



Horsley & Witten, Inc.

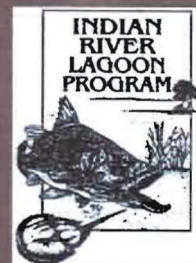
Sextant Hill - 90 Route 6A
Sandwich, MA 02563
www.horsleywitten.com
Phone (508) 833-6600
Fax (508) 833-3150

On-Site Sewage Disposal Systems Pollutant Loading Evaluation

Test and Validation of Indian River Lagoon Nitrogen Model

Prepared for:

*Indian River Lagoon Program
1900 South Harbor City Blvd., Suite 107
Melbourne, FL 32901-4749*



January 28, 2000

TABLE OF CONTENTS

	<u>Page</u>
1.0 INTRODUCTION	1
2.0 WATER SAMPLING STRATEGY	4
2.1 Hydrogeologic Analysis	4
2.2 Capture Zone Modeling	10
3.0 NITROGEN LOADING MODEL	13
3.1 Nitrogen in OSDS Effluent	14
3.2 Nitrogen in Lawn Fertilizers	15
3.3 Nitrogen in Stormwater Runoff	16
3.4 Population Data	16
4.0 FIELD INVESTIGATIONS	18
4.1 Well Installations	18
4.2 Groundwater Sampling	19
4.3 Field Data Collection for the Nitrogen Loading Modeling	20
5.0 DISCUSSION	24
5.1 Precipitation at Study Sites	24
5.2 Groundwater Elevation in Surficial Aquifer	24
5.3 Salt Water Intrusion	24
5.4 Discussion of Water Quality Analyses	26
5.4.1 Quality Control Review	26
5.4.2 Chloride	27
5.4.3 Nitrogen	27
5.4.4 Dissolved Oxygen Concentrations	29
5.5 Comparison of Modeled Total Nitrogen to Predicted Total Nitrogen	29
5.6 Controlling Factors in Nitrogen Model	31
5.6.1 Accuracy of Nitrogen Inputs	31
5.6.2 Understanding of Hydrologic Conditions	33
5.6.3 Transformation to Other Nitrogen Species	34
6.0 SUMMARY OF FINDINGS	37
REFERENCES	

LIST OF TABLES

Table

1.	Pumping Test Data, Northern Sites	6
2.	Pumping Test Data, Southern Sites	7
3.	Hydraulic Conductivity Solutions	8
4.	Recharge Calculations	10
5.	Recommended Pumping Schedules for Sampling, Based on MODFLOW Model Results	11
6.	Upgradient Distance Represented in Water Samples	13
7.	Summary of Total Nitrogen Concentrations in OSDS Effluent	15
8.	Extent of Recharge in Pervious and Impervious Areas	16
9.	Population Data (U.S. Census data, 1990)	17
10.	Laboratory Analysis Methods	20
11.	Summary of Nitrogen Model Inputs and Results	22
12.	1999 Rainfall Data Three Days Prior to Sampling Events	25
13.	Comparison of Modeled Nitrogen Concentrations Results to Measured Nitrogen concentrations	30

LIST OF FIGURES

Figure

1.	Site Locations
2.	Port St. John Site
3.	Site Map Port St. John
3a.	Port St. John. Areal Extent of Drawdown from Simultaneous Pumping
4.	Port St. John
5.	Palm Bay Site
6.	Site Map Palm Bay
6a.	Palm Bay. Areal Extent of Drawdown from Simultaneous Pumping
7.	Palm Bay
8.	Riverside Landing Site
9.	Site Map Riverside Landing
9a.	Riverside Landing. Areal Extent of Drawdown from Simultaneous Pumping
10.	Riverside Landing
11.	Sebastian Site
12.	Site Map Sebastian
13.	Sebastian
14.	River Shores Site
15.	Site Map River Shores
15a.	River Shores. Areal Extent of Drawdown from Simultaneous Pumping
16.	River Shores
17.	St. Lucie Site
18.	Site Map St. Lucie
18a.	St. Lucie. Areal Extent of Drawdown from Simultaneous Pumping
19.	St. Lucie
20.	Jensen Beach Site

21. Site Map Jensen Beach Site
- 21a. Jensen Beach. Areal Extent of Drawdown from Simultaneous Pumping
22. Jensen Beach
23. Rio Site
24. Site Map Rio
- 24a. Rio. Areal Extent of Drawdown from Simultaneous Pumping
25. Rio
26. Precipitation March through October, 1999 Melbourne Station
27. Precipitation March through October, 1999 St. Lucie Station
28. Groundwater Elevations at Each Site During Field Sampling
29. In-situ Depth Profiles Riverside Landing – October
30. In-situ Depth Profiles River Shores Site – October
31. Average Chloride Concentrations in Surficial Aquifer
32. Average Total Phosphorus Concentrations in Surficial Aquifer
33. Average TKN Concentrations in Surficial Aquifer
34. Average Ammonia concentrations in Surficial Aquifer
35. Average Nitrate Concentrations in Surficial Aquifer
36. Average Total Nitrogen Concentrations in Surficial Aquifer
37. Average Total Nitrogen Varying Seasonally, Northern Sites
38. Average Total Nitrogen Varying Seasonally, Southern Sites
39. Nitrogen Speciation at Each Site
40. Comparison of Average Total Nitrogen Concentrations in High and Low Yield Wells
41. Average Dissolved Oxygen Concentration in Surficial Aquifer
42. Sources of Nitrogen Loading
43. Nitrogen Transformations

APPENDIX A	Boring Logs
APPENDIX B	Well Sampling Logs
	Round 1
	Round 2
	Round 3
APPENDIX C	Nitrogen Loading Data
APPENDIX D	Nutrient Data
	Round 1
	Round 2
	Round 3
APPENDIX E	Field Photographs

ON-SITE SEWAGE DISPOSAL SYSTEMS POLLUTANT LOADING EVALUATION - TEST AND VALIDATION OF INDIAN RIVER LAGOON NITROGEN MODEL

1.0 INTRODUCTION

Horsley & Witten, Inc. (H&W) has prepared this report on behalf of the Indian River Lagoon National Estuary Program (IRLNEP) and the St. Johns Water Management District, working in cooperation with the South Florida Water Management District. The overall objective of the work is to assist these organizations in their efforts to protect and restore the Indian River Lagoon by developing tools for evaluating the effects of development and in particular, on-site sewage disposal systems (OSDS) on coastal water quality.

Excess nitrogen loading to the Indian River Lagoon has the potential to cause significant degradation and impairment of the lagoons' ecosystem. Nitrogen has been identified as the most significant nutrient controlling the water quality of coastal ecosystems. Excess nitrogen loading leads to increased production of macroalgae and phytoplankton, reduced oxygen levels, and poor habitat for fish and shellfish and reduced aesthetic appeal.

In Phase I of this project, under contract to the US Environmental Protection Agency, H&W completed the report "*Indian River Lagoon Septic System/Carrying Capacity Study*," dated April, 1996. As part of the study, a preliminary nitrogen loading model was completed for the watershed area to the Indian River Lagoon. The nitrogen loading model was used to assess current nitrogen loading to the lagoon and predict conditions that may result from new development and eventual build-out of the watershed. The model takes into account a variety of nitrogen sources including sewage, fertilizers, road runoff, and precipitation. The results of the preliminary model runs indicated OSDS contributed 12 percent of the nitrogen load to the lagoon.

H&W originally developed the model for projects in New England. In order to adapt the model for use in the Indian River Lagoon watershed, it was determined that a calibration step was necessary with regard to the part of the model dealing

with nitrogen related to (OSDS) nitrogen sources. This report discusses that calibration step.

In order to calibrate the model, H&W developed a series of eight test sites within the Indian River Lagoon watershed (Figure 1). The locations of the proposed test sites were established with the assistance of the IRLNEP and local health and environmental agencies. The selection criteria used for the identification of candidate sites included:

- Location within the Indian River Lagoon watershed,
- Relatively homogeneous dense residential land use with OSDS,
- Available land use information,
- Availability of soils and hydrogeologic information,
- Site suitability for development of large capture zone pumping wells,
- Accessibility for well installation and water sampling, and
- Local interest and community support.

The eight test sites include the following locations:

Brevard County

- Port St. John (corner of Haverhill and Espanola).
- Palm Bay (across from 321 Krefield), and
- Riverside Landing area (Ivory Street near Island Drive),

Indian River County

- Sebastian Highlands (George and Vine Streets)
- River Shores (12th and 4th Streets)

St. Lucie County

- St. Lucie Village (opposite 2931 Indian River Road)

Martin County

- Jensen Beach (across from 4240 Indian River Drive)
- Rio area (River Terrace)

Port St. John, Palm Bay, Riverside Landing, and Sebastian Highlands were grouped as the Northern Sites for sampling events and River Shores, St. Lucie Village, Jensen Beach, and Rio were designated the Southern Sites.

In order to calibrate the model, H&W designed a water sampling strategy (capture zone sampling) that goes beyond simple monitoring well construction and sampling. The system provides a unique design for obtaining groundwater data for model calibration data that are representative of the area under study.

A groundwater monitoring system was installed at each of the study sites. Site-specific hydrogeologic and groundwater data were collected and a groundwater model was developed for each site. The groundwater model was used to identify the areal extent of groundwater drawdown under pumping conditions and the groundwater capture zone, defined as the area of land contributing groundwater to the well. Individual site locus maps, pumping drawdown maps, and mapped capture zones are presented in Figures 2 through 25.

Site-specific land use data was collected from each site and entered into the nitrogen loading model to predict groundwater nitrogen concentrations. In normal application, the nitrogen loading model would be used to predict groundwater concentration and the resulting nitrogen loading to the lagoon would be based on the volume of groundwater discharge.

Following the initial model run, the groundwater monitoring system was used to collect representative samples of groundwater by pumping all three sampling wells simultaneously at up to 50 gallons per minute each to establish large capture zones. The concentrations of nitrogen in groundwater samples collected with the capture zone sampling methodology were compared to model predictions and used as a basis for model calibration and discussion.

In addition to collecting groundwater samples for analyses of nitrogen concentrations, groundwater was tested for other wastewater-related contaminants and general water quality parameters to develop a more complete understanding of groundwater conditions.

2.0 WATER SAMPLING STRATEGY

2.1 Hydrogeologic Analysis

The surficial aquifer is comprised of unconsolidated sand, limestone, coquina and clay and extends over most of the watershed to the lagoon except in the western portion of Volusia County where the underlying Hawthorn Formation is exposed at land surface. Steward and VanArman (1987) refer to the units comprising the surficial aquifer as the Fort Thompson Formation, located in the western parts of the counties and the Anastasia and Tamiami Formations, both located in the eastern parts of the counties. Within this report, these formations will be taken as a whole and will be referred to as the surficial aquifer. This aquifer varies in thickness from zero feet, in the far western parts of the counties, to 150 feet thick in the eastern parts (Woodward-Clyde, 1994, Steward and VanArman, 1987).

The surficial aquifer is recharged by precipitation over its entire areal extent. Ground water within this aquifer flows from areas of high hydraulic head to areas of lower hydraulic head such as rivers, ponds, lakes and the lagoon. In some instances in the western portions of the counties water from the surficial aquifer may seep into the lower aquifer to recharge it in response to a greater hydraulic head in the surficial aquifer (Steward and VanArman, 1987). In the south eastern parts of the watershed where the confining unit is thick, ground water in the surficial aquifer is prevented from migrating downward into the Floridan Aquifer and discharges into the lagoon. Since most of the septic systems exist in the eastern portions of the counties where the population is greatest, virtually all of the effluent from these OSDS which discharge to the ground end up in the lagoon.

Four monitoring wells were installed in clusters at eight study sites in the Indian River Lagoon watershed. Each well was installed to a depth of approximately 25 feet. At each site, three wells were installed in-line approximately equidistant from one another and aligned perpendicular to the estimated groundwater flow direction for the site. A fourth well was installed upgradient or downgradient from the line of wells to provide data on local hydraulic gradients.

To determine the representative hydraulic conductivity or permeability for each site, single-well pumping tests were conducted at three monitoring wells at each of

the eight study sites. At each well, a submersible pump was used to extract water at a constant rate until equilibrium was achieved with respect to drawdown in the well. A summary of the pumping data is provided in Tables 1 and 2 for the Northern and Southern Sites.

The drawdown and pumping data were used in conjunction with measurements of the physical parameters of the well to calculate a hydraulic conductivity value for local sediments. The Hvorslev (1951) method for single well pump tests was utilized to calculate the hydraulic conductivity at each well. The hydraulic conductivity is determined using the following equation:

$$K = \left(\frac{F}{2\pi LH} \right) * \ln \left(\frac{L}{S} + \sqrt{1 + \left(\frac{L}{S} \right)^2} \right)$$

where;

K = hydraulic conductivity (length/time),

F = flow rate measured at outlet of pump (volume/time)

L = screen length, if water level at end of test is lower than top of screen, then

L equals the distance from the final water level to the bottom of the screen,

H = difference between static and final water level elevations (L), and

S = screen diameter (L), 0.333 ft for all wells.

Hydraulic conductivity values for each of the well tests are provided in Table 3, along with a mean value for each study site. The results indicate that the sediments at each site are fairly homogeneous, with only minor variations in the conductivity values from well to well. However, a wide variety of sediment types are represented in these eight sites. The Riverside Landing site is highly conductive (180.9 ft/day), and the Sebastian site (3.9 ft/day) is highly constricted with respect to groundwater flow.

Table 1. Pumping Test Data, Northern Sites.

Site and Well Name	Static Groundwater Elevation (ft)	Pumping Rate (gpm)	Pumping Duration (hrs)	Well Depth (ft)	Static Depth to Water (ft)	Depth to Water, During Pumping (ft)	Drawdown (ft)
<u>Riverside Landing</u>							
rl1	94.75	40	3.5	24.0	5.25	7.00	1.75
rl2	94.83	50	3.5	24.0	4.95	7.00	2.05
rl3	94.89	50	3.5	24.0	4.60	7.50	2.90
rl4	94.63	na	na	24.0	5.00	Na	
<u>Sebastian</u>							
seb1	96.01	3	1	24.5	3.99	17.50	13.51
seb2	96.15	3	1	24.7	3.90	19.90	16.00
seb3	96.57	3	1	24.5	3.53	20.10	16.57
seb4	97.07	na	na	24.2	3.25	Na	
<u>Port St. John</u>							
psj1	94.9	25	6	25.0	5.10	9.80	4.70
psj2	95	25	6	23.5	5.16	11.05	5.89
psj3	95.12	25	6	23.5	4.98	10.95	5.97
psj4	95.87	na	na	23.8	4.53	Na	
<u>Palm Bay</u>							
pb1	97.21	20	5.5	23.7	2.63	11.72	9.09
pb2	97.21	17	5.5	23.7	2.50	11.90	9.40
pb3	97.27	20	5.5	23.7	2.55	11.65	9.10
pb4	97.35	na	na	23.8	2.65	Na	

Table 2. Pumping Test Data, Southern Sites.

Site and Well Name	Static Groundwater Elevation (ft)	Pumping Rate (gpm)	Pumping Duration (hrs)	Well Depth (ft)	Static Depth to Water (ft)	Depth to Water, During Pumping (ft)	Drawdown (ft)
<u>Jensen Beach</u>							
jb1	93.77	30	7	24.0	6.23	10.24	4.21
jb2	93.78	30	7	24.0	6.23	10.23	4.00
jb3	93.78	30	7	24.0	6.15	10.80	4.65
jb4	93.25	na	na	24.0	8.00	Na	
<u>Rio</u>							
rio1	93.52	30	7	24.5	6.48	14.53	8.05
rio2	93.44	25	7	24.5	6.10	15.62	9.52
rio3	93.43	25	7	24.6	5.40	12.48	7.08
rio4	93.54	na	na	24.3	7.40	Na	
<u>River Shores</u>							
rs1	97.54	25	7	24.6	2.46	15.70	13.24
rs2	97.58	15	7	24.1	2.43	15.50	13.07
rs3	97.64	12	7	24.0	2.40	9.20	6.80
rs4	97.46	na	na	24.6	3.00	Na	
<u>St. Lucie</u>							
sl1	98.1	8	6	25.0	1.90	11.80	9.90
sl2	98.09	8	6	24.7	1.62	13.23	11.61
sl3	98.11	8	6	24.2	1.65	14.85	13.20
sl4	98.04	na	na	23.5	2.70	Na	

Table 3. Hydraulic Conductivity Solutions.

Site and Well	Hydraulic Conductivity (ft/day)	Mean Site Value (ft/day)
Port St. John		55
psj1	58	
psj2	54	
psj3	53	
Palm Bay		23
pb1	24	
pb2	20	
pb3	24	
Riverside Landing		180
rl1	190	
rl2	200	
rl3	150	
Sebastian		3.9
seb1	3.6	
seb2	4.1	
seb3	4.1	
Jensen Beach		71
jb1	74	
jb2	74	
jb3	66	
Rio		40
rio1	47	
rio2	36	
rio3	38	
River Shores		20
rs1	26	
rs2	16	
rs3	16	
St. Lucie		8.0
sl1	8.2	
sl2	7.8	
sl3	8.1	

Recharge provides water to an aquifer via infiltration of precipitation. It serves as the source of water to the groundwater system which ultimately discharges to nearshore coastal waters (including the Indian River Lagoon). Recharge also dilutes pollutants which may be present in the groundwater systems. Recharge rates for the Indian River Lagoon study area were estimated based on available data. Rainfall in this region of Florida averages 52 inches per year, with an estimated 70% loss due to surface evapotranspiration (ET) (Adams, 1991). A surface runoff loss of 7.5% is considered reasonable, based on regional land uses. Total annual recharge is thus calculated as:

$$\text{Recharge} = \text{Rainfall} - \text{ET Loss} - \text{Runoff Loss}$$

This produces an estimated recharge rate of 11.7 inches per year for the study area. This rate is supported by other groundwater modeling studies conducted in the area (Fairbank and Hohner, 1995; Williams, 1995; Toth, 1995). Fairbank and Hohner (1995) presented areal recharge rates in terms of average excess precipitation, calculated as rainfall minus ET_{actual} . These produced a mean recharge rate of 14 inches per year, with a standard deviation of 2 inches per year. Toth (1995) calculated groundwater recharge rates from isotopic analysis of water samples. This study produced recharge rates ranging from approximately 6 to 12 inches per year for sites in the St. Johns River Management District. Williams (1995) presented the results of a groundwater modeling study conducted in Brevard County. Model calibration results indicated that recharge rates ranged from 6 to over 12 inches per year in that study area. The results of each of these studies, when viewed in unison, demonstrate that there is a range of recharge rates that may be considered applicable for the Indian River Lagoon study area. These recharge rates are dependent on time, location, and method of analysis used to determine the recharge rate.

Assuming a soil porosity of 33%, this corresponds to an annual contribution of 2.95 feet to the water table aquifer (Table 4, below). In other words, groundwater flowing through the system is depressed 2.95 feet in elevation per year as it moves through the aquifer. This final calculation was used to calculate the extent of the capture zones for each of the study sites. The width of the capture zones were determined from the field data and deterministic MODFLOW models, as described in the following section.

Table 4. Recharge Calculations.

Parameter	Value
Recharge Rate	52 in/yr
Evapotranspiration Loss	70%
Runoff Loss	7.5%
Recharge Rate	11.7 in/yr

2.2 Capture Zone Modeling

To determine the effective area of groundwater captured by the three downgradient monitoring wells, a series of groundwater models was applied. The first model utilized was the three-dimensional numerical model MODFLOW (McDonald and Harbaugh, 1983). It was selected as the groundwater model for this investigation because of its powerful modeling and output visualization capabilities and is considered the industry standard for groundwater modeling.

The objective of this modeling analysis is to determine the pumping time required to ensure that the net drawdown cone for the three wells captures the area between the wells, while extending upgradient as far as possible in a practical amount of pumping time (less than eight hours). Pumping schedules were tested at each site based on the pumping rates used in the single well pump tests described above. The model output data were analyzed to determine the optimum pumping schedule for sampling at the water wells.

A generic MODFLOW model grid was created for the study sites. Site-specific well locations and hydrogeologic data were provided separately for the analysis of each site. Specific hydrogeologic data used in the model for each site were taken from the well test information (Tables 1, 2, and 3).

The MODFLOW grids consisted of cells that were 1-foot by 2 feet in the x and y directions, respectively. The hydraulic gradient across the model domain was established based on field measurements of hydraulic head at the sites. These were represented in the MODFLOW models as constant head cells on either side of the domain, with the heads specified to simulate the observed hydraulic gradients.

The models represent flow along the gradient, and the boundaries to the north and south are represented as no-flow cells.

The models were each run under steady state conditions without pumping. The final modeled heads were used as input conditions for the transient pumping models. Each site model was run with an eight-hour pumping schedule, segmented into one-hour increments. The output data were analyzed to determine the development of the composite drawdown cone for each site over the pumping period.

Pumping strategies for future sampling events were selected based on the development of the drawdown cones. The optimal pumping time required prior to sampling is defined as the time needed for the drawdown cones for the individual wells to intersect and have a composite drawdown of at least 0.3 feet between the wells. The recommended pumping schedules for each of the sites is shown in Table 5. Full connection of pumping wells were applicable required up to twenty hours at some sites. However, a practical pumping limit of eight hours was estimated to provide a representative capture zone sample and was applied to each study site. Insufficient flow was obtained from the Sebastian site, and wells were bailed rather than pumped. Color-shaded contour maps of the composite drawdown cones for each site illustrate the total drawdown due to pumping at the end of the recommended pumping period for each site.

