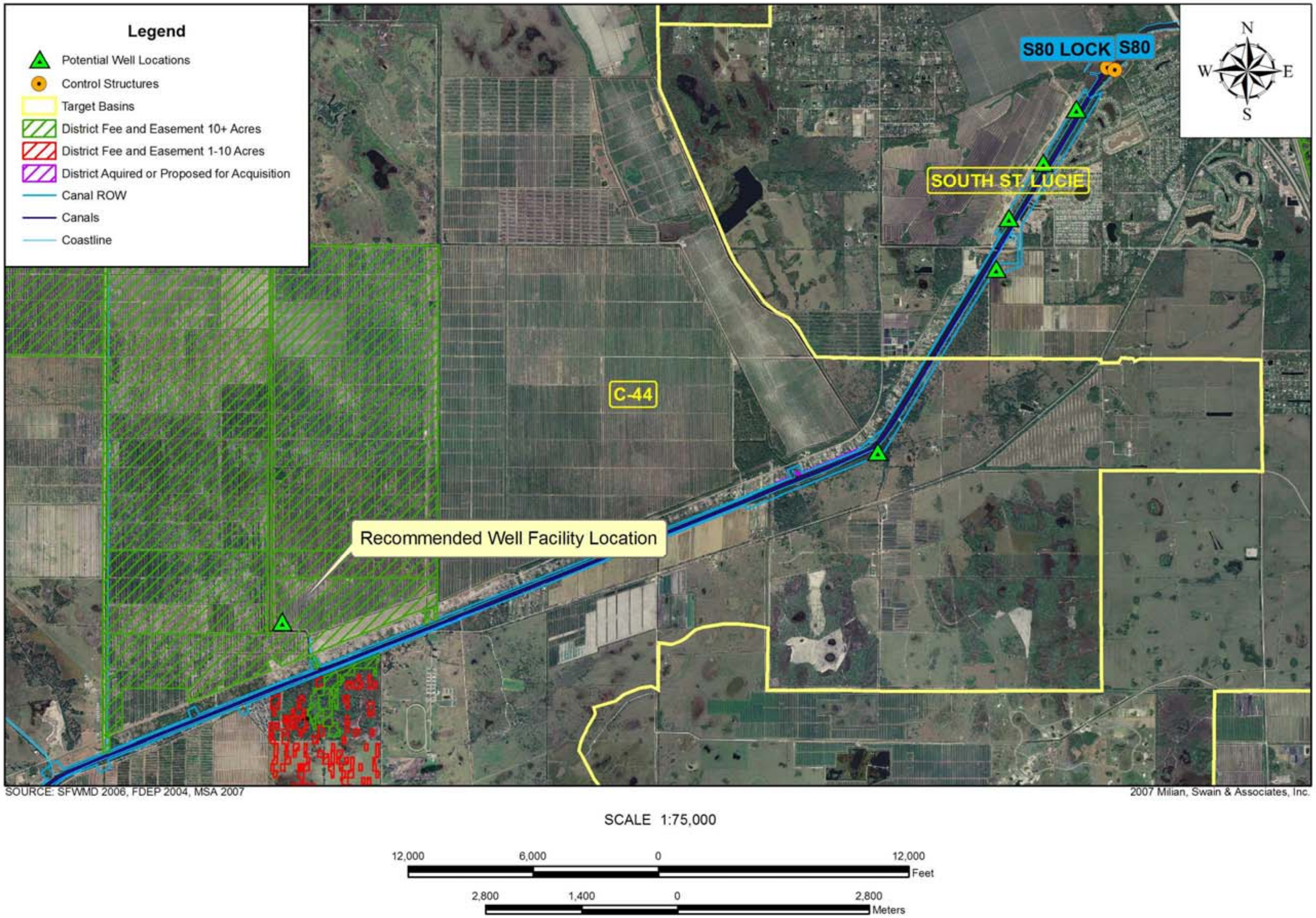

Figure 5-4 C-44 Basin Potential Injection Well Facility Locations

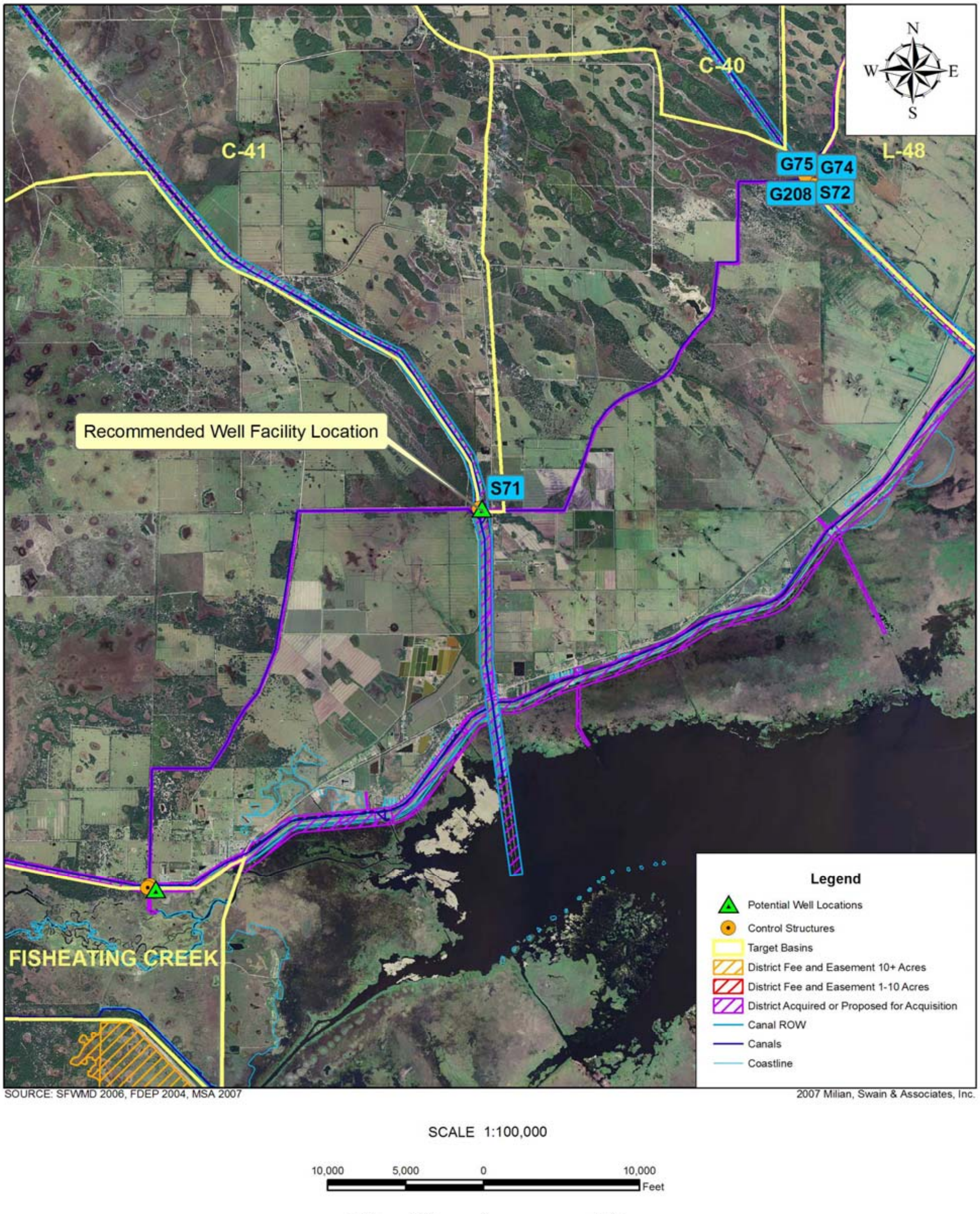

Figure 5-5 C-41 Basin Potential Injection Well Facility Locations

SOURCE: SFWMD 2006, FDEP 2004, MSA 2007

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SCALE 1:100,000

12,500 6,250 0 12,500 Feet

2,500 1,250 0 2,500 Meters

Figure 5-6 South S-191 Basin
Potential Injection Well Faciliity Locations

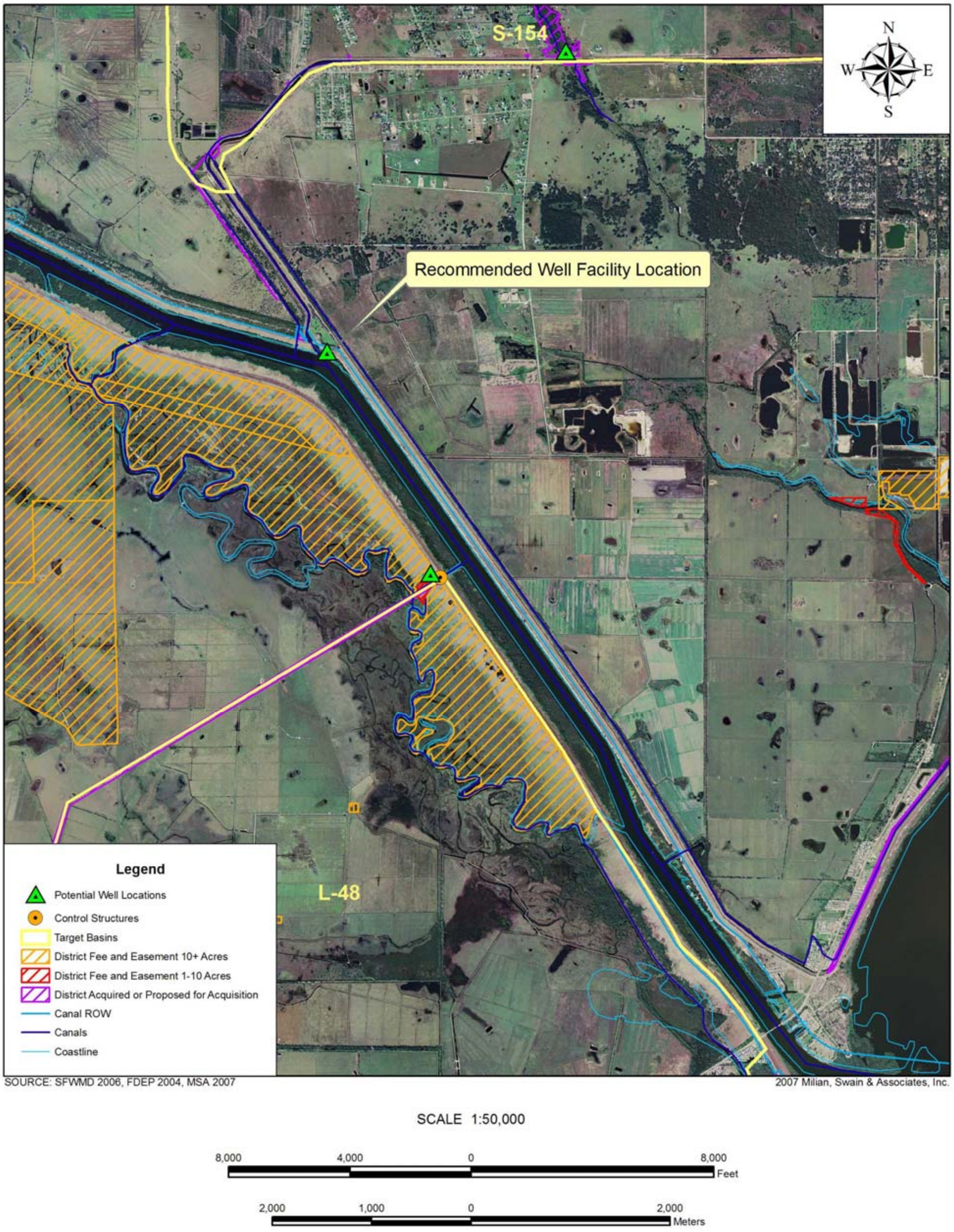


Figure 5-7 South S154 Basin
Potential Injection Well Facility Locations

Based on review of the site evaluation criteria and the associated benefits, the preferred locations for implementation of the LOER deep well injection program are as follows:

C-40

The primary criterion affecting this site's ranking is phosphate TMDL reduction; however, the site also experiences high flows for somewhat shorter durations than the C-41. This site has sufficient area for several injection wells, which would be aligned along the canal. The wells should be located downstream from the S-72 structure so that they can be used when needed for reducing excess discharges from Lake Okeechobee in the event that low flows would occur in the canal. This site has hydraulic connectivity to the L-48 Basin via the L-59 Canal, and the C-41 Basin via the L-60 Canal. This site presents greater uncertainty regarding hydrogeologic conditions and little testing has been done in this region. The C-40 Basin is shown in Figure 5-2.

West Caloosahatchee Basin at Berry Groves (C-43)

This is the site of a reservoir thereby providing the associated benefits. Any deep wells located here could be operated to enhance or optimize the benefits that reservoir offers toward reducing estuary discharge and other improvements. The site has the advantage that injection wells could be used to manage basin discharge in addition to discharge from Lake Okeechobee. There is sufficient area for several injection wells, which could be aligned along the Townsend Canal. This site offers a higher confidence level regarding hydrogeologic conditions. The site offers no phosphate TMDL reduction benefit. The West Caloosahatchee Basin is shown in Figure 5-3

C-44 Basin

This site has sufficient area for several injection wells. Injection wells at this site could be operated to provide a phosphate TMDL reduction benefit. The site has the advantage that injection wells could be used to manage basin discharge in addition to discharge from Lake Okeechobee. This site offers an higher confidence level regarding hydrogeologic conditions. The C-44 Basin is shown in Figure 5-4.

C-41 Basin

This site has sufficient area for several injection wells which would be aligned along the C-41 Canal. The primary criterion affecting this site's ranking is phosphate TMDL reduction criteria. The site also experiences long duration flows at relatively high rates, which contributes to it having the lowest unit cost phosphate reduction benefit. If hydrogeologic conditions are appropriate several injection wells could be constructed at this location, and they could experience a high use rate for either LOER or phosphate reduction purposes. The wells should be located downstream from the S-71 structure so that they can be used when needed for reducing excess discharges from Lake Okeechobee in the event that low flows might occur from the C-41 basin. This site has hydraulic connectivity to the C-40 Basin via the L-60 Canal, and the Fisheating Creek Basin via the L-61 Canal. This site presents greater uncertainty regarding hydrogeologic conditions and little testing has been done in this region. The C-41 Basin is shown in Figure 5-5.

S-191 (Taylor Creek/Nubbin Slough)
The primary criterion affecting this site's ranking is phosphate TMDL reduction; however, the site also experiences relatively long duration flows, which contributes to its low unit cost phosphate reduction benefit. The site allows co-location with an STA. There are at least two alternative sites within the basin, and the final selection would require further investigation. This site presents greater uncertainty regarding hydrogeologic conditions and little testing has been done in this region. The S-191 Basin is shown in Figure 5-6.

S-154 Basin below the discharge structure
The primary criterion affecting this site's ranking is phosphate TMDL reduction; however, the site also experiences high flows for shorter durations than the C-40 and C-41. This site may need additional property acquisition if several wells are to be located here. The wells should be located downstream from the structure so that they can be used when needed for reducing excess discharges from Lake Okeechobee in the event that low flows would occur in the canal. This site presents greater uncertainty regarding hydrogeologic conditions and little testing has been done in this region. The S-154 Basin is shown in Figure 5-7.

Exploration Well Drilling

It is recommended that an exploration well be drilled at each of the above sites and that the sites be reevaluated with regard to the goals and objectives of the program after the test drilling has been completed. Depending on available funding, we recommend that the individual sites be explored in the following order:

1. C-40
2. C-43 at Berry Groves
3. C-41
4. Taylor Creek /Nubbin Slough (S-191)
5. C-44
6. S-154

SECTION 6
CONCEPTUAL DESIGN OF THE INJECTION SYSTEM

6.1 Hydrogeologic Criteria and Design Parameters

Much of the design criteria, other than regulatory based, are determined by the hydrogeology. The hydraulic characteristics of the formation receiving the injected water provides the criteria that determine the flow and pressure that will affect the injection well and system design. The target injection zone is expected to have a transmissivity ranging between about 300,000 and 1,000,000 ft^2/day. The total dissolved solids in the target zone are anticipated to be greater than 30,000 mg/l. The depth of the injection zone is anticipated to be greater than 2600 feet. The base of the underground source of drinking water is conservatively estimated to range between 1000 and 2000 feet below land surface. For sites that are 10 or more miles inland, the base of the lowermost USDW will be nearer to 2000 feet below land surface. The actual depth to the base of the USDW at any site will be dependent upon the specific site selected and the water quality observed during the construction of a well.

6.1.1 Design Injection Pressure and Flow Rates

The typical injection well should be designed to operate at pressures approaching 70 psi. The maximum formation pressure increase at the base of the injection casing is anticipated to be less than 15 psi. The estimated maximum injection pressure of 70 psi pressure is based on the following:

- Static pressure of 20 to 30 psi due to buoyancy of the injected water
- Friction loss in the injection casing of 25 psi
- Formation pressure buildup of 10 to 15 psi.

6.1.2 Materials of Construction

6.1.2.1 Casing Strings other than the Final Casing String

The driller will be given the option to use a variety of mild steel casing types and specifications. Typical specifications require that all but the final casing string meet the following specifications: 0.375 inch wall mild steel casing meeting API 5L Grade B, ASTM A53 Grade B, or Spiral Weld A139 Grade B standards. Spiral Welded pipe is the most commonly selected casing for all of the inner casing strings.

6.1.2.2 Longstring (Final) Casing

All injection well designs proposed for this program are based on the need to provide the largest diameter wells acceptable to the FDEP and the utilization of the most cost effective materials. Typical well construction materials used for deep injection wells include mild steel, stainless steel, plastic or fiberglass lined pipe, and fiberglass pipe.

Mild steel is the least expensive of the proposed materials and is the standard material specified in the regulations. Mild steel is also the most corrosion prone material of those stated above. Currently, injection wells for municipal wastewater in Florida have demonstrated life times in excess of twenty years. However, some mild steel tubing and packer type completions utilized in wells disposing of R.O. concentrate and municipal waste or R.O. concentrate alone have failed in less than ten years. This suggests that corrosion of mild steel will likely be a factor in estimating the ultimate life of wells proposed for the LOER program.

Plastic coated pipe can be very protective as long as the pipe lining remains intact. For this type pipe, the protective coating is placed directly on the pipe. However, a break in this coating can lead to acceleration of the corrosion. Running of the wire-line tools required for mechanical integrity testing can generate the types of damage that could result in high rates of localized corrosion. Currently this material is not available in the sizes greater than 16 inches and therefore it is not considered for the LOER program.

Plastic lined and fiberglass lined pipe has been utilized successfully in the oil and gas industry to minimize corrosion. The liners are grouted in place and are generally more rugged and can take more abuse than the coatings on plastic coated pipe. The maximum outside diameter of the pipe used in this process is 10 3/4 inches. Therefore, this pipe is not suitable for the LOER program.

Stainless steel, fiberglass, and PVC pipe rely on the corrosion resistance of the material for an extended life. However, under certain conditions, some stainless steels can be susceptible to biological degradation. Currently, fiberglass is limited in the ultimate pipe size of 18-inches I.D. although larger diameters are in the design process and could likely be manufactured if there was sufficient incentive. Stainless steel pipe can be constructed to meet the larger diameters that may ultimately be desired for the injection wells in the LOER program; however, this is typically the most expensive option assuming 0.5-inch wall thickness will be a requirement. PVC pipe is limited in both diameter and recommended working depths.

If well lifetimes in the range of 20 to 30 years are acceptable to meet the requirements of this project, then mild steel casing is clearly the most economical. For the conceptual design process, mild steel (longitudinal weld) is the recommended alternative. The mild steel casing selected for the longstring casing would need to meet API 5L Grade B or ASTM A53 Grade B requirements. These specifications are met by both longitudinally welded and seamless pipe.

The estimated cost and life expectancy of 24-inch well casings of the various materials are given Table 6-1.

TABLE 6-1. COMPARISON OF COSTS FOR A 24-INCH O.D. FINAL CASING

Material of Construction	Estimated Cost for 3000 Feet	Life Expectancy (Estimate)
Mild Steel (Longitudinally Welded)	$ 300,000	> 20 years
Mild Steel (Seamless)	$ 600,000	> 20 years
Fiberglass (est)	$ 1,100,000	> 40 years
Stainless Steel (est)	$ 2,000,000	> 40 Years

6.2 Multiple Open-Hole Completion

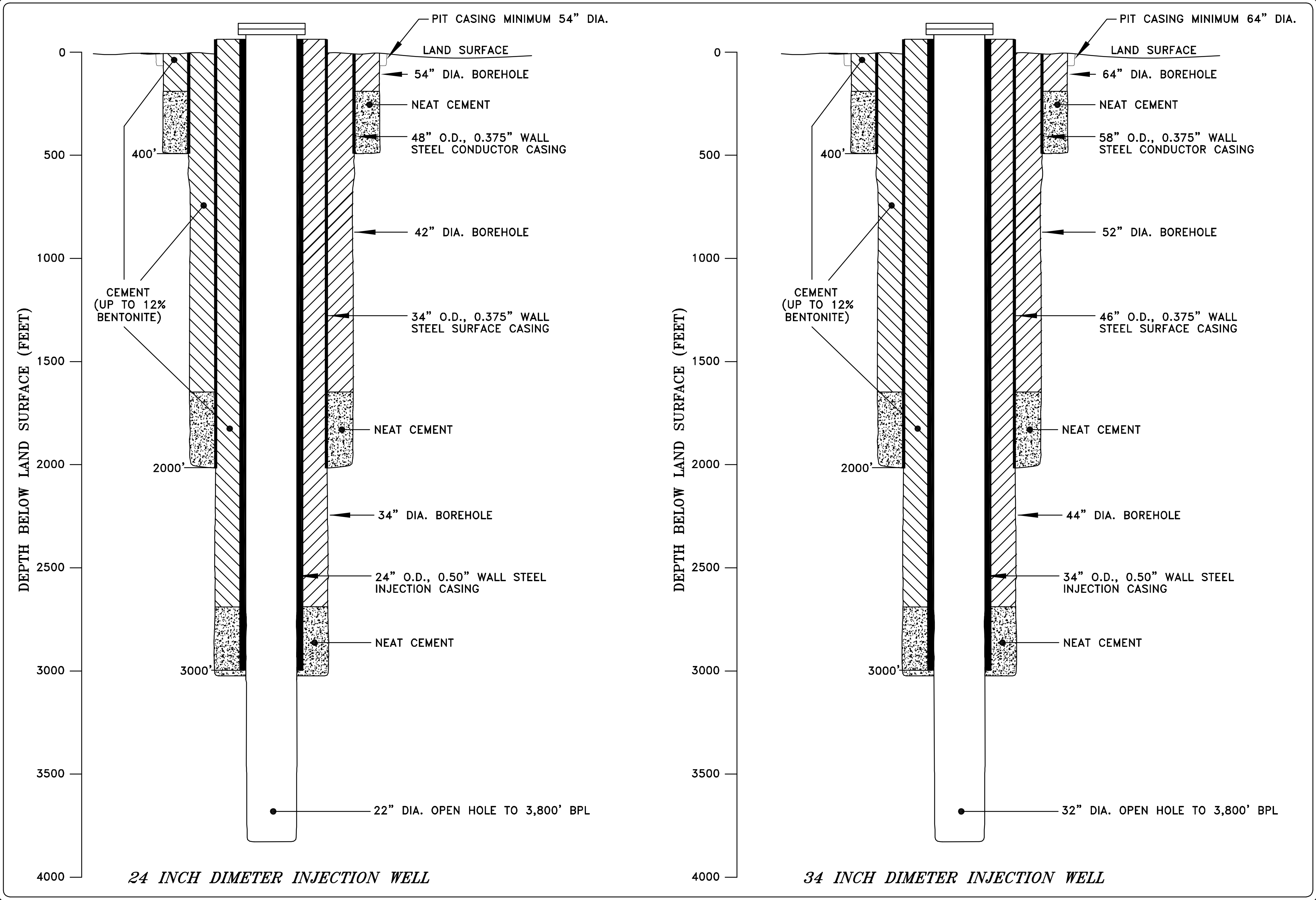
When a well is being completed, there is no guarantee that a single borehole will provide the maximum communication with the transmissive portion of the injection formation. Therefore, one method of increasing the contact with the transmissive portion of a formation would be to complete multiple boreholes extending from the base of a single injection casing. These boreholes would be drilled at different depths within the injection interval to increase communication with the more transmissive portions of the formation if the first hole does not provide sufficient communication/injectivity with the formation. It is anticipated that at least 3 holes could be drilled beneath the base of the final casing string. Such a completion could greatly enhance the injection capacity for a well that did not meet the initial target injection rate and pressure.

6.3 Well Diameter and Construction Limitations

Drilling rigs and cranes are limited to the amount of load they can lift. Therefore, weight of the casing can become a limiting factor. The string weight of 24-inch O.D., 0.5-inch wall pipe is approximately 340,000 lbs. and the string weight of 34-inch O.D., 0.5-inch wall pipe is approximately 500,000 lbs in the absence of buoyancy. These string weights exceed capacity of many of the drilling rigs that are based in Florida. However, at least one Florida-based contractor has equipment capable of handling these casing sizes. Other contractors have similar equipment in neighboring states, and some contractors have expressed an interest to invest in such equipment for jobs that look promising in the long term. Well diameters exceeding 34-inches are possible; however, it is not felt that such large diameters would offer any cost or operational advantages. For the LOER program, the recommended range of final casing size is 24 to 34-inches.

6.4 Injection Well Construction Details

Figure 6-1 provides diagrams for the design of a 24-inch and a 34-inch injection well that will meet the requirements of this program. The casing set points shown represent estimated depths and the actual depths will be determined by site specific hydrogeologic conditions.



Water Resource Solutions	PROJECT NAME: SFWMD	DWG. NUMBER: 1161401mp1
	PROJECT NUMBER: 1161401	DATE: 05/31/07

FIGURE 6–1. PROPOSED CONSTRUCTION DETAIL FOR INJECTION WELLS.

6.4.1 Exploration Well

Before constructing an injection well at a given site, an exploration well will be constructed to verify the geology and hydrogeology of the particular site under an FDEP UIC permit. Specifically, the exploration well will be utilized to determine the location of the USDW at a specific site, the types and number of confining zones at the location that exist between the base of the USDW and the injection zone, and the basic hydraulic properties of the injection interval.

Figure 6-2 provides a diagram of a typical exploratory well that will be utilized to evaluate a given site. As indicated the figure, casing will be set below the base of the USDW. Ultimately, the exploration well would be completed as a dual zone monitoring well that is currently anticipated to be required at these sites.

An abbreviated construction plan for such an exploration well is provided in Section 8.

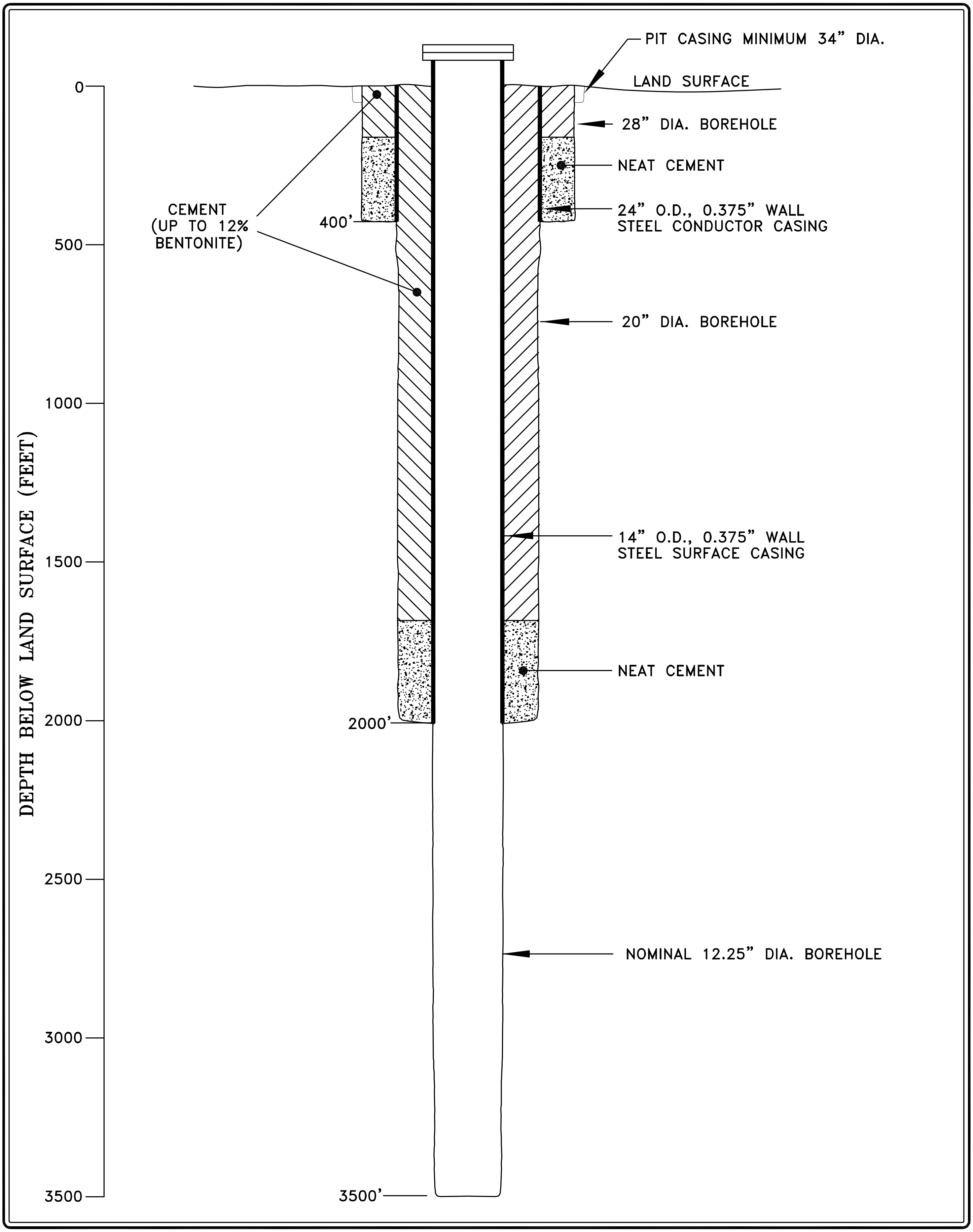
6.5 Pretreatment and Pumping System

6.5.1 Introduction

The purpose of the proposed pumping and pretreatment system is to convey the excess waters to the injection well, provide an appropriate level of treatment, and inject the water into the desired subsurface interval. The proposed system includes a primary low-pressure pumping station at the surface water source and secondary high-pressure pumps at each deep injection well. The pretreatment system consists of coarse trash rack at the intake structure, and hydrodynamic separators sized to centrifugally remove settleable solids on the discharge of the primary low pressure pumping system. Figure 6-3 shows a schematic of the proposed intake, pumping and preliminary treatment system. Some assumptions are made in this conceptual design due to lack of site-specific information that will control some elements of the design. When a specific site is determined, the conceptual design can be adapted to fit the specific situation.