**Table 5. Recommended Pumping Schedules for Sampling,
Based on MODFLOW Model Results.**

Site	Pumping Rate* (gpm)	Pumping Time (hrs)
Port St. John	25/25/25	8
Palm Bay	20/17/20	8
Riverside Landing	40/50/50	8
Sebastian	NA	NA
River Shores	25/15/12	8
St. Lucie	8/8/8	8
Jensen Beach	30/30/30	8
Rio	30/25/25	8

*Pumping rates shown indicate the respective rates for wells 1, 2 and 3 at each site.

The lateral widths and downgradient limits of the capture areas for each well site were determined using MODFLOW. Recharge rates were used in conjunction with site hydrogeologic data to determine the upgradient limits of the capture zones. Assuming a soil porosity of 33%, this corresponds to an annual contribution of 2.95 feet to the water table aquifer. In other words, groundwater flowing through the system is depressed 2.95 feet in elevation per year as it moves through the aquifer. This final calculation was used to calculate the extent of the capture zones for each of the study sites.

Given that groundwater flowing through the water table aquifer is depressed 2.95 feet in elevation each year due to recharge contributions, it was possible to compute the approximate distance upgradient that is represented by the water samples. Distance is computed by:

$$X = \left(\frac{Ki}{n} \right) \frac{h_{sample}}{y_{rate}}$$

where;

X = upgradient distance (length),

K = hydraulic conductivity (length/ time),

i = hydraulic gradient (dimensionless),

n = porosity (dimensionless),

h_{sample} = depth of water sample (length), and

y_{rate} = rate of groundwater elevation decrease (length/ time).

The distance calculation assumes an aquifer of infinite extent. Final determinations of the representative capture zone for the water samples included consideration of local hydrologic features such as groundwater divides and the presence of surface water bodies. The calculation also assumes there are no major changes in geology in the upgradient area. Upgradient distances vary in proportion with local hydraulic conductivity (Table 6). Sites that exhibit low hydraulic conductivities

have shorter distances to the upgradient limit and derive water from areas closer to the wells.

Table 6. Upgradient Distance Represented in Water Samples.

<u>Site</u>	<u>Distance (ft)</u>
Port St. John	1680
Palm Bay	215
Riverside Landing	1100
Sebastian	na
River Shores	55
St. Lucie	70
Jensen Beach	650
Rio	1200

3.0 NITROGEN LOADING MODEL

Horsley & Witten developed the nitrogen spreadsheet model used to estimate nitrogen loading and predict nitrogen concentrations in groundwater (Nelson et. al, 1988). The model quantifies the contribution of nitrogen loading from each nitrogen source within the capture zones, and calculates the total mass of nitrogen (lbs/year) discharged annually and predicts the concentration of nitrogen in groundwater. This method has been used extensively for quantifying nitrogen loads to surface and ground waters. In particular, the model has been approved by the Massachusetts Department of Environmental Protection to predict nitrogen concentrations in water contributing to drinking water wells (Horsley & Witten, 1996). The model has also been utilized to estimate nitrogen loading in several estuarine embayments as part of the EPA-sponsored Buzzards Bay National Estuary Program (Horsley & Witten, Inc., 1991) and the Delaware Inland Bays Program (Horsley & Witten, Inc., 1997).

Nitrogen is present in groundwater as nitrate (NO_3), nitrite (NO_2), ammonia (NH_3) or organic nitrogen. The loading rates used in the model represent total nitrogen values. The loading methodology quantifies the amount of nitrogen as the total amount that can enter the lagoon and affect water quality. Total nitrogen is equal to total Kjeldahl nitrogen (TKN) plus nitrate. TKN is the sum of organic nitrogen (amino acids) and ammonia. Nitrate and nitrite are inorganic forms of nitrogen.

The model accounts for all sources of nitrogen in the analysis, including on-site disposal systems (OSDS), lawn fertilizers, stormwater runoff from roads, sidewalks, and roofs.

Inputs to the nitrogen loading model consist of the area of the modeled capture zone, the number of homes within the capture zone, fertilized lawn areas, impervious surfaces, (roofs, driveways, sidewalks and roads), the number of people per home generating wastewater, and the percentage of seasonal residences.

The numbers of homes and vacant lots, roof size and lawn size were measured and estimated through visual surveys of the neighborhoods, from satellite imagery (www.terraser.com USGS, March 1994, February 1995), and assessor's maps of each area. Home lots that were bisected by the modeled capture zone were included based on the percentage of the lot within the capture area. If 25% or more of the home lot was within the capture area, the lot was counted and it was assumed that the OSDS fell within the capture area boundary.

3.1 Nitrogen in OSDS Effluent

Wastewater flow generation was estimated at 55 gallons per person per day and the effluent nitrogen concentration at 35 mg/l. The quantity of nitrogen produced by a given on-site sewage disposal system is a function of the volume and concentration of the effluent discharged, which in turn is dependent on the per capita water usage and the occupancy rate. Daily rates of water use may range from 36 to 150 gallons per person per day (Nelson, et al, 1988), with average rates ranging between 50 to 75 gallons per day (gpd). In estimating sewage flow rates, however, it is important to differentiate between the amount of water actually used and the amount ultimately discharged to ground water as sewage flow. Typically, 20% of the water used may be lost through evaporation or transpiration during irrigation and other outside uses. For the purpose of this study, a ground water discharge rate of 55 gpd per person was used for sewage flow.

A review of the literature indicates that nitrogen concentrations in raw sewage can range from 20 to 100 mg/l. In a properly functioning OSDS, some removal of this nitrogen occurs within the septic tank and in the soils below the leaching area.

Studies have indicated that between 30 to 60% of the nitrogen may be removed in this manner (Porter, 1978; Andreoli et al., 1979). Literature values for total nitrogen concentrations in effluent sampled either from the leaching area or from ground water immediately below the leaching area are summarized in Table 7.

Table 7. Summary of Total Nitrogen Concentrations in OSDS Effluent

<u>Source</u>	<u>Concentration</u>
Bouma et al., 1972	30 mg/l
Walker et al., 1973	40 mg/l
Magdoff, 1974	31 mg/l
Reneau, 1977	23 mg/l
Ellis, 1982	34 mg/l
Nelson, et al., 1988 (summary)	34 mg/l

These reports suggest that an average effluent concentration of nitrogen of 35 mg/l is a conservative yet representative value to use. While this concentration would apply to an effluent for a combined graywater/blackwater system, the loading calculated from this concentration and wastewater flow would also apply to houses with separate graywater/blackwater systems.

3.2 Nitrogen in Lawn Fertilizers

The model uses input for amounts of fertilizer applied to lawns. On an annual basis it has been estimated that three pounds of nitrogen per 1,000 square feet per year is applied to a typical lawn in Massachusetts (Nelson, et al., 1988; Horsley & Witten, Inc., 1991). Similar fertilizer application rates were found in a 1995 study by University of Florida Cooperative Extension (Knox, et. al, 1995).

For this study, fertilized lawn areas were estimated by visual survey in the field. Lawns that appeared healthier (greener) and irrigated were assumed to have been fertilized. Suburban lawns areas are typically 5,000 square feet on average (Nelson, 1988). Comparison of satellite imagery and field surveys within the study areas confirm this estimate to be reasonable.

3.3 Nitrogen in Stormwater Runoff

In the study area, stormwater runoff from roads and driveways was generally diverted through stormwater drainage systems to areas outside of the capture zones. Therefore stormwater runoff does not contribute nitrogen directly to the modeled capture zones. However, roofs may contribute stormwater to the groundwater. Based upon visual surveys of each area, approximately 25% of the runoff from roofs was diverted to the driveway, which was then connected to the stormwater drainage system. The remaining 75% of the roof drainage was directly recharged to the property. Therefore, the roads, driveways and 25% of the roof area were not considered part of the total recharge area in the nitrogen loading model and were subtracted from the total modeled recharge areas for each site (Table 8). Runoff from sidewalks was typically recharged directly back to adjacent groundwater and was considered paved area recharged on-site in the model.

Table 8. Extent of Recharge in Pervious and Impervious Areas

Percentage of Areas Recharged <u>On-Site</u>	Percentage of Areas Recharged <u>Off-Site</u>
100% sidewalks	100% roads
75% roofs	100% driveways
	25% roofs

A recharge rate of 12 inches per year was used for pervious surfaces and 46.8 inches per year for impervious surfaces, based upon 90% of the annual rainfall of 52 in/yr (Horsley & Witten, Inc., 1996, Adams, 1991). Recharge to impervious (paved) surfaces is greater because there is no loss through evapotranspiration.

3.4 Population Data

Occupancy and population estimates for each site were obtained by examining 1990 U.S. Census data. Each area's census tract was identified. Information obtained included the number of people within a tract and the number of households. These data were used to estimate the number of people per

household. The Table 9 summarizes the number of people per household within the study areas.

Table 9. Population Data (U.S. Census data, 1990).

Site	Number of people/household
Port St John	2.43
Palm Bay Site	2.95
Riverside Landing	2.23
Sebastian	2.31
River Shores	No data found
St. Lucie	2.77
Jensen Beach	2.41
Rio	2.09

The seasonality of Florida's population was examined to provide a best estimate of the volume of wastewater discharged. A phone survey was conducted by the University of Florida, Bureau of Economic Resources and Business concerning Florida's "snowbird population" (Galvez, 1997). Results of the study indicated that in the central region of Florida, which includes Brevard County, 13% of the population are "snowbirds" who reside in Florida an average of 5.2 months per year. The other counties of interest, St. Lucie, Martin, and Indian River, were located in the Southeast region. The southeast region had a higher percentage of "snowbirds," with 35% of the sampled population staying an average of 6.1 months of the year.

The Martin County Growth Management Department was contacted and provided a March 1998 Technical Bulletin with information on seasonal populations derived from occupancy permits and electricity usage. Information was grouped by Traffic Planning Zones. The Palm City Traffic Zone includes the Palm Bay study site. The study estimates in April 1999 that the peak population in this area increased by 3,613 people or 18% of the total area population, which falls within the range found by Galvez, 1997.

Water usage data was obtained for two other study sites, Port St. John and Riverside Landing, both within Brevard County. Water supply is serviced to Port St. John by the City of Cocoa, and Riverside Landing is served by the City of Melbourne. The City of Cocoa provided information which indicated a single property within the Port St. John study site had no water usage since May of 1999; this property is assumed to be a seasonally operated home. Based on this information, the percentage of seasonal homes in Port St. John is 6%.

As with the Port St. John site, the Riverside Landing site had one seasonal home used, or 14% of the properties within the study area. Thus the frequency range of seasonally occupied homes varies between 6% and 14%. These ranges coincide with those estimated by the University of Florida in the Central Region that includes Brevard County. Based on these reviews, seasonal population estimates from the University of Florida study were used, with 13% for Brevard County and 35% for the other study sites located in the south central region.

4.0 FIELD INVESTIGATIONS

4.1 Well Installation

A total of four 4-inch diameter polyvinyl chloride (PVC) groundwater monitoring wells were installed using the hollow stem auger drilling method at each site location in January and February of 1999. Boring logs are included in Appendix A. Three of the wells were arranged as pumping wells in an orientation perpendicular to the estimated direction of groundwater flow. These wells were spaced evenly, with the distance between them determined by the well yields at each location. One well was located upgradient or downgradient from the pumping wells to determine the direction of groundwater flow.

Each well was installed to a depth of approximately 25 feet. Filter sand was filled around the screens. Expandable locking plugs were placed on the top of each riser and a flush-mounted road box was cemented around the PVC pipe. During well installation, soil samples were collected from selected borings from below the water table and analyzed for total phosphorous. Following well installation, water levels were measured to determine the direction of groundwater flow.

4.2 Groundwater Sampling

Groundwater was sampled on three separate occasions from March through October of 1999, to represent spring, summer and fall conditions. Pumping times for each site were consistent within each sampling round but varied between the spring, summer and fall rounds (7 hours in spring, 3.5 - 4 hours during the summer, and 8 hours during the fall). Pumping times during the summer event were adjusted in the field based on the stabilization of field parameters.

Pumping rates varied by site, based on the local geology, ranging from 15-50 gpm. At each study site the three sampling wells were pumped simultaneously. Two sites, Sebastian and St. Lucie, exhibited low pumping yields and could not be pumped for long periods of time. Groundwater at these two sites was purged of 3 well volumes prior to sampling. For the remaining sites where well yield was adequate, a 2-inch hose was placed approximately 17 feet below ground surface and pumped water was discharged hydraulically downgradient of the wells. Specific measurements such as depth to groundwater, pumping rate, and pumping time etc. are presented on the field logs for each site (Appendix B).

Field parameters were monitored periodically during pumping using a Hydrolab Surveyor/MiniSonde multiparameter probe. Field parameters included dissolved oxygen, salinity, pH, specific conductance, and temperature. Groundwater was pumped out of the well and continuously discharged into a 5-gallon bucket where the parameters were measured. Measurements were taken every 0.5 hour until the parameters stabilized.

Groundwater samples were collected at the end of the pumping period from each of the three installed monitoring wells. After pumping water samples were taken from each discharge hose from the three wells, and a field duplicate was taken from one well. Samples were placed in a cooler with ice and transferred to the laboratory at the end of each day. Laboratory samples were submitted to the Brevard Teaching & Research Laboratory in Palm Bay, Florida (now Midwest Research Institute) for analysis. Laboratory methods are included in Water samples were analyzed for nitrate, nitrite, ammonia, total organic carbon, total Kjeldahl nitrogen (TKN), total phosphorus, chloride, and fecal coliform bacteria.

Table 10. Laboratory Analysis Methods

Parameter	Method
Total Kjeldahl Nitrogen	EPA 351.2
Nitrate	EPA 353.2
Ammonia	EPA 350.1
Total Phosphorus	EPA 365.4
Chloride	EPA 300.0
Total Coliform	EPA SM9221B
Total Organic Carbon	EPA 415.1

During the third round of sampling, additional laboratory samples were collected and changes in field parameter methodology were made to clarify site conditions.

- Samples were taken with a polyethylene bailer and the duplicate was taken from the discharge hose at all sites to detect any differences in ammonia concentrations due to potential volatilization in air.
- Depth profiles for salinity were taken at sites which exhibited high chloride values during the first two rounds, River Shores and Riverside Landing, using the Hydrolab multiprobe to determine potential saltwater contamination. Dissolved oxygen content was also measured in-situ.
- Total organic carbon was added as a parameter for analysis in the groundwater samples at several sites, Port St John, Riverside Landing, Sebastian, River Shores, Jensen Beach, and Rio, because it serves as an energy source for denitrifying bacteria.
- Dissolved oxygen was measured at all sites both in the well and in a bucket after pumping.

4.3 Field Data Collection for the Nitrogen Loading Modeling

Site specific land use information was gathered at each site and input into the nitrogen loading model determine the annual nitrogen loading and the predicted nitrogen concentration in groundwater. A summary table of the model inputs and results for each site is provided (Table 11). A brief description of field data and

derivation of the inputs for each site is provided below. Nitrogen Loading Model spreadsheets are included in Appendix C.

The Port St. John modeled capture zone included fifteen lots, including six lots containing single family residences, one containing a single story office building, four vacant lots and four with less than 25% of their area contained within the capture zone. The office building was assumed to have the same wastewater loading as a single-family residence. A stormwater drainage system for roads diverted road runoff outside of the capture zone. One lawn within the capture zone appeared to be fertilized.

The Palm Bay modeled capture zone was relatively small due to limited pumping capacity. Two lots were contained within the capture zone, including one with a single-family residence, and a vacant lot with trees and natural vegetative cover. Stormwater drainage for the road system in the area diverted stormwater runoff to a canal outside of the capture zone.

The modeled capture zone at the Riverside Landing site contained eight lots, seven of which contained single family residences and one of which was vacant. All developed home lots appeared to have fertilized lawns. Stormwater from impervious surfaces within the capture area is diverted to a detention pond outside of the capture zone. A third of the stormwater loading to the detention pond was included in the model to account for this additional runoff. A second nitrogen model was run for Riverside Landing to verify locations of OSDSs. Compared with other study sites, Riverside Landing was a newer subdivision and homes were designed with pools and enclosed porches in the backyards. To confirm the placement of OSDSs on these lots, data on their locations within the lots were obtained from the Brevard County Environmental Health Services. Using this new data, four OSDSs were located outside of the capture zone, lowering the number of septic systems to three and thus lowering the predicted nitrogen loading and groundwater concentration.

The River Shores modeled capture zone, similar to the Palm Bay site, was relatively small due to the limited pumping capacity at the site. Contained within the capture zone was one vacant lot with natural vegetative cover. There were no impervious surface, homes, lawns, or on site disposal systems included in the capture zone.

Table 11. Summary of Nitrogen Model Inputs and Results

Nitrogen Model Input	Port St. John	Palm Bay	Riverside Landing	Riverside Landing (verified)	River Shores	St. Lucie	Jensen Beach	Rio
Total Recharge Area (acres)	3.33	0.50	2.18	2.18	0.2	0.20	7	2.86
Total # Lots	15	2	8	8	0	0	2	20
# OSDS	7	1	7	3	0	0	2	14
% Seasonal Population	13%	13%	13%	13%	0	0	35%	35%
# People/Home	2.43	2.95	2.23	2.23	0	0	2.41	2.09
# Fertilized Lawns	1	1	7	7	0	0	1	0
Average Roof Size (sq ft)	1500	1600	2500	2500	0	0	2500	1500
Recharged On-Site Impervious Surface (sq ft)	400	0	37,070	37,070	0	0	19707	4800
Recharged Off-Site Impervious Surface (sq ft)	25,300	1,150	14,771	14,771	0	0	0	24,800
Modeled N-load (lbs/acre)	99	21	118	71	0.04	0.04	94	192
Modeled N-concentration in groundwater (mg/l)	7.44	10.11	8.86	6.00	0.08	0.08	7.92	12.4

The St. Lucie site wells also exhibited limited pumping capacity, thus limiting the size of the capture zone. Most of the area contained within the capture zone area was impervious. No developed lots were within the modeled capture zone. A storm drainage system was noted within the capture zone and it was assumed to divert stormwater to the Indian River Lagoon.

The Jensen Beach site capture area contained two distinct land uses, separated by a gravel bed railroad track. On the west side of Indian River Drive within the capture zone was an apartment complex. Further west within the capture zone closer to Skyline Drive, there is a single-family residential neighborhood. Six apartment units and one residential home were contained within the capture area. Impervious areas included portions of Indian River Drive and a parking lot associated with the apartment building. No stormwater drainage system was noted along Indian River Drive or within the parking lot for the apartment complex; these areas were considered as recharged on site.

Single family residential home land use was characteristic of the Rio site. Typically several small, narrow lots (25' x 100') were combined to form one residential home lot. The total number of residential lots within the capture zone was twenty. Six had less than 25% of their area within the capture zone and were excluded, resulting in fourteen homes within the capture zone. Lawns did not appear to be fertilized in this area. A stormwater drainage system diverted stormwater outside of the capture zone and into the Indian River Lagoon.

Field data were gathered to verify and calibrate the modeled results. Many environmental parameters may affect nitrogen concentrations in groundwater, including the hydrology (precipitation, recharge to aquifer), sampling methodology, aquifer characteristics, and other factors such as dissolved oxygen and total organic carbon. These data were collected to assist in the interpretation of the results.

5.0 DISCUSSION

5.1 Precipitation at Study Sites

Precipitation data were gathered from the National Weather Service from the website www.srh.noaa.gov for two representative sites, Melbourne and St. Lucie stations. The Melbourne site is representative of the northern study sites Port St. John, Riverside Landing, Palm Bay and Sebastian. The St. Lucie site is representative of the southern sites River Shores, St. Lucie, Jensen Beach, and Rio. Figures 26 and 27. show precipitation data for the entire sampling period. Precipitation data three days prior to the sampling events were further evaluated for any potential effects related to an individual sampling events (Table 12). With few exceptions, groundwater sampling occurred during periods of little precipitation within the three days prior to sampling. The exceptions included the September sampling events at Port St. John, Riverside Landing and Sebastian which were conducted during and after heavy rainfall, with 7.98 inches of rain falling in one day.

5.2 Groundwater Elevation in Surficial Aquifer

The groundwater table increased in elevation during the study period (March through October) at each station (Figure 28.) Water levels increased by approximately 2 feet at Port St. John and Riverside Landing. Water levels at the Palm Bay and Sebastian sites increased slightly more, by 3.0 feet and 2.6 feet, respectively. The southern sites, River Shores, St. Lucie, Rio, and Jensen Beach experienced similar increases in water elevation to the northern sites. Water elevation increases ranged from 1.4 feet at River Shores to 2.3 feet at Rio.

The water table elevations coincide with the amount of rainfall noted during the times of sampling, with spring months dryer than the later months of sampling.

5.3 Salt Water Intrusion

Two sites exhibited chloride concentrations indicative of the presence of salt water (Riverside Landing and River Shores). Vertical profile sampling of salinity was performed in wells at these sites. Data from the Riverside Landing site indicates a

Table 12. 1999 Rainfall Data Three Days Prior to Sampling Events.