The design concept includes two-stage pumping of water from the Lake Okeechobee surface source (canal assumed) to the deep injection wells. A two stage process was selected to minimize head loss through the system, keep the pump size reasonable, facilitate construction, allow for custom fabricating of the individual well pumps to maximize efficiency, and minimize operation and maintenance costs.

With this two-stage process, more efficient high flow/low head pumps at the intake can be selected for the fist storage of the system to pump through hydrodynamic separators to a common wet well. This allows for use of low pressure piping from the hydrodynamic separators to the injection wells. For the second stage, individual high pressure injection pumps can be tuned to match the unique characteristics of each associated deep injection well. This should provide ability to select higher efficiency pumps using trimmed impellers. The injection pumps can be specified individually to match the characteristic of the wells after the well testing is completed. The alternative to the two stage pumping



Water Resource Solutions	PROJECT NAME: SFWMD	DWG. NUMBER: 1161401mp1
	PROJECT NUMBER: 1161401	DATE: 05/31/07

FIGURE 6–2. PROPOSED CONSTRUCTION DETAIL FOR EXPLORATION WELL.

process would be single stage pumping, which would require that the entire piping system be pressure pipe with pumps selected for the maximum flow injection pressure. This alternative would not be as efficient and would not allow hydrodynamic separators.

For conceptual design, the injection system is assumed to consist of four (4) injection wells and all associated pumping, treatment, and transmission facilities. A system of this size can be scaled up or down depending upon the actual number of wells used at any site. For this purpose it is assumed that the number of injection wells installed at any site would range between three (3) and ten (10). The wells are assumed to be 24-inch diameter wells having a pumping capacity of 18 MGD each for a total capacity of 64 MGD. It is anticipated that the injection wells will range in size between 24 and 34 inches in diameter.

Figures 6-3 and 6-4 show the conceptual design of the proposed intake structure and primary pumping station. The primary pumping system will use four vertical turbine pumps each flowing into one twin-system hydrodynamic separator. The primary pumps will be installed adjacent to each other and will be located above the wet well. The secondary pumps will be located at each injection well. They will be fed by gravity flow and located as close as possible to the wells to minimize head loss in the pressure flow.

Depending on the total suspended solids concentration and size, the design will alternatively include hydrodynamic separators to reduce the concentration and size of the suspended solids so that clogging is minimized in the deep injection wells. Hydrodynamic separators are generally used to treat storm water to separate suspended solids and floatable objects. Hydrodynamic separators are capable of removing settleable suspended solids completely and they do not require an outside power source.

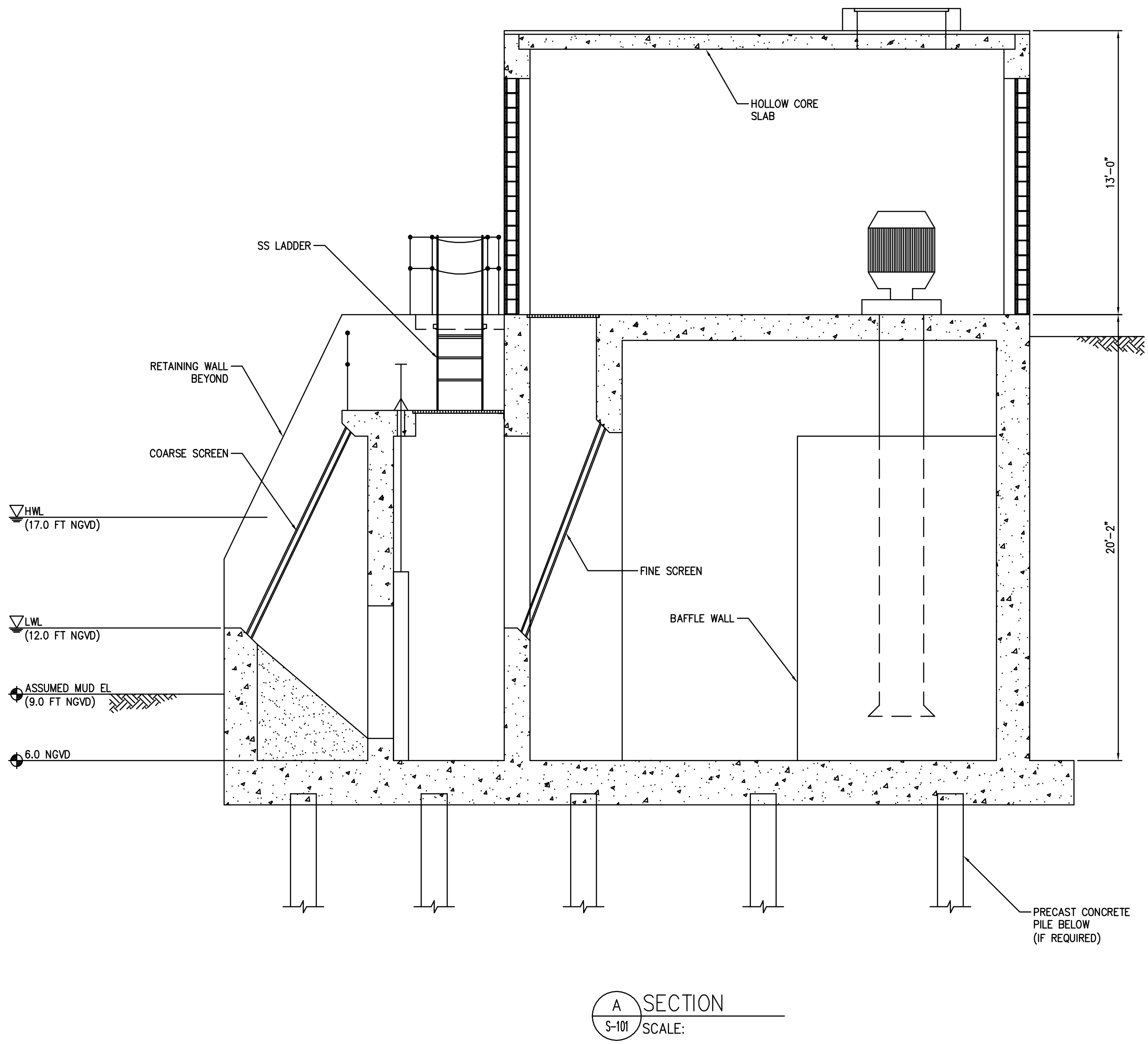
6.5.2 Pretreatment and Pumping Processes

The overall proposed system can be summarized in the following processes: Debris, and large objects removal is accomplished using coarse screens. Small objects and large sediments removal is accomplished using fine screens. Primary pumping transmits the source water from the intake structure to the hydrodynamic separators. Flow is by gravity flow piping from the hydrodynamic separators to the secondary pumps for injection, which will be located at the deep injection wells.

The hydraulic profile is shown on Figure 6-5. The low water level (LWL) and high water level (HWL) are based on a report of US Army Corps of Engineers.
(http://www.saj.usace.army.mil/cco/HHD/HHDFactSheet_FAQsWeb.pdf)

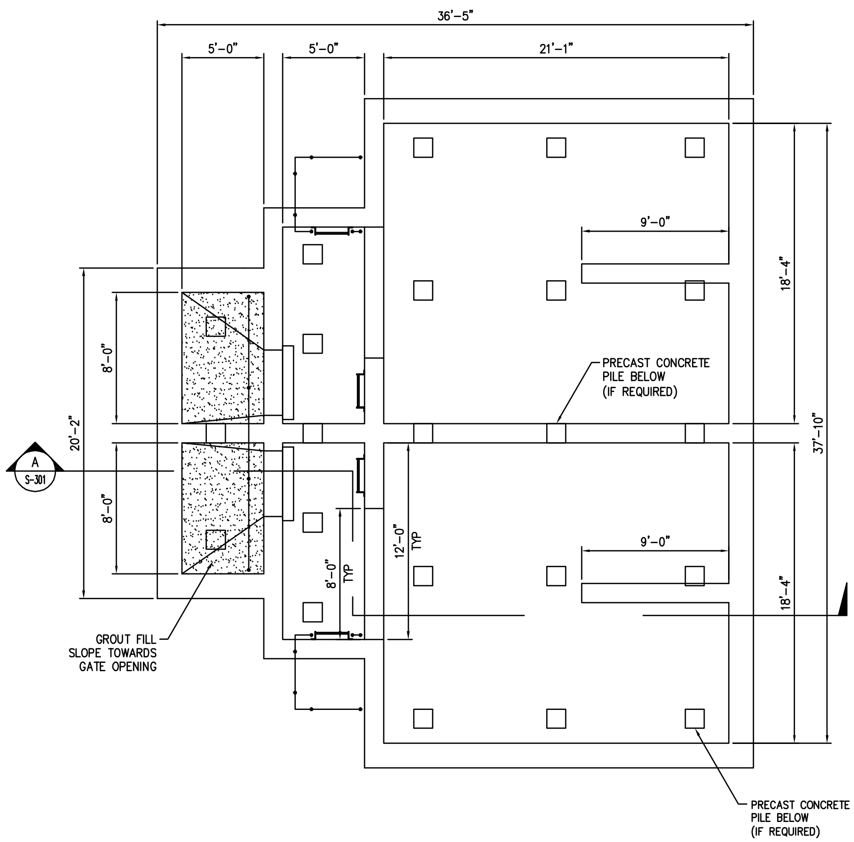
6.5.3 Coarse and Fine Screening

The proposed pretreatment starts with bar screens to eliminate coarse objects such as debris, bark, leaves, and fish. Bar screening will prevent any large objects from entering the pretreatment system. The influent will enter the intake structure through the bar screens. The opening width will be 0.5 inches. There are several cleaning systems

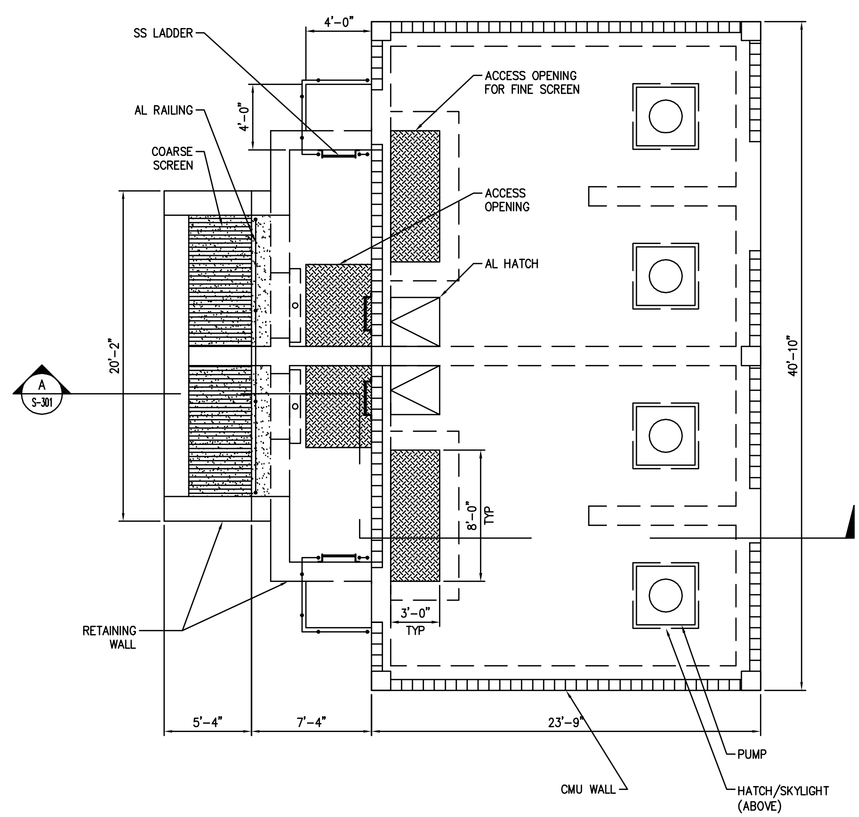


Water Resource Solutions	PROJECT NAME: LAKE OKECHOBEE INJECTION WELL STUDY	DWG. NUMBER: 1161401rj1	Boyle
	PROJECT NUMBER: 1161401	DATE: 05/31/07	

FIGURE 6–3. INTAKE AND PRIMARY CONCEPTUAL DESIGN PUMPING STATION.



FOUNDATION PLAN
SCALE:



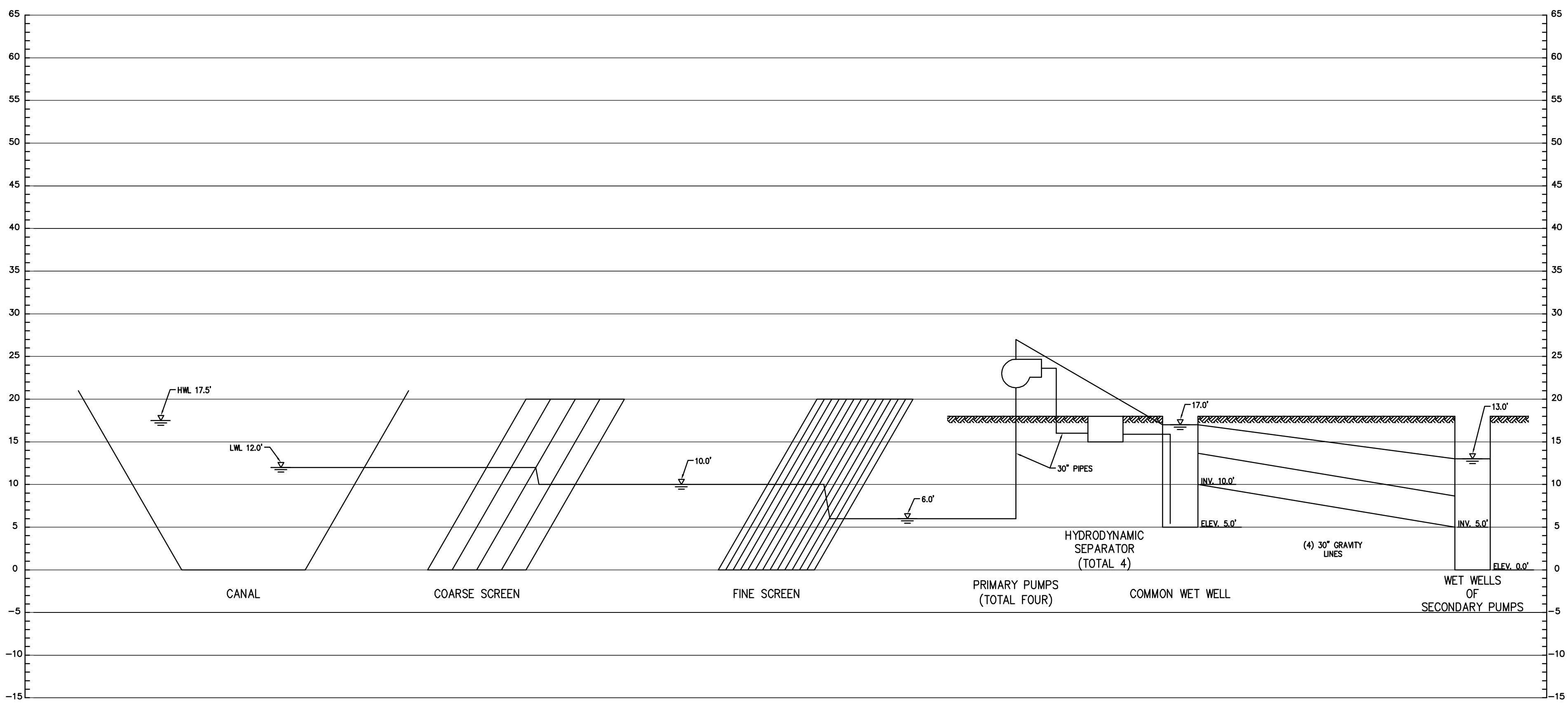
TOP PLAN
SCALE:

NOTES:

1. DIMENSIONS ARE PRELIMINARY.

Water Resource Solutions	PROJECT NAME: LAKE OKECHOBEE INJECTION WELL STUDY	DWG. NUMBER: 1161401rj1	Boyle
	PROJECT NUMBER: 1161401	DATE: 05/31/07	

FIGURE 6-4. PLAN VIEW OF INTAKE AND PRIMARY PUMPING STATION.



NOTE: SUBJECT TO CHANGE

Water Resource Solutions	PROJECT NAME: LAKE OKECHOBEE INJECTION WELL STUDY	DWG. NUMBER: 1161401rj1	Boyle
	PROJECT NUMBER: 1161401	DATE: 05/31/07	

FIGURE 6–5. HYDRAULIC PROFILE FOR LOER INJECTION WELL PUMPING AND PRETREATMENT FACILITIES.

available for the bar screens; high flow rates and potentially significant amount of debris from the intake source requires a careful selection of the bar screen and the cleaning method that will perform efficiently and minimize the capital, and Operation and Maintenance costs.

The most economical option is using a bar screen without a mechanical cleaning system, however, this may not be feasible if the rate of floating and suspended large objects is high. Therefore, bar screens with cleaning mechanisms such as a raking system (Figure 6-6) may be more efficient based on the expected rate of floating objects. The bar screens will be installed parallel to the direction of flow (if the system is installed in a canal).

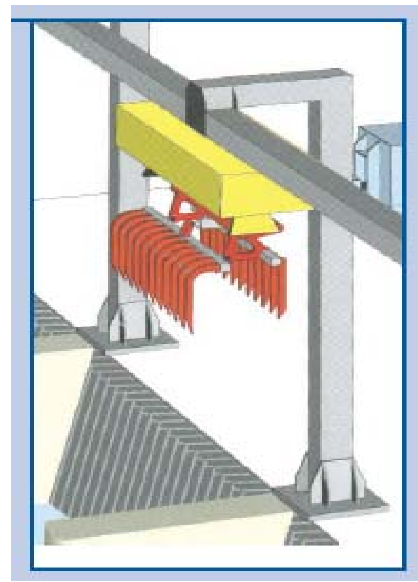


Figure 6-6. Bar screen with a raking system. Source: Bracket Green USA, Inc.

Influent water will flow through coarse screens where miscellaneous debris larger than 0.5 inch (13 mm) will be removed. The flow will split toward two fine screens with an opening size of 3 mm. Settleable suspended solids will be removed using hydrodynamic separators, which will be located between the intake structure and deep injection wells (as discussed below). The proposed coarse and fine screens will be the same size with an approximate cross-section 100 sq. ft. Use of wedge wire and catenary type screens will be considered. Similar to bar screens, the fine screens will be cleaned manually or using a cleaning mechanism such as spray nozzles depending on the coarse particles concentration in the source water.

6.5.4 Intake Structure

The intake structure is a reinforced, cast-in place concrete structure approximately 36 x 41 ft in plan dimension. This structure primarily contains fine and coarse screens for grit removal and vertical turbine pumps to transmit water to hydrodynamic separators. The structure has a dual train that can be operated independently by gates behind the fine screens.

The structure also supports a superstructure that houses the motors for the pumps and other electrical components. This superstructure will be constructed utilizing reinforced cast-in-place concrete building frames with reinforced masonry walls and a precast hollow-core roof system. The precast roof will have access hatches or skylights to facilitate pump removal.

Depending on soil conditions, the intake structure will be supported on a mat foundation or precast concrete piles. Temporary sheet piling and cofferdams may be required for construction of this structure.

6.5.5 Primary Pumping Station

Primary pumps are to pump water from source water to hydrodynamic separators. Adequate head is needed to meet the requirement of hydrodynamic separators and the requirement to flow the separator discharge water by gravity to wet wells of secondary pumps. The hydraulic calculations are shown as follows:

1) Coarse screen headloss:

$$h_{L1} = \frac{1}{C}\left(\frac{V^2 - v^2}{2g}\right) = \frac{1}{0.6} \times \left[\frac{(1.8m/s)^2 - (0.6m/s)^2}{2 \times 9.81 m/s^2}\right] = 0.24m \approx 0.787\,ft$$

Therefore, assume coarse screen headloss h_{L1} = 2.0 ft with a safety factor no less than 2.5.

2) Fine screen headloss:

$$h_{L2} = \frac{1}{2g}\left(\frac{Q}{CA}\right) = \frac{1}{2g}\left(\frac{V}{C}\right) = \frac{1}{2 \times 9.81 m/s^2} \times \left[\frac{(1.8m/s)^2}{0.6}\right] = 0.45m \approx 1.50\,ft$$

Note: Some values are taken from the reference book: Wastewater Engineering.

Therefore, assume fine screen headloss h_{L2} = 4.0 ft with a safety factor no less than 2.5.

3) Hydrodynamic separator headloss is assumed to be h_{L3} = 5.0 ft.
4) The pipe friction and minor head loss is assumed to be h_{L4} = 4.0 ft.
5) Lake Okeechobee lowest water level is 12.0 ft, and total dynamic head (THD) at the outlet of hydrodynamic separators shall be 27.0 ft, which is needed to provide adequate flow to wet well with maximum 18.0 ft NGVD. The outside ground level is about 18.0 ft NGVD. Therefore, the water level at water sources is assumed to be 15 ft (notice that the water level will vary depending on the location of specific water sources). The static head is calculated to be h_S = 27.0 ft – 15.0 ft = 12.0 ft.

Note: The lowest water level of 12.0 ft is based on the report of US Army Corps of Engineers (http://www.saj.usace.army.mil/cco/HHD/HHDFactSheet_FAQsWeb.pdf). According to that report, no water is needed to discharge into to DIWs when the Lake Okeechobee water level is equal to or less than 12.0 ft.

Thus, the total dynamic head (TDH) is
$H = h_{L1} + h_{L2} + h_{L3} + h_{L4} + h_S$ = 2.0 + 4.0 + 5.0 + 4.0 + 12.0 = 27.0 ft ≈ 12 PSI.

The design condition of each primary pump is (18 MGD, 12 PSI). Four vertical pumps (130hp) are estimated.

The power consumption cost is calculated as follows:

$$\frac{Cost}{year \cdot pump} = 130hp \times \frac{0.7457KW}{1hp} \times \frac{120days \times 24hours/day}{1year} \times \$0.09/KWH \approx \$25{,}000$$

Note: The pumps are assumed to continuously run 24/7 for 120 days per year. The energy unit cost of \$0.09/KWH is used for purchased power or on-site generators, which is based on the actual data of Peace River Facility.

6.5.6 Hydrodynamic Separators

The proposed design is based on preventing the intrusion of settleable suspended solids to the deep injection wells to avoid clogging. Hence, in addition to coarse and fine screens at the headworks, pretreatment alternatives, such as sedimentation, filtration, and use of hydrodynamic separators, was evaluated. Using hydrodynamic separators appears to be advantageous, because settleable solids can be removed before they reach the deep injection wells without the use of an outside power source. Hydrodynamic separators generally consist of a circular structure used to remove solids and floating objects. The module consists of a settling tank through which the influent is subjected to centrifugal action using flow velocity and gravity. The solids settle into a sump as a result of the centrifugal action and placed at the base of the structure. Hydrodynamic separators have been effectively used in treating storm water runoff, and they do not require significant additional space or a covering structure, since they are installed below ground. However, periodic monitoring and cleaning should be anticipated depending on the size and concentration of the suspended solids in the source water. For instance, based on an assumed 30 mg/L TSS in the source water, and 70 percent entrapment in the sumps of the hydrodynamic separators, the units may require cleaning on a 7 to 15 day period. A common cleaning method for hydrodynamic separators is using vacuum trucks. This type of cleaning is rather routine and it is often contracted to companies that specialize in this service. Figure 6-7 shows the cross-section of a typical hydrodynamic separator.

It should be noted that the rate of entrapment hence the frequency of maintenance of the hydrodynamic separators may be significantly different depending on the solids size, concentration, and density in the source water. An experimental, smaller scale pilot pretreatment system using screening and a hydrodynamic separator is proposed to be used in the preliminary design phase. Testing the proposed system using the pilot plant will enable to monitor the solids removal efficiency and required frequency of maintenance, thereby, if the sumps are filled in a shorter time than desired, a discharge system for the collected solids will be designed.

Flow rates and pressures in the pipelines between the primary pumping and hydrodynamic separators will be monitored using a Supervisory Control and Data Acquisition (SCADA) system. Accordingly, flow rates and pressures in each pipe to the hydrodynamic separators will be measured. The real time flow data can be monitored at a remote location or in a control room, which can be built into the intake structure.

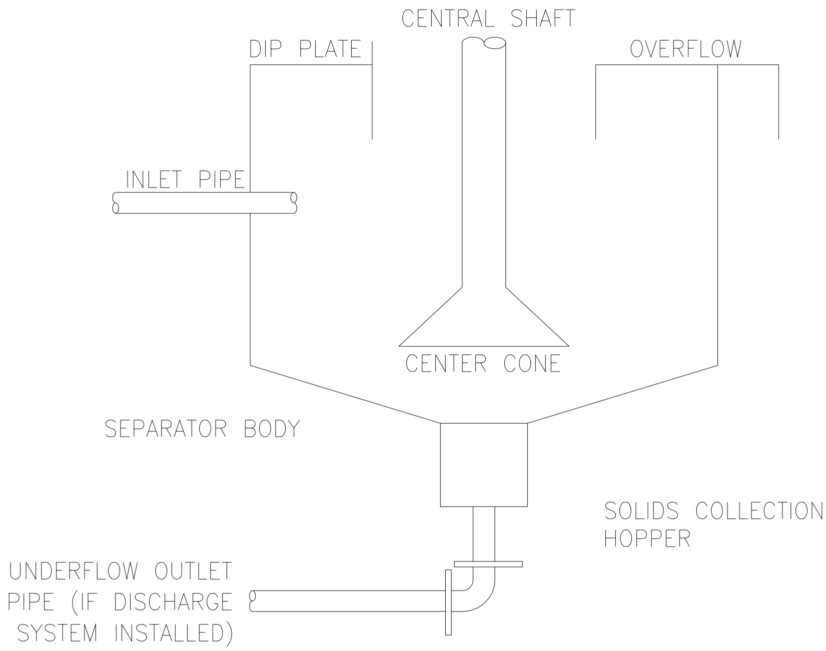


Figure 6-7. Cross-section of a typical hydrodynamic separator
Source: Fenner and Tyack, 1997.

6.5.7 Piping

Four 24-inch diameter injection wells are assumed to be located in a linear arrangement and each well will have a maximum capacity of 18 MGD. Therefore, the maximum capacity of this deep injection well system will be 18 MGD × 4 = 72 MGD. Four primary and four secondary pumps are proposed. The suction and discharge lines of each pumps will be 30-inch ductile iron pipe (or other high pressure pipe) with a velocity of 5,67 ft/s. The four gravity lines of total 64 MGD (18 MGD each) to the four DIW wet wells shall be 30-inch pipes with a velocity of 15.67 ft/s. Gravity lines will be lower cost than pressure lines. For a 4 well system it is estimated that the individual pipelines to the wells will range from about 150 to 500 feet. A schematic of piping layout and size are shown on Figure 6-8.

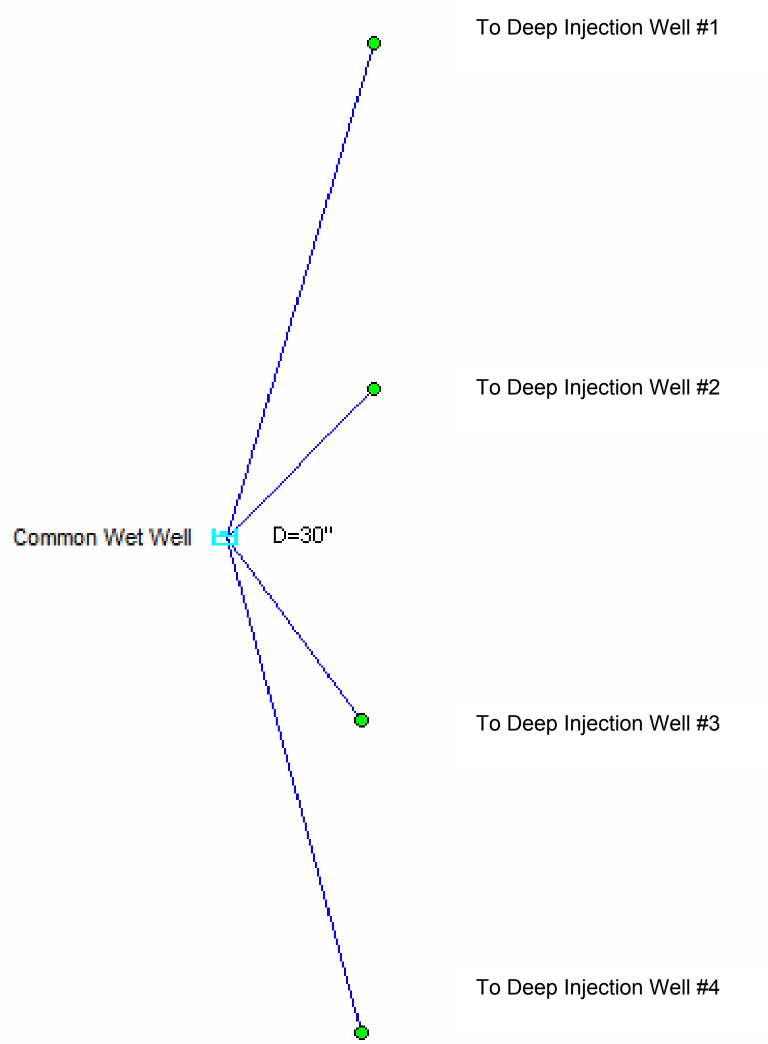


Figure 6-8 Schematic layout of gravity lines from the common well to the four wet wells of the injection wells

6.5.8 Secondary Pumping Station

The backpressure of deep injection wells is estimated to be 70 PSI. The design condition of each secondary pump is (18 MGD, 70 PSI). Four vertical pumps (650hp) are used.