Date	Sites Sampled	Melbourne Rainfall (inches)	Date	Sites Sampled	St. Lucie Rainfall (inches)
March 19		0.00	April 23		0.00
March 20		0.00	April 24		0.00
March 21		Trace	April 25		0.00
March 22	Palm Bay	0.00	April 26	River Shores	0.00
March 23	Port St. John	0.00	April 27	St. Lucie	0.00
March 24	Sebastian	Trace	April 28	Jensen Beach	0.37
March 25	Riverside Landing	0.00	April 29	Rio	0.12
June 12		0.00	June 20		1.60
June 13		0.00	June 21		0.00
June 14		0.00	June 22		0.31
June 15	Sebastian, Port St. John	0.00	June 23	River Shores, St. Lucie	0.00
June 16	Riverside Landing, Palm Bay	0.93	June 24	Jensen Beach, Rio	0.00
September 22		0.00	October 5		0.81
September 23		0.00	October 6		0.00
September 24	Palm Bay	0.00	October 7		0.00
September 25	Port St. John	7.98	October 8	St. Lucie	0.51
September 26	Riverside Landing, Sebastian	0.26	October 9	Jensen Beach	0.01
			October 10	Rio	0.00
			October 11	River Shores	0.00

steep gradient, with more fresh water found in the top 20 feet of the well and more saline water, 18 ppt range in the bottom 5 feet, for comparison open ocean water is 35 ppt (Figure 29). Data from the River Shores site indicates a gradually more saline environment (Figure 30). The average percentage of salt water dilution of the samples taken at these sites was calculated using 35 ppt as a 100% solution. Riverside Landing and River Shores samples were found to have a 3% and 6% saltwater content, respectively. Consequently, the groundwater samples at these sites may be diluted with salt water by 3% and 6%.

The percent of salt water in the sample is important to detect any salt water intrusion from the Lagoon. The salt water would not contain OSDS loading of nitrogen and it would have negligible concentrations of nitrogen, thus salt water could dilute the concentration of nitrogen detected in the sample. The percentage of dilution was calculated based on the chloride concentration and then subtracted from the total volume. A criteria of 0.900 ppt or 900 mg/l of chloride was used to indicate salt water influence. Saltwater in the open ocean is approximately 35 ppt. The criteria is equivalent to approximately a 3% salt water concentration.

5.4 Discussion of Water Quality Analyses

Field and laboratory analytic data collected during the course of the study were examined for comparison with model results and to develop an understanding of groundwater conditions. Laboratory data are included in Appendix D.

5.4.1 Quality Control Review

Groundwater samples were shipped under chain-of-custody to Brevard Teaching and Research Laboratories, Inc. for analyses. Samples collected for each sampling round at each study site included one laboratory duplicate. A review of laboratory records for the data set indicates that:

- All laboratory blanks were below method detection limits,
- Matrix spike recoveries were within acceptable limits, and
- Duplicate samples demonstrated acceptable reproducibility.

Fecal coliform samples were run within 24 hours, which is beyond certified hold times due to limitations of the sampling program possibly resulting in an over estimation of coliform .

Field duplicates at each site were taken from one well. Nitrogen concentrations between duplicate samples of the same well were within the standard deviations found between all wells. Chloride levels were highly variable between duplicates and individual wells at each site.

Figures 31 through 36 represent water quality data from the sampling sites taken in spring, summer, and fall of 1999. Three wells at each station were sampled after being pumped or bailed. One duplicate sample was taken for one of the wells. The concentrations in the summary Figures represent averages of the three wells sampled at each site for each sampling event.

5.4.2 Chloride

Chloride, as noted earlier, was significantly higher at Riverside Landing and River Shores (Figure 31). This may be due to salt water intrusion at these sites. The other sites exhibited levels of chloride ranging from approximately 400 mg/l to 50 mg/l. A large amount of variability was seen in the chloride concentrations, even between wells at the same site. The chloride data revealed no obvious seasonal or geographical trends.

Chloride in the groundwater may not always be indicative of salt water intrusion. The water in the surficial aquifer is largely not utilized as a drinking water source because it is usually highly mineralized (Woodward-Clyde, 1994b). Chloride levels have been shown to vary from 250 mg/l to upwards of 10,000 mg/l (Steward and VanArman, 1987). On average, most chloride levels are within the range of 250 mg/l to 1,000 mg/l (Woodward Clyde, 1994b).

5.4.3 Nitrogen

Nitrogen speciation is sensitive to environmental conditions, thus nitrogen is found in various forms in the environment. The nitrogen species analyzed included ammonia nitrogen (NH_3), inorganic nitrate nitrogen (NO_3), and total Kjeldahl

nitrogen (TKN), which is a measure of both organic and ammonia nitrogen. Total nitrogen is the combination of TKN (organic and ammonia) and inorganic nitrate. The nitrogen loading model represents total nitrogen; thus comparison between total nitrogen measured in the field is appropriate.

The sample averages of the three wells from each site were calculated for TKN (Figure 33), ammonia-N (Figure 34), nitrate-N (Figure 35), total nitrogen (Figure 36). Average concentrations of total nitrogen ranged from < 1 mg/l to > 4 mg/l. The widest ranges in total nitrogen concentrations were found at the Jensen Beach and Rio sites. Both sites had spring and summer concentrations of total nitrogen of less than 1.0 mg/l, while average September concentrations were approximately 4 mg/l.

Standard deviations were calculated for averages of total nitrogen and compared at each site to distinguish any seasonal variations (Figures 37 and 38). Review of these data indicate no distinguishable seasonal variation, with the exception of Jensen Beach and St. Lucie sites, where the September monitoring shows a slight increase in total nitrogen. The large standard deviations at the Rio and Jensen Beach sites are due to differences in nitrate concentrations found at one well during the September sampling round.

Nitrogen speciation was plotted at each site for each sampling round to distinguish the relative forms of nitrogen found (Figure 39). Nitrate, the most bioavailable form of nitrogen, was found in very low concentrations at several sites and was found at or near the limits of detection at many sites. Sites that had consistently low concentrations over the time of sampling for nitrate include Palm Bay, Sebastian, River Shores, and St. Lucie. Port St. John, Riverside Landing, Jensen Beach and Rio samples had nitrate present during each sampling event. Ammonia nitrogen was found at each site where measured. No ammonia results are available for River Shores, St. Lucie, and Jensen Beach for the Spring sampling round due to a laboratory error.

There were no discernible differences in total nitrogen concentrations between low and high yield wells from different sites (Figure 40).

Concentrations of nitrate nitrogen were plotted against total organic carbon concentrations from the fall sampling round to determine any relationships. With the exception of the two outlying data points found at Jensen Beach and Rio, the graph depicts a strong negative relationship between concentrations of total organic carbon and nitrate concentrations.

5.4.4 Dissolved Oxygen Concentrations

Dissolved oxygen concentrations measured in-situ during the final sampling round were less than 1 mg/l at all sites (Figure 41). Measured concentrations may have been artificially elevated in the first two sampling rounds due to the sampling methodology. Dissolved oxygen concentrations found in the first two sampling rounds ranged from less than 1 mg/l to greater than 3 mg/l. The sampling protocol was changed during the third sampling event to more accurately measure in-situ concentrations.

5.5 Comparison of Modeled Total Nitrogen to Predicted Total Nitrogen

Total nitrogen concentrations from the field samples were compared with the model predicted concentrations (Table 13.) The predicted concentrations of nitrogen in groundwater were significantly greater than measured nitrogen in groundwater concentrations in all cases, with the exception of the St. Lucie and River Shores sites. These sites exhibited lower than predicted concentrations of nitrogen. The other sites may be exhibiting nitrogen attenuation. An empirical nitrogen attenuation factor was derived from the predicted and measured total nitrogen concentration data for those sites exhibiting nitrogen attenuation. The percentage of nitrogen attenuated ranged from 45% to 98%, with an average nitrogen attenuation factor for all sites equal to 83%.

Table 13. Comparison of Modeled Nitrogen Concentrations Results to Measured Nitrogen Concentrations.

Site	Modeled Total Nitrogen (mg/l)	Measured Total Nitrogen (mg/l)
Port St. John	7.53	
March		1.693
June		1.059
September		1.286
	Annual Average	1.346
Palm Bay Site	10.11	
March		0.939
June		0.823
September		0.577
	Annual Average	0.780
Riverside Landing Site	6.00	
March		1.490
June		0.886
September		1.747
	Annual Average	1.37
Sebastian Site	Not modeled	
March		2.031
June		2.252
September		1.888
	Annual Average	2.057
River Shores	0.08	
April		1.110
June		1.260
September		2.031
	Annual Average	1.467
St. Lucie	0.08	
April		0.654
June		0.586
September		2.301
	Annual Average	1.180
Jensen Beach	7.92	
April		0.613
June		0.679
September		4.343
	Annual Average	1.878
Rio	12.4	
April		0.291
June		1.150
September		4.071
	Annual Average	1.837

5.6 Controlling Factors in Nitrogen Model

Three factors have the most significant effect on the predicted concentrations derived from the nitrogen loading model:

- The accuracy of the nitrogen inputs,
- A complete understanding of the hydrologic conditions, and
- The assumption that nitrogen acts conservatively in the aquifer i.e., that nitrate is formed and does not transform to other nitrogen species.

5.6.1 Accuracy of Nitrogen Inputs

The first factor controlling nitrogen modeling is the nitrogen input or nitrogen loading rate that is based on land use. The inputs and assumptions made are discussed thoroughly in the nitrogen modeling methods Section 3. The largest source of the nitrogen load is associated with wastewater loadings from OSDS (Figure 42). Runoff from lawns, roofs, and other impervious surfaces represent much smaller contributions of nitrogen to the system. The exact location of the OSDSs within the capture zones may be affecting the results of the modeling. Data collected at the Riverside Landing site to verify the OSDS locations indicates that several were not located appropriately during the first run of the model. With improved OSDS location information, the modeled nitrogen concentration is 6.00 mg/l, lower than the original 8.86 mg/l prediction.

The Riverside Landing site may not be representative of the other sites. Riverside Landing is a relatively new residential development and home designs usually include either an enclosed back porch or pool, thus forcing the OSDSs to be placed in front or side yards. Verification of OSDS location at other sites was difficult to obtain due to the age of the neighborhoods.

The nitrogen loading model was originally developed and tested on Cape Cod, Massachusetts (Nelson, et al., 1988). Hydrologically this area has sandy, permeable soils with high dissolved oxygen levels and little nitrogen attenuation in groundwater. The model was previously tested using groundwater taken from a large water supply source, where pumping had occurred for an extended period of

time at a high rate, thus mixing the sample and providing a more homogenous water source.

The difference between modeling and measured nitrogen values may be due, in part, to complexities in the hydrologic system in the vicinity of the sampling sites that can not be incorporated into the capture zone modeling. The model is sensitive to the size of the delineated well capture area, and the presence or absence of infiltrated stormwater. The accuracy of the capture area is based on accurate data on recharge and aquifer permeability, and on the extent of vertical groundwater flow in the aquifer.

The capture areas were delineated based, in part, on the measured hydraulic conductivity of the aquifer sediments and the hydraulic gradient between monitoring wells. However, they are also based on a recharge rate taken from the literature. This input is difficult to quantify for a specific location, and may vary at each sampling site based on local soil and subsurface sediment conditions, and topography. For example, the Riverside Landing site on the barrier beach may have a higher recharge rate because the dune sands in this area are more permeable than the sediments at other sites. The hydraulic conductivity at this site is three times higher than that measured at any other site (Table 3).

The Riverside Landing site is a good site to investigate the model's sensitivity to recharge inputs because the upgradient limit of the capture area to the sampling wells was clearly defined using a water table divide. The amount of recharge was not used to calculate the limit as it was at other sites. Given this simplified hydrologic setting, the capture area is likely to be the most accurate of all those delineated. A sensitivity run was conducted for this site, raising the recharge rate in the model to 24 in/yr. This is twice the initial recharge rate, but still within the range of what could be expected in a sandy environment given the 52 in/yr. annual precipitation rate.

Using this increased value the modeled nitrogen concentration is 4.27 mg/l, down from the 6.00 mg/l value modeled using the 12 in/yr. recharge rate (Appendix C). Given that the actual overall average nitrogen concentration was 1.37 mg/l, the resulting attenuation factor is reduced from 77% to 68%.

5.6.2 Understanding of Hydrologic Conditions

The modeling of the capture areas was done as accurately as possible given available information. However, there are three additional factors to consider that affect the area contributing water to the sampling wells. First, the hydraulic conductivity in the vicinity of the wells was assumed to be the same throughout the entire capture area. For the sites with low hydraulic conductivity, the use of this assumption results in a small capture area, when, if more permeable sediments are present upgradient, the capture area may actually be larger. The same argument could be made at the sites with permeable sediments. Less permeable sediments upgradient of the wells would make the actual capture areas smaller.

Second, the vertical component of groundwater flow is not fully considered in the capture area delineations. If a strong downward gradient exists upgradient of the sampling wells, the actual capture area would be smaller, and a portion of the nitrogen included in the modeling would flow underneath the wells and not be reflected in the water quality data. The water quality data from the Ayers Associates study (1993) suggests that septic system effluent plumes may have moved downward as they moved downgradient, thereby flowing underneath the three to eight foot long well screens used for sampling.

A strong upward gradient from the underlying Floridan aquifer into the upper aquifer could also be providing water to the sampling wells and affecting the measured nitrogen concentrations, possibly diluting the samples with water containing less nitrogen. The presence of this gradient along the western Indian River Lagoon shore has been described by Skipp (1988). If the sampling wells are collecting water discharging from the Floridan aquifer, nitrogen may be diluted.

Third, while the sampling wells have twenty-foot screens, it is not possible to determine if the water samples represent average conditions throughout the depth of the well. While the soil samples indicated uniform materials throughout the well borings, a small zone could be providing a relatively high proportion of the pumped water. The nitrogen concentration of this zone would then have a significant influence on the concentration attributed to entire twenty-foot section of the aquifer.

A series of clustered, multi-level monitoring wells could be used to confirm the accuracy of the capture area delineations. They would provide data on vertical hydraulic gradients, as well as more information about the hydraulic conductivity of the aquifer in areas away from the sampling wells. A cluster could be installed at the sampling site with one well in the lower Floridian aquifer, and two wells in the upper aquifer. This would provide information on the contribution from the lower aquifer, as well as about the thickness of the shallow aquifer. Two additional, two-well clusters upgradient of the sampling sites would help evaluate vertical flow in the shallow aquifer, and would provide better information to map the upgradient limits of the capture areas.

It should also be mentioned that the model is sensitive to the presence or absence of infiltrated stormwater. The majority of runoff at each of the sites is believed to be captured and discharged to a surface water body outside of the capture zones. However, if some infiltration is taking place, it would dilute other nitrogen sources and result in a slightly lower modeled nitrogen concentration. The possibility of stormwater infiltration in a drainage swale at the Port St. John site has been suggested (personal communication, Brevard County Planning Department). Additional data on stormwater infiltration could be used to refine the model predictions.

5.6.3 Transformation to Other Nitrogen Species

Denitrification has been noted as an important process in aquifers given the appropriate conditions. Denitrification is a biological process performed primarily by facultative heterotrophic microorganisms. The transformation of nitrogen in OSDS effluent to nitrogen gas is a two step process, with each step requiring specific environmental conditions. First, the organic forms of nitrogen present in raw effluent (as well as ammonia) must be oxidized and transformed into nitrate-nitrogen. Oxygen must be present within OSDS disposal facility, or within the unsaturated or saturated zone directly beneath the OSDS in order for this conversion to take place. Evidence to evaluate whether or not this nitrification process is taking place within the study areas was not collected as part of this investigation. However, the water quality data from a previous evaluation (Ayers Associates, 1993), suggests that at least some of the effluent is being converted to nitrate-nitrogen. In this study, average nitrate concentrations were higher than

average total Kjeldahl nitrogen concentration in samples from wells directly adjacent to OSDS disposal facilities.

Once nitrogen is converted to nitrate, anoxic conditions must be present to allow for denitrification. Nitrate is first transformed to nitrite, and then nitrite is transformed to nitrogen gas which volatilizes out of the aquifer and enters the atmosphere. In an anoxic environment, organic carbon is usually required for denitrification to occur (Figure 43). However, denitrification based on oxidation of sulfide and ferrous iron (Starr and Gillham, 1993) instead of organic carbon has also been observed in aquifers.

The water quality data collected during this study suggests that environmental conditions exist to facilitate the denitrification of nitrate to nitrogen gas. Little to no oxygen was detected in the water quality samples suggesting anoxic conditions exist in the vicinity of the sampling sites. Also, organic carbon was detected in concentrations that have been shown at other sites to be sufficient to allow for denitrification (Starr and Gillham, 1993).

Evidence of potential denitrifying conditions were observed in the field. Surficial aquifer waters were regularly used in these areas to irrigate lawns and many homes have iron deposits left on concrete structures which are wetted during lawn irrigation. The rust color is indicative of reduced iron in an anoxic aquifer oxidizing as the water is exposed to the atmosphere.

The denitrification process has been observed in other, similar environments. Denitrification was measurable in an Ontario sandy aquifer in which the water table was sufficiently shallow for organic matter from soil to reach the aquifer (Starr and Gillham, 1993). The shallow (two-three meters) depth to water and the presence of organic carbon concentrations observed in this study are similar to those observed at the sampling sites.

Overall, nitrate removal from groundwater denitrification averaged about 85% over a three year period in Maryland (Correll, et al, 1992). Seventy-five percent of the overall removal (64% of nitrogen removed) is attributed to denitrification within the root zone of a deciduous forest. The remaining removal was through uptake and storage into the forest biomass. The difference in vegetation between

this site and the sampling sites should be considered in applying this rate to the current study. A similar deep root system may not be present at all sites to facilitate the same rate of denitrification.

In addition to denitrification, ammonium adsorption can also reduce nitrogen concentrations within an aquifer. The combination of denitrification and ammonium adsorption to aquifer sediments was found to reduce total nitrogen concentrations by 16% in a wastewater plume on Cape Cod, Massachusetts (DeSimone & Howes, 1996).

The Riverside Landing site can be used to evaluate a estimate denitrification rate as the capture area is thought to be accurate given the hydrologic controls at this site. As mentioned above, the difference between the modeled and measured concentrations is 68% using a 24 in/yr. recharge rate in the model calculations. If no other factors are contributing to the nitrogen loss, then denitrification is responsible. This denitrification rate can then be applied to the other sites using the average overall attenuation of 83% that was observed. Of the total attenuation, 68% is due to denitrification and 16% is due to complexities in the hydrologic system that effect the capture area delineation.

Future studies to confirm the presence of denitrification in the surficial aquifer may include measurement of nitrogen gas and a biological assay of bacteria within the substrate to determine if denitrifying bacteria exist at these locations. In addition, other parameters to assist in confirming and quantifying the denitrification process include measurements of dissolved organic nitrogen, dissolved and particulate carbon, and dissolved sulfide.

Finally, while denitrification is likely occurring at many of the sites, the presence of higher nitrate concentrations in groundwater samples taken during the September 1999 sampling event at Rio and Jensen Beach is not consistent with the denitrification hypothesis. Denitrification may be occurring at a slower rate or the hydrologic and chemical conditions may be different at these sites. Seasonal variations in recharge and occupancy may also be a factor.

6.0 SUMMARY OF FINDINGS

1. Measured total nitrogen concentrations in groundwater averaged 1.5 mg/liter at the eight study sites over the study period. This represents a total of 55 residential lots over a cumulative total recharge area of 18.45 acres (or an average lot size of 0.33 acres).
2. Estimated nitrogen loading from the 55 residential lots to groundwater is 613 pounds (279 kilograms) per year or 11 pounds (5 kilograms) per lot per year. Approximately 93% of this load is attributable to septic system effluent.
3. Total nitrogen concentrations from the field samples were compared with the estimated nitrogen loading. The corresponding concentrations of nitrogen in groundwater associated with the estimated loading were significantly greater than that measured groundwater. An empirical nitrogen attenuation factor was derived from the estimated loading and measured total nitrogen concentration data for those sites exhibiting nitrogen attenuation. The percentage of nitrogen attenuated ranged from 45% to 98% with an average nitrogen attenuation factor for all sites equal to 83%.
4. The calculated attenuation of nitrogen may be due to complexities in the hydrologic system that affect the capture zone delineations. Variations in on-site recharge, vertical groundwater flow gradients and stormwater infiltration have been identified as inputs to the capture zone and nitrogen models that can significantly alter the modeled nitrogen concentrations
5. Denitrification in groundwater is also a likely contributor to the observed nitrogen attenuation. The conditions exists at the sampling sites to support denitrification, including shallow depths to groundwater, low dissolved oxygen concentrations and sufficient dissolved organic carbon. Using the Riverside Landing site as an example where the hydrologic system is best known, a denitrification rate of 68% is estimated.

6. Two simple investigations could improve the findings of this study. Installing a series of cluster wells at one or two sites could refine the capture area delineations and therefore the model estimates. Measurements of denitrification rates and/or an evaluation of the presence of denitrifying bacteria in aquifer samples could be used confirm the extent of nitrogen loss through this process.