The power consumption cost is calculated as follows:

$$\frac{Cost}{year \cdot pump} = 650hp \times \frac{0.7457KW}{1hp} \times \frac{90days \times 24hours/day}{1year} \times \$0.09/KWH \approx \$125{,}000$$

Note: the pumps are assumed to continuously run 24/7 for 90 days per year. The energy unit cost of $0.09/KWH is used for purchased power or on-site generators, which is based on the actual data of Peace River Facility of the Peace River/Manasota Regional Water Supply Authority.

The conceptual plan and section of the secondary pumps are shown on Figure 6-9. Magnetic flow meters and pressure gauges will be installed to continuously monitor the flows according to UCI.

6.5.9 Alternative to Eliminate the Hydrodynamic Separators

At some or all sites it may be possible to operate without using hydrodynamic separators for removal of solids. This could occur if it was found that the injection zone contained large enough flow channels that they could not be plugged by solids that would pass though the screen system. In this case an alternative design would pump directly from the primary pumping station to the injection wells. For the initial pilot well at any site, it is recommended that the system be built to accommodate hydrodynamic separators; however, the separators could be bypassed for extended periods to research the need for such a process. The results of this testing could cause the design to be modified to not include hydrodynamic separators in the final design for some or all facilities.

6.6 Cost Estimates for Development of a Typical Multi-Well System

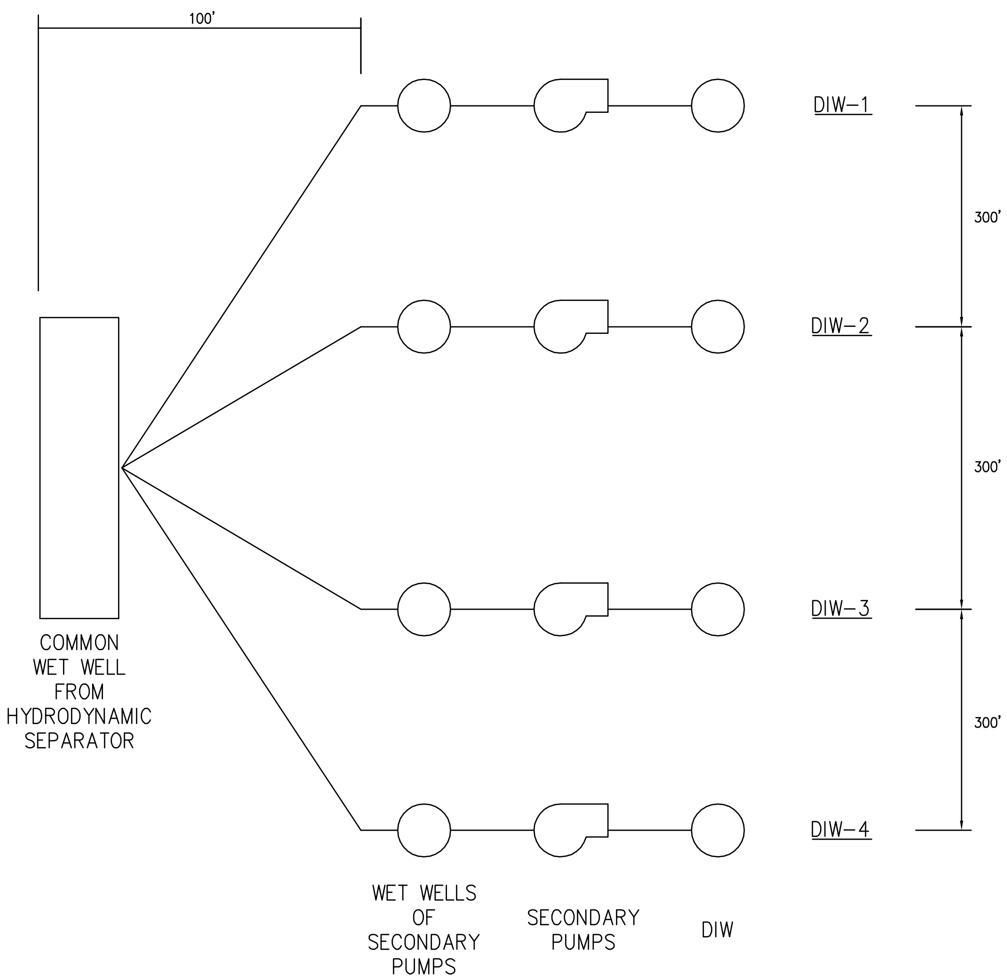
6.6.1 Injection System Costs

The cost estimate is based on a system consisting of four deep injection wells including all intake, pumping, and pretreatment facilities, which is assumed would represent a typical size installation. A four well system is assumed to use 24-inch diameter wells, representing the most conservative approach for estimating the cost of the injection well portion of the project. Larger diameter wells would be expected to reduce the cost of the wells per unit volume injected by 10 to 20 percent. The recommended well size range for ultimate design of the complete LOER system ranges from 24 to 34 inches; however, since well sizes above 24 inches have not been typically used, it is recommended to first utilize 24-inch diameter wells. After several wells have been in operationally tested, it is recommended to begin experimenting with larger diameters in areas where the geology is appropriate. The capacity of the conceptual system of four wells is 72 MGD (111 cfs). For the pumping, piping, and pretreatment components of the system, it is not expected that increasing the system capacity will provide a reduction in cost per unit of flow volume.

A cost estimate for the 72 MGD injection well system is given in Table 6-2.

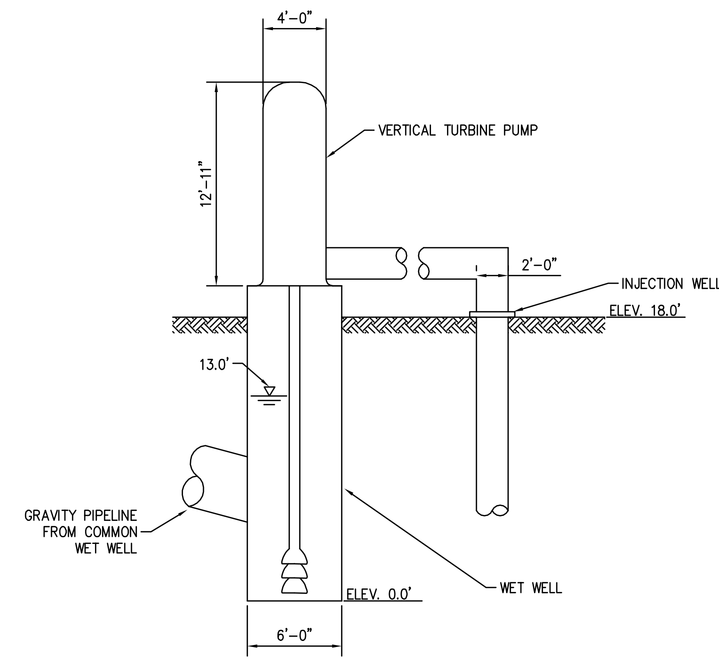
6.6.2 Operational Costs

Annual operational costs are estimated based on a 120-day period continuous of usage during the year (Table 6-3). The table also gives cost of operations per acre foot of water injected.



PLAN

SCALE: N.T.S.



SECTION

SCALE: N.T.S.

Water Resource Solutions	PROJECT NAME: LAKE OKECHOBEE INJECTION WELL STUDY	DWG. NUMBER: 1161401rj1	Boyle
	PROJECT NUMBER: 1161401	DATE: 06/21/07	

FIGURE 6-9. SCHEMATIC OF INJECTION SYSTEM BETWEEN HYDRODYNAMIC SEPARATORS AND INJECTION WELLS.

TABLE 6-2. COST ESTIMATE FOR A COMPLETE 4 WELL SYSTEM

ITEM NO.	ITEM DESCRIPTION	UNITS	QUANTITY	PRICE	
				Per-Unit	Extended
1	**Screening Facilities including coarse/fine screens**				
1.1	Screening Facilities*	EA	1	$ 4,655,000	$ 4,655,000
2	**Pump Station including primary pumps, intake structure and coarse/fine screens**				
2.1	Primary Station (Flow = 72 MGD, TDH < 40 FT)*	EA	1	$ 2,221,000	$ 2,221,000
3	**Well Surface Facilities including secondary pumps, common well and wet wells**				
3.1	Well Surface Facilities (Flow = 18 MGD, TDH = 40 - 80 FT)*	EA	4	$ 1,940,000	$ 7,760,000
4	**Deep Injection Wells**				
4.1	Deep Injection Wells (24-inch) – mild steel	EA	4	$ 4,500,000	$ 18,000,000
4.2	Monitor Wells (Average 1 Monitor Well per 3 Deep Injection Wells)	EA	2	$ 1,000,000	$ 2,000,000
5	**Pipes**				
5.1	30" Ductile Iron Pipe	LF	800	$ 600	$ 480,000
5.2	30" Concrete Pipe	LF	900	$ 450	$ 405,000
6	**Flow Meters**				
6.1	Flow Meters	EA	8	$ 15,000	$ 120,000
6.2	Installation Fees**	EA	8	$ 18,750	$ 150,000
7	**Hydrodymamic Separators**				
7.1	Hydrodymamic Separators	EA	8	$ 75,000	$ 600,000
7.2	Installation Fees**	EA	8	$ 93,750	$ 750,000
8	**Extend Electric Utility**				
8.1	Extend Electric Utility	EA	1	$ 300,000	$ 300,000
				SUB-TOTAL =	$ 37,441,000
				CONTINGENCY (15%) =	$ 7,488,000
				TOTAL CONSTRUCTION =	**$ 44,929,000**
				PROFESSIONAL SERVICE (15%) =	$ 8,985,000
				TOTAL PROJECT COST =	**$ 53,914,800**
				PROJECT COST PER MGD =	**$748,817**
				PROJECT COST PER 24" WELL =	**$ 13,478,000**

Note:

* Based on ENR Pump Station Total Construction Cost Calculation.

** 1.25 ratio is applied based on experiences of similar projects.

TABLE 6-3. OPERATION AND MAINTENANCE COST – 4 WELL SYSTEM

ITEM NO.	ITEM DESCRIPTION	QUANTITY	ANNUAL COST PER-UNIT	EXTENDED
1	**Solids Disposal**			
	Solids Disposal including transportation	1	$ 66,000	$66,000
2	**Energy Cost**			
	Energy Cost for Primary Pumps (based on $0.09/kWh)	4	$ 25,0000	$100,000
	Energy Cost for Secondary Pumps (based on $0.09/kWh)	4	$125,000	$560,000
		TOTAL COST PER YEAR =		**$726,000**
		TOTAL COST PER ACRE FT =		**$25.42***

* Based on 120 days operation per year.

6.6.3 Costs for Exploration and Testing

The cost to conduct and exploration well program is shown in Table 6-4.

TABLE 6-4. EXPLORATION WELL COST

ITEM NO.	ITEM DESCRIPTION	QUANTITY	EXTENDED
1	**Construction**		
	Drilling, Testing, Equipment, Site Restoration	1	$1,900,000
	Contingency	10%	$190,000
2	**Engineering**		
	Test Program Design, FDEP permit for UIC and NPDES	1	$75,000
	Construction Oversight, Data Analysis and Administration	1	$340,000
		TOTAL COST	$2,505,000

SECTION 7
EVALUATIONS FOR COMPARISON OF ALTERNATIVES REGARDING PHOSPHATE REDUCTION

In addition to reducing impacts of high discharges on the estuaries, injection wells offer an opportunity to improve the quality of water in Lake Okeechobee. Deep injection wells located on upstream tributaries that carry high concentrations of phosphorous would reduce the amount of phosphorous flowing into the lake and help meet the target total maximum daily load (TMDL) from those tributaries. Any surface waters injected would no longer flow to Lake Okeechobee or estuary systems. Therefore, the amount of phosphorous removed from the system depends only on the injection rate, the duration of injection, and the water quality from the basin in where the injection wells are sited.

The evaluation the costs and benefits are presented in two ways:

- *Costs and benefits based on reducing phosphate loading (Independent of LOER objectives)* - This evaluation can be done for the purpose of comparing injection wells to other alternatives for removal of phosphate, and also for ranking alternative sites relative to each other. For making the evaluation it is assumed that injection wells would, in some cases, be operated at times when injection would not be occurring to meet estuary discharge objectives. The evaluation of costs and benefits for an injection well system operating in this manner are based on a single well operating at 18 MGD. The duration of pumping for this type of analysis is based on the time period that a discharge of approximately 18 MGD could be occurring in the basin during an average year. For determining the duration of injection, the probability of exceedence of the of any basin discharge rate was computed based on historical data (See Appendix A). The duration of injection is assumed to be the amount of time that approximately 18 MGD of flow is available from the basin. In some of the basins this duration can extend for several months, while in others the full volume of flow is available for only two months or less. Basins having a longer time of operation (higher utilization) would result in lower cost per unit of phosphate removed annually; assuming the same water quality was available in the basins.

- *Cost and benefit based on reducing phosphate loading in association with of LOER objectives* - This type of system would involve wells that inject water for LOER objectives only and the advantage of phosphate reduction is coincidental with injection. In this case for some locations only a portion of the time the injection system would be functioning to benefit the goal of reducing phosphate loading. The cost benefit evaluation for this purpose is intended only for comparing alternative sites operating for LOER objectives, and should not be used to compare injection wells to other alternatives for phosphate reduction. Sites having a benefit for phosphorous reduction can be comparatively ranked on this basis in the site selection matrix for siting wells for LOER purposes. This analysis assumes that wells would operate a maximum of 4 months per year.

The quantity of phosphorous removed per year and the cost per metric ton of phosphorous reduction is shown in Table 7-1. The table is based on basin discharges and basin phosphorus load as presented in the South Florida Environmental Report, 2007 (Chapter 10 Lake Okeechobee Protection Plan – State of the Lake) and is shown in Table 7-2. The tributary basins selected for the analysis are those that contribute higher phosphate loading to Lake Okeechobee. Injection wells could be located on the discharge points from these basins and operated to benefit both the LOER program and also to lower the loading of phosphorous to the lake. Table 7-1 shows range of cost per metric ton of phosphorous removed to be between about \$110,000 and \$1,070,000 (under the phosphate reduction program). The lowest unit cost is achieved in the C-40 basin, which is not only due to the comparatively high concentration of phosphorous in the outflow, but also due to the extended duration of high discharge, thus allowing longer periods of injection at full capacity of the well. The unit cost for the C-41 basin is nearly the same as the C-40 basin for the same reasons. This analysis is particularly useful if only a limited number of injection wells were to be installed, so that the largest benefit could be achieved for all purposes. It should be noted that this analysis is based on trying to capture only the discharge that occurs at a rate of approximately 18 MGD. Locating more injection capacity on these basins can increase the benefit regarding phosphorous removal but it does not necessarily accomplish phosphorous reduction at the most economical rate, because the additional wells may not be able to operate for the optimum duration. It also is important to note that the cost and benefit analysis will not be the same for every year because the analysis is highly dependent on the basin phosphorous concentration, which is variable. The data from water year 2006 shows somewhat higher phosphorous levels than average and this reduces the annual cost per unit removed.

For benefits other than the LOER program, the primary advantage to locating multiple wells in an upstream basin is that the higher flows, which are of shorter duration, can be captured. In these locations the injection wells should be sited downstream of structures so that they can operate for longer periods of time; capturing the maximum amount of discharge from their designated basin (to reduce the TMDL), and also capturing water from other sources downstream that would ultimately be released from the lake to the estuaries. Using the C-41 canal as an example and while operating only for the purpose of phosphate reduction; if 2 wells were located downstream from structure S-72, one well would remove 14.7 tons of phosphorous from the basin while operating 9 months, the second well would remove 12.7 tons by operating for 8 months. Using the same technique to evaluate 2 wells located on the S-154 basin; one well would remove 3.8 tons, while operating 3.7 months and the second well would remove 2.6 tons while operating 2.6 months. In the case of the S-154 basin, the wells could operate for greater periods of time and thus remove a greater amount of phosphorous, but a portion of that phosphorous would have been from Lake Okeechobee rather than from the upstream basin. All of the wells installed would accomplish the same amount of benefit to the LOER program, but individually they would contribute different benefits toward meeting the TMDL for phosphorous from their individual basin.

Table 7-1 Cost Estimates for Phosphorus Load Reductions to Lake Okeechobee Based on a Single 16 MGD Injection Well System (Based on WY 2006)

Basin	Average total P Conc. (ppb)	Monthly Reduction of P by Injection Per Well @ 18 MGD (Mtons/month)	Estimated Period of Operation in LOER Program (Months)	Estimated Period of Operation Based on Phosphorous Reduction (Months)	LOER Program P Reduction for Wet Period of 4 months (Mtons)	P Reduction Program Loading Reduction Based on Duration Flow is Availabile (Mtons)	LOER Program Annual Cost per Mton of Phorphorous Reduced ($Million)	P Reduction Program Annual Cost per Mton of Phorphorous Reduced ($Million)
C-40 Basin (S-72)	1062	2.19	4.0	6.6	8.77	14.44	0.15	0.10
C-41 Basin (S-71)	864	1.78	4.0	9.3	7.13	16.51	0.19	0.10
Fisheating Creek	180	0.37	4.0	7.6	1.49	2.81	0.91	0.51
Taylor Creek/Nubbin Slough (S-191)	618	1.28	4.0	7.9	5.10	10.06	0.27	0.16
L-48 Basin (S-127)	192	0.40	4.0	3.8	1.59	1.51	0.56	0.56
C-44 (S-308)	293	0.60	4.0	4.0	2.42	2.42	0.86	1.01
S-133 Basin	313	0.65	4.0	5.4	2.58	3.49	0.53	0.43
S-135 Basin	167	0.34	4.0	5.0	1.38	1.72	0.99	0.87
S-154 Basin	595	1.23	4.0	3.7	4.91	4.48	0.28	0.32

Table 7-2. Surface water inflows and total TP concentrations and loading rates for the major tributary basins in the Lake Okeechobee watershed (WY2006).

Source	Discharge (ac-ft)	Discharge (ha-m)	Area (square miles)	Average TP Concentration (ppb)	TP Load (mt)
715 Farms (Culv 12A)	56	7	4	88	0.0
C-40 Basin (S-72) – S68	11,613	1,433	87	1,062	15.2
C-41 Basin (S-71) – S68	69,363	8,556	176	864	73.9
S-84 Basin (C-41A) – S68	85,267	10,518	180	316	33.2
S-308C (St. Lucie – C-44)	14,493	1,788	190	293	5.2
East Beach DD (Culv 10)	230	28	10	114	0.0
East Shore DD (Culv 12)	3,486	430	13	155	0.7
Fisheating Creek	305,442	37,677	462	180	67.9
Industrial Canal	17,126	2,113	23	152	3.2
L-48 Basin (S-127 total)	29,984	3,699	32	192	7.1
L-49 Basin (S-129 total)	23,960	2,956	19	72	2.1
L-59E	39,058	4,818	15	245	11.8
L-59W	39,535	4,877	15	314	15.3
L-60E	25,029	3,087	6	211	6.5
L-60W	5,486	677	6	135	0.9
L-61E	7,011	865	22	0	0.0
L-61W	10,669	1,316	22	0	0.0
Taylor Creek/Nubbin Slough (S-191)	187,793	23,165	188	618	143.2
S-131 Basin	25,556	3,152	11	138	4.3
S-133 Basin	46,253	5,705	40	313	17.8
S-135 Basin (S-135 total)	42,392	5,229	28	167	8.7
S-154 Basin	49,214	6,071	37	595	36.1
S-2	10,335	1,275	166	181	2.3
S-3	1,988	245	101	231	0.6
S-4	22,238	2,743	66	218	6.0
S65 A through E Basins	637,563	78,645	749	32	25.1
South FL Conservancy DD (S-236)	13,106	1,617	15	126	2.0
South Shore/South Bay DD (Culv 4A)	413	51	7	Not available	0.0
Nicodemus Slough (Culv 5)	3,344	412	28	Not available	0.0
Rainfall					35.0
Upper Kissimmee basins at S-65	1,474,473	181,880		117	211.9
Lake Istokpoga (S-68)	527,974	65,127		87	56.7
S-5A Basin (S-352 WPB Canal)	0	0		0	0.0
East Caloosahatchee (S-77)	0	0		0	0.0
L-8 Basin (Culv 10A)	12,093	1,492		154	2.3
Totals	3,742,543	461,652		172	795.4

SECTION 8
PROJECT IMPLEMENTATION PLAN

8.1 Project Implementation Sequence

If the District elects to move forward with implementation of a deep injection well program to help control estuary discharges and assist in reducing phosphorus loads to Lake Okeechobee, it is recommended that work begin with an exploration well at each recommended injection well system location. If an initial exploration well does not reveal the appropriate high permeability interval at the target depth, it may be desirable to drill a second exploration well nearby. A possibility exists that a test well may miss the highly productive solution channels that are present in the target interval. Such a site might be unnecessarily bypassed due to the test well results presenting non-representative conditions. The decision to undertake a second exploration well at a site should be made on a case by case basis using the data acquired from the test program and existing conditions data from other nearby projects.

The project implementation plan is based on the construction of an initial deep injection well system consisting of 20 wells of 24 inch diameter. A system of 20 injection wells could provide a significant benefit to the estuaries; however, a larger system would provide greater benefit. The final injection system may ultimately range size between 20 and 100 wells and should be determined by the District Governing Board based on funding and operational performance of the wells. The actual diameter of wells is expected to range between 24 and 34 inches as determined by site specific testing, with the larger wells constructed in the later part of the program. For initial cost estimates and conservative planning purposes a 24 inch diameter well design is used for the first several wells. If larger diameter wells can be used earlier in the implementation program then greater benefits can be accomplished on a per well basis because the flow capacity would increase. The wells are proposed to be located at the six sites identified in Section 5 of this report, and therefore six exploration wells are proposed. The schedule for the six exploration wells is planned to be staged into two groups of three wells each and if there is sufficient availability of drilling contractors, multiple wells could be drilled simultaneously. Also, both stages of the exploration program could be conducted concurrently if funding is available. Permitting and construction of one pilot injection system at each of the sites would follow immediately after an exploration well confirms that conditions are appropriate.

Each pilot injection well system would be operated for a period of one year. During the period of operation, a site specific study would be undertaken to optimize the number of injection wells for that location relative to the information that is available regarding well performance, data from other injection wells, new hydrologic conditions data, and information from other related projects that have been in operation. After review of the pilot wells' performance, efficiency and costing data, a plan for full scale implementation would be generated.

The recommended implementation plan components are as follows:

Identification of Lands, Easements and Acquisition

For any locations where land is needed to implement the program, the District should proceed to acquire the necessary property or easements for implementation. Since an exploration well is needed at all sites, the exploration program should begin at those sites where sufficient property is known to be available.

Exploration Program

Drill six exploration wells to a depth between about 3200 and 4000 feet. The depth would be based on the conditions encountered. Well depths could be less than this range if appropriate conditions are encountered at shallower depths. The drilling should be conducted first and the sites ranked highest, as described in Section 5.

An FDEP permit will be required for drilling each exploration well. The design and permitting process for an exploration well is expected to take six to eight months. Permitting for all six sites may be undertaken simultaneously; however, due to the need for site specific research at each site, the permitting program is divided into two groups of three exploration wells each. This approach will speed up the process of preparing the permit applications. Construction and testing time is estimated at 5 to 6 months per well. The individual sites for the exploration wells are prioritized based on Section 5 of this report. The exploration drilling should proceed at sites in the following order:

1. C-40 below S-72
2. C-43 at Berry Groves Reservoir
3. C-41 below S-71
4. Taylor Creek/Nubbin Slough (S-191)
5. C-44 St Lucie Canal
6. S-154 Basin

As each exploration well is completed a reassessment should be done that addresses how the site would function relative to its potential use as presented in this report. Sites indicating positive potential should move immediately into the design and permitting phase. The exploration drilling program would meanwhile continue until all sites have been investigated.

Design and Permitting

Based on conditions encountered, proceed with permitting and design of the recommended number of injection wells for full implementation at each site where favorable conditions have been encountered. Design and permitting should address all wells anticipated for each site. However, construction should be staged; allowing for drilling and testing one injection well of 24-inch diameter for the first well. The permitting should use a 34-inch design for the remaining wells at the site; however, the size of the follow-up wells would be based on the operational testing conducted on the first well, and FDEP approval of the larger wells. Permitting a 34-inch diameter well would allow for changing to a smaller size, if necessary, without the need to undertake a full UIC permit modification. The permitting process will specify the monitoring system and the implementation program. Based on the conceptual design, a modular approach should be used for the surface facilities, which would be appropriate for the staged construction program.

Construction and Testing

Construct a deep injection well of 24-inch diameter at each site and install all facilities for pumping and treatment and the required monitoring wells for the first well. It is estimated that the construction period for an injection well system will be approximately 210 days.

Operational Testing & Full Scale Implementation Plan

The injection well system at each site would be operated for one year to observe how the system performs. Once the pilot injection well at a location has been individually tested and evaluated for its injection capacity and other conditions, then a more detailed analysis should be performed to optimize the ideal number of wells for use in that basin to address all the potential benefits and costs. Issues to be considered in the final analysis include injection well size and optimum capacity for the location.

Expansion to the Full Size System

After completing the optimization study at each location, and formulating the full-scale implementation plan, construction of the remaining injection wells and facilities should proceed. Based on the assumption of a twenty five well system, three to four additional wells would be needed at each site. The time required to complete the project would depend on budget and availability of drilling equipment. Considering that there is currently only one company operating in Florida that is experienced in drilling these types of wells, the speed of implementation could be limited. Experienced drilling companies outside of Florida should be encouraged to participate in the work. It is anticipated that the construction and start-up of a 26 well system would take in excess of 5 years.

8.2 Implementation Schedule

The implementation schedule is shown in Figure 8-1. Based on the estimated time for permitting and exploration, the first injection wells could begin operation in about the last quarter of 2009. The expansion to a 20 injection well system could begin in about the second quarter of 2011. The schedule assumes that the wells would range in diameter between 24 and 34 inches.

8.3 Estimated Cost of the LOER Injection Well Program

Based on the cost estimates provided in Section 6, the total cost for implementing an injection well system consisting of 20 deep injection wells including monitor wells and other facilities is $286,000,000. The cost breakdown is shown in Table 8-1. The cost would be lower if larger diameter wells are used.