REFERENCES:

- Adams, K. March 1992. A Three-Dimensional Finite Difference Flow Model of the Surficial Aquifer in Martin County, Florida. South Florida Water Management District, Technical Publication 92-02.
- Adams, K.M. 1991. Chemical Characteristics of Water in the Surficial Aquifer System and Major Canals, Martin and Northern Palm Beach Counties, Florida. Student Thesis. Florida Atlantic University, Boca Raton, Florida.
- Andreoli, A., et al. 1979. Nitrogen removal in a subsurface disposal system, J. WPCF 51,4.
- Ayres Associates. February 1993. An Investigation of the Surface Water contamination Potential from On-Site Sewage Disposal Systems (OSDS) in the Turkey Creek Sub-Basin of the Indian River Lagoon – Final Report
- Bouma, J., W. Ziebell, W. Walker, P. Olcott, E. McCoy, and F. Hole. 1972. Soil absorption of septic tank effluent, Univ. Wis.-Ext. Geol. Nat. Hist. Surv. Info. Circ. No. 20.
- Butler, D.E. and D.J. Padgett. July 1995. A Three-Dimensional Finite-Difference Ground Water Flow Model of the Surficial Aquifer System in St. Lucie County, Florida. South Florida Water Management District, Technical Publication 95-01.
- Correll, D.L., T.E. Jordan, D.E. Weller. 1992. Nutrient Flow in a Landscape: Effects of Coastal Land Use and Terrestrial Community Mosaic on Nutrient Transport to Coastal Waters. Estuaries Vol. 15, No. 4, p. 431-442.
- Desimone, L.A.. and B.L. Howes. 1996. Denitrification and Nitrogen Transport in a Coastal Aquifer Receiving Wastewater Discharge. Environmental Science and Technology, 30, 1152-1162.

- Ellis, B.G. and K. Childs. 1973. Nutrient movement from septic tanks and lawn fertilization water quality protection project. Houghton Lake, Michigan, Michigan Dept. Nat. Res. Tech. Bull. No. 73-5.
- Fairbank, P.K. and S.M. Hohner. August 1995. Mapping Recharge (Infiltration/Leakage) Throughout the South Florida Water Management District. South Florida Water Management District, Technical Publication 95-02.
- Galvez, J. 1997. The Florida Elusive Snowbird. University of Florida Bureau of Economic Resources and Business.
- Hopkins, E. December 1991. A Water Resource Analysis of the Jensen Beach Peninsula, Martin County, Florida. South Florida Water Management District, Technical Publication 91-03.
- Horsley & Witten, Inc. 1991. Quantification and control of nitrogen inputs to Buttermilk Bay, Buzzards Bay, MA, pp. 66
- Horsley & Witten, Inc. 1996. Nitrogen loading computer model, prepared for Massachusetts Department of Environmental Protection, Division of Water Supply.
- Hvorslev, M. J. 1951. Time lag and soil permeability in ground-water observations, U.S. Army Corps of Engineers, Waterways Experiment Station Bulletin 36, Vicksburg, MS.
- Howes, B. L. and Li Feng. 1999. Evaluation of Nitrogen Loading to Great, Green and Bourne Ponds, Falmouth, MA To Support Embayment Restoration. Prepared for Horsley & Witten, Inc.
- Knox, G.W., G.D. Israel, G.L. Davis, R.J. Black, J.M. Schaefer, and S.P. Brown. September, 1995. Environmental Landscape Management: Uses of Practices by Florida Consumers. University Of Florida Cooperative Extension Service. Bulletin 307.

- Kroeger, K.D., J.L. Bowen, D. Corcoran, J. Moorman, J. Michalowski, C. Rose, I. Valiela. April, 1999. Nitrogen Loading to Green Pond, Falmouth, MA: Sources and Evaluation of Management Options. Environment Cape Cod. Vol. 2, No. 1. 15-26.
- Lukasiewicz, J. and K.A. Smith. March 1996. Hydrogeologic Data and Information Collected from the Surficial and Floridan Aquifer Systems, Upper East Coast Planning Area, Part 1 –Text. South Florida Water Management District Technical Publication 96-02.
- Lukasiewicz, J. and K.A. Smith. March 1996. Hydrogeologic Data and Information Collected from the Surficial and Floridan Aquifer Systems, Upper East Coast Planning Area, Part 2 –Appendices. South Florida Water Management District, Technical Publication 96-02.
- Magdoff, F.R., D. Keeney, J. Bouma, and W. Ziebell. 1974. Columns representing mound-type disposal systems for septic tank effluent: II. Nutrient transformations and bacterial populations, J. Environ. Qual. 3(3):228-234.
- McDonald, M. and A. Harbaugh. 1984. A modular three-dimensional finite-difference ground-water flow model, USGS Open-File Report 83-875.
- Nelson, M.E., S.W. Horsley, T.C. Cambareri, M.D. Giggey, J.R. Pinnette, 1988. Predicting Nitrogen Concentrations in Groundwater – An Analytical Model. Presented and Published with the National Water Well Association Conference, Stamford CT. Sept. 27-29.
- Porter, K. S. 1978. Nitrates in the Long Island comprehensive waste treatment management plan: VII Summary Documentation, Long Island Regional Planning Board, Hauppauge, New York.
- Reneau, R.B. 1977. Changes in inorganic compounds from septic tank effluents in a soil with a fluctuating water table, J. Environ. Qual., 6(2):173-178.

- Seitzinger, S.P. 1988. Denitrification in freshwater and coastal marine ecosystems: Ecological and geochemical significance. *Limnology and Oceanography*, 33(4, part 2), 702-724.
- Skipp, D. January, 1988. Ground Water Flow Model of Brevard, Indian River, Orange, Osceola, and Seminole Counties, Florida. St. Johns River Water Management District, Technical Publication, SJ88-2.
- Starr, R.C. and R.W. Gillham. 1993. Denitrification and Organic Carbon Availability in Two Aquifers. *Ground Water*, 31 (6), 934-947.
- Stewart, J.S., and Van Arman, J.A., 1987, Indian river Lagoon Joint Reconnaissance Report; St. Johns River Water Management District and South Florida Water Management District, Contract No. CM-137.
- Szell, G.P. 1993. Aquifer Characteristics in the St. Johns River Water Management District, Florida. St. Johns River Water Management District, Technical Publication SJ93-1.
- Toth, D.J. 1995. Groundwater Recharge Rates Calculated from the Isotropic Content of Ground Water: A Pilot Study. St. Johns River Water Management District, Technical Publication SJ95-3.
- Valiela, I., G. Collins, J. Kremer, K. Lajtha, M. Geist, B. Seely, J. Brawley, and C.H. Sham. 1997. Nitrogen Loading from Coastal Watersheds to Receiving Estuaries: New Method and Application. *Ecological Applications*. 7(2). 358-380.
- Valiela, Ivan. and J. Costa. 1988. Eutrophication of Buttermilk Bay, a Cape Cod coastal embayment: concentrations of nutrients and watershed nutrient budget, *Environmental Management*, 12(4):539-553.
- Walker, W.G., J. Bouma, D. Keeney, and P. Olcott. 1973. Nitrogen transformations during subsurface disposal of septic tank effluents in sands: II, Ground water quality. *J. Environ. Qual.* 2:521-525.

Williams, S. 1995. Regional Ground Water Flow Model of the Surficial Aquifer System in the Titusville/Mims Area, Brevard County, Florida. St. Johns River Water Management District, Technical Publication SJ95-5.

Woodward-Clyde Consultants. 1994. Status and Trends Summary of the Indian River Lagoon, Indian River Lagoon National Estuary Program, Melbourne, FL.

FIGURES



Legend

 Site Location

*Horsley & Witten, Inc.
Environmental Services*

90 Route 6A Sextant Hill
Sandwich, MA 02563
phone: 508-833-6600
fax: 508-833-3150



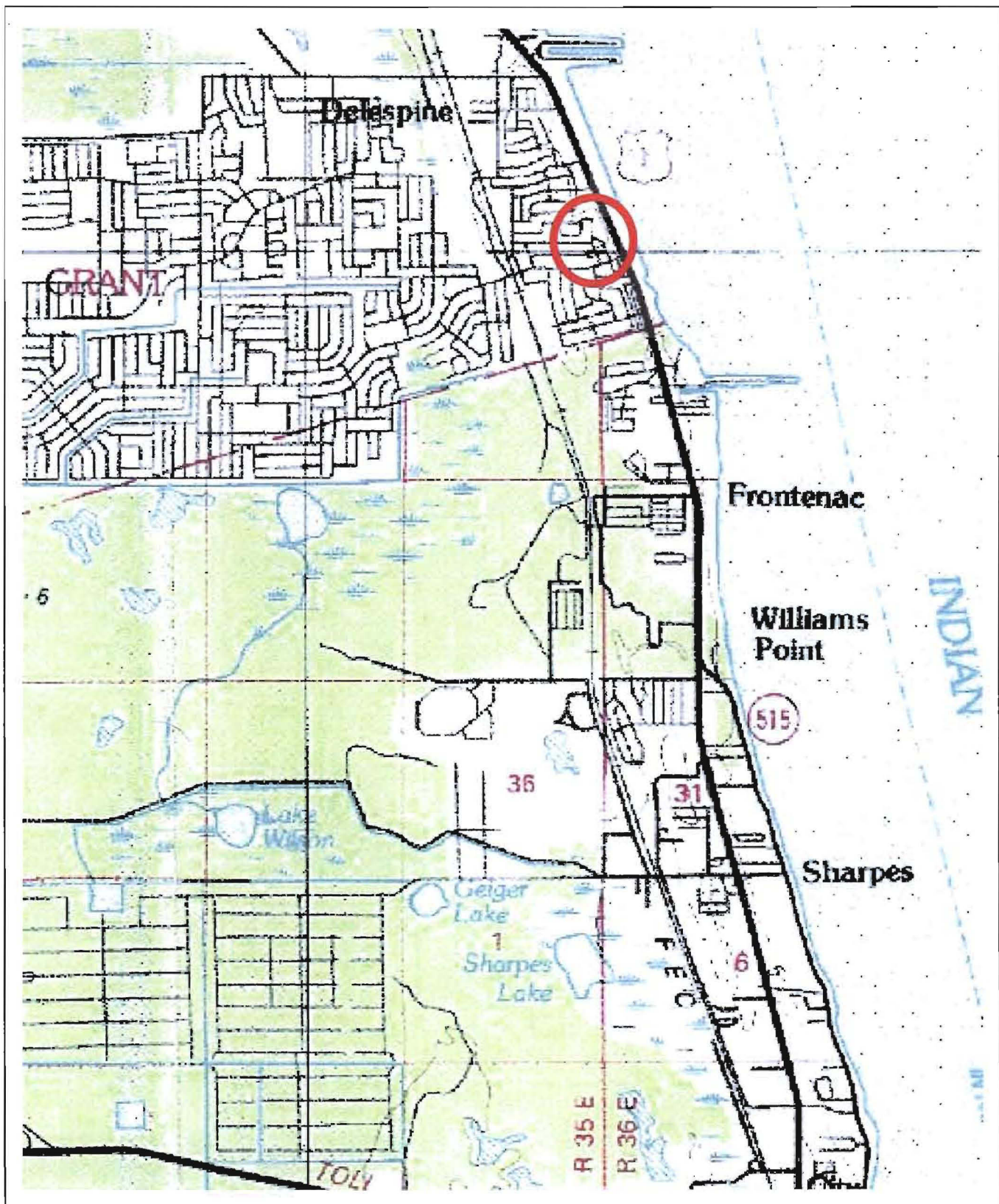
Figure 1.

Site Locations

NORTH



Date: 26 January 2000
 Drawn By: JAS
 Designed By: JAS
 Approved By: JFB
 Scale: AS SHOWN
 Sheet No: 1 OF 1
 Revision Date: 26 January 2000



Legend

○ Site Location

Horsley & Witten, Inc.
Environmental Services

90 Route 6A Sextant Hill
Sandwich, MA 02563
phone: 508-833-6600
fax: 508-833-3150



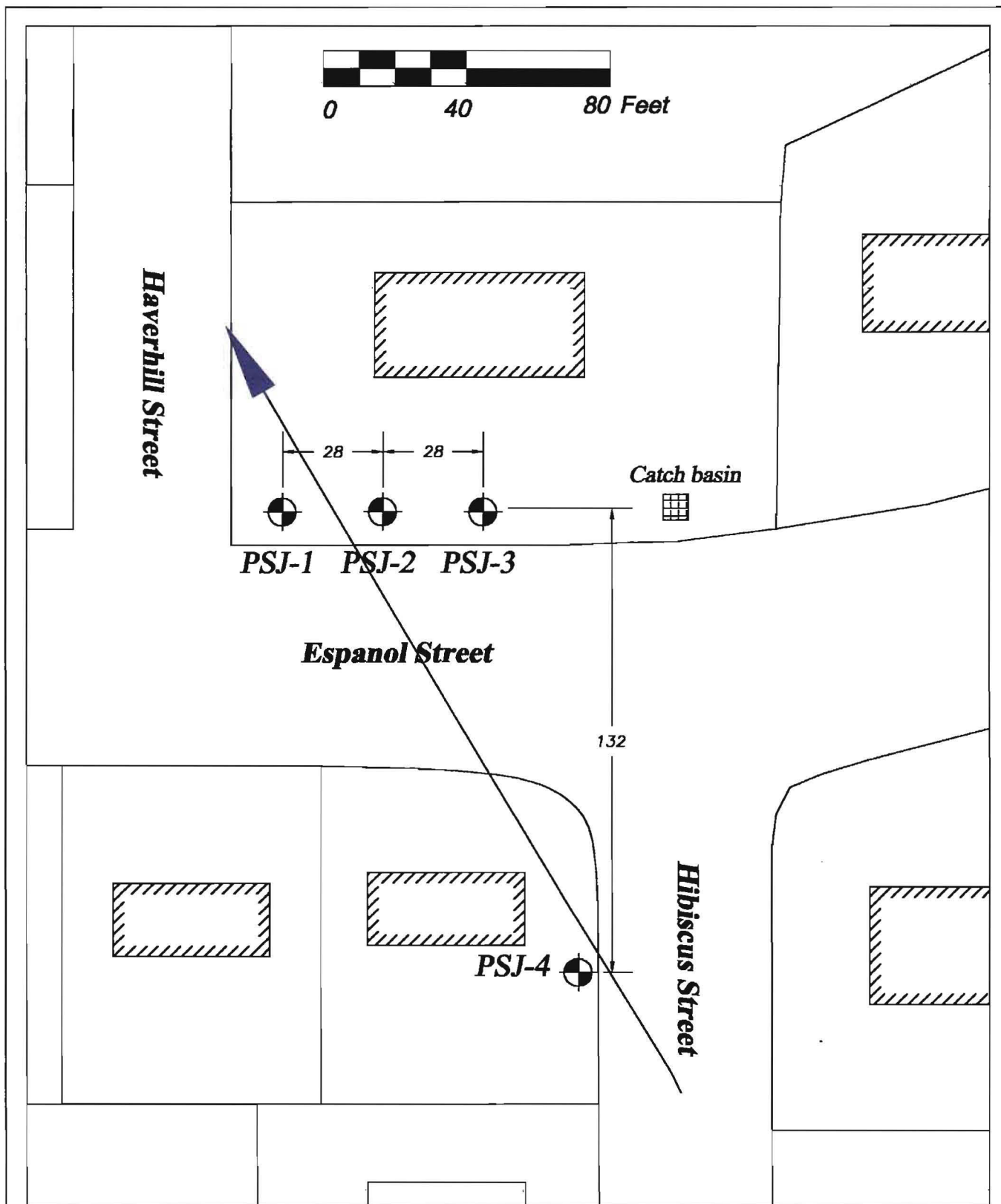
Figure 2.

Port St. John Site

NORTH



Date: 26 January 2000
Drawn By: JAS
Designed By: JAS
Approved By: JFB
Scale: AS SHOWN
Sheet No: 1 OF 1
Revision Date: 26 January 2000



Legend

Source: Port St. John Assessors Map

⊕ Groundwater Monitoring Well

← Approximate Direction of Groundwater Flow

Horsley & Witten, Inc.
Environmental Services

Sixtant Hill Office Park
90 Route 6A
Sandwich, MA 02563
phone: 508.833.6600
fax: 508.833.3150



Figure 3 Site Map

Port St. John



Date: December 1, 1999

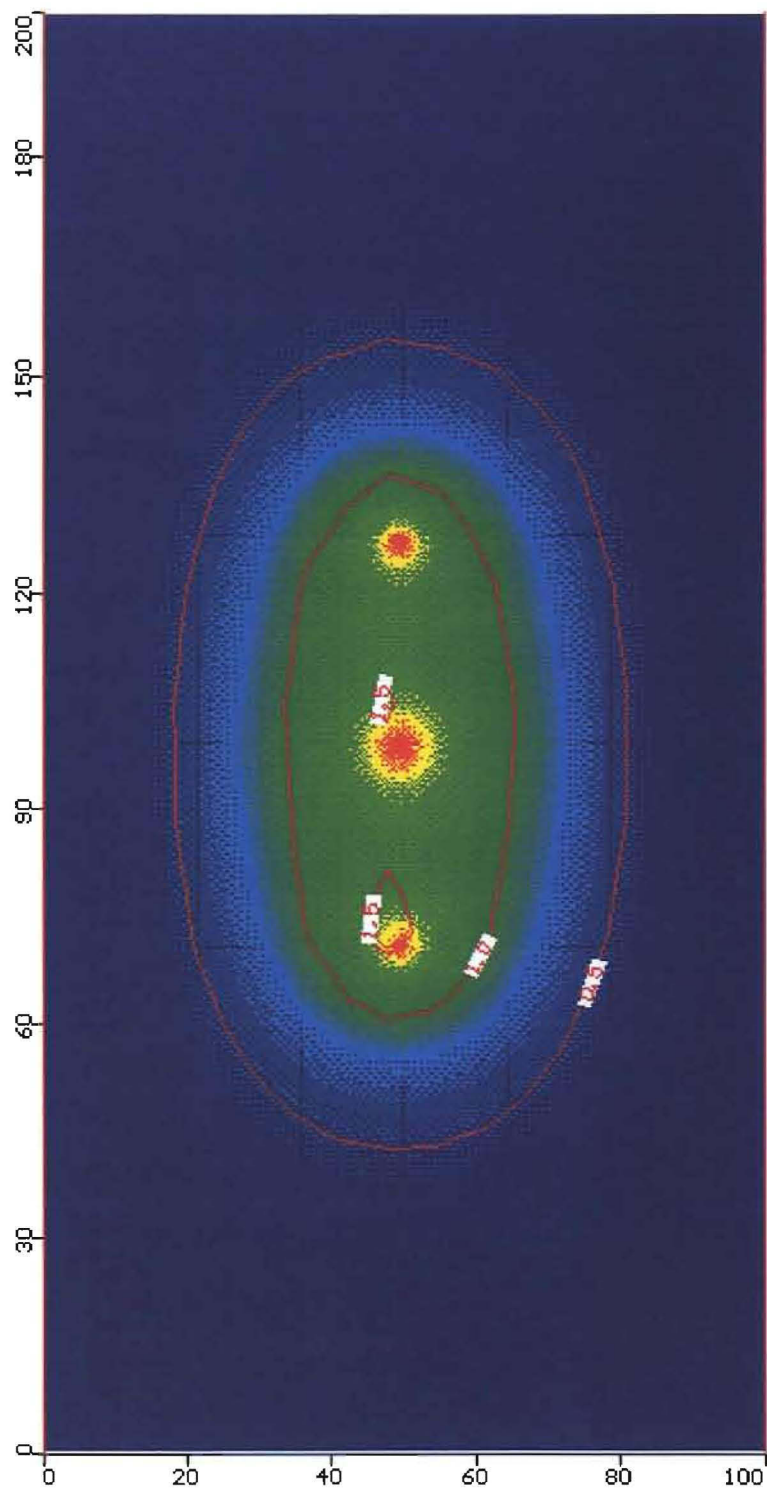
Drawn By: JEL

Approved By: JFB

Scale: 1"=40'