TABLE 8-1. ESTIMATED LOER INJECTION WELL PROGRAM COST*

ITEM NO.	ITEM DESCRIPTION	QUANTITY	COST PER WELL $ Million	EXTENDED $ Million
1	Injection Wells, Pumping and Treatment Systems	20	$ 13.5	$270
2	Exploration Wells and Testing	6	$ 2.5	$15
3	Optimization Studies	6	$ 0.2	$1.2
		TOTAL COST		**$286**

* Costs are estimated in 2007 dollars

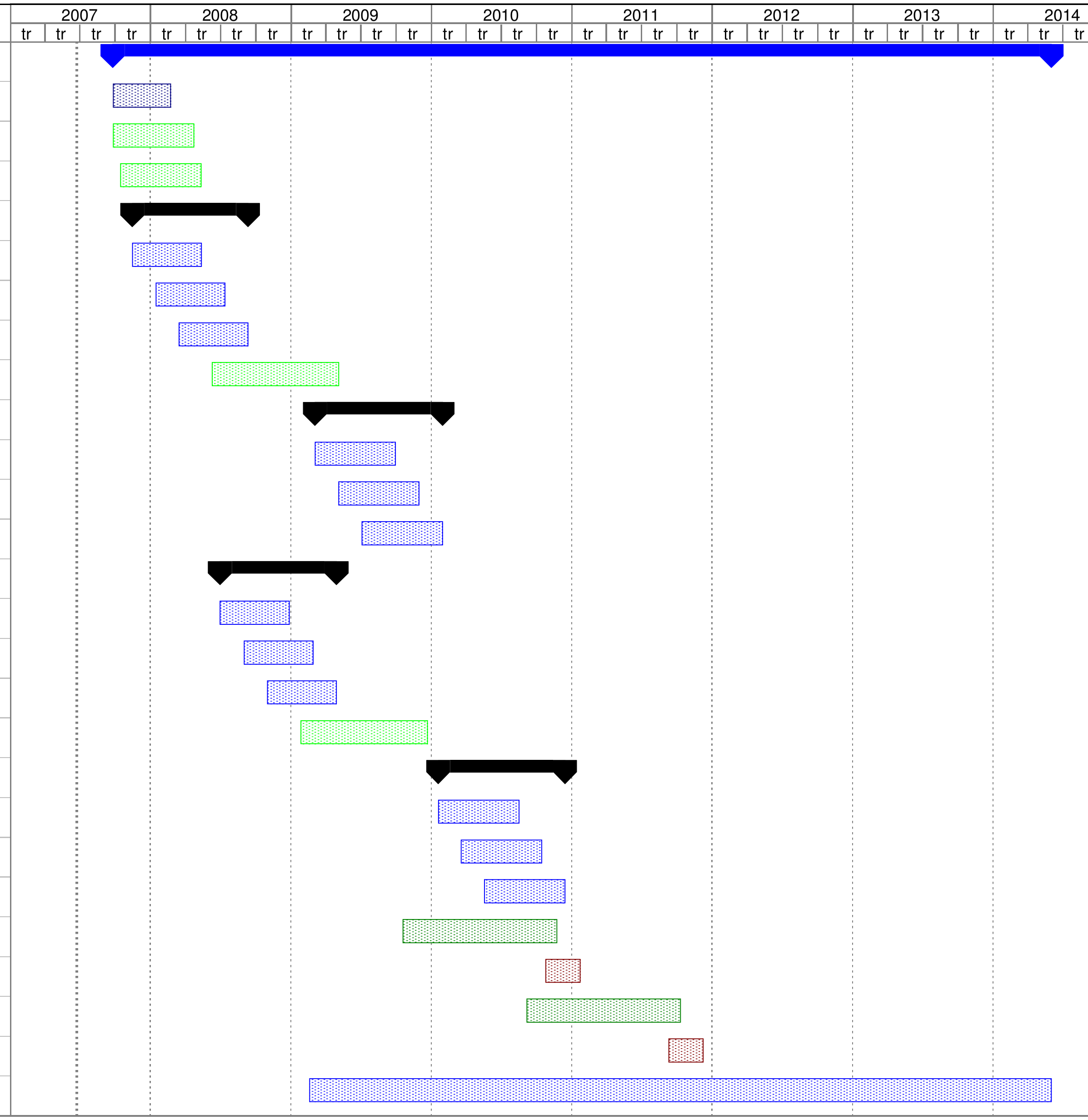
The costs presented for a 20 well system increase proportionally for an expanded system, with the exception that exploration and testing would likely not be included in the expansion. Figure 8-2 shows the costs for expanding the system up to 100 injection wells based on 24-inch diameter wells. The construction cost for injection wells has increased within the past 10 years at a rate that has exceeded the rate of inflation. The graph shown also shows costs for the expanded system based on a 9 percent annual inflation rate and is shown in dollars of the year the project is initiated.

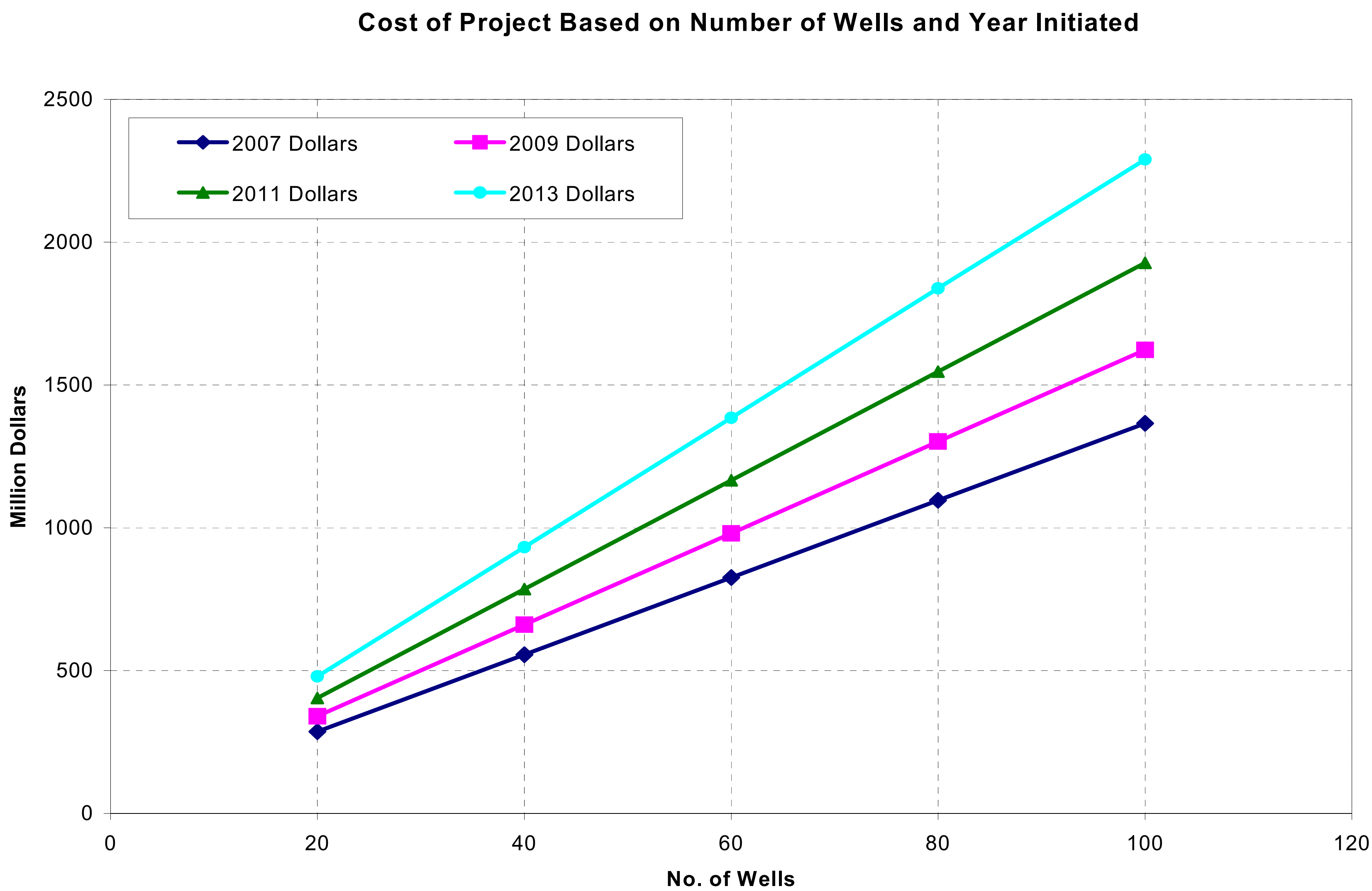
If wells can be constructed of a diameter larger than 24 inches, then it a lower project cost can be expected because less wells would be needed to dispose of the same volume of water. The costs for treatment and pumping elements would remain the same.

FIGURE 8-1 LOER INJECTION WELL PROGRAM IMPLEMENTATION SCHEDULE (20 WELLS)

Water Resource Solutions
A Division of ENTRIX

ID	Task Name
1	**LOER INJECTION WELL PROGRAM IMPLEMENTATION**
2	Identify and Acquire Property and Easements
3	Exploratory Well Permitting - Wells 1-3
4	Exploratory Well Permitting - Wells 4-6
5	**Exploratory Wells 1-3 Construction**
6	Exploratory Well 1 Construction and Reporting
7	Exploratory Well 2 Construction and Reporting
8	Exploratory Well 3 Construction and Reporting
9	Design and Permit Pilot Injection Systems #1-3
10	**Pilot Injection System #s 1-3 Construction**
11	Injection Well 1 Construction and Reporting
12	Injection Well 2 Construction and Reporting
13	Injection Well 3 Construction and Reporting
14	**Exploratory Wells 4-6 Construction**
15	Exploratory Well 4 Construction and Reporting
16	Exploratory Well 5 Construction and Reporting
17	Exploratory Well 6 Construction and Reporting
18	Design and Permit Pilot Injection Systems #4-6
19	**Pilot Injection System #s 4-6 Construction**
20	Injection Well 4 Construction and Reporting
21	Injection Well 5 Construction and Reporting
22	Injection Well 6 Construction and Reporting
23	Operational Testing Injection Systems 1-3
24	Evaluations and Optimization of Systems 1-3
25	Operational Testing Injection Systems 4-6
26	Evaluations and Optimization of Systems 4-6
27	**Expansion of Injection Well System to 20 Wells**





Water Resource Solutions

Project : Elementary School L
Project Number: 1144106 Date: 6/22/07

FIGURE 8-2. COST OF PROJECT BASED ON NUMBER OF WELLS AND THE YEAR INITIATED.

8.4 Exploration Well Program

The following discussion describes the work scope for the design, permitting, contractor selection, construction oversight, administration of construction oversight, and preparation and submission of a final completion report for the construction and testing of a Class I exploratory well in accordance with the Florida Department of Environmental Protection, Underground Injection Control (UIC) program. The exploratory well will be utilized to identify target injection intervals for a system of Class V injection wells that will be use to control excess discharges from Lake Okeechobee as part of the LOER Program.

The exploration well program for any site is divided into four tasks.

Task 1 Test Program Design and Permit Application Submission For the Construction of a Class V UIC Exploratory Well.

Subtask 1.1 - Well Design and Well Testing Program Design

The work to be accomplished under this subtask includes well design and the development of a well testing program. The well design will outline casing sizes, materials of construction, and casing setting points based on known geology, and final casing sizes for the injection well.

The well testing program will be designed to gather the critical information required for assessing the hydrogeology of the overlying zones and completing an injection well within the Oldsmar formation. The testing will focus on obtaining water quality data with depth, and formation information with depth, including the identification and evaluation of confinement, formation transmissivity within flow units, formation porosity, and lithology. These data will need to be correlated with known reference information obtained from the literature. The well design program will outline casing sizes, material of construction, and casing set depths based on known geology and final casing sizes for the injection well.

Subtask 1.2 - Area of Review

An area of review (AOR), as required by the FDEP, is designed to identify any wells and potential conduits through which injected water might flow from the injection zone upwards into an underground source of drinking water. The area of review also requires that all wells, faults, and significant surface features be identified using currently available records possessed by the FDEP, South Florida Water Management District, the United States Geological Survey, the Florida Geological Survey, and other relevant agencies.

The AOR should address a radius of at least 3 to 8 miles depending on the number of wells that are proposed to be sited at that location. In addition to wells, the area of review will show the relevant surface features of interest within the 3 to 8 mile area of review. A literature investigation should be conducted to identify any faulting that may exist within a 3 to 8 mile radius of the well location. Any identified faults should be presented on the AOR map.

Subtask 1.3 - Geologic and Hydrogeological Investigation

As required by the FDEP (Chapter 62-528 FAC), the investigation must provide a description of all geological units that will be penetrated by the drilling activity. The lateral extent and lithologic composition of these units must be described based on a detailed literature review and review of any other drilling records from the area. All faults and other similar features within the AOR must also be identified. Cross section need to be provided. The information provided in these documents is the information that which must be provided to the public if they register concerns over the proposed activity. This information also provides the basis for the FDEP to approve or deny the permit application for the injection well application.

Subtask 1.4 - Plugging and Abandonment

A well plugging and abandonment program will also be provided as required by the regulations.

Task 2 Develop Final Well Construction and Testing Specifications and Contractor Selection Process

Based on the information developed within the permit application, and FDEP comments, a set of final technical specifications will be developed for inclusion in the contractor bidding and selection process. Well testing and construction details will include methods of construction, casing sizes, cementing requirements, depth for core sample collection, packer test locations, packer test objectives, and pump test design and test objectives. Coordinate and input to the bid process, review bid submittals and make recommendations regarding contractor selection.

Task 3 Well Construction and Testing Oversight

Well construction and testing will likely be conducted on a 24/7 schedule. A team of on-site hydrogeologists shall provide oversight of the construction and testing activities during the construction and testing of the well. The field personnel and senior staff shall review progress, project schedule, well testing procedures, test results, and data collection. Weekly progress reports shall be prepared each week for submission to the FDEP. These reports shall also be distributed to the District project team.

Task 4 UIC Well Completions Report

All data and records shall be documented in a Completion Report which shall provide a detailed description of the work that was performed and a description and discussion of the final well completion design. All weekly progress reports will be contained within this document. The Completion report shall provide a detailed discussion of the testing that was performed and a discussion of the results of this testing. The data summary shall include all lithologic descriptions, geophysical logging information, core test information, and pump test information. The report shall identify the properties of the target injection zones and explain how these intervals were selected based on confinement, location of the base of the USDW, injection interval transmissivity, injection rate requirements, and formation water quality.

SECTION 9
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Appendix A
Analysis to Determine Injection Well Capacity to Reduce Excess Flows to the Estuaries

1. Caloosahatchee Estuary

From the available data, the excess discharge to the Caloosahatchee Estuary (CE) can be calculated in 2 ways:

1. Excess discharge = Discharge through S-79 – ecological targets, and
2. Excess discharge = Discharge through S-79 – 2800 cfs.

The ecological targets are time varying and constitute "healthy" daily discharge to the estuaries. The ecological target data were provided by Peter Doering of the District. The use of ecological targets to estimate the excess discharge is considered a conservative approach because the actual data indicate that during most of the time period analyzed (1965 to 2000), the ecological targets are less than 2800 cfs. Excess discharge calculated using a constant flow target of 2800 cfs implies that only flows above this rate are detrimental to the estuary health.

Figure A-1 shows the discharges and ecological targets established for the CE from 1965 to 2000. Figure A-2 shows the excess discharge to CE from 1965 to 2000 based on the difference between the discharge through S-79 and the provided ecological targets. Figure A-3 shows the total duration of time when discharge to the CE was greater than the target discharge rates.

Table A-1 summarizes the effects of using injection well systems consisting of 20, 60 and 90 wells in reducing the number of days of excess discharge, based on the two different methods described above.

2. St. Lucie Estuary

Previous studies conducted in the SLE indicate that a favorable range of salinity conditions in the estuary can be accomplished by maintaining a discharge rate that ranges between 350 and 2000 cfs (Neidrauer, 2006). It is anticipated that this range can be accomplished by eliminating flow through S-80, and utilizing only the tributary downstream of S-80 (SLTRIB). However for analysis purposes, the excess discharge is calculated in two different ways as indicated below:

1. Excess discharge = Total discharge through S-80, and
2. Excess discharge = Total discharge through S-80+SLTRIB – 2000 cfs

Figure A-4 shows the discharge rates through S-80 from 1965 to 2000. Also shown in Figure A-4 are the effects of an operating injection well system consisting of 20, 60 and 90 wells in reducing the excess discharge days.

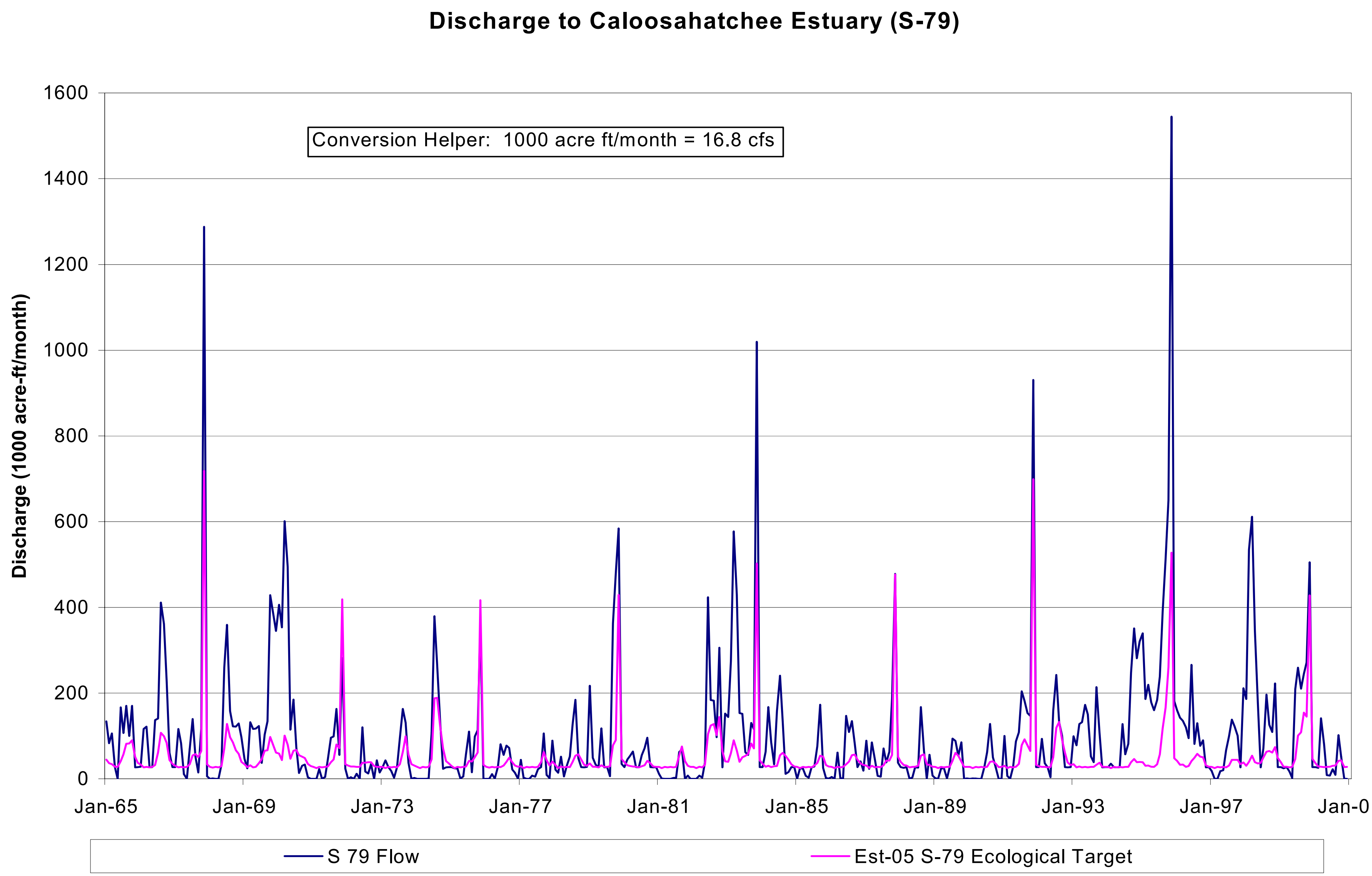

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FIGURE A-1. THE SIMULATED DISCHARGES AND ECOLOGICAL TARGETS FOR THE CALOOSAHATCHEE ESTUARY FROM 1965 TO 2000.

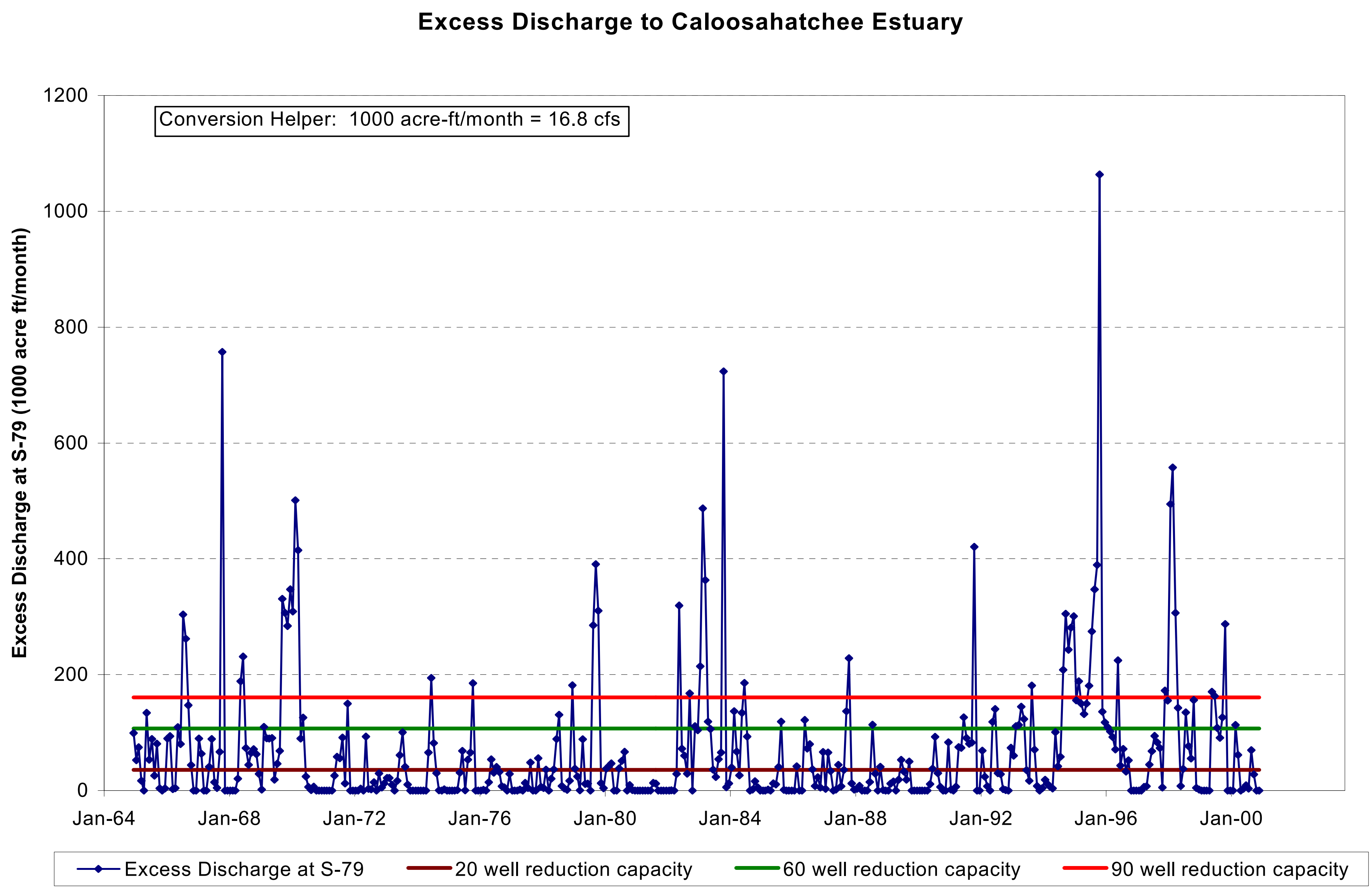

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FIGURE A-2. THE EXCESS DISCHARGE TO THE CALOOSAHATCHEE ESTUARY CALCULATED AS THE DIFFERENCE BETWEEN THE DISCHARGE THROUGH S-79 AND THE ECOLOGICAL TARGETS AND POTENTIAL REDUCTION PROVIDED BY INJECTION WELLS.

Table A-1

Effects of Utilizing Injection Wells to Reduce the Number of Excess Discharge Days

No. fo Months of Excess Discharge							
	O Wells	**20 Wells**	**Percentage Reduction**	**60 Wells**	**Percentage Reduction**	**90 Wells**	**Percentage Reduction**
Caloosahatchee Estuary (Discharge at S-79 - Ecological Targets)	186	161	13%	124	23%	101	37%
Caloosahatchee Estuary (Discharge at S-79 - 2800 cfs)	82	66	20%	39	52%	28	65%
St. Lucie Estuary (S-80+SLTRIB - 2000 cfs)	11	3	77%	1.4	88%	1.2	90%

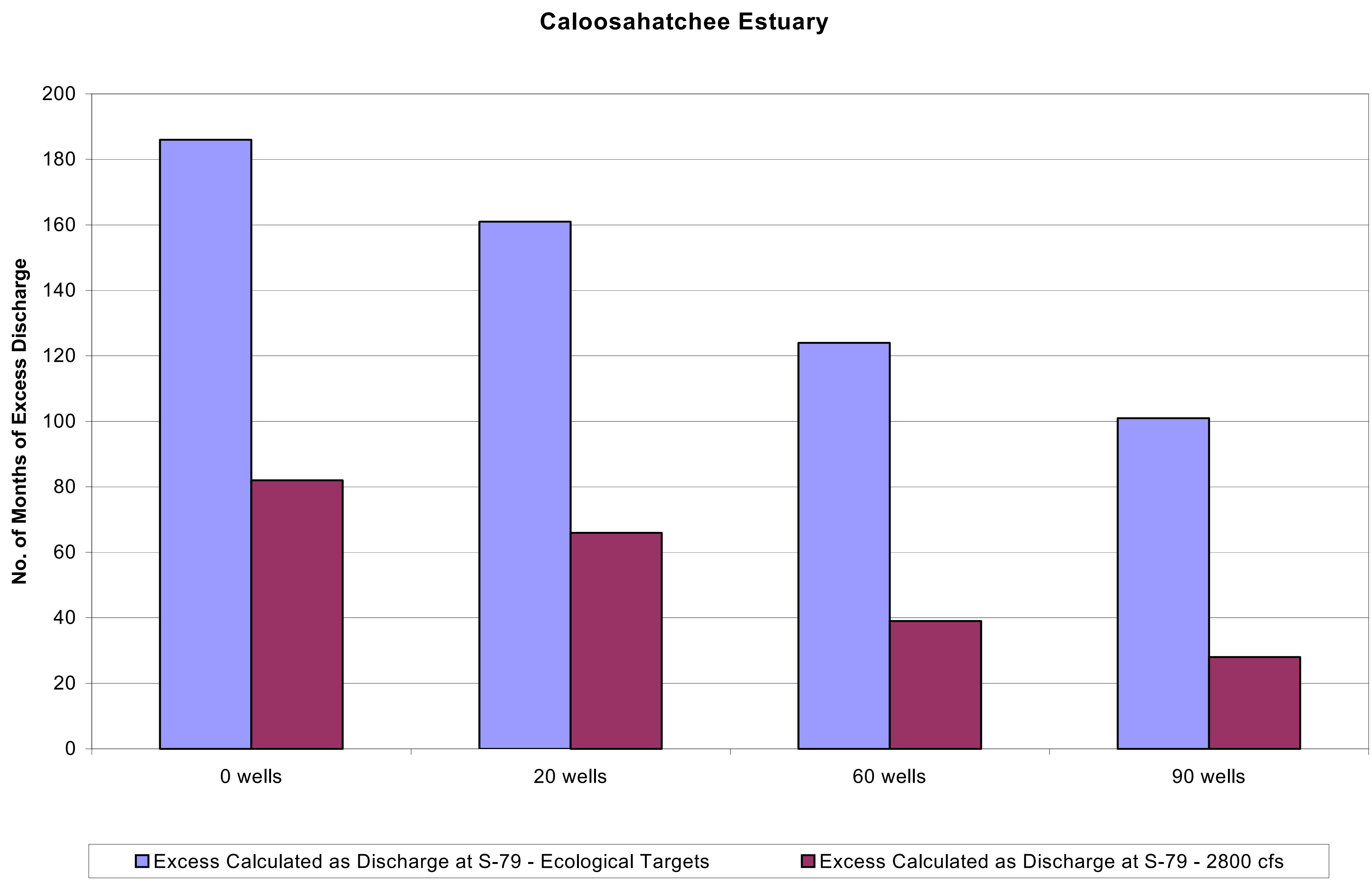

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FIGURE A-3. THE DURATION OF TIME WHEN DISCHARGE THROUGH S-79 WAS ABOVE THE TARGET DISCHARGE TO THE ESTUARY. THE PLOTS ARE BASED ON DAILY DISCHARGE DATA FROM 1965 TO 2000.

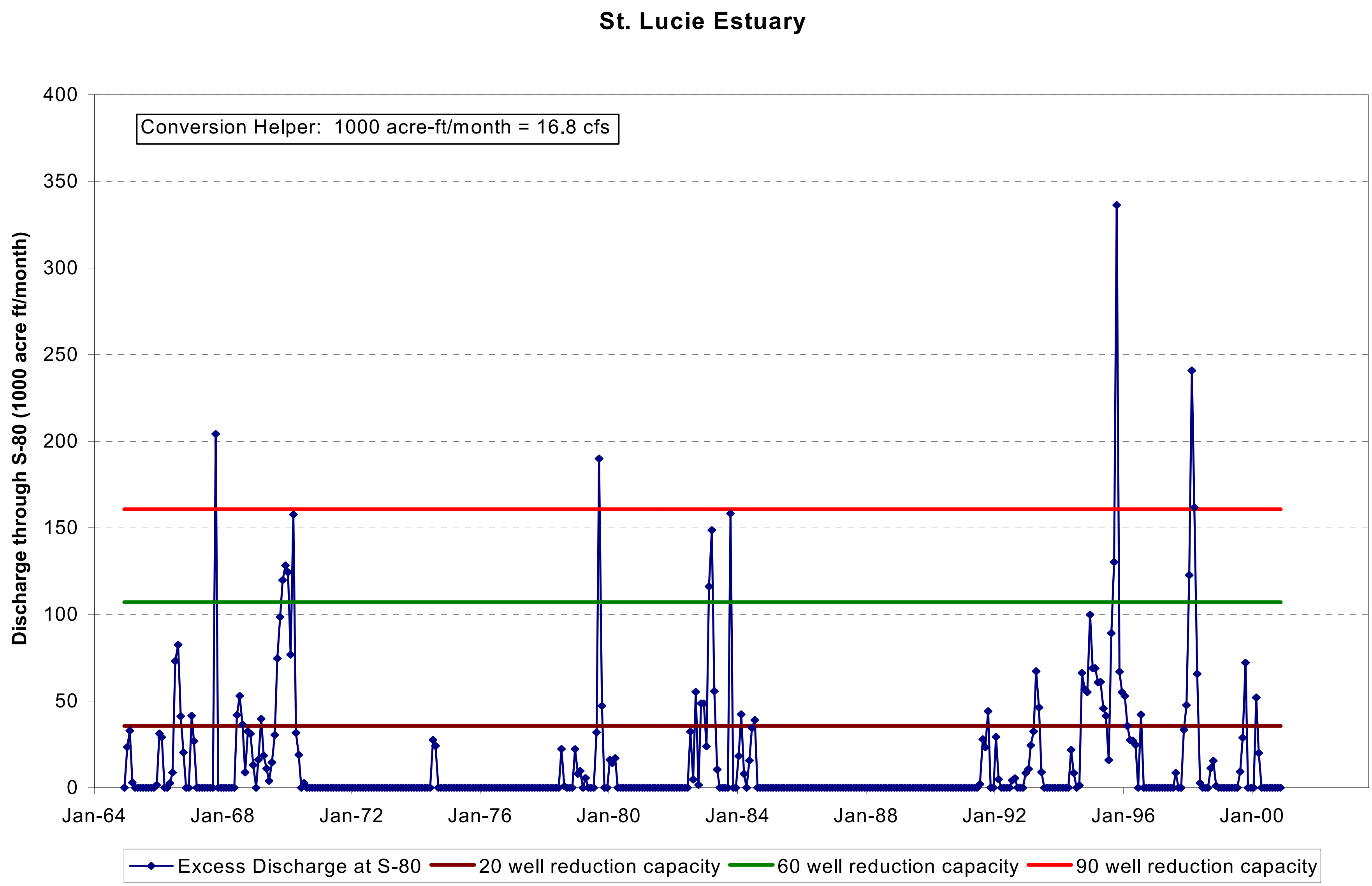

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FIGURE A-4. PLOT SHOWING DISCHARGE THROUGH S-80 AND POTENTIAL REDUCTION BY INJECTION WELLS.

Figure A-5 shows the total time period when discharge from S-80 + SLTRIB (SLE) exceeded 2000 cfs during the period of record (January 1, 1965 to December 31, 2000). Also shown in this figure is the effectiveness of injection well systems to reduce the number of excess flow days.

Table A-1 summarizes the effects of using injection well system consisting of 20, 60, or 90 wells could reduce the number of days of excess discharge.

3.0 Statistical Analysis to Determine Return Periods of Flow Events

3.1. Introduction

In addition to the target disposal volume it is important to consider the statistical frequency or return period of actual discharge events in order to evaluate what might be a reasonable target for capacity of an injection well system. The objectives of the analysis presented in this section are to calculate:

1. Return periods of high discharge events to the Caloosahatchee Estuary (CE)
2. Return periods for the rate of lake level rise during wet season
3. The number of wells needed to handle flow events that may occur during 1-in10, 1-in-5, and average years.

3.2. Ratio of Excess Discharges for the Caloosahatchee and St. Lucie Estuaries

For this analysis, only the return periods of discharge events to the CE are calculated. However, it is noted that the discharges to the CE and SLE generally follow a ratio whereby the excess discharges to St. Lucie estuary are about one-fourth of the discharges to the Caloosahatchee Estuary. Therefore, it seems reasonable to assume that the number of injection wells required to handle excess discharges to St. Lucie Estuary will be about one-fourth the number of wells required for the Caloosahatchee Estuary. The average annual and monthly excess discharges to the CE and SLE are presented in Table A-2.

3.3. Return Periods

3.3.1. Data

The data used to calculate return periods include the annual cumulative discharges to the Caloosahatchee Estuary from 1965 to 2000, which were computed from the daily discharge data to the CE. The daily discharge data were generated by the LORSS SFWMM model. The simulated Lake Okeechobee stages were also used to calculate the return periods of the rate of lake level rise during wet periods.

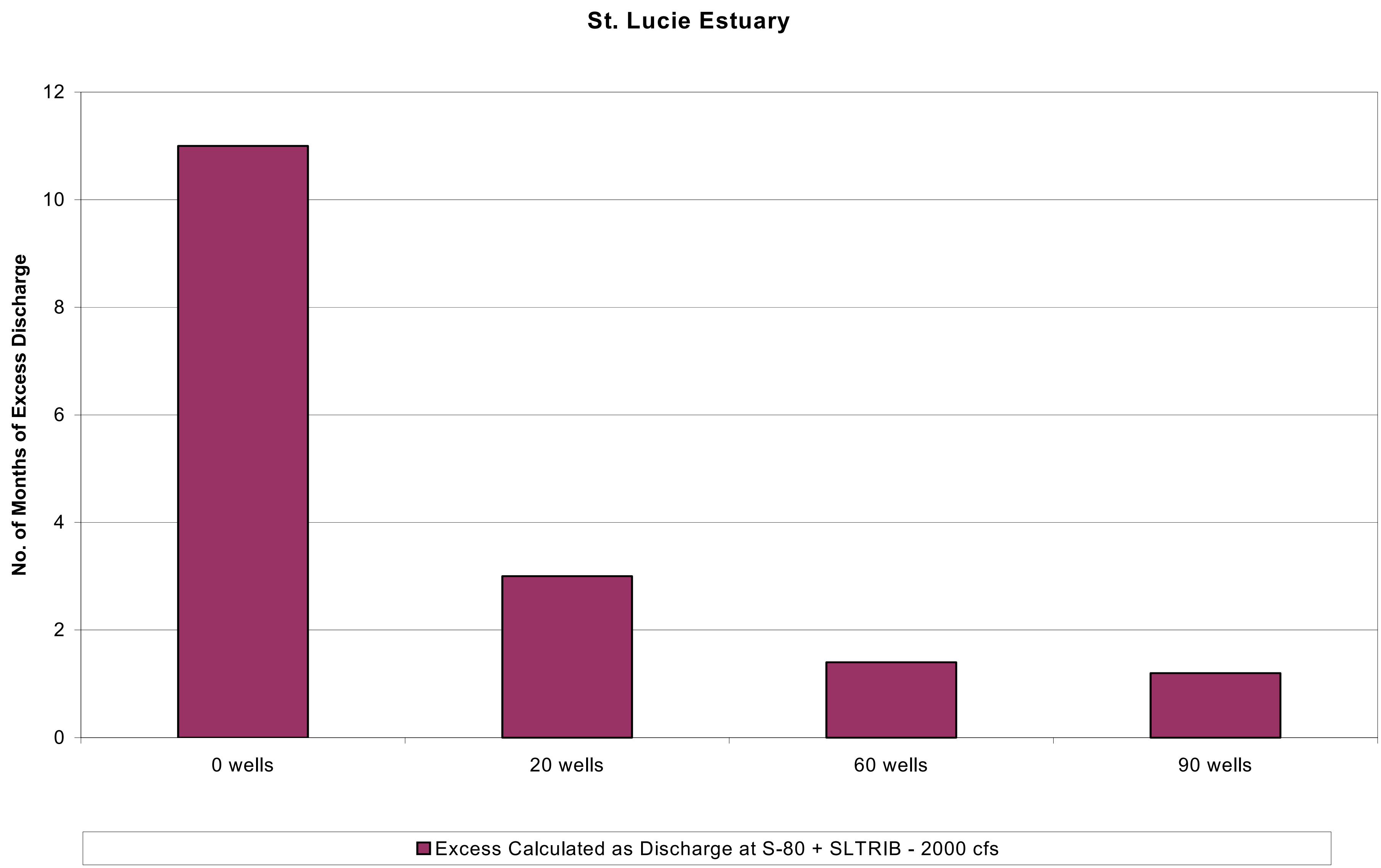

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FIGURE A-5. THE DURATION OF TIME WHEN DISCHARGE THROUGH S-80 + SLTRIB WOULD HAVE BEEN ABOVE THE TARGET DISCHARGE TO THE ESTUARY BASED ON DAILY DISCHARGE DATA FROM 1965 TO 2000.

Table A-2 Comparison of Caloosahatchee and St. Lucie Discharges Based on Discharge Data from 1965 to 2000

	Caloosahatachee Estuary(CE)	**St.Lucie Estuary(SLE)**	**Ratio (SLE : CE)**
Average Annual Flow (1000 acre-ft)	1056	145	1:7
Average Monthly Flow (1000 acre-ft)	102	14	1:7
Max. Annual Discharge (1000 acre-ft)	3551	848	1:4
90 Percentile Monthly Excess Discharge (1000 acre-ft) [A]	173	45	1:4

A: Excess Discharge to CE is calculated as the difference between discharge through S-79 and the ecological targets to the Estuaries from 1965 to 2000
Excess Discharge to SLE is calculated as the total discharge through S-80 from 1965 to 2000

3.3.2. Methodology

The return periods or recurrence intervals were calculated using the Weibull method provided below:

$$RI = (N+1)/M,$$

Where,

RI = Recurrence Interval (return period)
N = Number of years of data
M = Rank of Peak Discharges

If a discharge event (annual discharge in this case) has a recurrence interval of 10, then it is assumed that once in 10 years a discharge equal or higher than that event is likely to occur. It also means that there is a 10 percent chance that a 1-in-10 year discharge can occur in any given year, or a 90 percent chance that a discharge event less than that discharge is likely to occur.

3.3.3. Return Periods of Discharge Events to CE

The annual cumulative discharges to the Caloosahatchee Estuary for every year from 1965 to 2000 is graphically presented in Figure A-6 and tabulated in Table A-3. The recurrence intervals of total annual discharge volumes are also provided in Table A-3.

Figure A-7, which shows the recurrence intervals and discharges in logarithmic scale, suggests that an annual discharge of 2200 kaf or more is likely to occur once in ten years, and an annual discharge of 1600 kaf or more may be expected once in five years. From Table A-3, it is estimated that the average annual discharge is about 1050 kaf.

For this evaluation, it is also important to analyze the highest monthly discharge volume for every year since a high discharge year may have relatively low monthly discharges, if excess water is steadily released throughout the year. The highest monthly discharge for every year from 1965 to 2000 was calculated to account for monthly variations in discharge rate. The data are presented in Figure A-8.

The monthly discharge for the period of record ranged between 0 to 1.5 million acre feet (November, 1995), with a mean of 102 kaf and a standard deviation of 16 kaf.

3.3.4. Return Periods for Rate of Lake Level Rise

The lake-level rise from June 1 through November for every year from 1965 to 2000 was calculated and provided in Table A-4. The recurrence intervals of the lake level rises during wet months were calculated and presented in Figure A-9.

F A-6

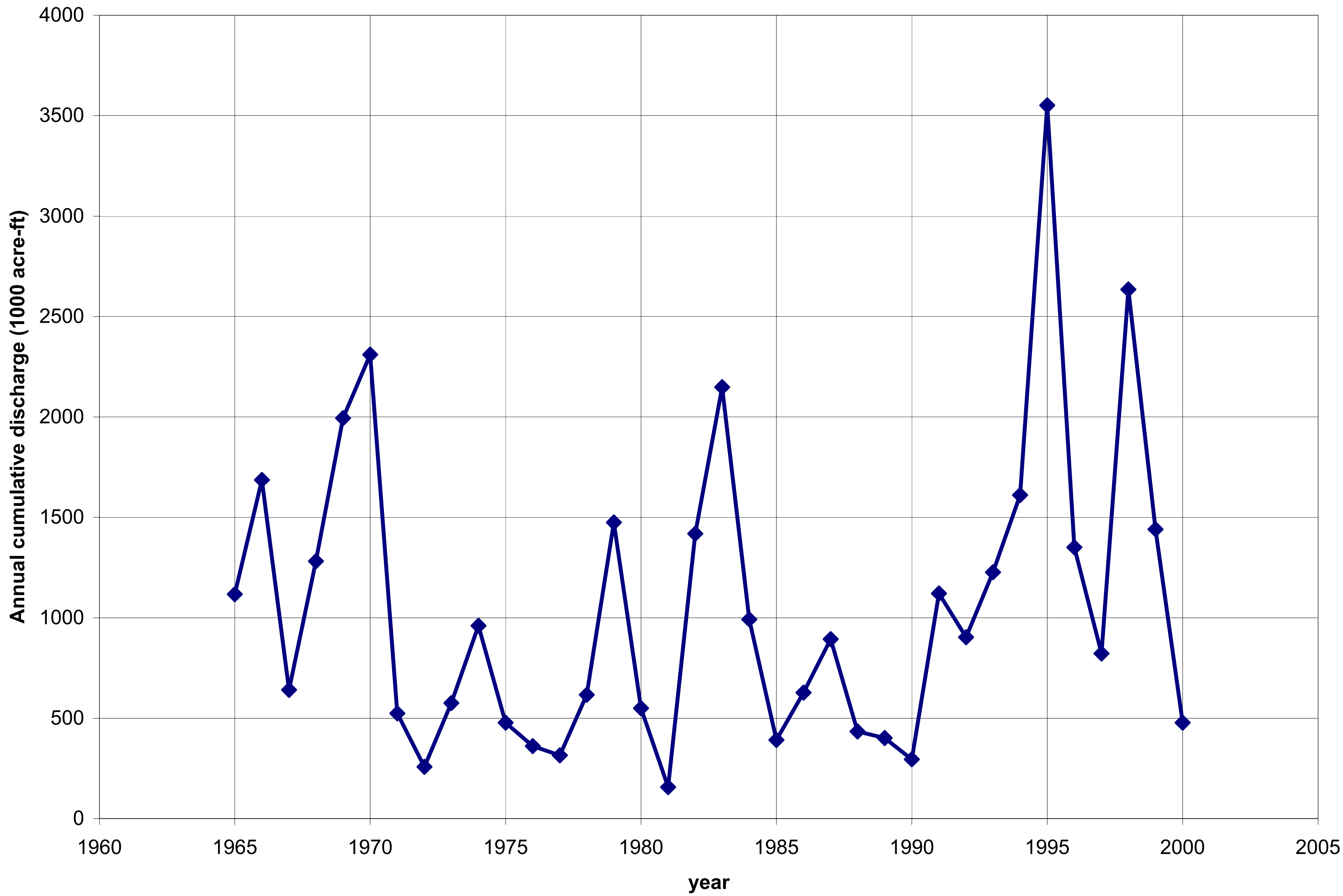

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FIGURE A-6 ANNUAL CUMULATIVE DISCHARGE TO THE CALOOSAHATCHEE ESTUARY (S-79).

Table A-3

Annual Cumulative Discharges and Recurrence Intervals of Discharges Based on Data from 1965 to 2000

Model Year	Annual Discharge Volume (1000 acre-ft)	Rank	Recurrence Interval (years)	No. of times the discharge will likely occur in 100 years (Rank/Total # of Years)*100
1965	1117	15	2.47	42
1966	1686	6	6.17	17
1967	641	21	1.76	58
1968	1282	12	3.08	33
1969	1994	5	7.40	14
1970	2311	3	12.33	9
1971	524	26	1.42	72
1972	258	35	1.06	97
1973	575	24	1.54	67
1974	961	17	2.18	47
1975	478	28	1.32	78
1976	361	32	1.16	89
1977	315	33	1.12	92
1978	616	23	1.61	64
1979	1474	8	4.63	22
1980	549	25	1.48	69
1981	156	36	1.03	100
1982	1419	10	3.70	28
1983	2149	4	9.25	11
1984	992	16	2.31	44
1985	392	31	1.19	86
1986	628	22	1.68	61
1987	893	19	1.95	53
1988	434	29	1.28	81
1989	401	30	1.23	83
1990	295	34	1.09	94
1991	1121	14	2.64	39
1992	903	18	2.06	50
1993	1227	13	2.85	36
1994	1611	7	5.29	19
1995	3551	1	37.00	3
1996	1351	11	3.36	31
1997	822	20	1.85	56
1998	2635	2	18.50	6
1999	1440	9	4.11	25
2000	478	27	1.37	75

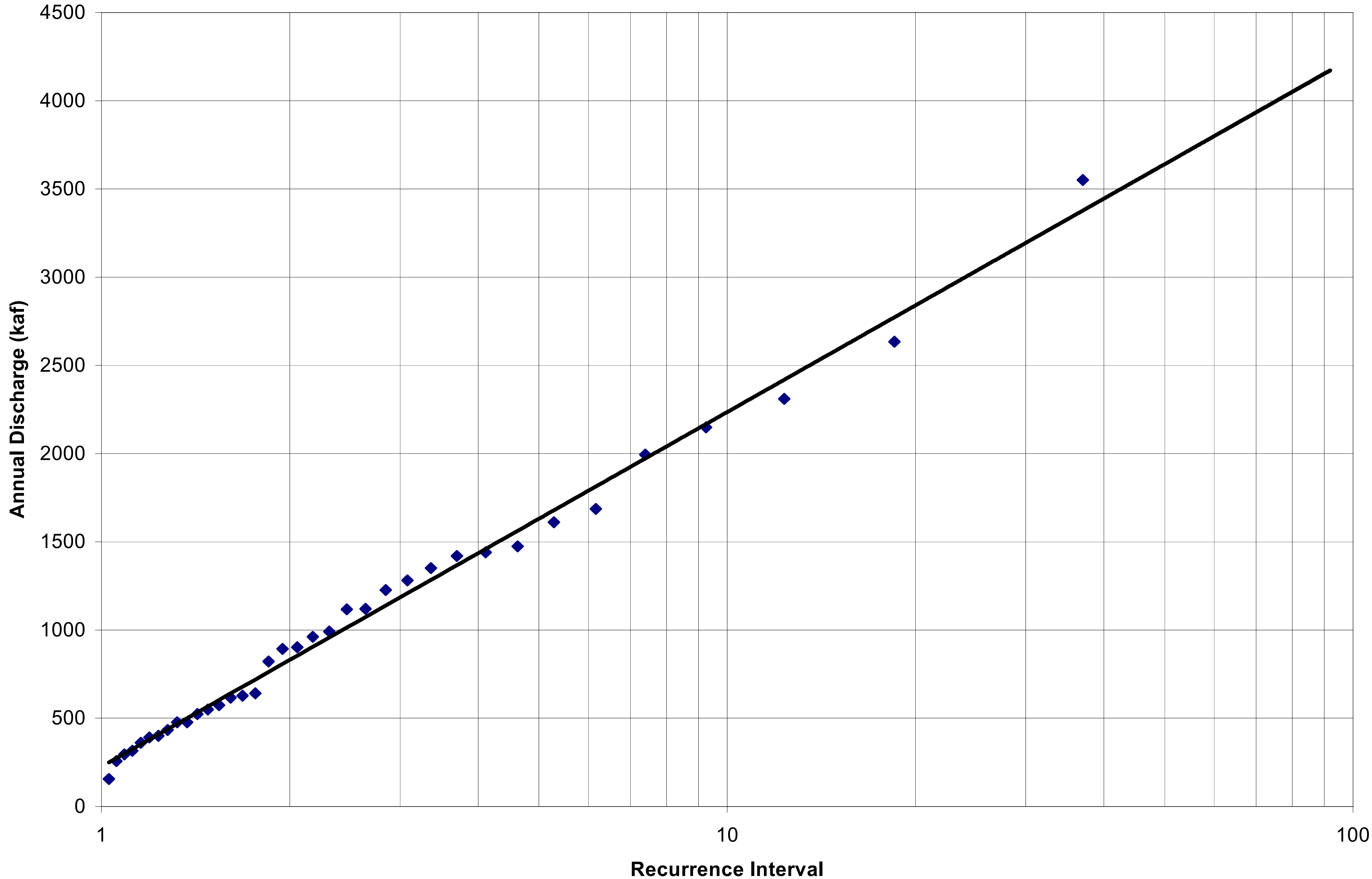

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FIGURE A-7 RECURRENCE INTERVALS OF ANNUAL DISCHARGES THROUGH S-79, ESTIMATED USING WEIBULL METHOD

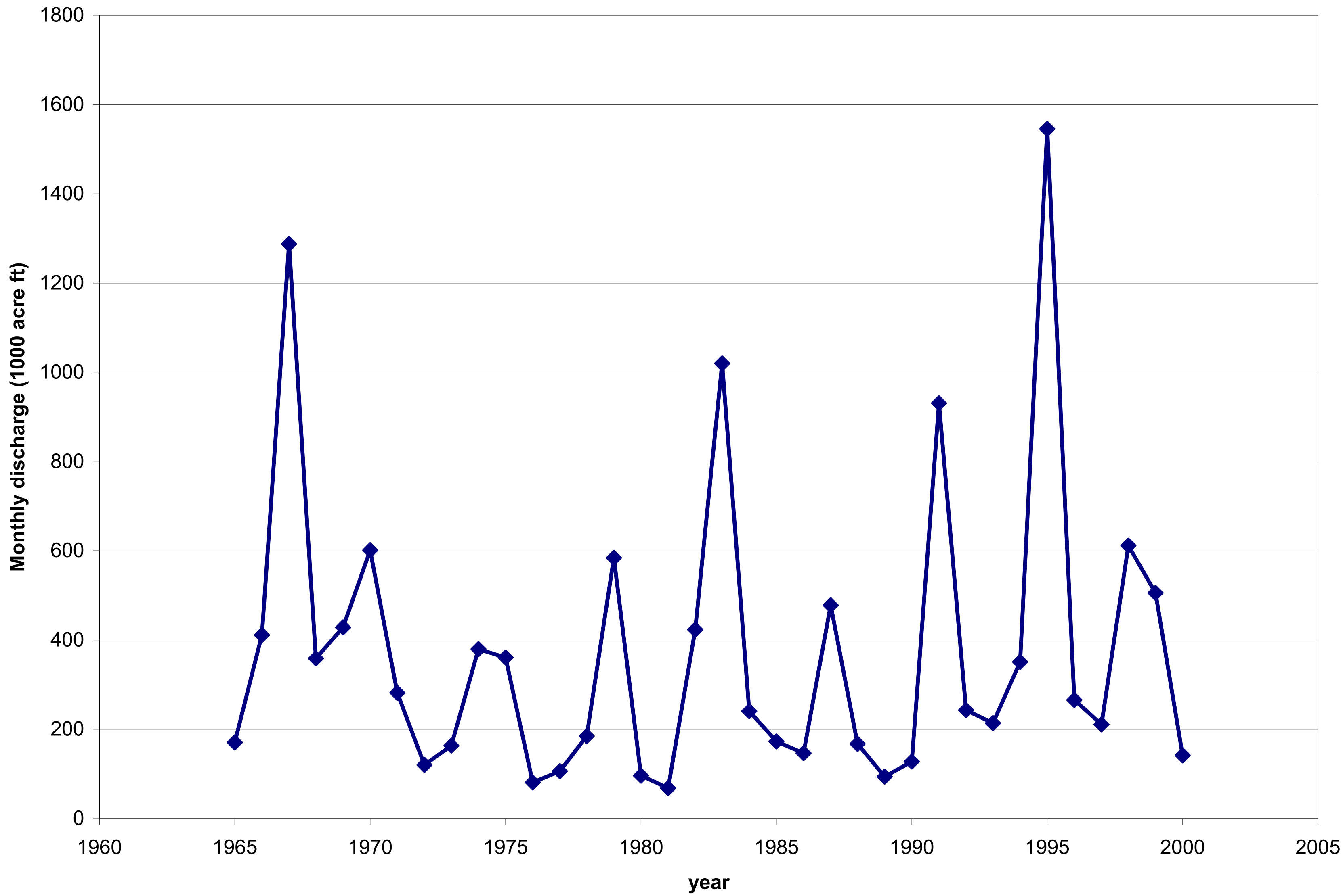

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FIGURE A-8 HIGHEST MONTHLY DISCHARGE THROUGH S-79 FOR EVERY YEAR FROM 1965 TO 2000.

Table A-4

The rise in lake level from June 1st to October 30th for every year from 1965 to 2000

Model Year	Lake Level Reading on June 1st (ft NGVD)	Lake Level Reading on October 30th (ft NGVD)	Rise in Lake Level (ft)
1965	11.28	13.68	2.40
1966	12.80	15.89	3.09
1967	10.66	13.01	2.35
1968	10.17	14.98	4.81
1969	12.99	16.62	3.63
1970	15.06	15.44	0.38
1971	10.60	13.23	2.63
1972	11.68	11.33	0.00
1973	10.07	13.14	3.07
1974	8.82	15.3	6.48
1975	11.42	13.32	1.90
1976	10.60	12.6	2.00
1977	10.30	11.16	0.86
1978	12.20	15.26	3.06
1979	14.97	16.23	1.26
1980	14.83	13.85	0.00
1981	9.62	10.25	0.63
1982	10.37	15.68	5.31
1983	13.88	15.17	1.29
1984	14.77	15.01	0.24
1985	11.14	12.89	1.75
1986	10.73	13.21	2.48
1987	12.03	11.99	0.00
1988	12.80	13.06	0.26
1989	10.15	11.31	1.16
1990	9.02	12.07	3.05
1991	11.87	14.91	3.04
1992	11.86	15.21	3.35
1993	13.94	13.81	0.00
1994	13.16	16.24	3.08
1995	13.75	17.17	3.42
1996	13.36	13.88	0.52
1997	12.02	14.02	2.00
1998	14.08	14.35	0.27
1999	11.89	16.29	4.40
2000	11.73	11.47	0.00

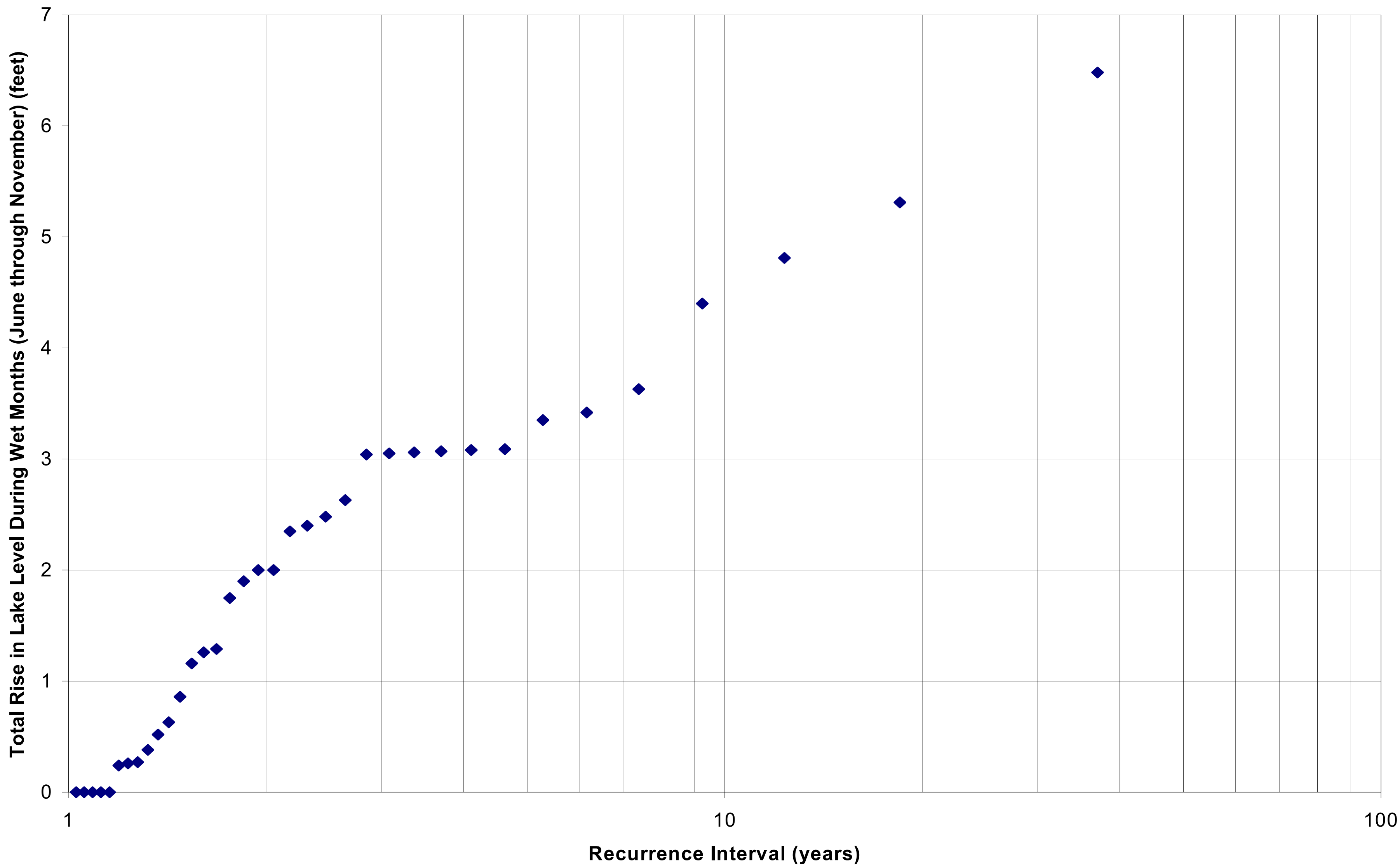

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FIGURE A-9. THE RECURRENCE INTERVAL OF LAKE LEVEL RISES DURING WET MONTHS.

Based on Figure A-9, it is estimated that the lake-level is likely to rise (during the wet season) by about 4.75 feet once in 10 years, about 3 feet once in 5 years and about 2 feet in an average year (1-in-2 years).

3.4. Number of Injection Wells Needed to Accommodate Selected Discharge Events

For the CE, to determine the injection well capacity or how many wells will be required to handle selected discharge events, the following three assumptions are made:

- The injection wells will be turned on only when discharge exceeds 2800 cfs (167 acre- ft/month). Wells will not be used in anticipation of an upcoming need;
- The wells used to discharge excess water are 24 inches in diameter with a capacity of 18 MGD (30 cfs); and
- While the wells are in operation, the discharge to the CE is 2800 cfs (167 acre-ft/month) and to the SLE is 0 cfs.

<u>1-in-10 year Discharge Event:</u> Based on the Weibull analysis, an annual discharge of 2200 kaf or more is likely to occur once in ten years. In order to determine the number of wells needed to handle a 1–in-10 year discharge, model year 1983 was selected. The annual discharge to the CE during 1983 was about 2100 kaf, which is approximately equal to an expected 1-in-10 year discharge.