Sheet No: 1 OF 1

H&W File No.: c:\647\drawings\pel



Legend

— Drawdown, in feet

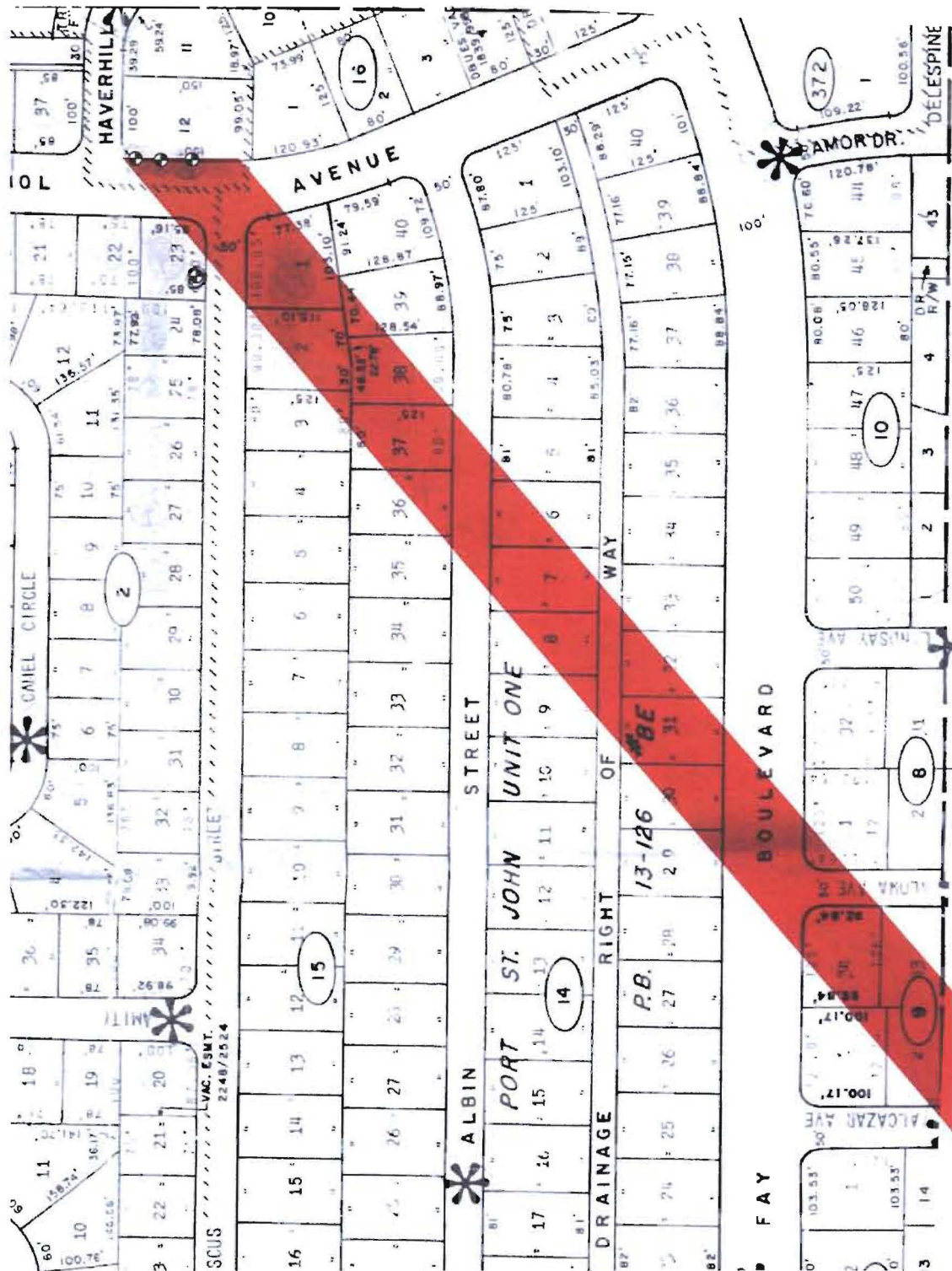
Horsley & Witten, Inc.
Environmental Services

90 Route 6A Sextant Hill
Sandwich, MA 02563
phone: 508-833-6600
fax: 508-833-3150

Figure 3a.
Port St. John.
Areal Extent of
Drawdown from
Simultaneous Pumping



Date: 12 August 1999
Drawn By: PMT, JAS
Designed By: PMT
Approved By: JFB
Approx. Scale: 1" = 200'
Sheet No: 1 OF 1
Revision Date: 12 August 1999



Legend

- Capture Zone
- Monitoring Wells

Horsley & Witten, Inc.
Environmental Services

90 Route 6A Sextant Hill
Sandwich, MA 02563
phone: 508-833-6600
fax: 508-833-3150



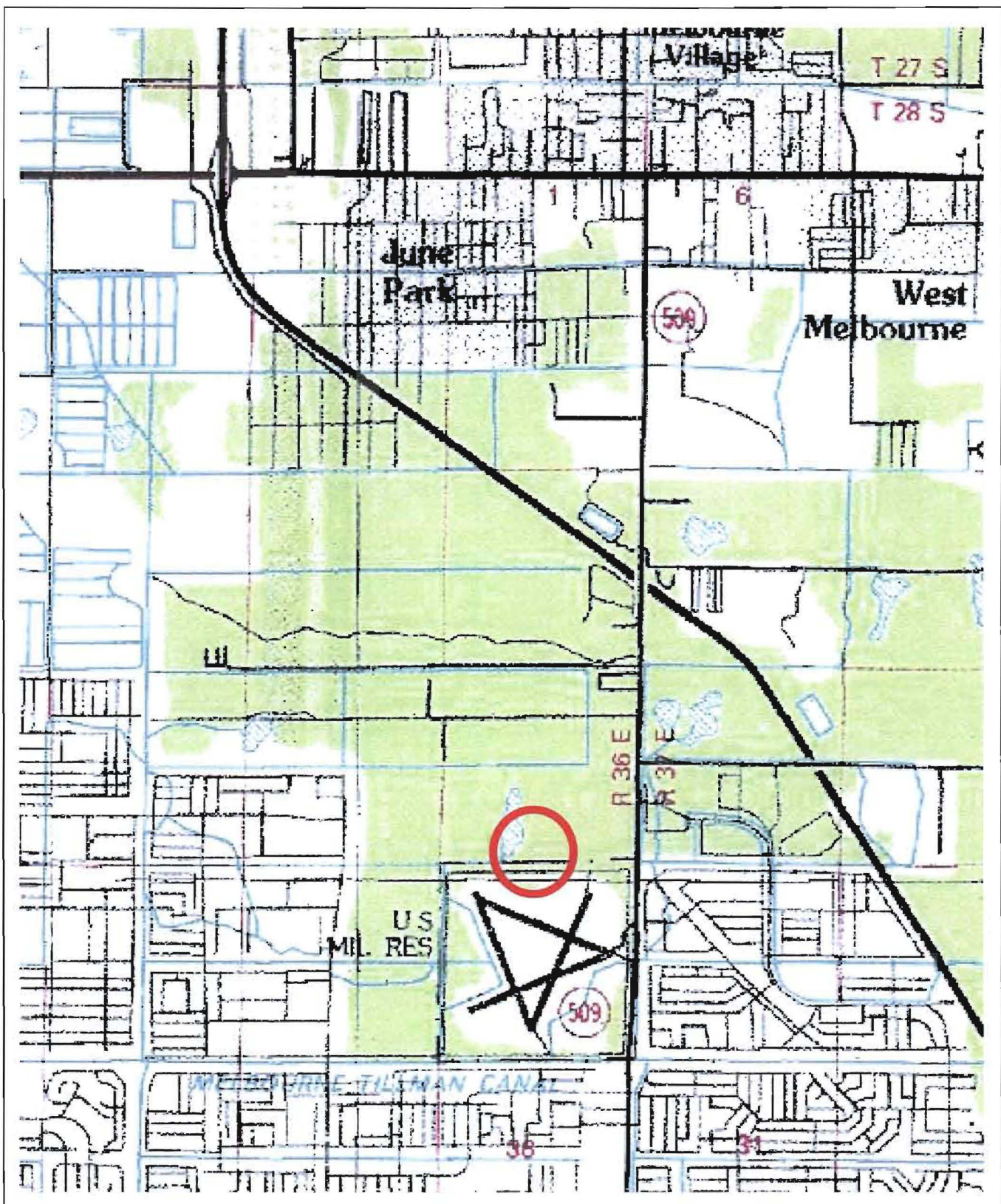
Figure 4.

Port St. John

NORTH



Date: 12 August 1999
 Drawn By: JAS, SW
 Designed By: JAS
 Approved By: JFB
 Approx. Scale: 1" = 200'
 Sheet No: 1 OF 1
 Revision Date: 28 January 2000



Legend

○ Site Location

Horsley & Witten, Inc.
Environmental Services

90 Route 6A Sextant Hill
Sandwich, MA 02563
phone: 508-833-6600
fax: 508-833-3150



Figure 5.

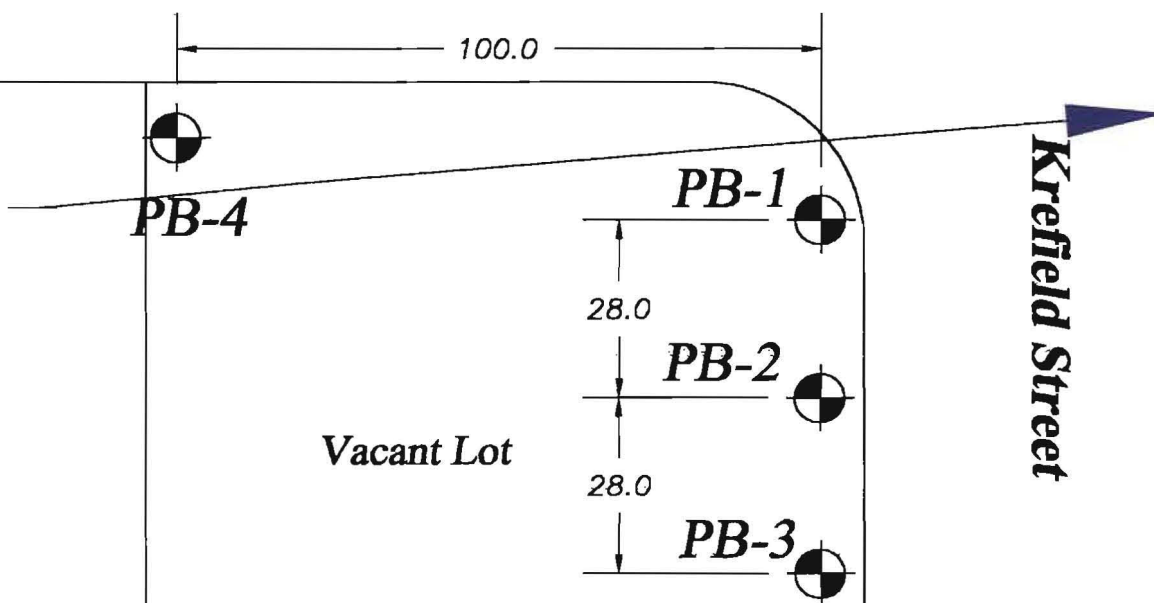
Palm Bay Site

NORTH



Date: 26 January 2000
Drawn By: JAS
Designed By: JAS
Approved By: JFB
Scale: AS SHOWN
Sheet No: 1 OF 1
Revision Date: 26 January 2000

Prum Street



Legend

- Groundwater Monitoring Well
- Approximate Direction of Groundwater Flow

Horsley & Witten, Inc.
Environmental Services

Seaboard Hill Office Park
90 Route 6A
Sandwich, MA 02563
phone: 508.833.6600
fax: 508.833.3150



Figure 6
Site Map

Palm Bay



Date: December 1, 1999

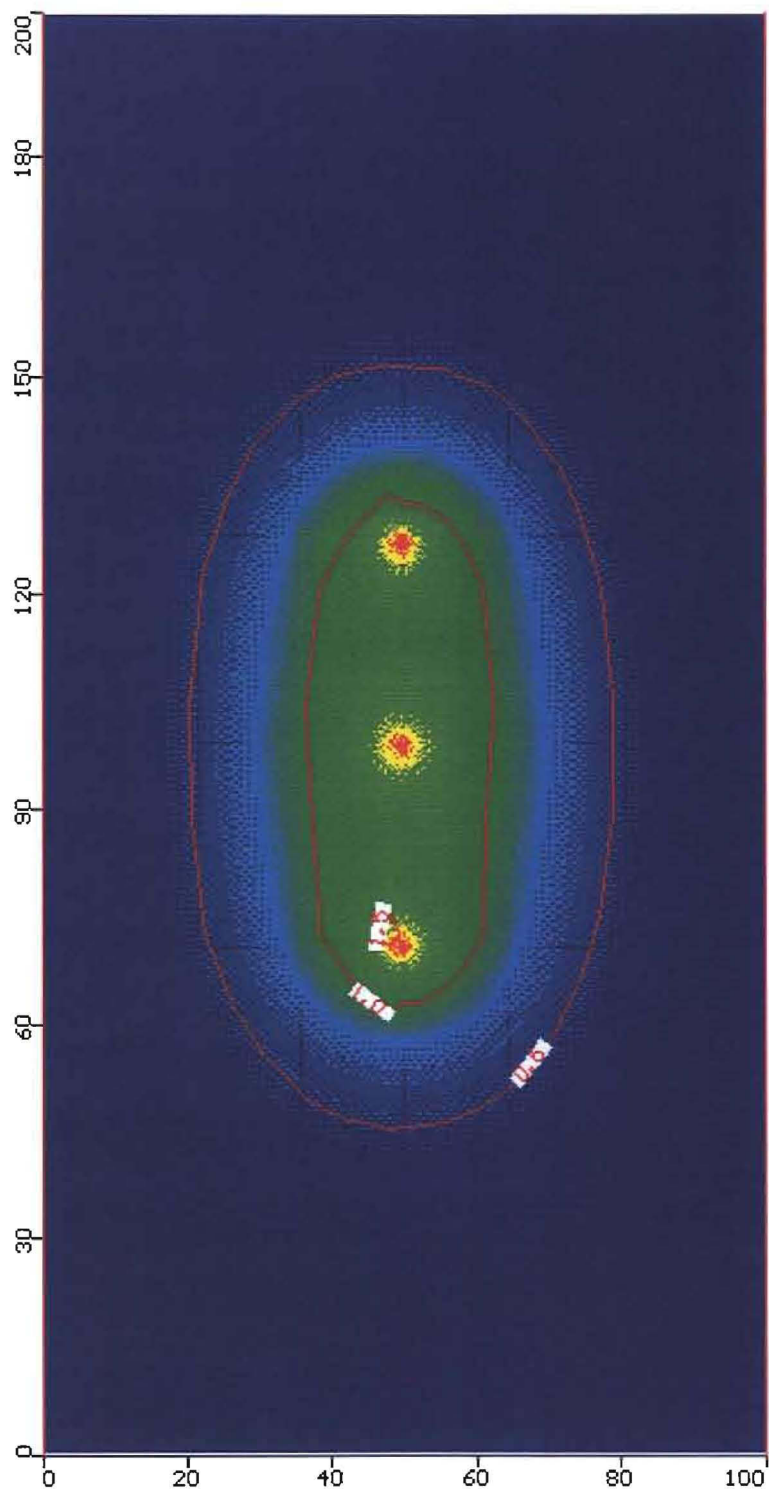
Drawn By: JEL

Approved By: JFB

Scale: 1"=30'

Sheet No: 1 OF 1

H&W File No.: 01647drawing/palm bay



Legend

— Drawdown, in feet

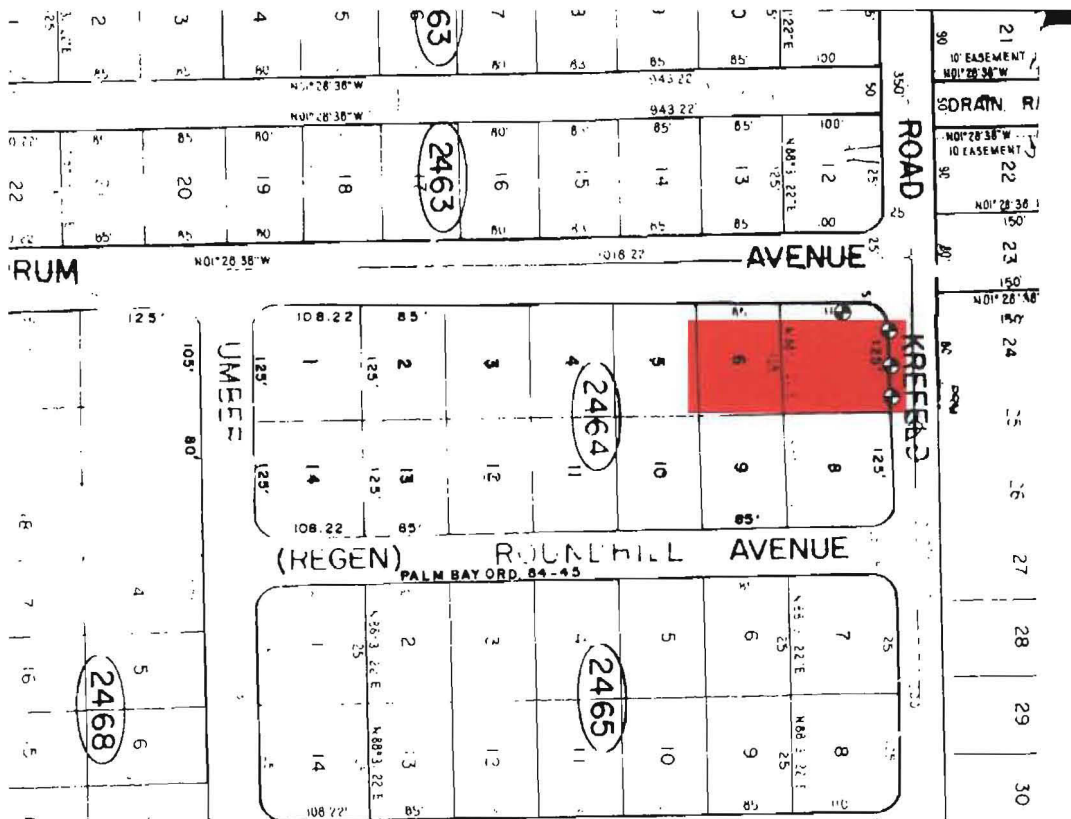
Horsley & Witten, Inc.
Environmental Services

90 Route 6A Sextant Hill
Sandwich, MA 02563
phone: 508-833-6600
fax: 508-833-3150

Figure 6a.
Palm Bay.
Areal Extent of
Drawdown from
Simultaneous Pumping



Date: 12 August 1999
Drawn By: PMT, JAS
Designed By: PMT
Approved By: JFB
Approx. Scale: 1" = 200'
Sheet No: 1 OF 1
Revision Date: 12 August 1999



Legend

- Capture Zone
- Monitoring Wells

Horsley & Witten, Inc.
Environmental Services

90 Route 6A Sextant Hill
Sandwich, MA 02563
phone: 508-833-6600
fax: 508-833-3150



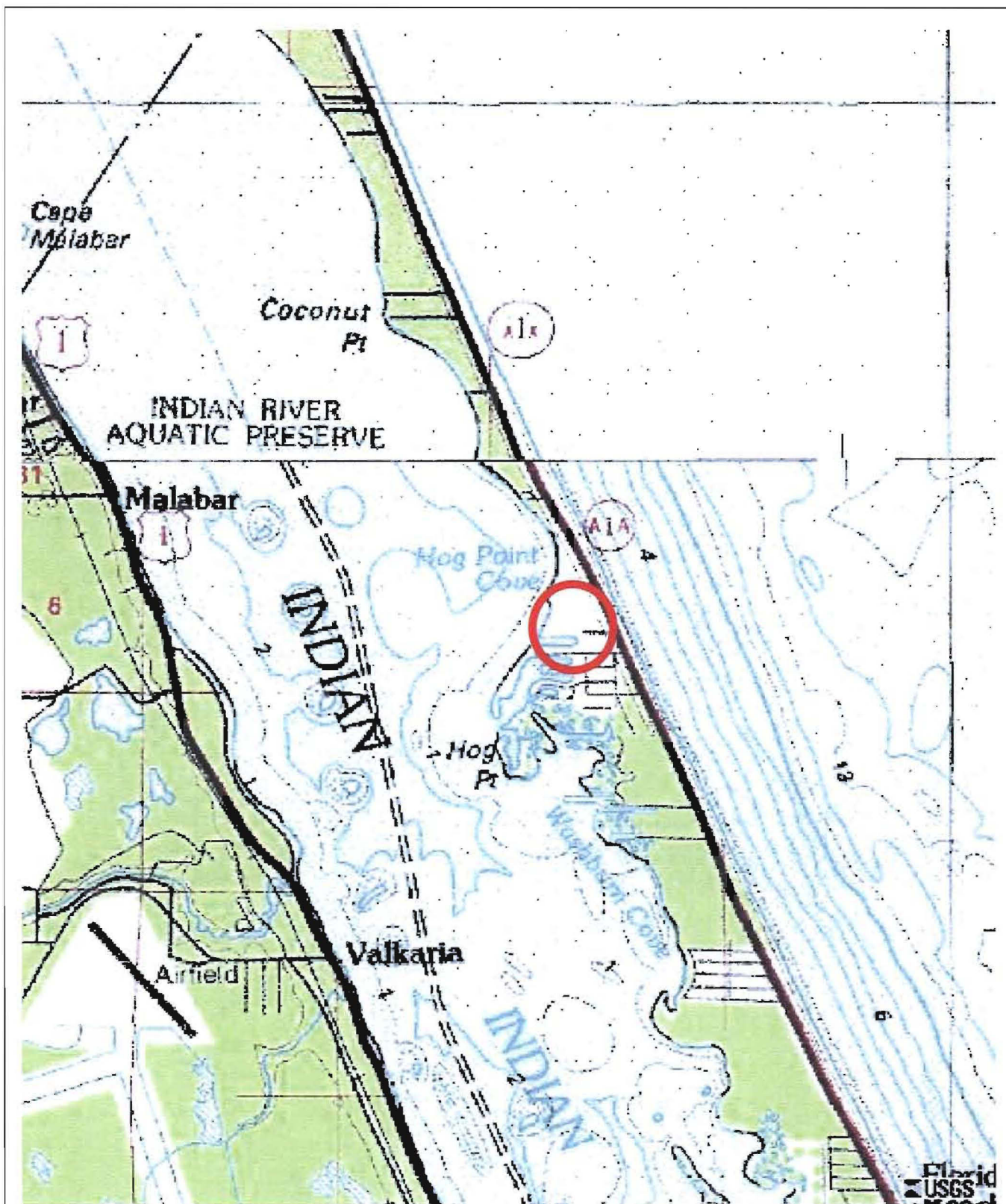
Figure 7.