Figure A-10 shows the discharges to CE that occurred in model year 1983. The figure also shows how operating injection well systems consisting of a 20, 60 and 90 wells can reduce the discharge to the estuary.

Based on the results presented in Figure A-10 the following conclusions are derived for model year 1983:

1. The excess volume discharged to the CE in 1983 is about 780 kaf.
2. The excess volume discharged to the CE can be reduced by 14% if 20 wells are operated only during times when excess discharge occur.
3. The excess volume discharged to the CE can be reduced by 41% if 60 wells are operated only during times when excess discharge occur.
4. The excess volume discharged to the CE can be reduced by 61% if 90 wells are operated only during times when excess discharge occur.

<u>1-in-5 year Discharge Event:</u> An annual discharge of 1600 kaf or more is likely to occur once in five years. To estimate the number of wells needed to handle a 1– in- 5 year discharge, model year 1994 was selected. The annual discharge to the CE during 1994 was about 1600 kaf.

Figure A-11 shows the discharges to CE that occurred in model year 1994. Also shown in the figure are the effects of operating a 20, 60 and 90 well system in reducing the discharge to the estuary.

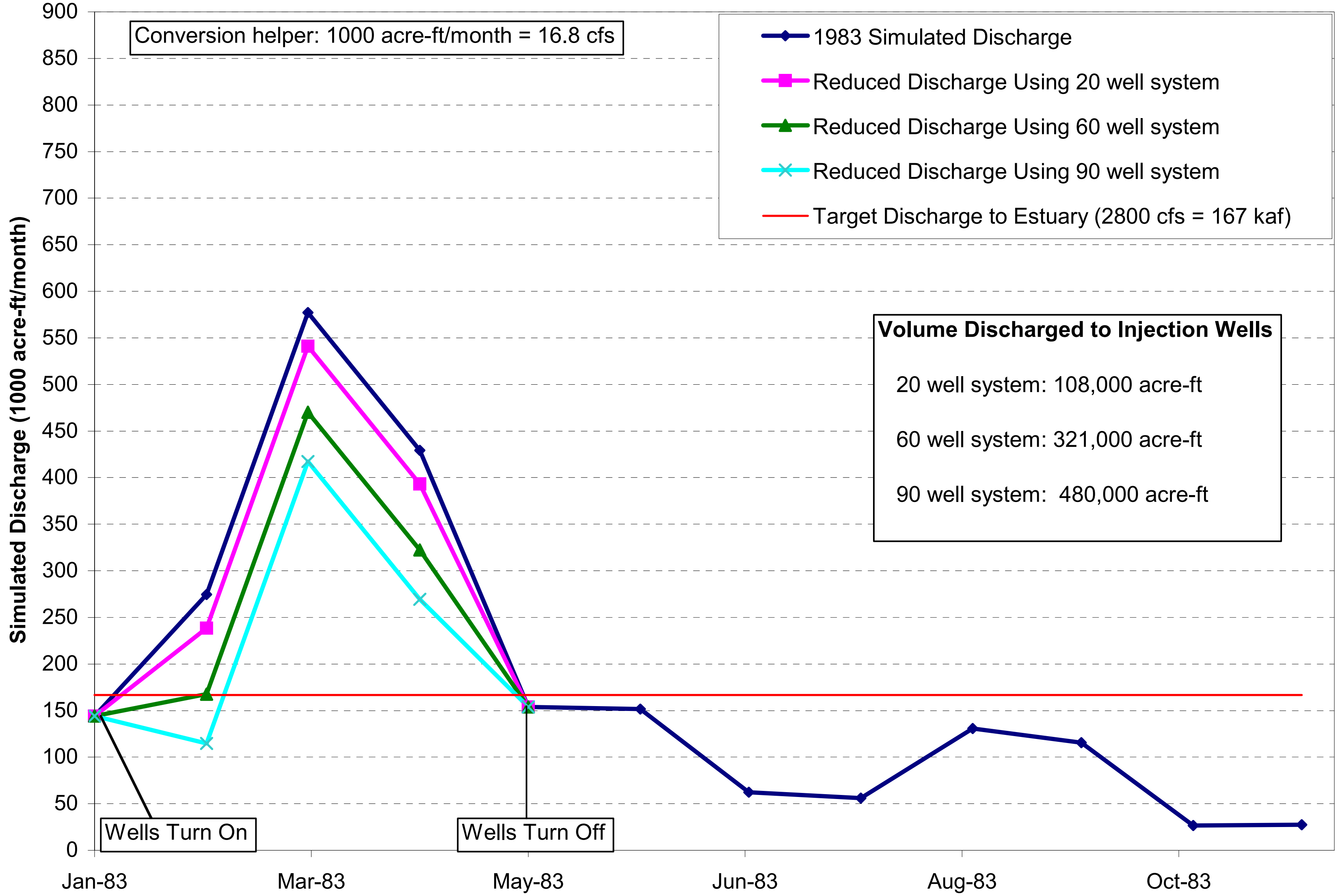

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FIGURE A-10. PLOT SHOWING REDUCTION IN DISCHARGE BY OPERATING A 20, 60 AND 90 WELL SYSTEM FOR A 1-IN-10 DISCHARGE YEAR BASED ON INSTANTANEOUS OPERATIONAL PLAN.

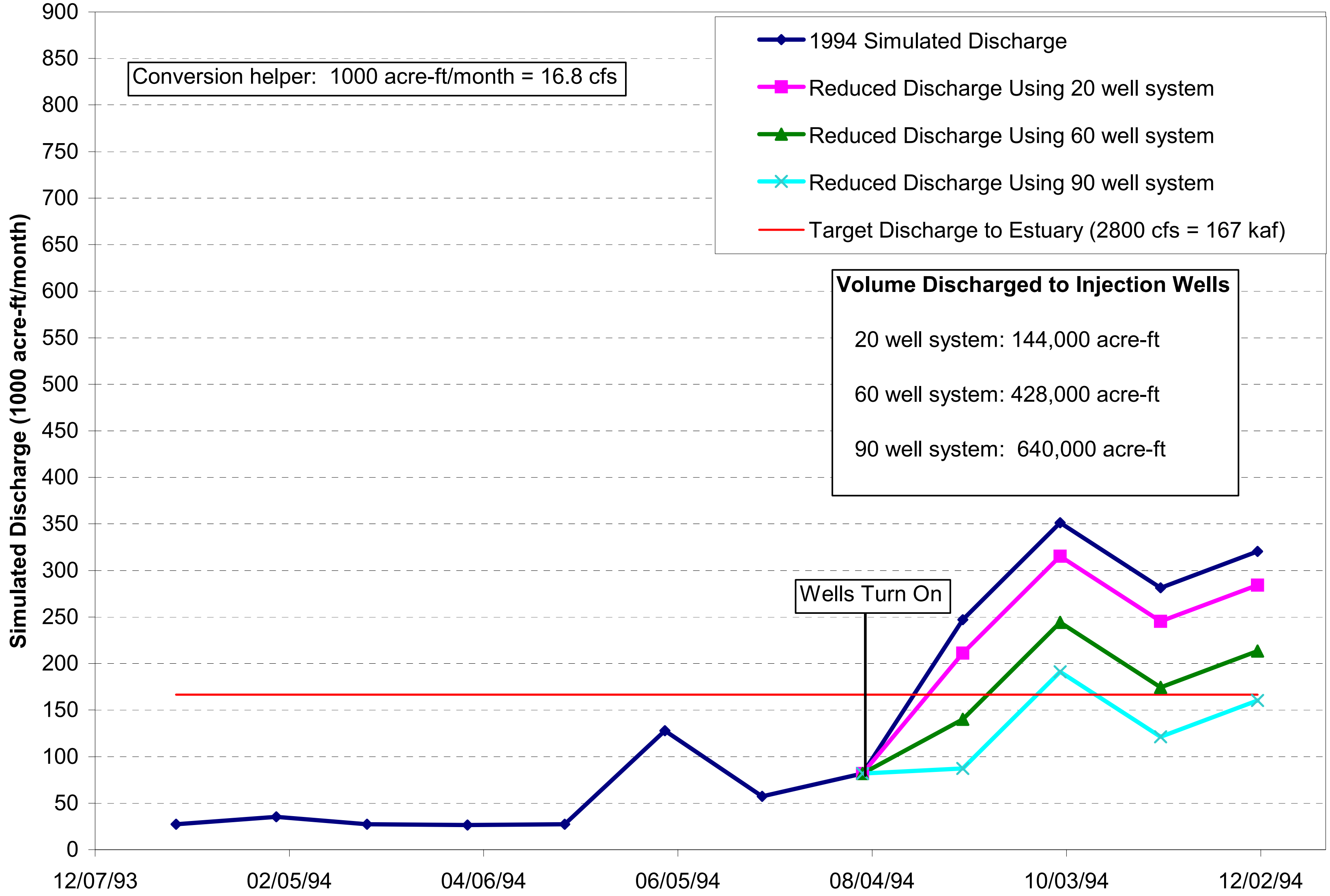

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FIGURE A-11. PLOT SHOWING REDUCTION IN DISCHARGE BY OPERATING A 20,60 AND 90 WELL SYSTEM FOR A 1-IN-5 DISCHARGE YEAR.

Based on the data/results presented in Figure A-11 the following conclusions are derived for model year 1983 (1-in-10 discharge year):

1 The excess volume discharged to the CE in 1994 is about 534 kaf.
2 The excess volume discharged to the CE can be reduced by 27% if 20 wells are operated only during times when excess discharge occur.
3 The excess volume discharged to the CE can be reduced by 80% if 60 wells are operated only during times when excess discharge occur.
4 The excess volume discharged to the CE can be reduced by 94% if 90 wells are operated only during times when excess discharge occur.

Average Discharge Year: An annual discharge of 1.05 million acre feet or more is likely to occur once in 2 years. To estimate the number of wells needed to handle an average (1– in- 2) discharge year, model year 1992 was selected. The annual discharge to the CE during 1992 was about 0.93 million acre-ft.

Figure A-12 shows the discharges to CE that occurred in model year 1992. Also shown in the figure are the effects of operating a 20, 60 and 90 well system in reducing the discharge to the estuary.

Based on the data/results presented in Figure A-12 the following conclusions are derived for model year 1992 (an average year):

1 The excess volume discharged to the CE in 1994 is about 76,000 acre-ft.
2 The excess volume discharged to the CE can be reduced by 50% if 20 wells are operated only during times when excess discharge occur.
3 The excess volume discharged to the CE can be reduced by 100% if 60 wells are operated only during times when excess discharge occur.

Summary Table: Table A-5 tabulates the excess volume discharged to the CE for a 1-in-10, 1-in-5 and an average years. The number of wells needed to partially and totally eliminate the excess discharges are also tabulated in the table. It is important to note that the results indicated from all of the above analyses could have been improved if the injection wells were used in anticipation of need to discharge.

3.5. Effects of Injection Wells in Lowering the Lake Elevation

The following assumptions are made for the analysis presented in this section: 1) The wells used to discharge excess water from the lake are 24 inches in diameter with a capacity of 18 MGD (30 cfs), and 2) While the wells are in operation the discharge to the CE is 2800 cfs (167 acre-ft/month) and to the SLE is 0.

1-in-10 year Lake-Level Rise: From the calculations presented in Section 3.2, it is estimated that once in 10 years the lake is likely to rise about 4.75 feet between early June and late November.

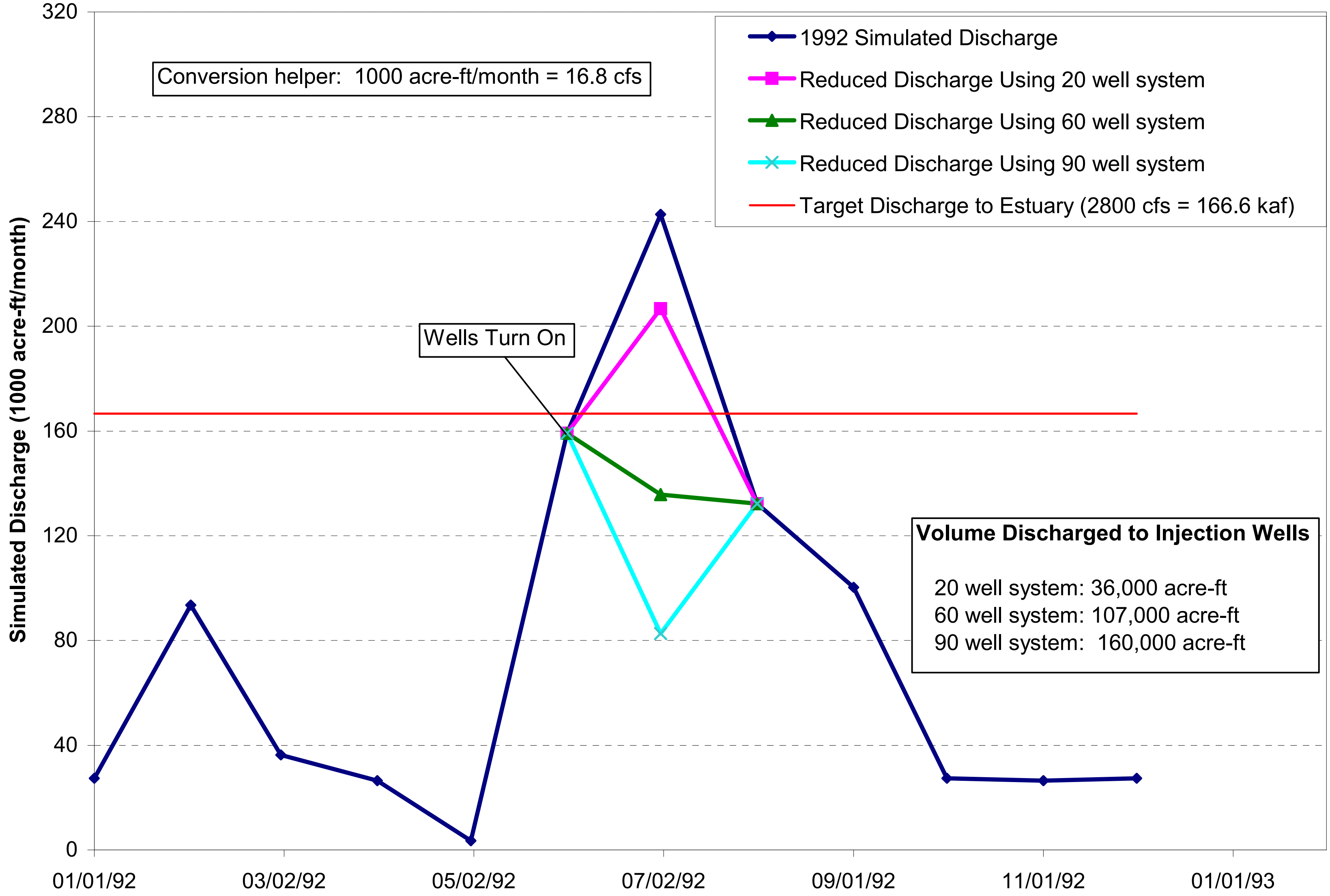

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FIGURE A-12. PLOT SHOWING REDUCTION IN EXCESS DISCHARGE UTILIZING A 20,60 AND 90 WELL SYSTEM FOR AN AVERAGE DISCHARGE YEAR.

Table A-5 Number of Wells Needed to Handle 1-in-10, 1-in-5 and Average Disharge Years

Discharge Year	Model Year	No. of Months of Excess Discharge	Volume of Excess Discharge (1000 acre-ft)	No. of 24" wells needed to eliminate all excess discharge	Percentage Reduction in Excess Discharge Volume Using Injection Wells		
					20 Wells	60 Wells	90 Wells
1-in-10	1983	3	781	146	13	41	61
1-in-5	1994	4	534	75	27	80	100
Average	1992	1	76	43	47	100	100

Note:

If 34" wells are used, the number of wells will be reduced by a factor of 0.4

The excess monthly discharge-volume is calculated as the simulated discharge volume - target estuary release volume of 166.1 acre-ft/month (2800 cfs)

For a 1-in-10 year scenario, if injections wells are in operation, the final lake level can be lowered depending on when the wells are turned on and how many wells are used.

Figures A-13 to A-16 show the effects of a system of 20, 40 and 90 wells in reducing the lake elevation for a 1-in-10 scenario. The results presented in these figures suggest that depending on the duration of injection well operation, 20 wells can lower the lake elevation between 0.4 and 1.6 feet, 60 wells can lower the lake elevation between 0.6 and 2.3 feet, and 90 wells can lower the lake level between 0.7 and 2.8 feet.

1-in-5 Year Lake-Level Rise: It is estimated that once in 5 years the lake is likely to rise about 3 feet or more between early June and late November.

Figures A-17 and A-18 show the effects of a 20, 40 and 90 well system in reducing the lake elevation for a 1-in-5 scenario. The results presented in these figures suggest that 20 wells can lower the lake elevation between 0.36 and 1.4 feet, 60 wells can lower the lake elevation between 0.62 and 2.5 feet, and 90 wells can lower the lake-level between 0.82 and 3.3 feet.

Average Year Lake-Level Rise: It is estimated that in an average year the lake is likely to rise about 2 feet or more between early June and late November.

Figures A-19 and A-20 show the effects of a 20, 40 and 90 well system in reducing the lake elevation for an average year.

The results presented in Figures A-19 and A-20 suggest that 20 wells can lower the lake elevation between 0.54 and 2.1 feet, 60 wells can lower the lake elevation between 0.94 and 3.7 feet, and 90 wells can lower the lake level between 1.2 and 4.9 feet.

Summary Table: The results from the analyses presented in this section are summarized in Table A-6.

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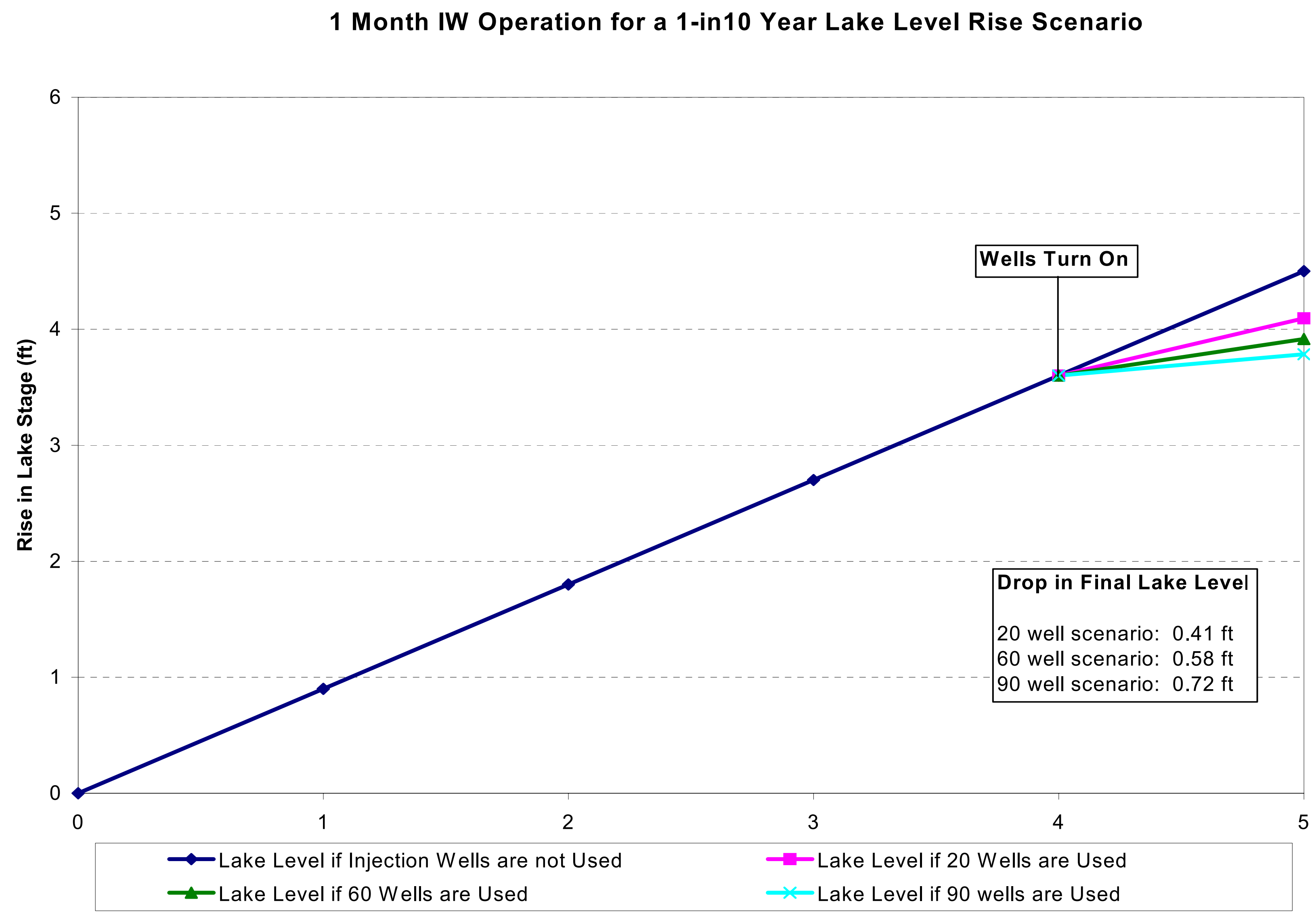

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FIGURE A-13. PLOT SHOWING DECLINE IN LAKE LEVELS UTILIZING INJECTION WELLS FOR 1 MONTH DURING A 1-IN-10 YEAR EVENT.

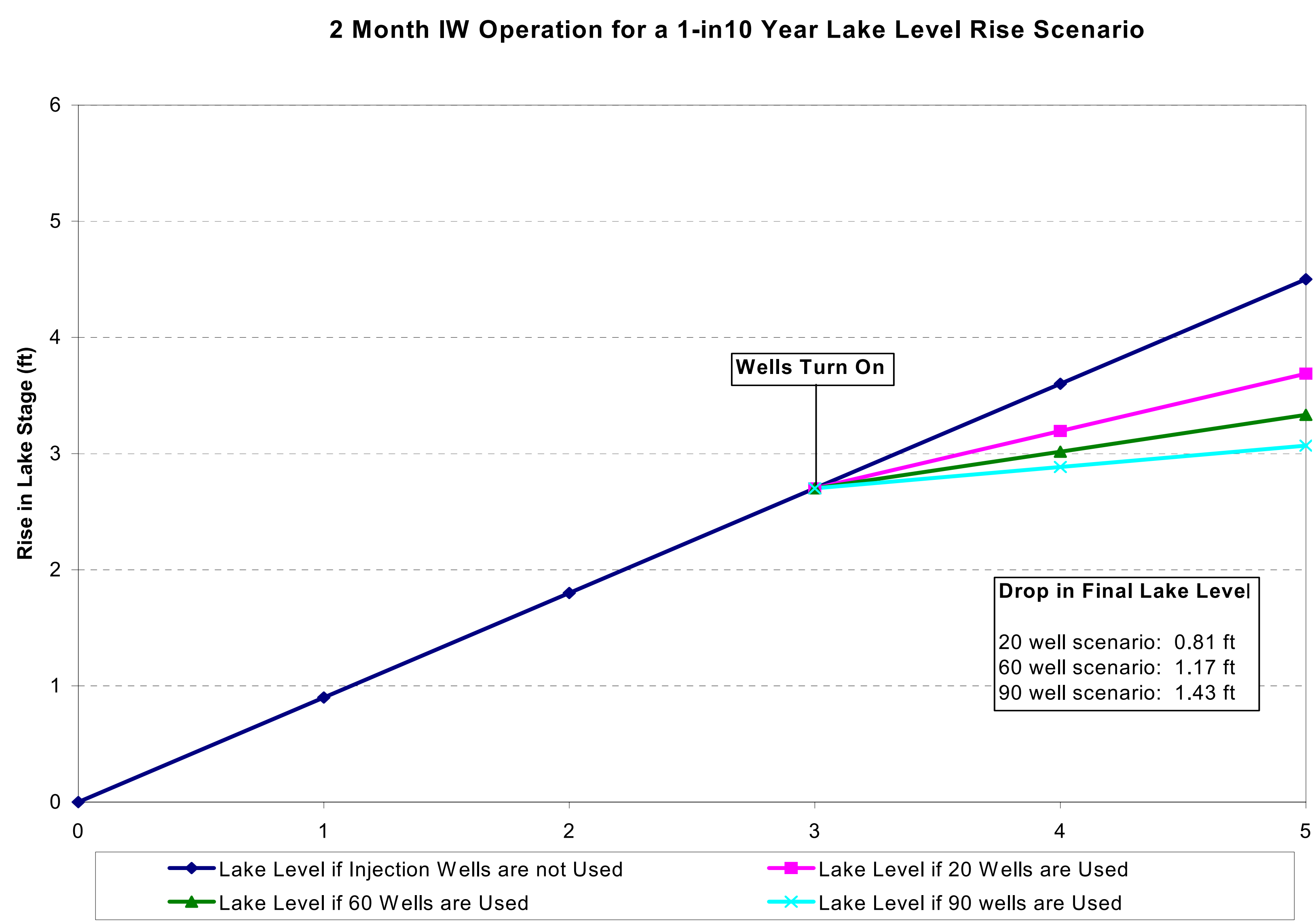

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FIGURE A-14. PLOT SHOWING DECLINE IN LAKE LEVELS UTILIZING INJECTION WELLS FOR 2 MONTHS DURING A 1-IN-10 YEAR EVENT.

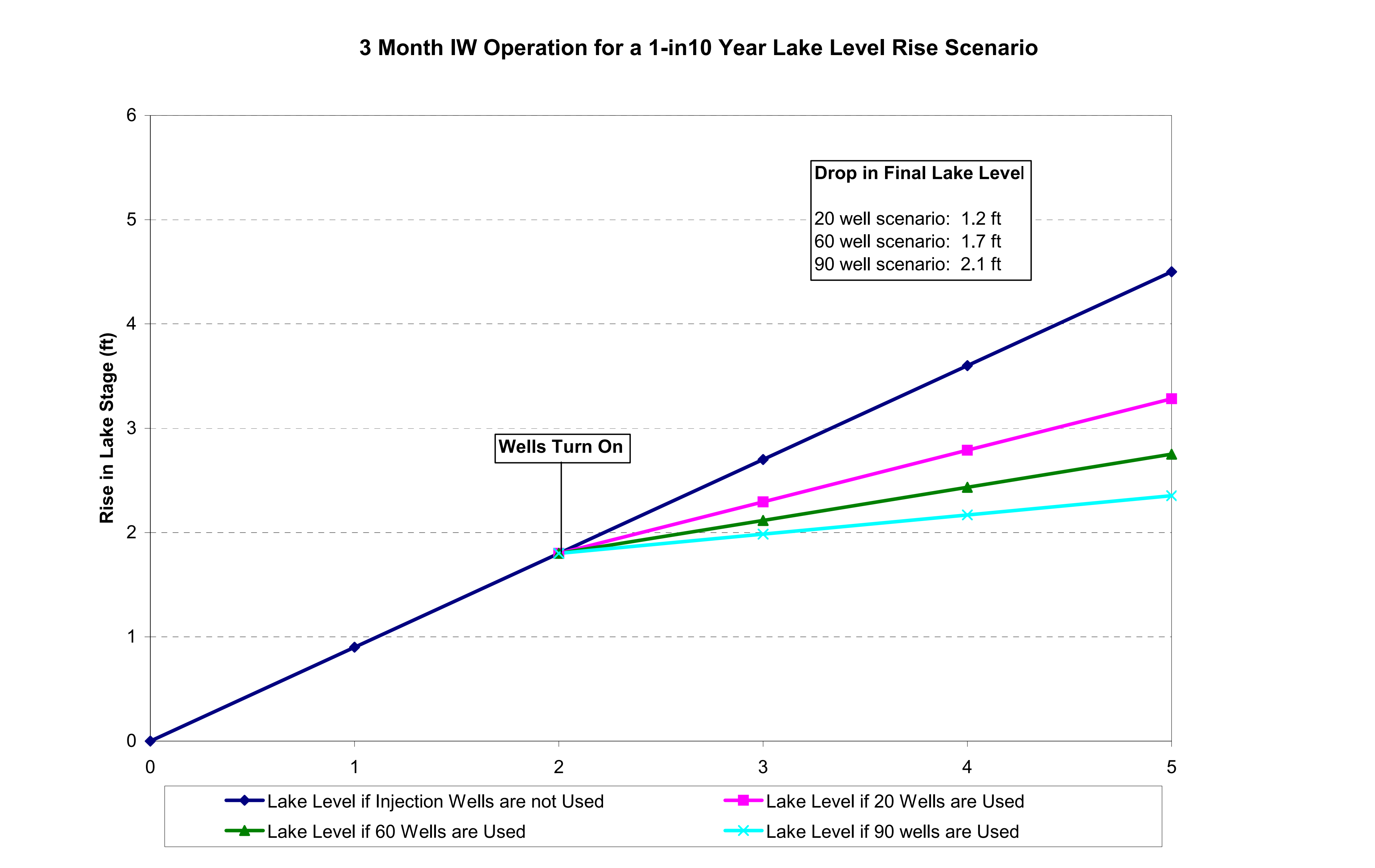

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FIGURE A-15. PLOT SHOWING DECLINE IN LAKE LEVELS UTILIZING INJECTION WELLS FOR 3 MONTHS DURING A 1-IN-10 YEAR EVENT.