Palm Bay



NORTH

Date: 12 August 1999
 Drawn By: JAS, SW
 Designed By: JAS
 Approved By: JFB
 Approx. Scale: 1" = 200'
 Sheet No: 1 OF 1
 Revision Date: 12 August 1999



Legend

 Site Location

Horsley & Witten, Inc.
Environmental Services

90 Route 6A Sextant Hill
Sandwich, MA 02563
phone: 508-833-6600
fax: 508-833-3150



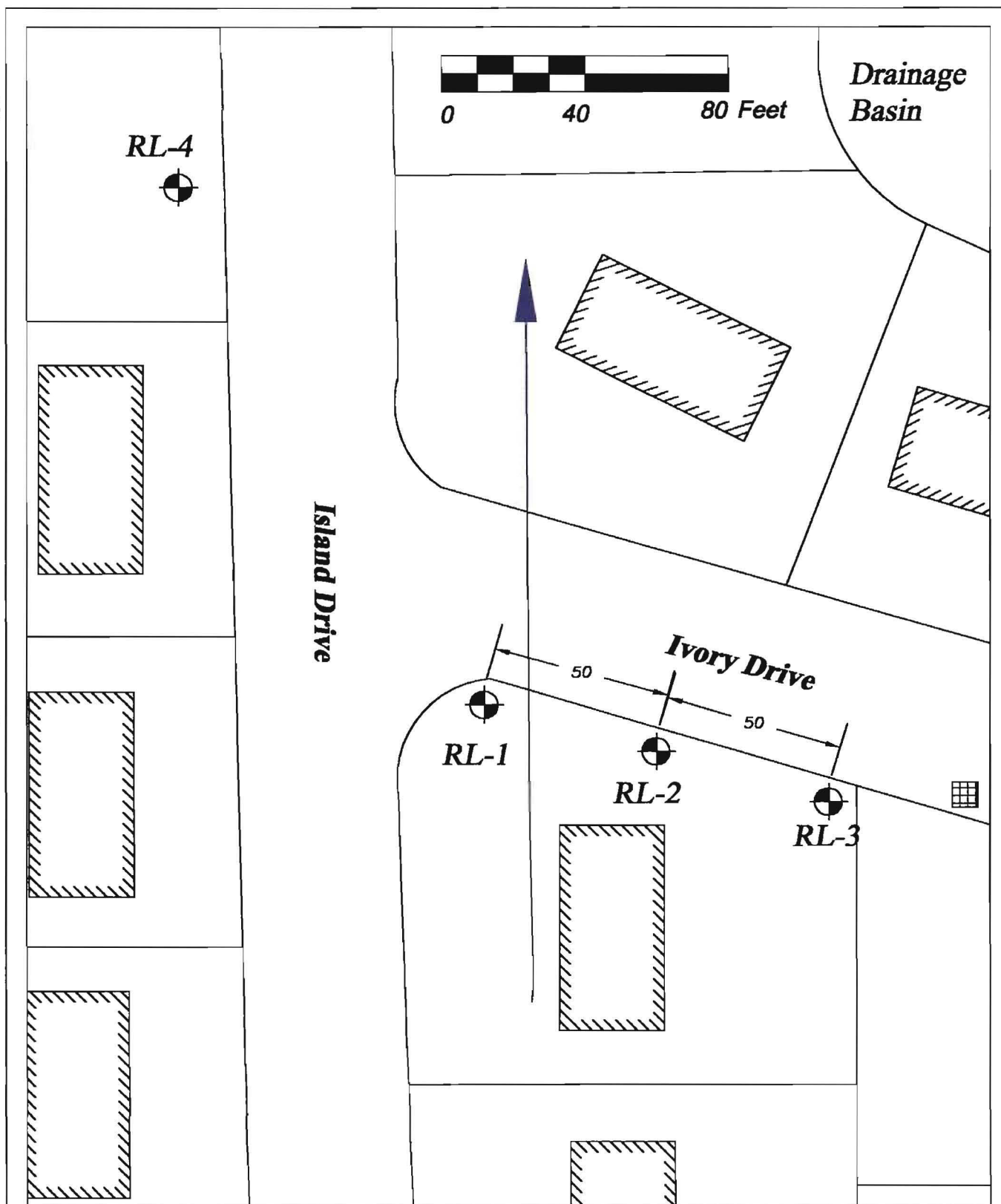
Figure 8.

Riverside Landing Site

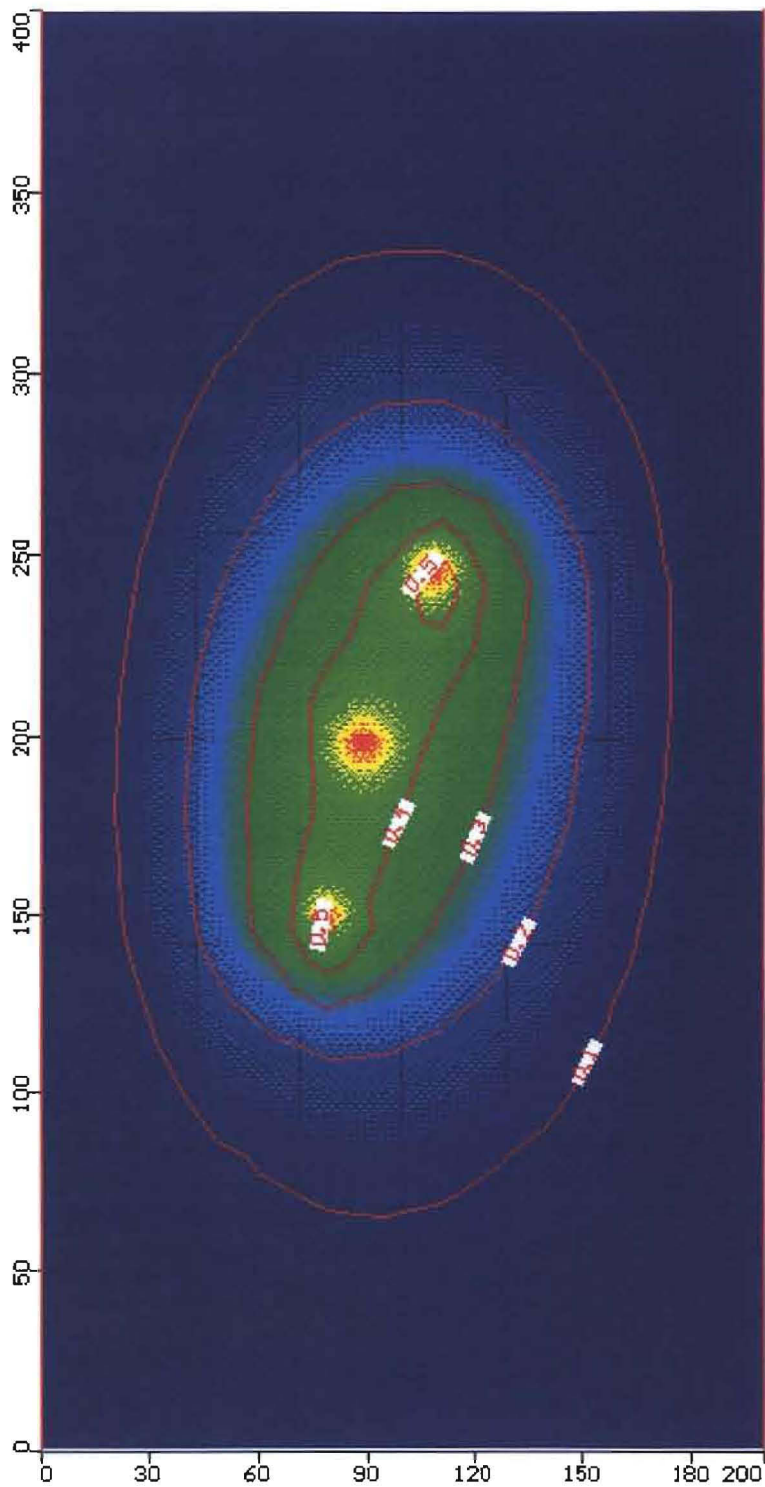
NORTH



Date: 26 January 2000
Drawn By: JAS
Designed By: JAS
Approved By: JFB
Scale: AS SHOWN
Sheet No: 1 OF 1
Revision Date: 26 January 2000



Legend ⊕ Groundwater Monitoring Well ← Approximate Direction of Groundwater Flow	Horsley & Witten, Inc. Environmental Services Seadant Hill Office Park 90 Route 6A Sandwich, MA 02563 phone: 508.833.6600 fax: 508.833.3150 	Figure 9 Site Map Riverside Landing	 NORTH	Date: <u>December 1, 1999</u> Drawn By: <u>JEL</u> Approved By: <u>JFB</u> Scale: <u>1"=40'</u> Sheet No: <u>1 OF 1</u> H&W File No.: <u>c:\647\drawings\riverside</u>
--	--	--	--	--



Legend

— Drawdown, in feet

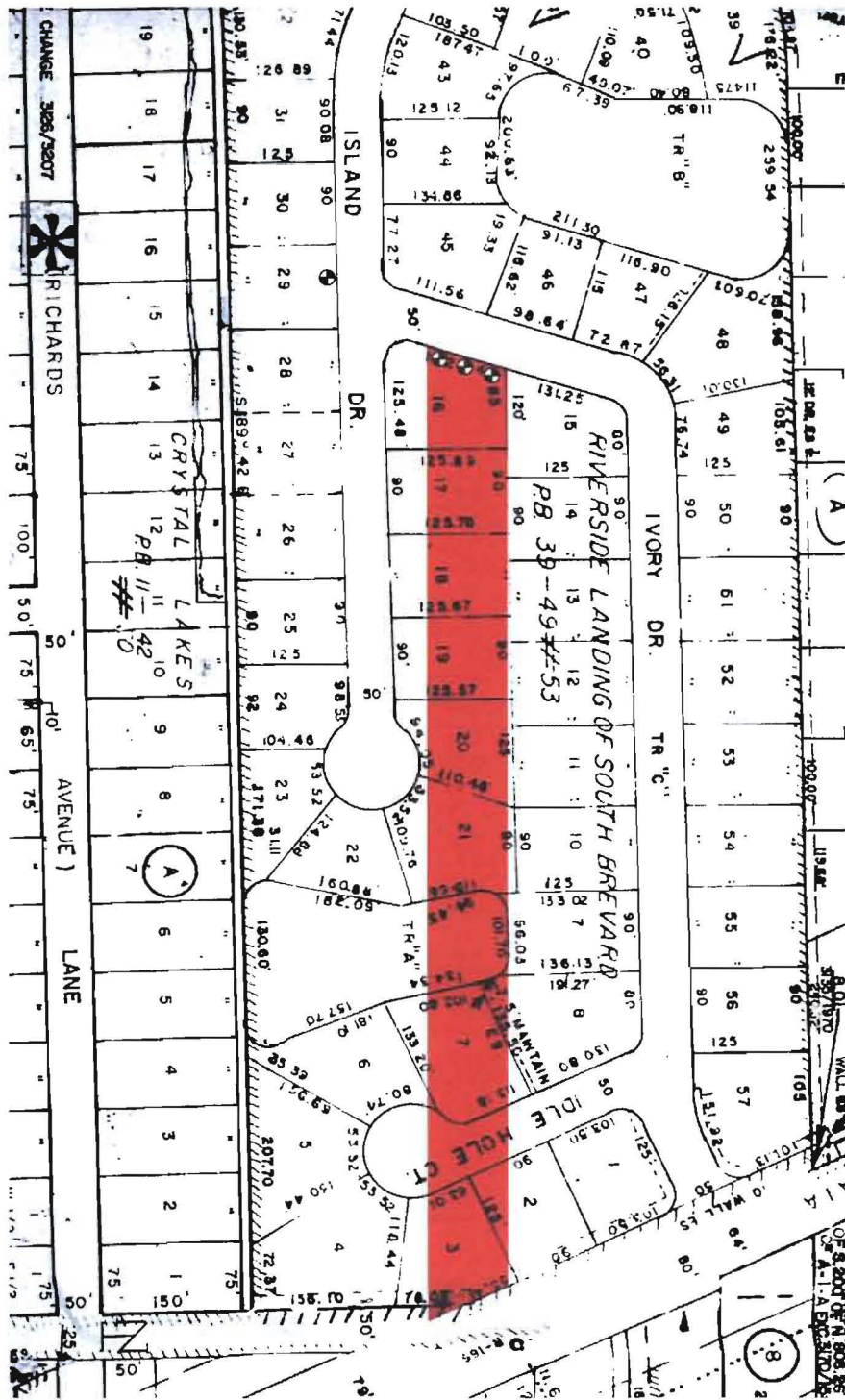
Horsley & Witten, Inc.
Environmental Services

90 Route 6A Sextant Hill
Sandwich, MA 02563
phone: 508-833-6600
fax: 508-833-3150

Figure 9a.
Riverside Landing.
Areal Extent of
Drawdown from
Simultaneous Pumping



Date: 12 August 1999
Drawn By: PMT, JAS
Designed By: PMT
Approved By: JFB
Approx. Scale: 1" = 200'
Sheet No: 1 OF 1
Revision Date: 12 August 1999



Legend

- Capture Zone
- Monitoring Wells

Horsley & Witten, Inc.
Environmental Services

90 Route 6A Sextant Hill
Sandwich, MA 02563
phone: 508-833-6600
fax: 508-833-3150

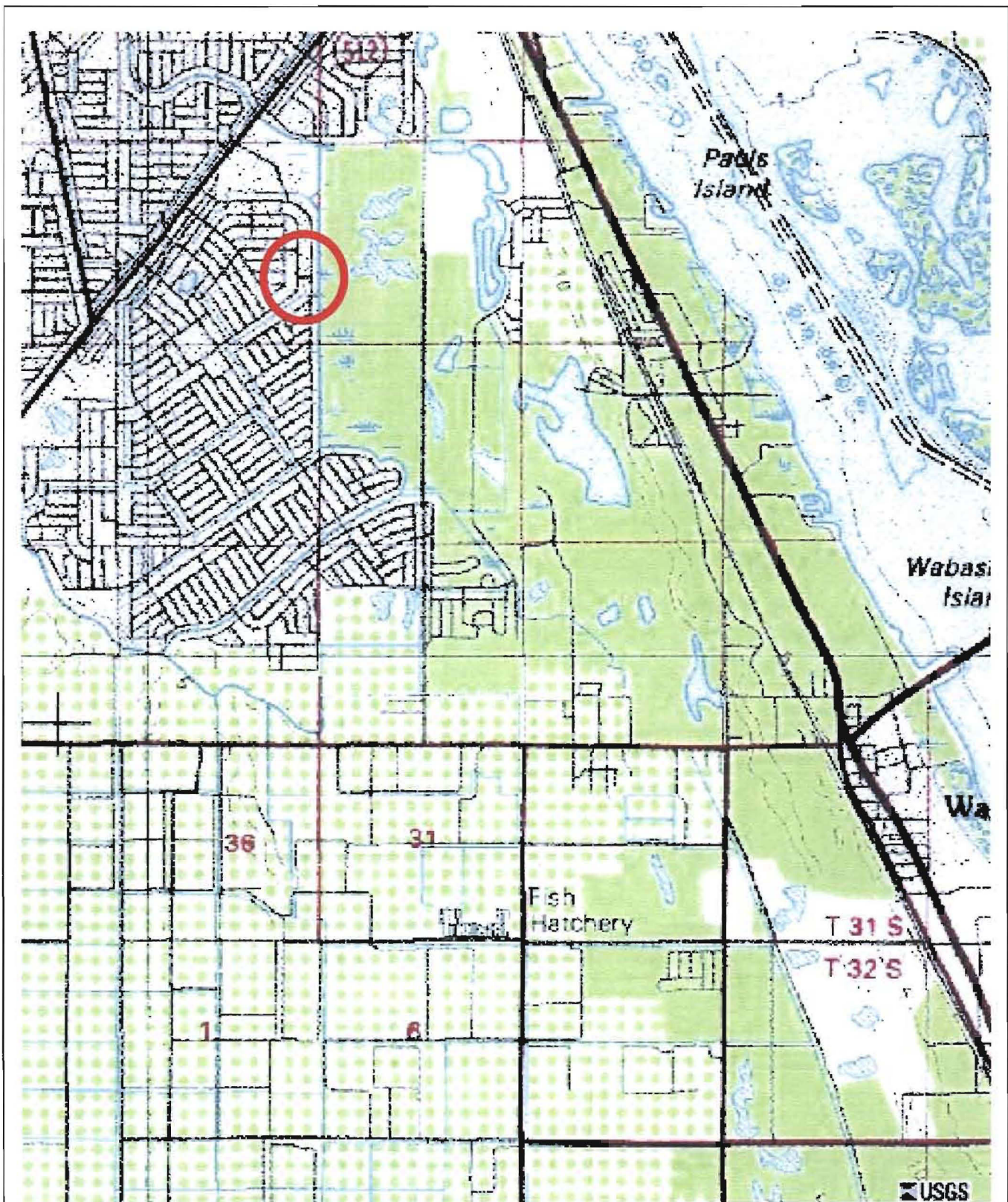


Figure 10.

Riverside Landing



Date:	12 August 1999
Drawn By:	JAS. SW
Designed By:	JAS
Approved By:	JFB
Approx. Scale:	1" = 200'
Sheet No:	1 OF 1
Revision Date:	12 August 1999



Legend

 Site Location

Horsley & Witten, Inc.
Environmental Services

90 Route 6A Sextant Hill
Sandwich, MA 02563
phone: 508-833-6600
fax: 508-833-3150



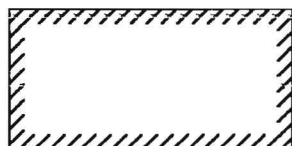
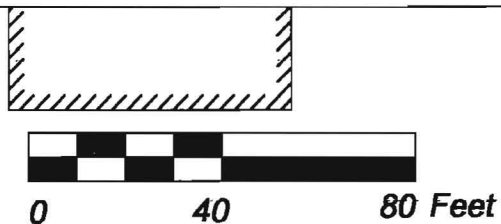
Figure 11.