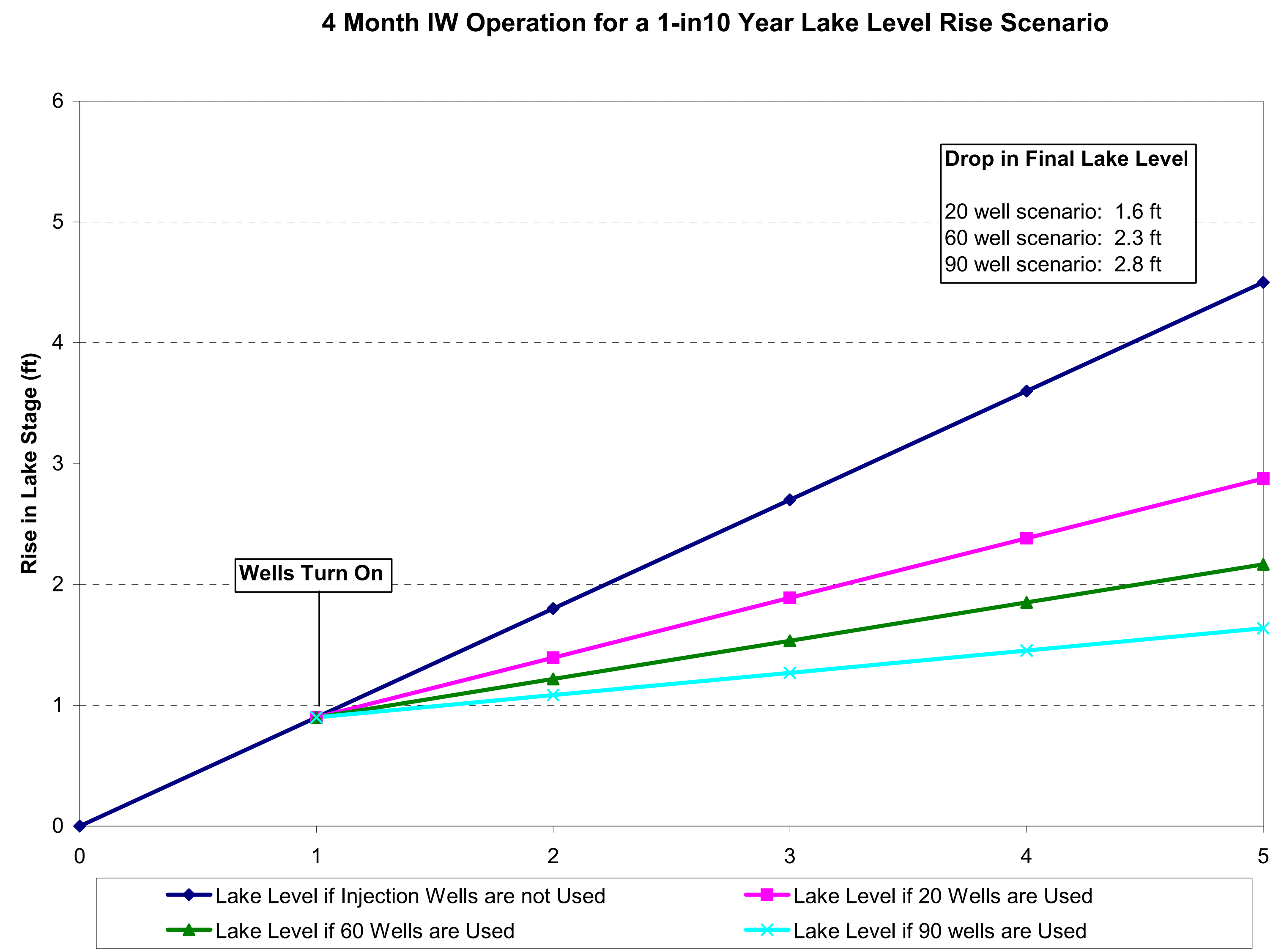

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FIGURE A-16. PLOT SHOWING DECLINE IN LAKE LEVELS UTILIZING INJECTION WELLS FOR 4 MONTHS DURING A 1-IN-10 YEAR EVENT.

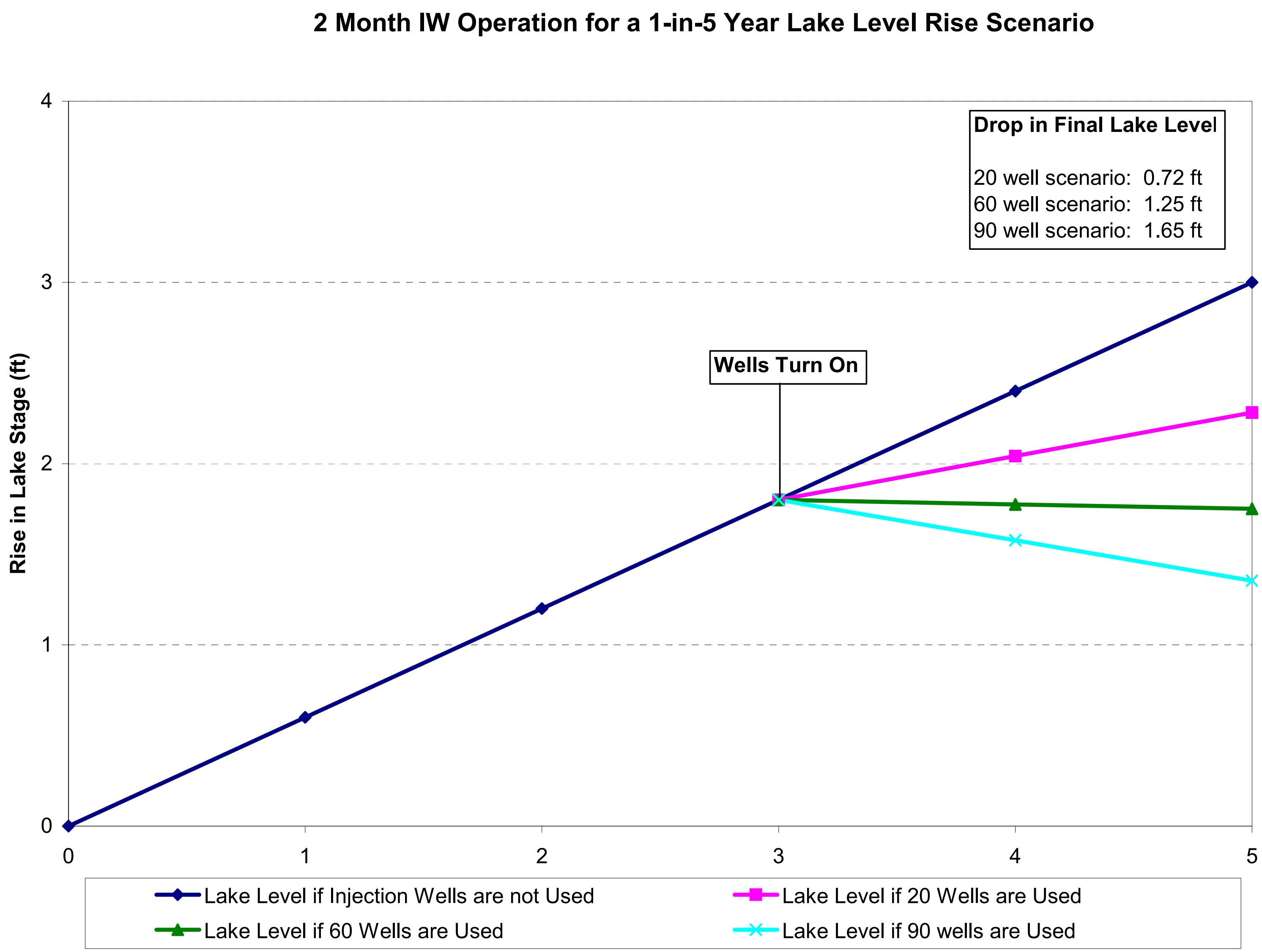

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FIGURE A-17. PLOT SHOWING DECLINE IN LAKE LEVELS UTILIZING INJECTION WELLS FOR 2 MONTHS DURING A 1-IN-5 YEAR EVENT.

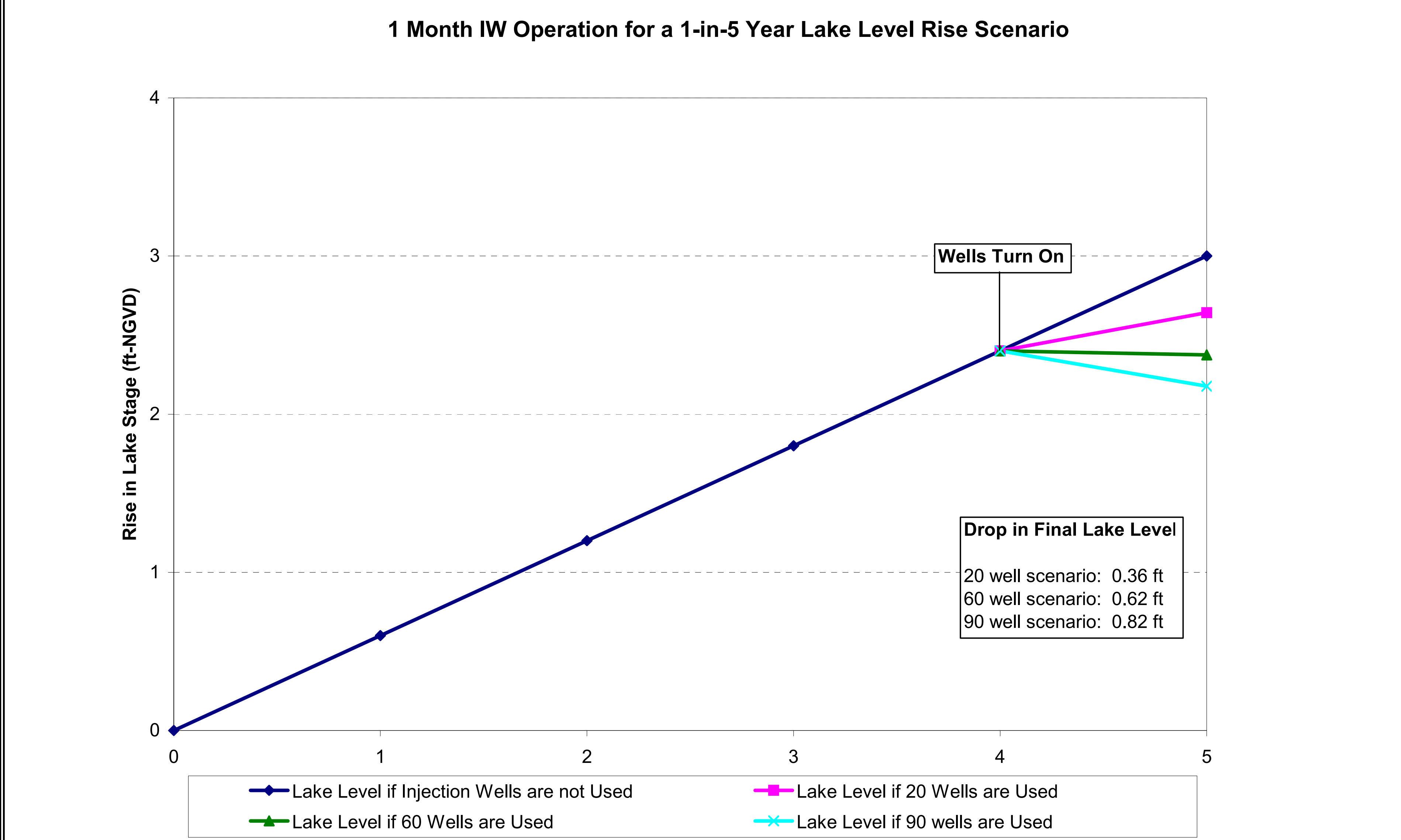

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FIGURE A-18. PLOT SHOWING DECLINE IN LAKE LEVELS UTILIZING INJECTION WELLS FOR 1 MONTH DURING A 1-IN-5 YEAR EVENT.

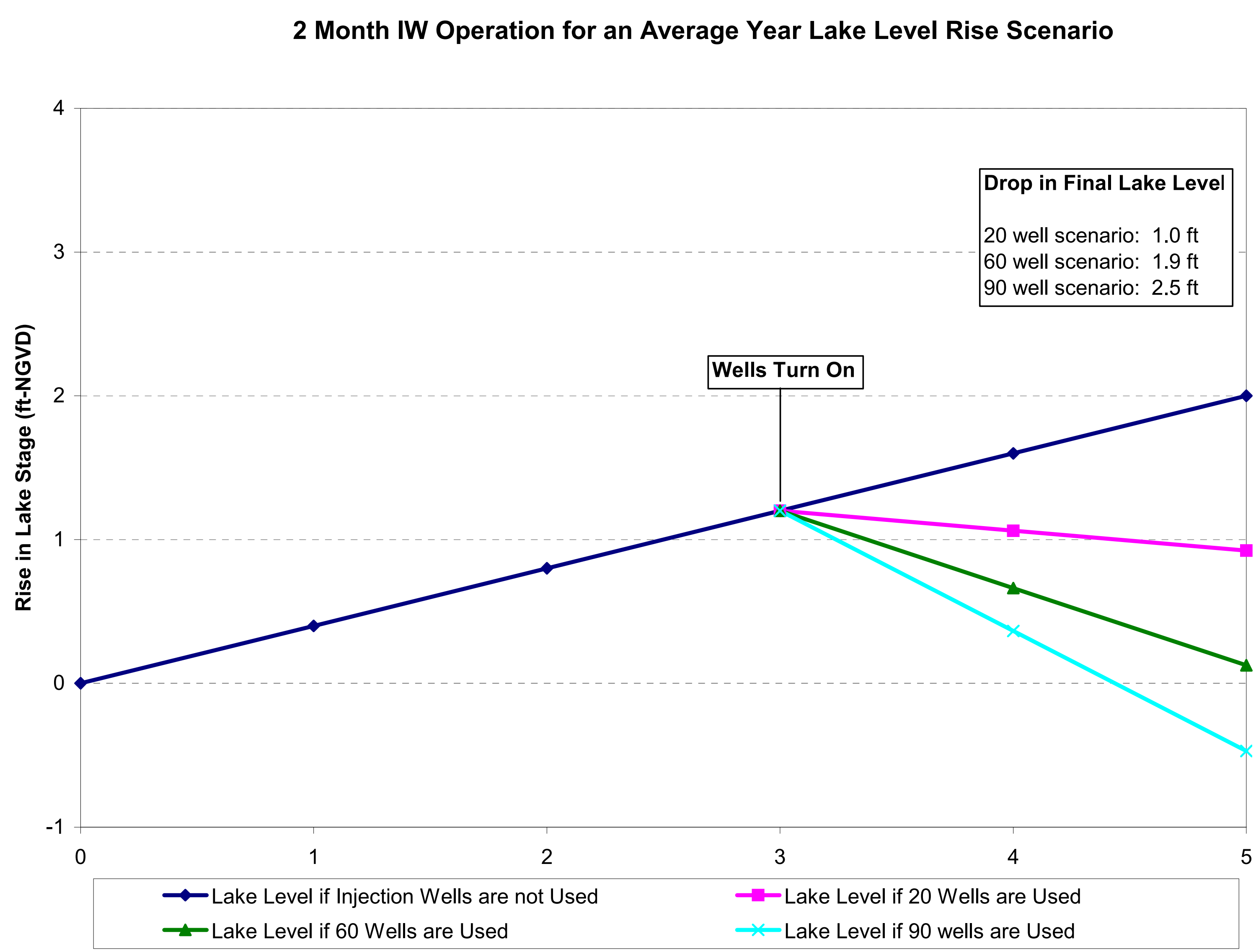

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FIGURE A-19. PLOT SHOWING DECLINE IN LAKE LEVELS UTILIZING INJECTION WELLS FOR 2 MONTHS DURING AN AVERAGE YEAR.

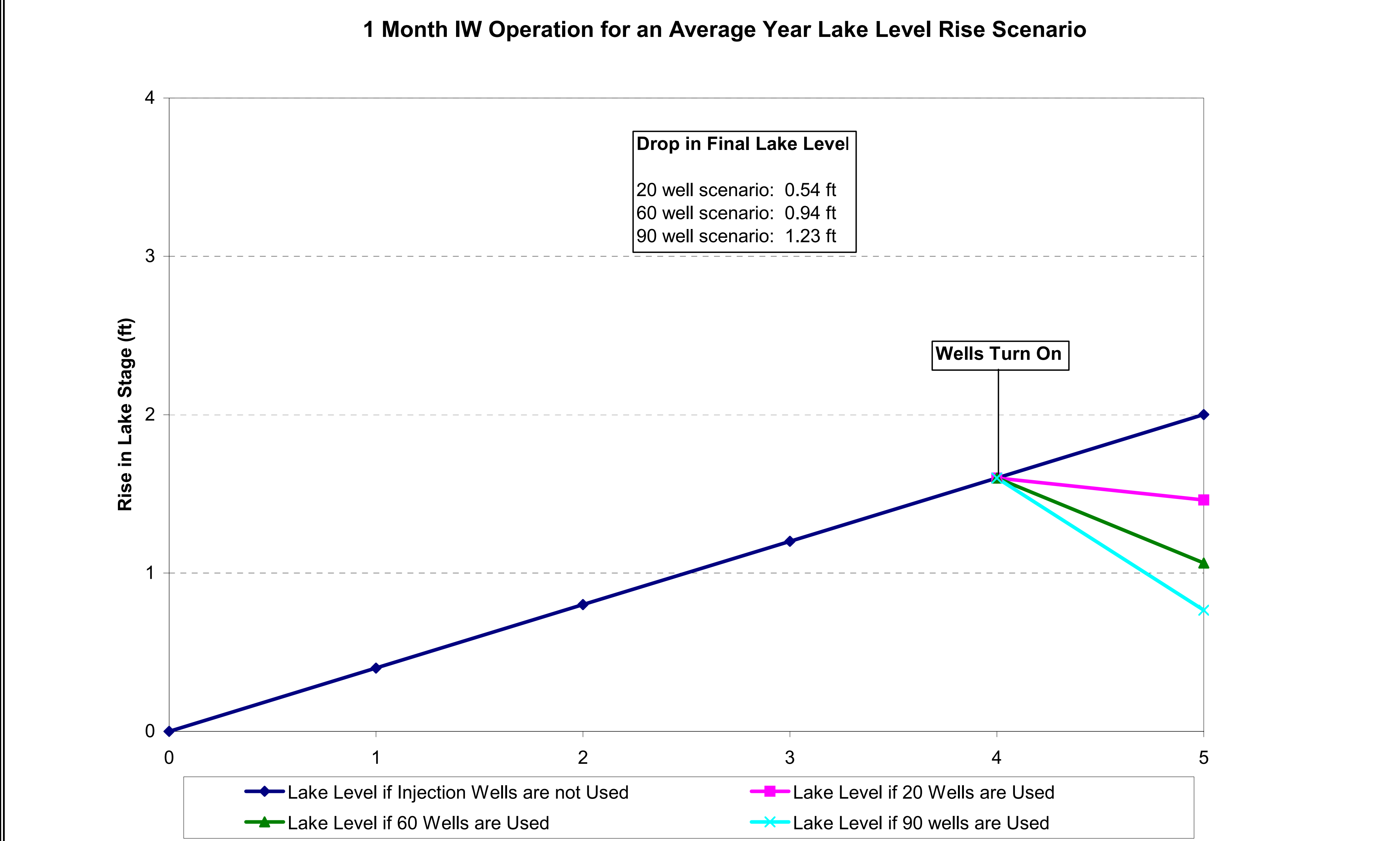

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FIGURE A-20. PLOT SHOWING DECLINE IN LAKE LEVELS UTILIZING INJECTION WELLS FOR 1 MONTH DURING AN AVERAGE YEAR.

Table A-6

Summary of Results for a Lake-Level-Based Injection Program

Probability of Occurrence (Years)	Expected Rise in Lake Level from June through November (ft)	No. of Wells	No. of Months of Operation	Final Drop in Lake Level (ft)	Discharge to the estuaries while wells are operating(cfs)
1-in-10	4.75	20	1	0.41	2800 cfs to CE and 0 cfs to SLE
			2	0.81	
			3	1.20	
			4	1.60	
		60	1	0.58	2800 cfs to CE and 0 cfs to SLE
			2	1.17	
			3	1.70	
			4	2.30	
		90	1	0.72	2800 cfs to CE and 0 cfs to SLE
			2	1.43	
			3	2.10	
			4	2.80	
1-in-5	3	20	1	0.36	2800 cfs to CE and 0 cfs to SLE
			2	0.72	
			3	1.00	
			4	1.40	
		60	1	0.62	2800 cfs to CE and 0 cfs to SLE
			2	1.25	
			3	1.80	
			4	2.50	
		90	1	0.82	2800 cfs to CE and 0 cfs to SLE
			2	1.65	
			3	2.50	
			4	3.30	
Average (1-in-2)	2	20	1	0.54	2800 cfs to CE and 0 cfs to SLE
			2	1.00	
			3	1.60	
			4	2.10	
		60	1	0.94	2800 cfs to CE and 0 cfs to SLE
			2	1.90	
			3	2.80	
			4	3.70	
		90	1	1.23	2800 cfs to CE and 0 cfs to SLE
			2	2.50	
			3	3.70	
			4	4.90	

APPENDIX B
TRIBUTARY INFLOWS TO LAKE OKEECHOBEE

Introduction

Injection wells may be utilized to attenuate flows contributed by tributaries upstream of Lake Okeechobee. This approach minimizes the need to release lake water to the estuaries. It also curtails the amount of pollutants entering the lake from the tributaries.

Daily inflows to Lake Okeechobee from 7 selected tributaries were analyzed in this study. The sites that were analyzed include FISHP(Fish Eating Creek), S-154-C (C-41 A), S-71-S (C-41), S-72-S (C-40), S-191-S (Nubbin Slough), S-133 (Taylor Creek) and S-127. Refer to Figure B-1 for locations of the sites.

Flow Analyses

The monthly cumulative discharges at the selected sites were calculated for a 16 year period from January 1991 to April 2006. The percentage of time the flows exceeded 18 MGD, 36 MGD and 54 MGD for the sites were estimated and provided in Figure B-2. In addition, the probability of exceedence (POE) of the monthly cumulative discharges were calculated as the inverse of recurrence intervals (explained in Appendix A). Figures B-3 to B-9 show the POE of monthly discharges and the number of wells that can be in operation at the selected sites. The well capacity in the analyses was assumed to be 30 cfs (18 MGD). For ease of review, the percentage values in the figures are converted to 'number of months a year'.

A discharge event with a POE of 25 percent implies that there is a 25 percent chance that a discharge with equal or higher magnitude than that event is likely to occur in any given month. It also means that the discharge event is likely to occur at least 3 times a year (25% of 12 months).

Results

The analytical results presented in Figures B-2 to B-9 are summarized below:

- Discharge through Fish Eating Creek allows at least 1 well to be in operation for about 8 months a year, and 5 or more wells to be in operation for about 6 months a year.

- Discharge through S-154 (C-41 A) allows at least 1 well to be in operation for about 4 months a year, 2 wells to be in operation for about 3 months a year, and 5 wells to be in operation for about 1.2 months a year.

- Discharge through S-71 (C-41) allows at least 1 well to be in operation for about 10 months a year, 2 wells to be in operation for about 8 months a year, and 5 wells to be in operation for about 6 months a year.

- Discharge through S-72 (C-40) allows at least 1 well to be in operation for about 7 months a year, 2 wells to be in operation for about 4.5 months a year, and 5 wells to be in operation for about 2.5 month a year.

- Discharge through S-191 (Nubbin Slough) allows at least 1 well to be in operation for about 8 months a year, 2 wells to be in operation for about 6 to 7 months a year, and 5 wells to be in operation for about 4 months a year.

- Discharge through S-133 (Taylor Creek) allows at least 1 well to be in operation for about 5 months a year, 2 wells to be in operation for about 3 months a year, and 5 wells to be in operation for about 15 days a year.

- Discharge through S-127 (C-48) allows at least 1 well to be in operation for about 3.5 months a year, 2 wells to be in operation for about 2 months a year, and 5 wells to be in operation for about 12 days a year.

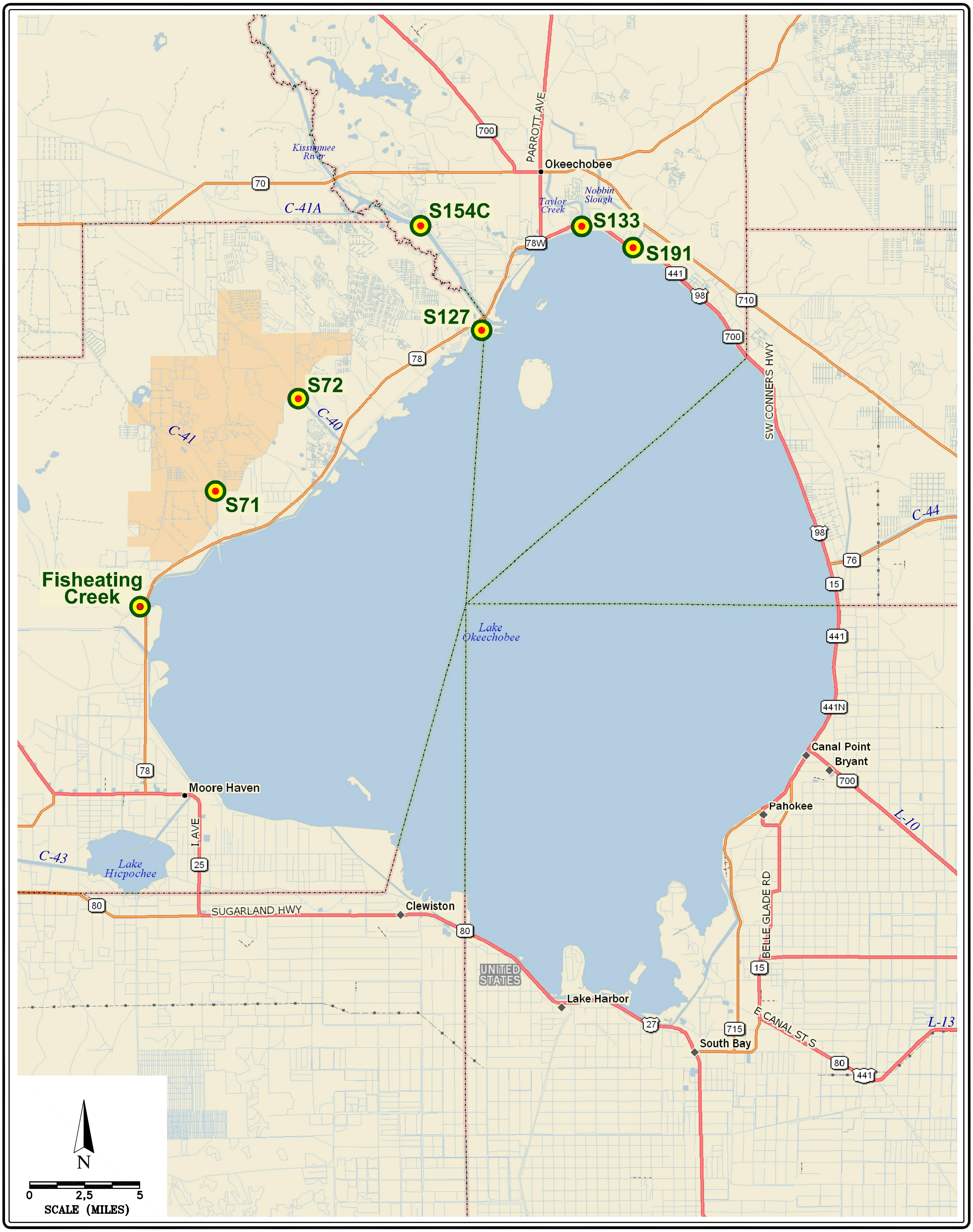

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FIGURE B–1. TRIBUTARY SITES SELECTED FOR INFLOW AND PHOSPHATE ANALYSES.