Sebastian Site

NORTH



Date:	26 January 2000
Drawn By:	JAS
Designed By:	JAS
Approved By:	JFB
Scale:	AS SHOWN
Sheet No:	1 OF 1
Revision Date:	26 January 2000



SEB-4

Vine Avenue

100

George Street

28 28

SEB-1 SEB-2 SEB-3

Vacant

Vacant

Vacant

Legend

- ⊕ Groundwater Monitoring Well
- ← Approximate Direction of Groundwater Flow

Horsley & Witten, Inc.
Environmental Services

Sextant Hill Office Park
80 Route 6A
Sandwich, MA 02563
phone: 508.833.6600
fax: 508.833.3150



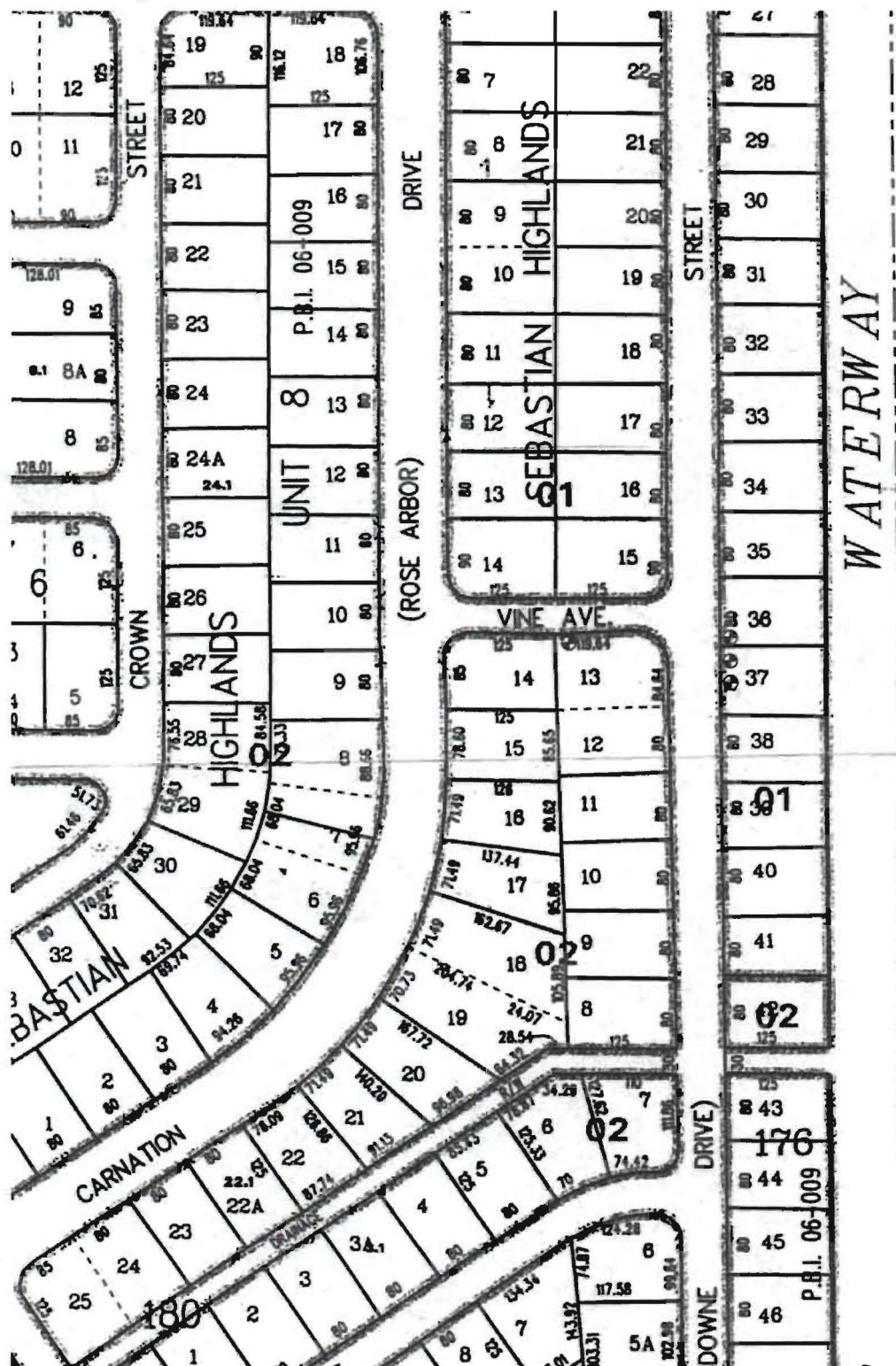
Figure 12
Site Map

Sebastian



NORTH

Date: December 15, 1999
 Drawn By: JEL
 Approved By: JFB
 Scale: 1"=40'
 Sheet No: 1 OF 1
 H&W File No.: c:\647\drawings\seb



Legend

- Capture Zone
*note: no capture zone modeled
- Monitoring Wells

Horsley & Witten, Inc.
Environmental Services

90 Route 6A Sextant Hill
Sandwich, MA 02563
phone: 508-833-6800
fax: 508-833-3150

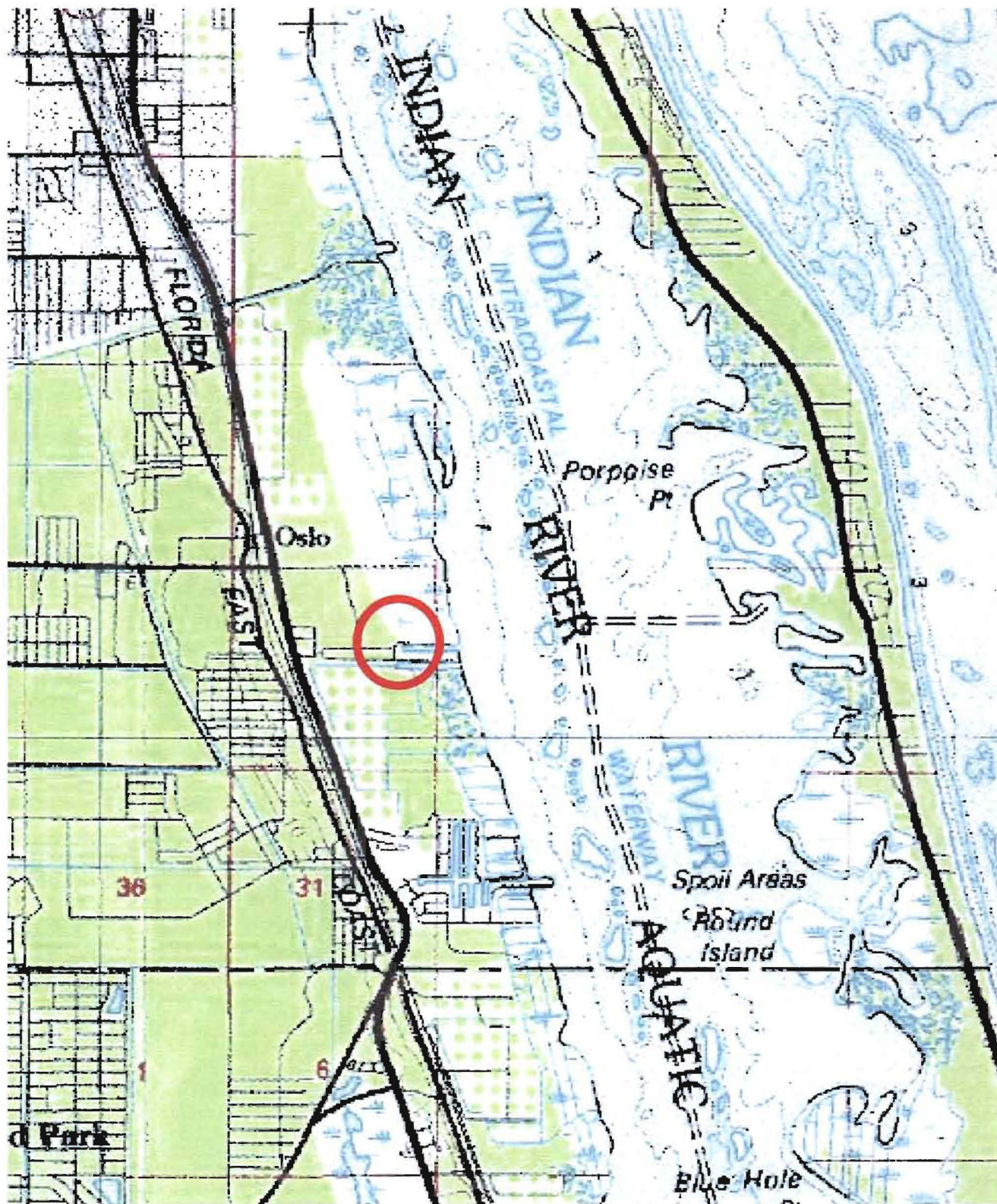
Figure 13.

Sebastian

NORTH



Date: 28 January 2000
 Drawn By: JAS, SW
 Designed By: JAS
 Approved By: JFB
 Approx. Scale: 1" = 200'
 Sheet No: 1 OF 1
 Revision Date: 28 January 2000



Legend

○ Site Location

Horsley & Witten, Inc.
Environmental Services

90 Route 6A Sextant Hill
Sandwich, MA 02563
phone: 508-833-6600
fax: 508-833-3150



Figure 14.

River Shores Site

NORTH



Date: 26 January 2000
Drawn By: JAS
Designed By: JAS
Approved By: JFB
Scale: AS SHOWN
Sheet No: 1 OF 1
Revision Date: 26 January 2000

12th Street SE



0 40 80 Feet



Vacant Lot

4th Avenue SE

RS-3

28

RS-2

28

RS-1

RS-4

105

12th Place SE

Legend

⊕ Groundwater Monitoring Well

← Approximate Direction of Groundwater Flow

Horsley & Witten, Inc.

Environmental Services

Sedant Hill Office Park
90 Route 6A
Sandwich, MA 02563
phone: 508.833.6800
fax: 508.833.3150



Figure 15
Site Map

River Shores

NORTH



Date: December 1, 1999

Drawn By: JFL

Approved By: JFB

Scale: 1"=40'

Sheet No: 1 OF 1

H&W File No.: g:1847\draw\river shores

Legend

— Drawdown, in feet

Horsley & Witten, Inc.
Environmental Services

90 Route 6A Sextant Hill
Sandwich, MA 02563
phone: 508-833-6600
fax: 508-833-3150

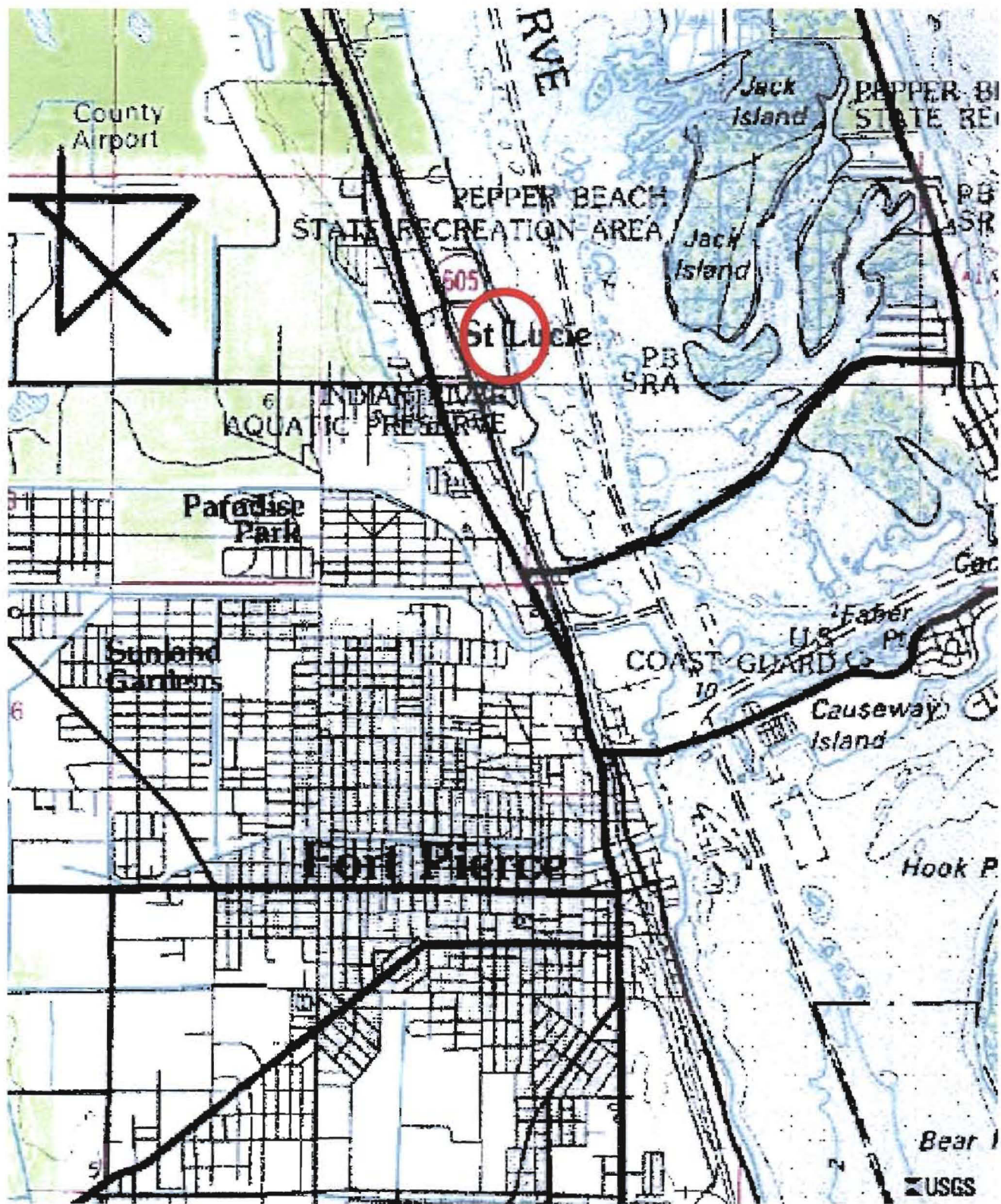
Figure 15a.
River Shores.
Areal Extent of
Drawdown from
Simultaneous Pumping



Date:	12 August 1999
Drawn By:	PMT. JAS
Designed By:	PMT
Approved By:	JFB
Approx. Scale:	1" = 200'
Sheet No:	1 OF 1
Revision Date:	12 August 1999



Legend Capture Zone • Monitoring Wells	Horsley & Witten, Inc. Environmental Services 90 Route 6A Sextant Hill Sandwich, MA 02563 phone: 508-833-6600 fax: 508-833-3150 	Figure 16. River Shores	NORTH 	Date: 12 August 1999 Drawn By: JAS, SW Designed By: JAS Approved By: JFB Approx. Scale: 1" = 200' Sheet No: 1 OF 1 Revision Date: 12 August 1999
---	---	--	--	---



Legend

○ Site Location

Horsley & Witten, Inc.
Environmental Services

90 Route 6A Sextant Hill
Sandwich, MA 02563
phone: 508-833-6600
fax: 508-833-3150



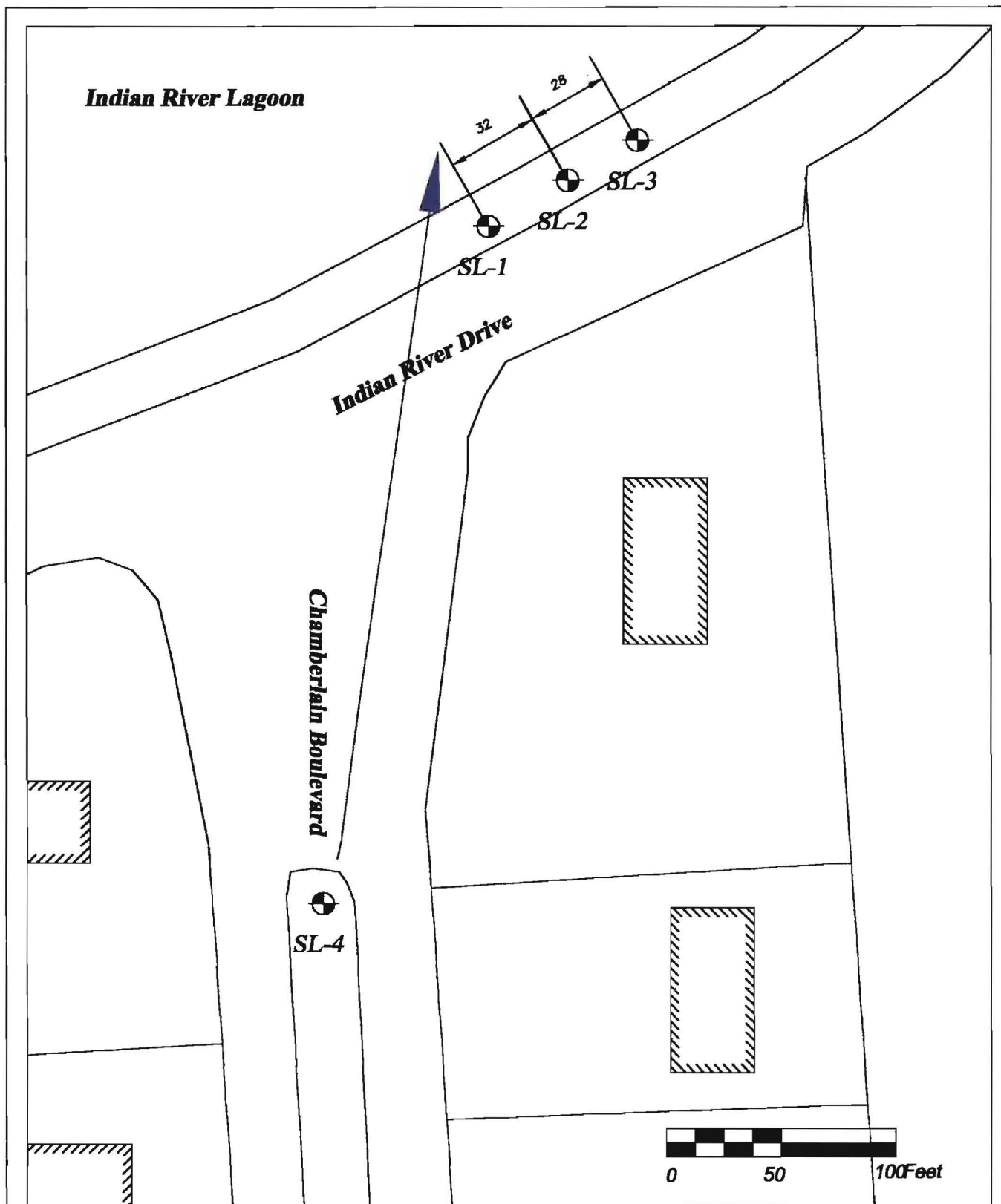
Figure 17.

St. Lucie Site

NORTH



Date: 26 January 2000
Drawn By: JAS
Designed By: JAS
Approved By: JFB
Scale: AS SHOWN
Sheet No: 1 OF 1
Revision Date: 26 January 2000



Legend

⊕ Groundwater Monitoring Well

← Approximate Direction of Groundwater Flow

Horsley & Witten, Inc.
Environmental Services

Sedent Hill Office Park
90 Route 6A
Sandwich, MA 02563
phone: 508.833.6600
fax: 508.833.3150



Figure 18
Site Map
St. Lucie



Date: December 1, 1999

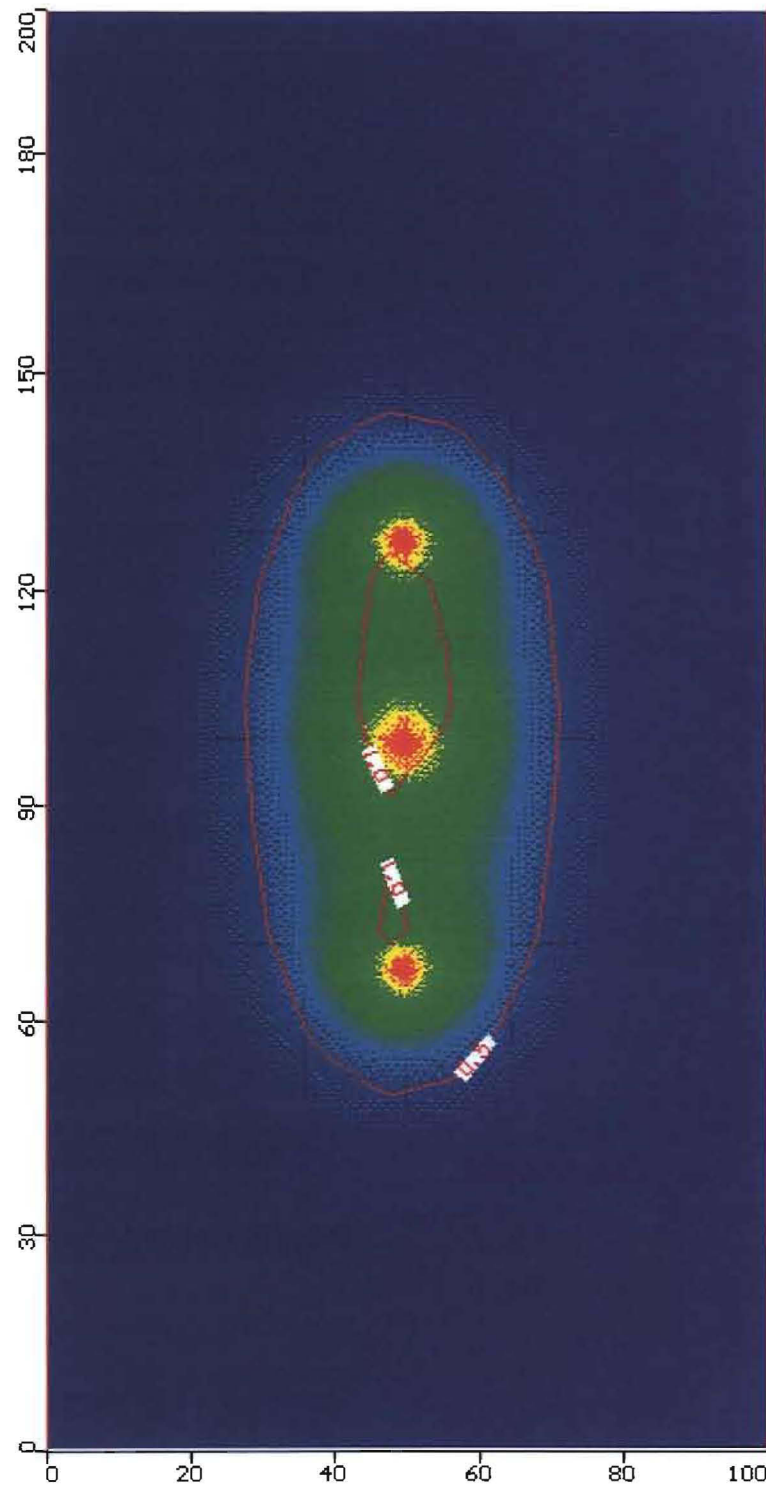
Drawn By: JEL

Approved By: JFB

Scale: 1"=50'