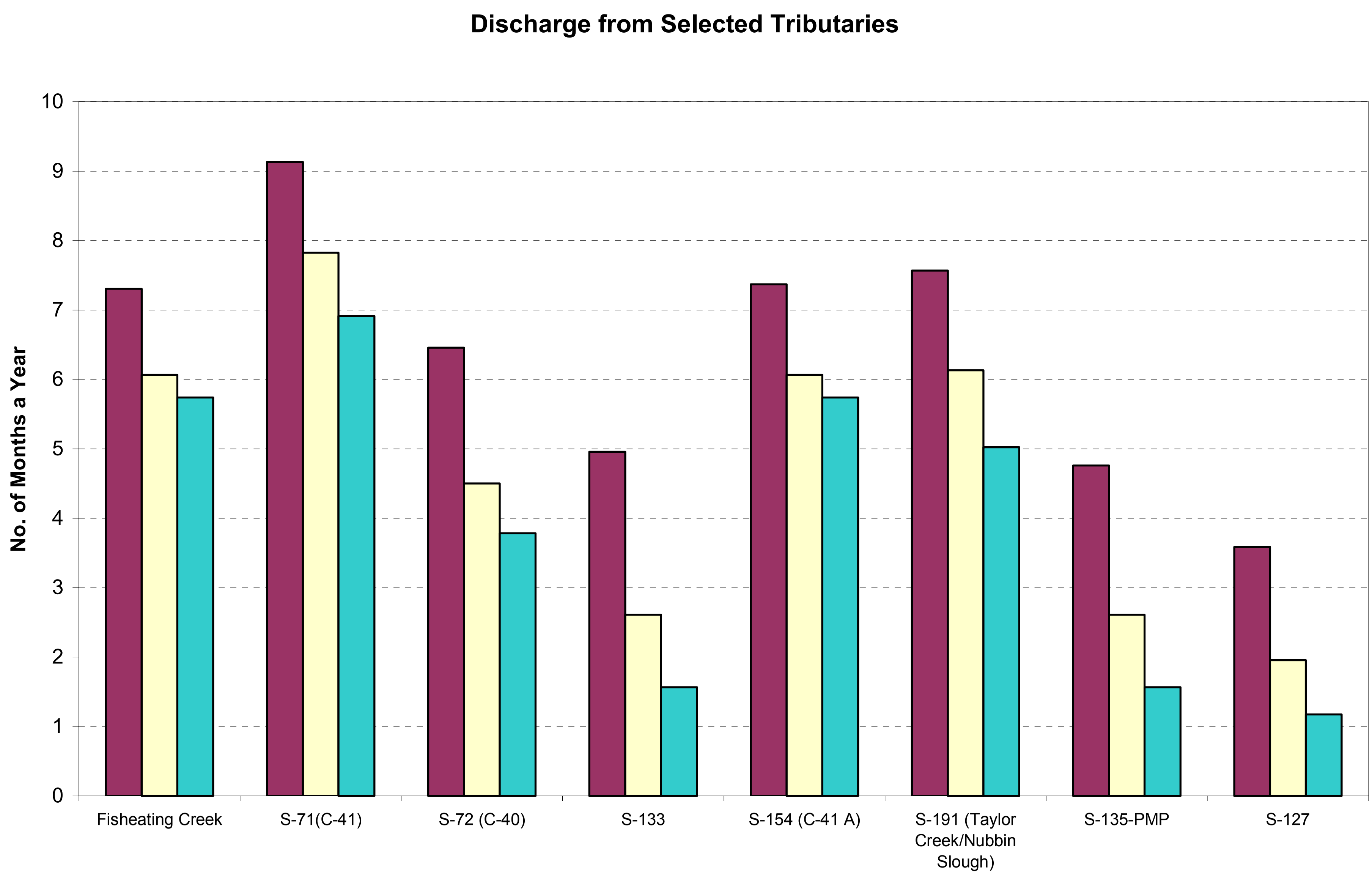

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FIGURE B-2. AVERAGE NUMBER OF MONTHS A YEAR THAT THE FLOW EXCEEDS 18 MGD, 36 MGD AND 54 MGD FOR SELECTED TRIBUTARIES.

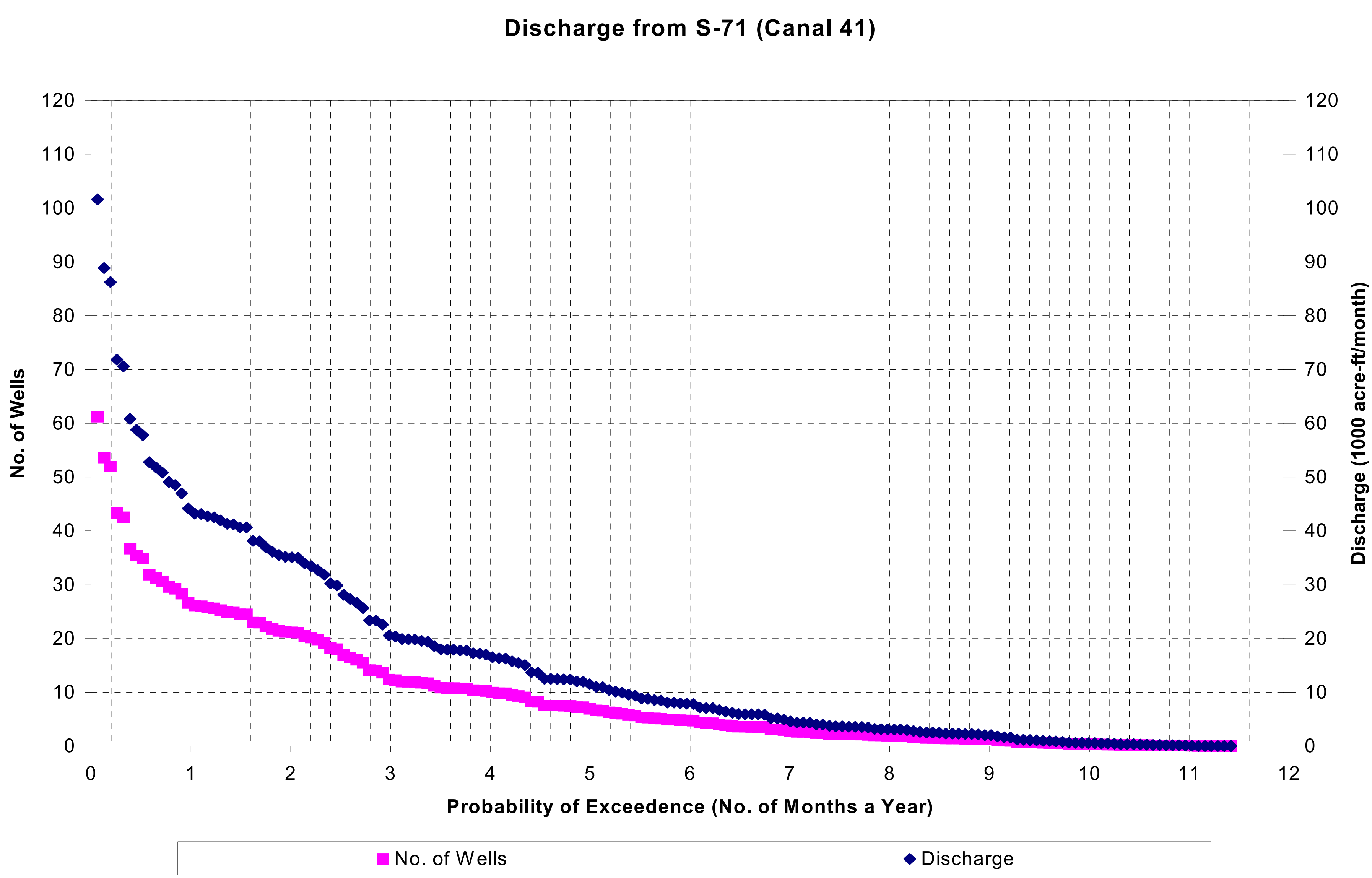

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FIGURE B-3. PROBABILITY OF EXCEEDENCE OF INFLOW DISCHARGES VS NO. OF WELLS FOR S-71.

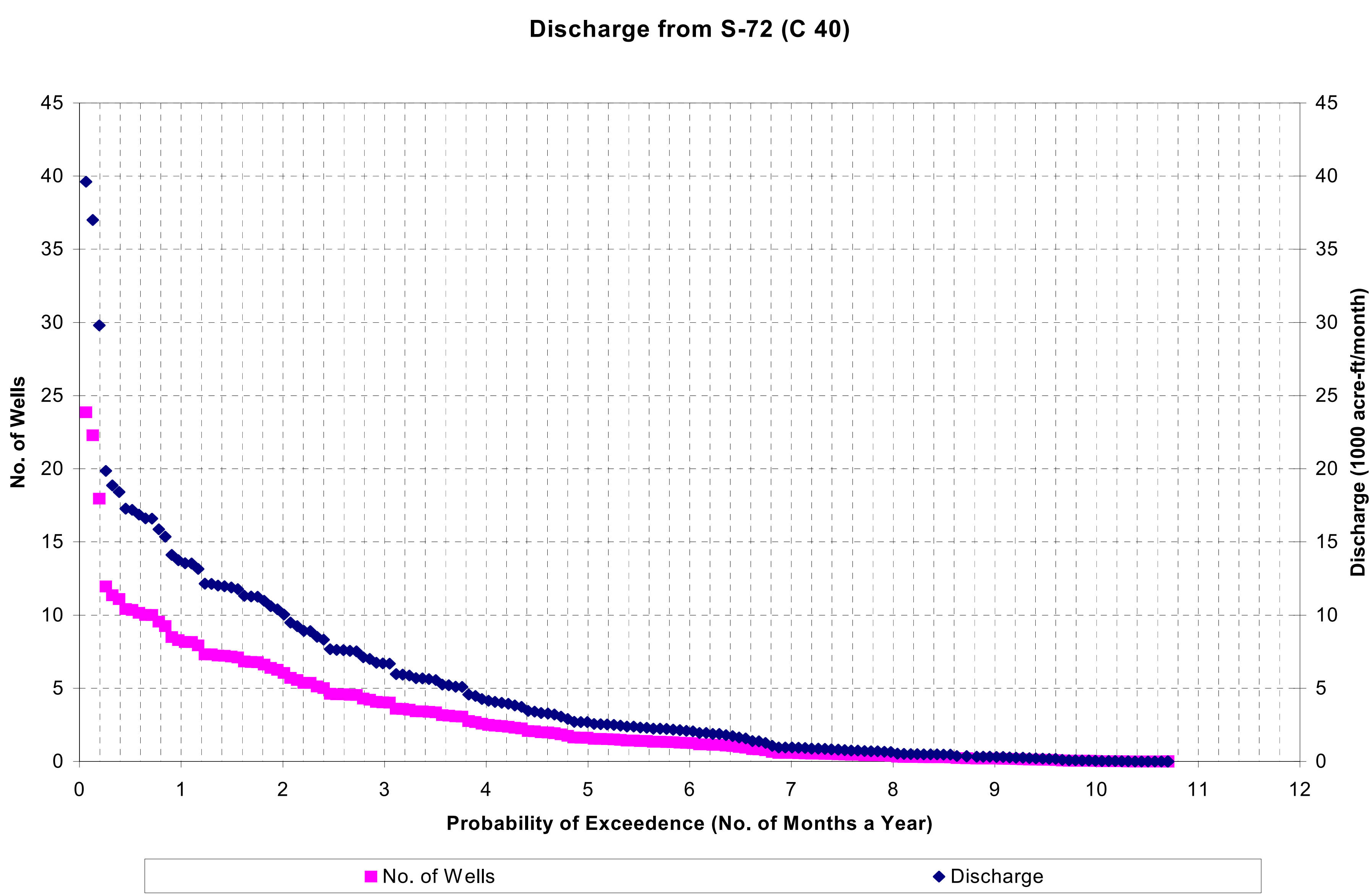

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FIGURE B-4. PROBABILITY OF EXCEEDENCE OF INFLOW DISCHARGES VS NO. OF WELLS FOR S-72 (C-40).

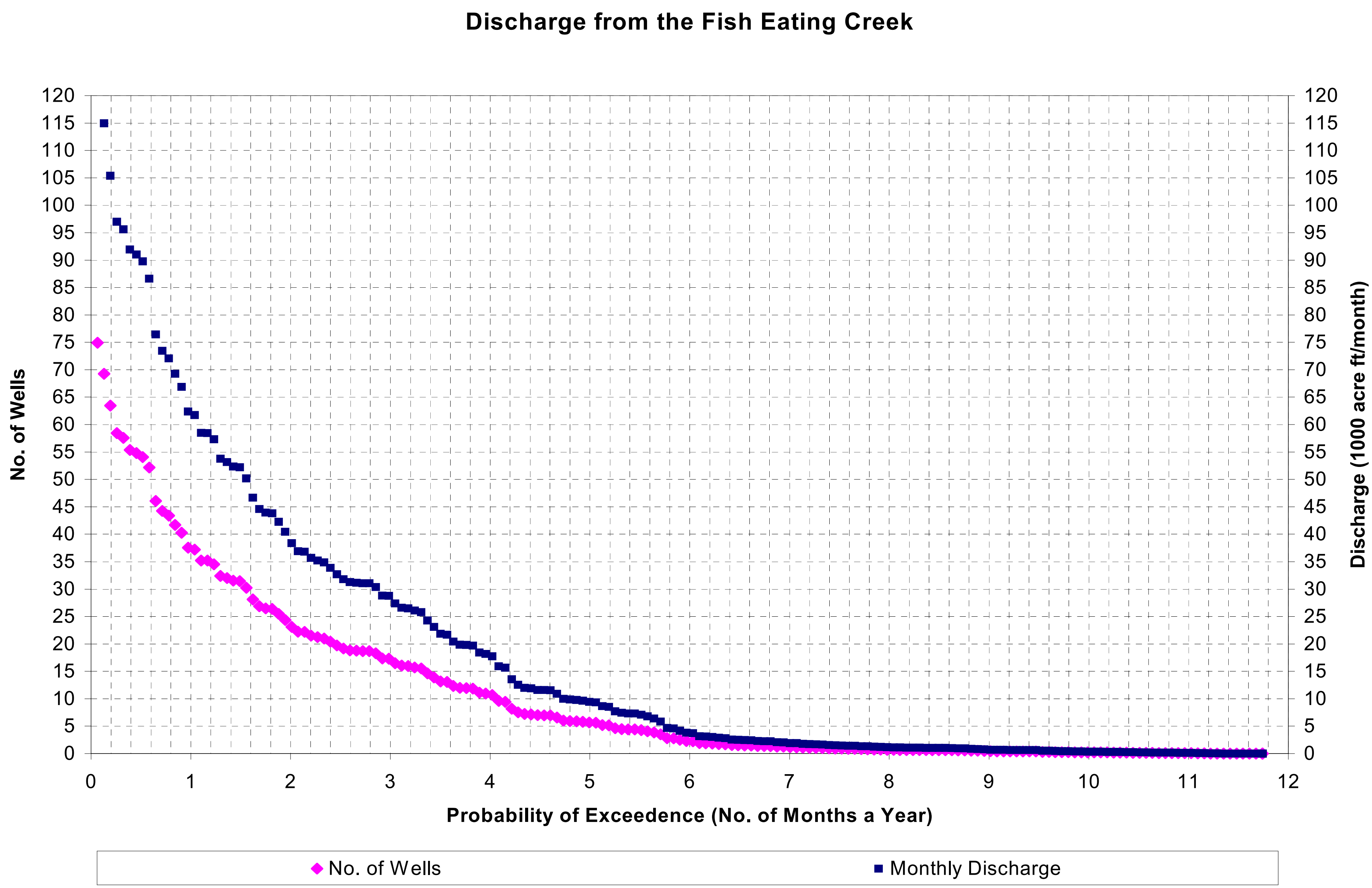

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FIGURE B-5. PROBABILITY OF EXCEEDENCE OF INFLOW DISCHARGES VS NO. OF WELLS FOR FISH EATING CREEK.

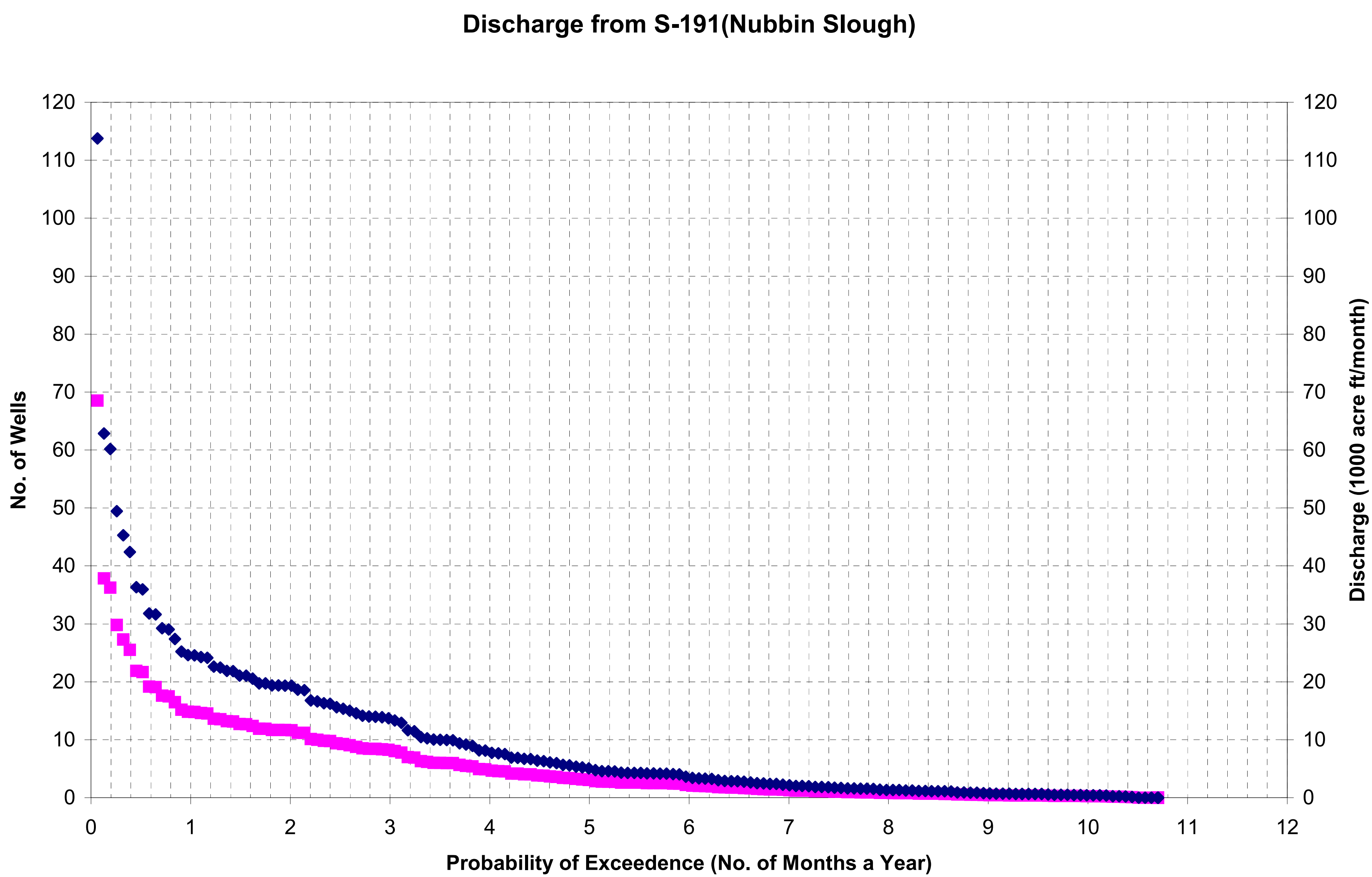

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FIGURE B-6. PROBABILITY OF EXCEEDENCE OF INFLOW DISCHARGES VS NO. OF WELLS FOR S-191.

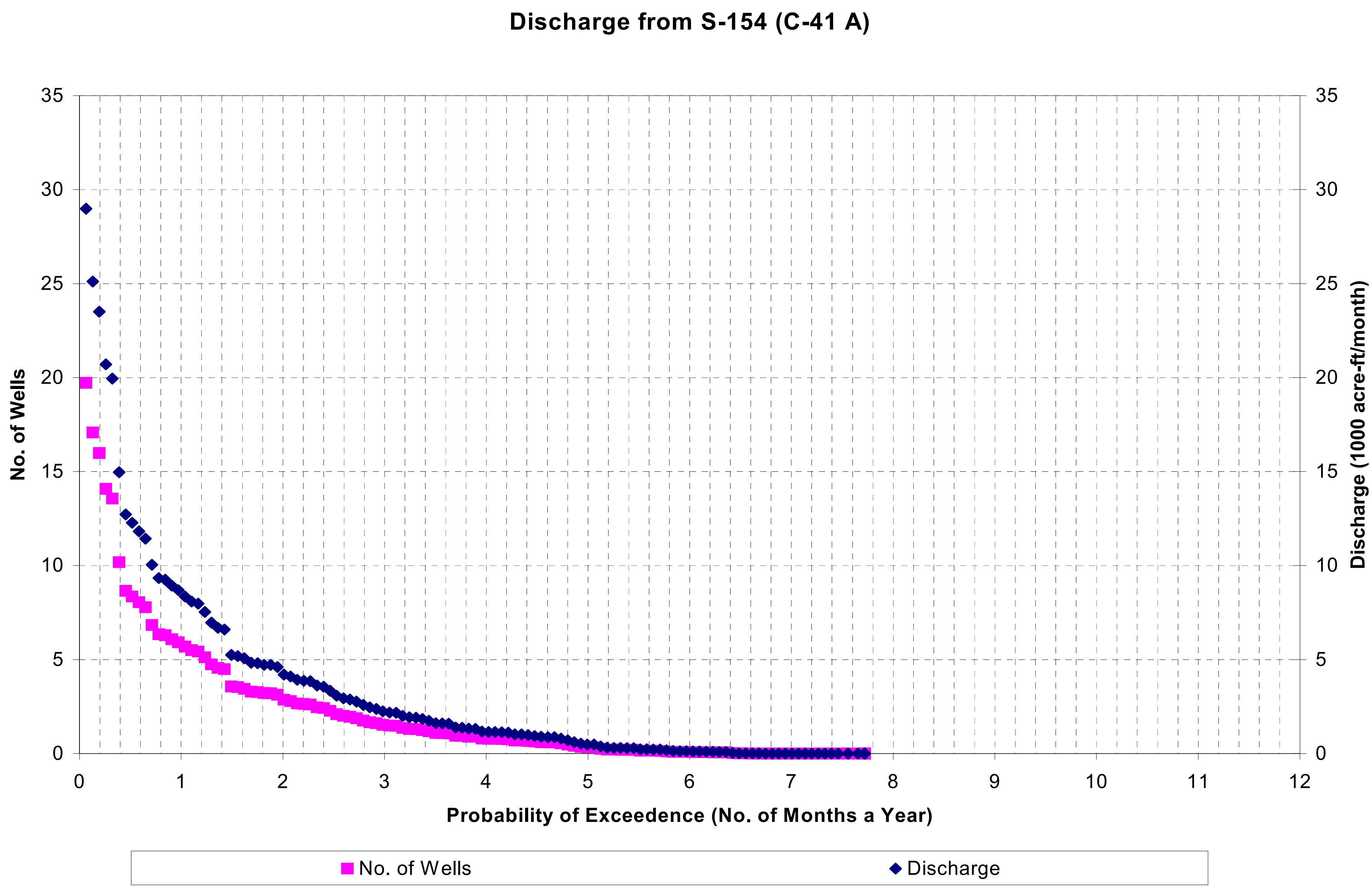

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FIGURE B-7. PROBABILITY OF EXCEEDENCE OF INFLOW DISCHARGES VS NO. OF WELLS FOR S-154.

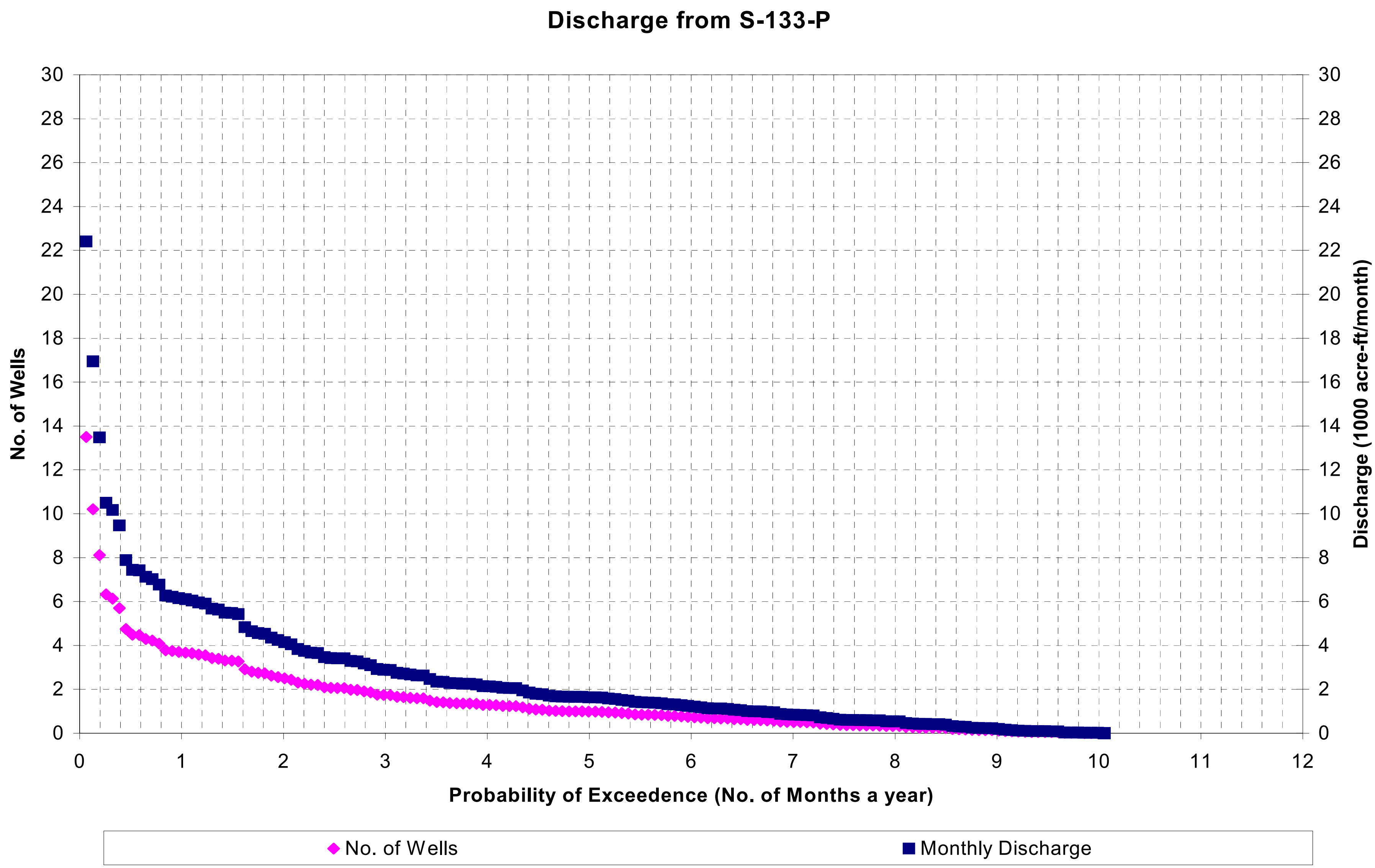

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FIGURE B-8. PROBABILITY OF EXCEEDENCE OF INFLOW DISCHARGES VS NO. OF WELLS FOR S-133-P.

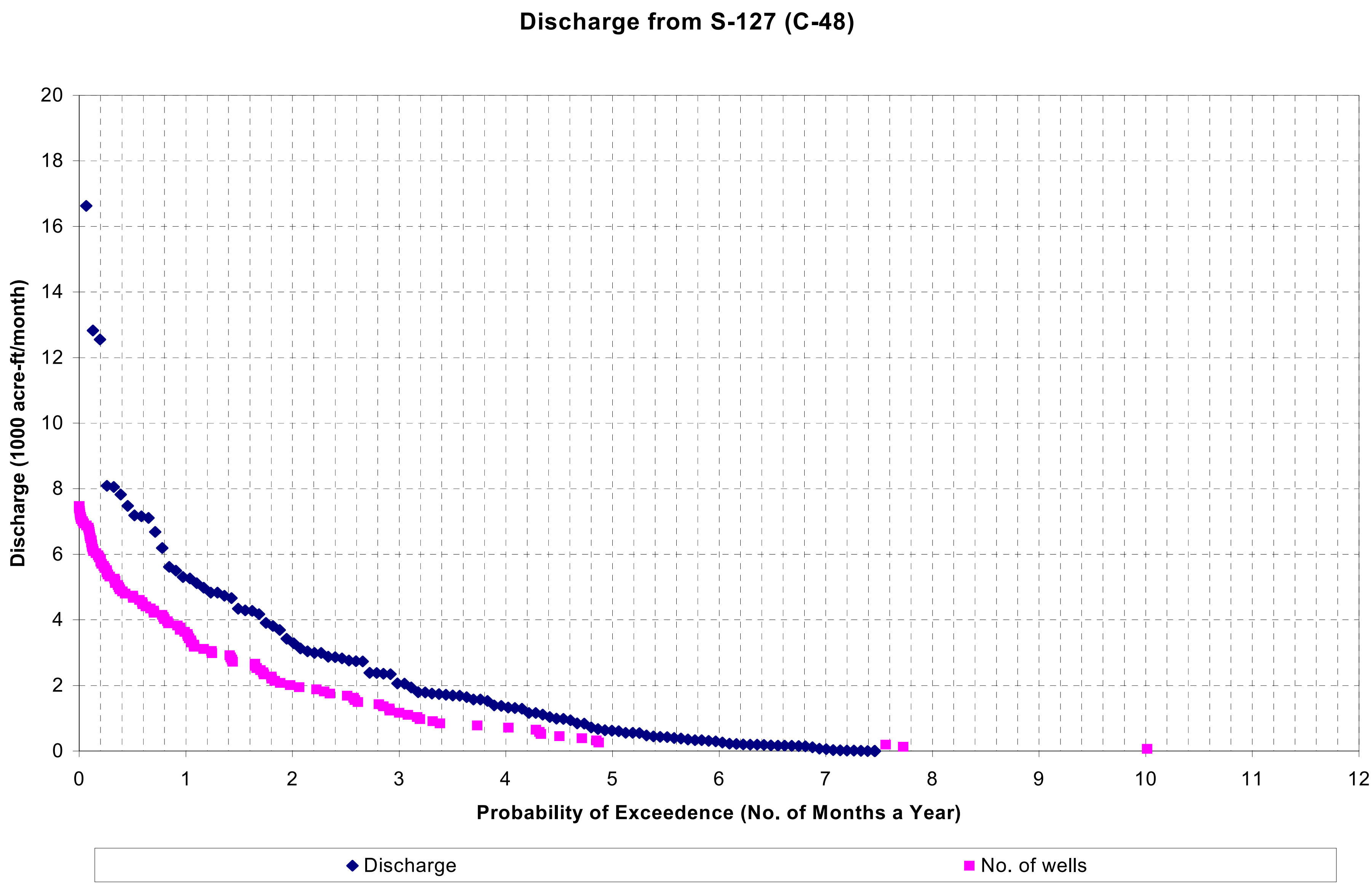

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FIGURE B-9. PROBABILITY OF EXCEEDENCE OF INFLOW DISCHARGES VS NO. OF WELLS FOR S-127-P.