Sheet No: 1 OF 1

H&W File No.: gc1847/dmw/st.lucie



Legend

— Drawdown, in feet

Horsley & Witten, Inc.
Environmental Services

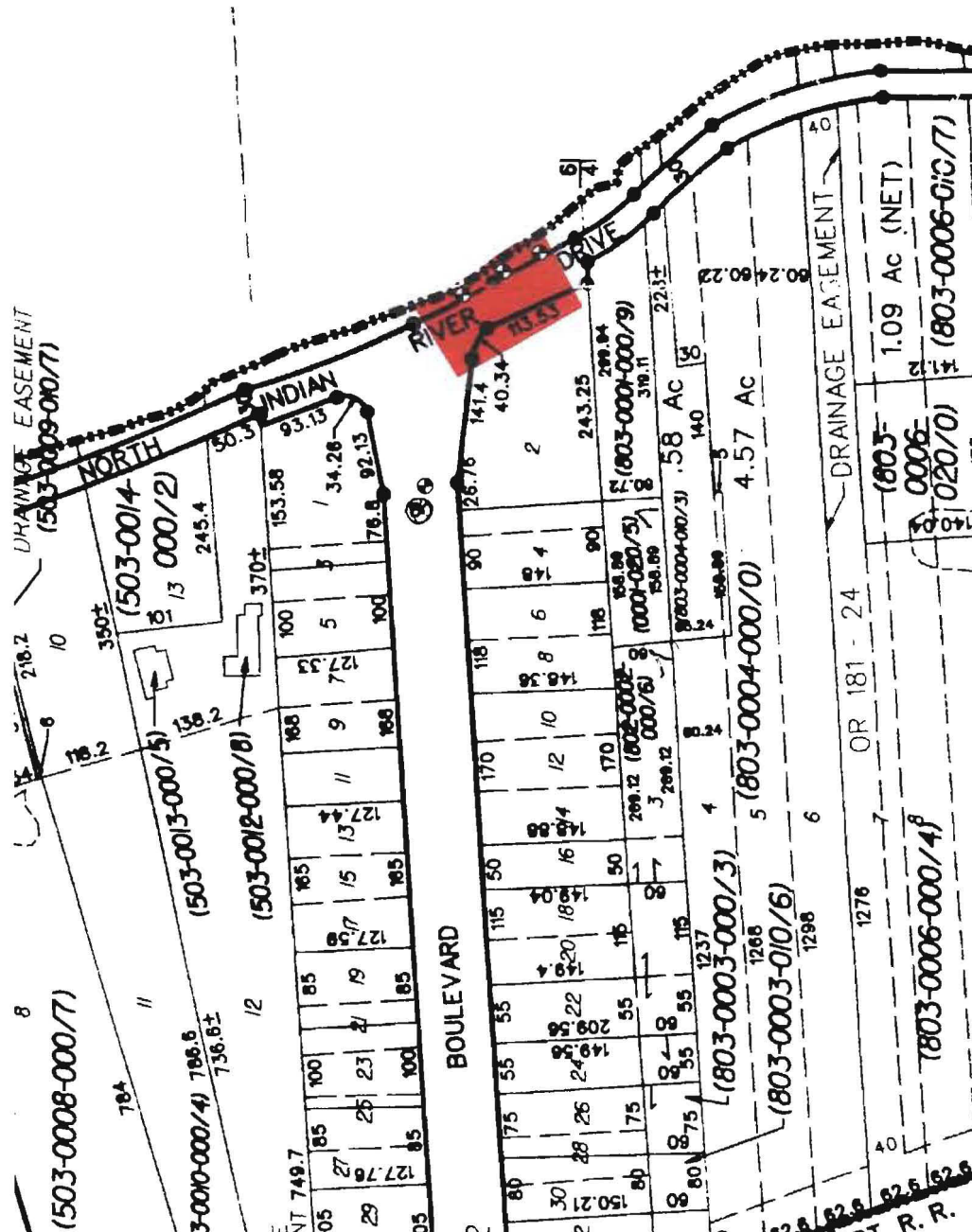
90 Route 6A Sextant Hill
Sandwich, MA 02563
phone: 508-833-6600
fax: 508-833-3150

Figure 18a.
St. Lucie.
Areal Extent of
Drawdown from
Simultaneous Pumping

NORTH



Date: 12 August 1999
Drawn By: PMT, JAS
Designed By: PMT
Approved By: JFB
Approx. Scale: 1" = 200'
Sheet No: 1 OF 1
Revision Date: 12 August 1999



Legend

- Capture Zone
- Monitoring Wells

Horsley & Witten, Inc.
Environmental Services

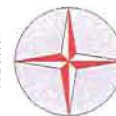
90 Route 6A Sextant Hill
Sandwich, MA 02563
phone: 508-833-6600
fax: 508-833-3150



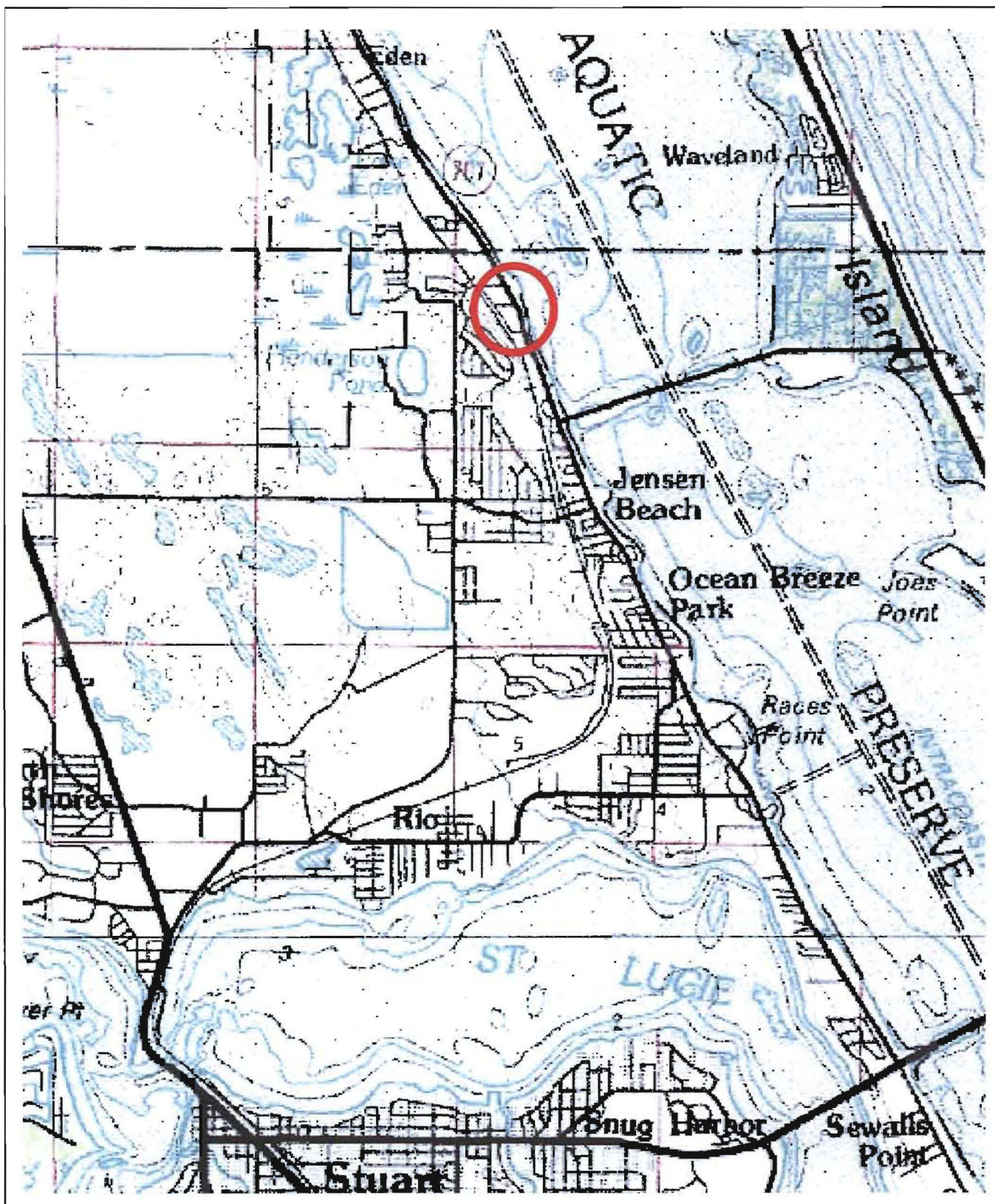
Figure 19.

St. Lucie

NORTH



Date: 12 August 1999
 Drawn By: JAS, SW
 Designed By: JAS
 Approved By: JFB
 Approx. Scale: 1" = 200'
 Sheet No: 1 OF 1
 Revision Date: 12 August 1999



Legend

 Site Location

Horsley & Witten, Inc.
Environmental Services

90 Route 6A Sextant Hill
Sandwich, MA 02563
phone: 508-833-6600
fax: 508-833-3150



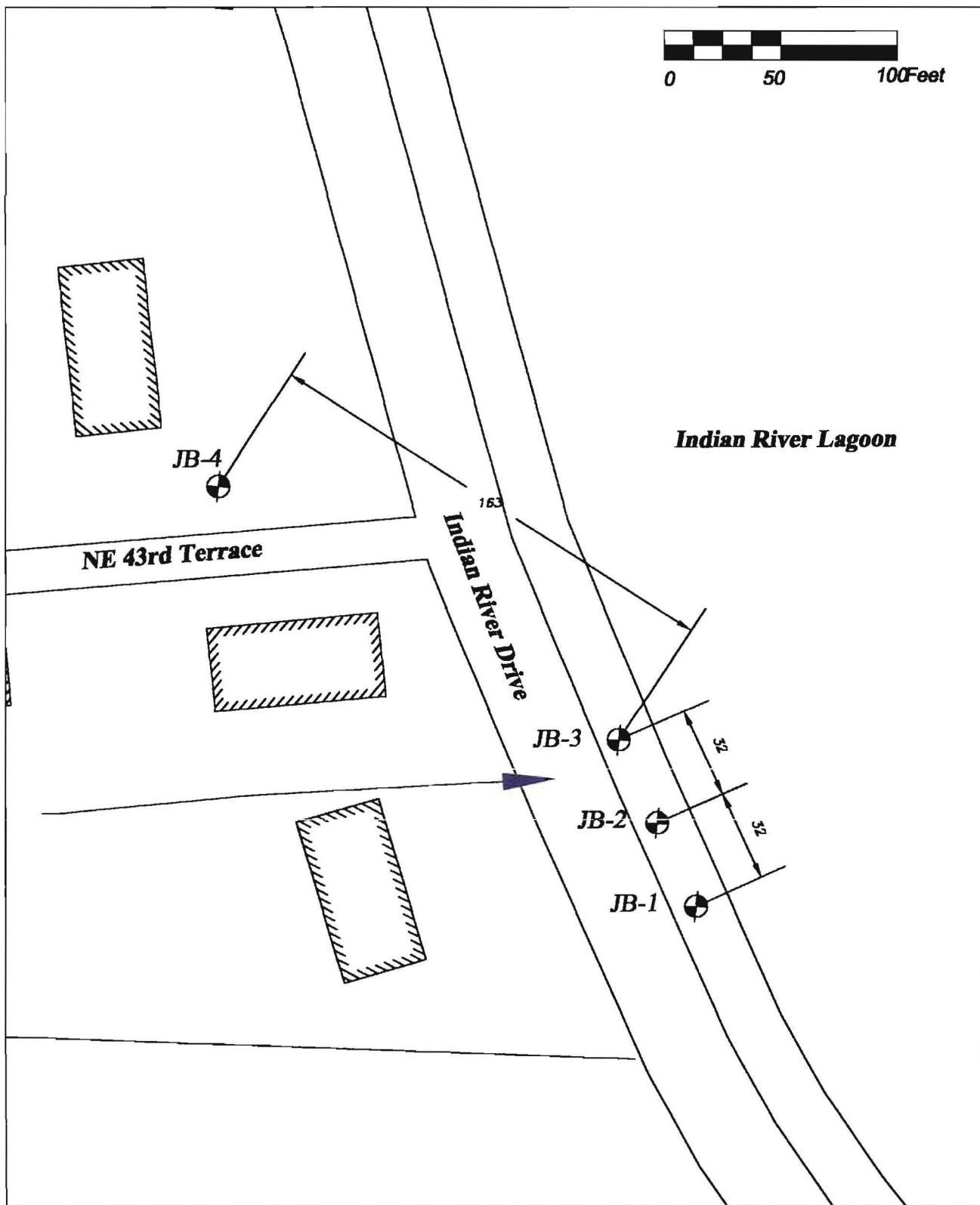
Figure 20.

Jensen Beach Site

NORTH



Date: 26 January 2000
Drawn By: JAS
Designed By: JAS
Approved By: JFB
Scale: AS SHOWN
Sheet No: 1 OF 1
Revision Date: 26 January 2000



Legend

- Groundwater Monitoring Well
- Approximate Direction of Groundwater Flow

Horsley & Witten, Inc.
Environmental Services

Sixtant Hill Office Park
90 Route 6A
Sandwich, MA 02563
phone: 508.833.6800
fax: 508.833.3150



Figure 21
Site Map

Jensen Beach Site

NORTH



Date: January 5, 2000

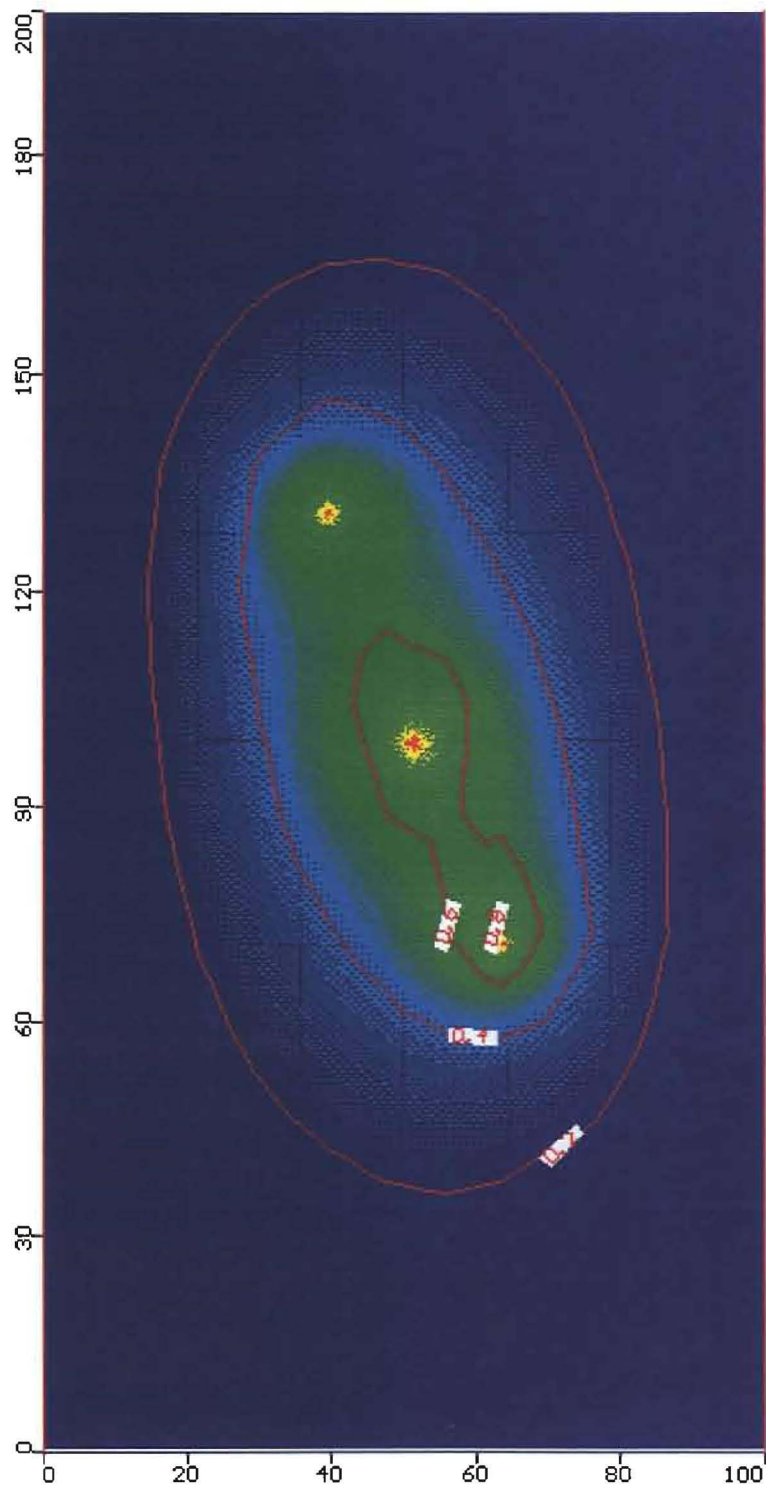
Drawn By: JFL

Approved By: JFB

Scale: 1"=50'

Sheet No: 1 OF 1

H&W File No.: c:\047\draw\jensen



Legend

— Drawdown, in feet

Horsley & Witten, Inc.
Environmental Services

90 Route 6A Sextant Hill
Sandwich, MA 02563
phone: 508-833-6600
fax: 508-833-3150

Figure 21a.
Jensen Beach.
Areal Extent of
Drawdown from
Simultaneous Pumping



Date: 12 August 1999
Drawn By: PMT, JAS
Designed By: PMT
Approved By: JFB
Approx. Scale: 1" = 200'
Sheet No: 1 OF 1
Revision Date: 12 August 1999



Legend

- Capture Zone
- Monitoring Wells

Horsley & Witten, Inc.
Environmental Services

90 Route 6A Sextant Hill
Sandwich, MA 02563
phone: 508-833-6600
fax: 508-833-3150



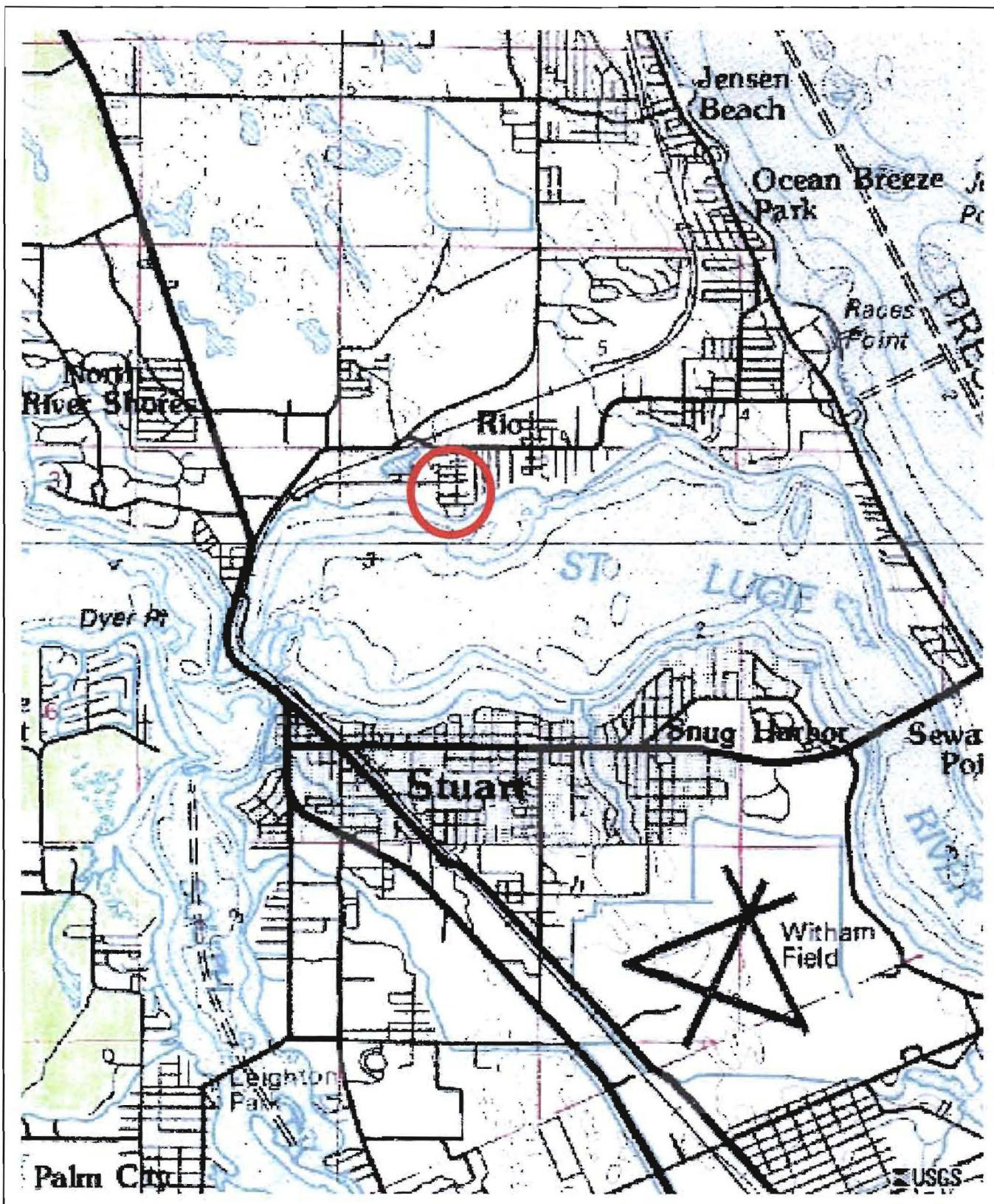
Figure 22.

Jensen Beach

NORTH



Date: 1 February 2000
 Drawn By: JAS, SW
 Designed By: JAS
 Approved By: JFB
 Approx. Scale: 1" = 200'
 Sheet No: 1 OF 1
 Revision Date: 12 August 1999



Legend

 Site Location

*Horsley & Witten, Inc.
Environmental Services*

90 Route 6A Sextant Hill
Sandwich, MA 02563
phone: 508-833-6600
fax: 508-833-3150



Figure 23.

Rio Site

NORTH



Date: 26 January 2000

Drawn By: JAS

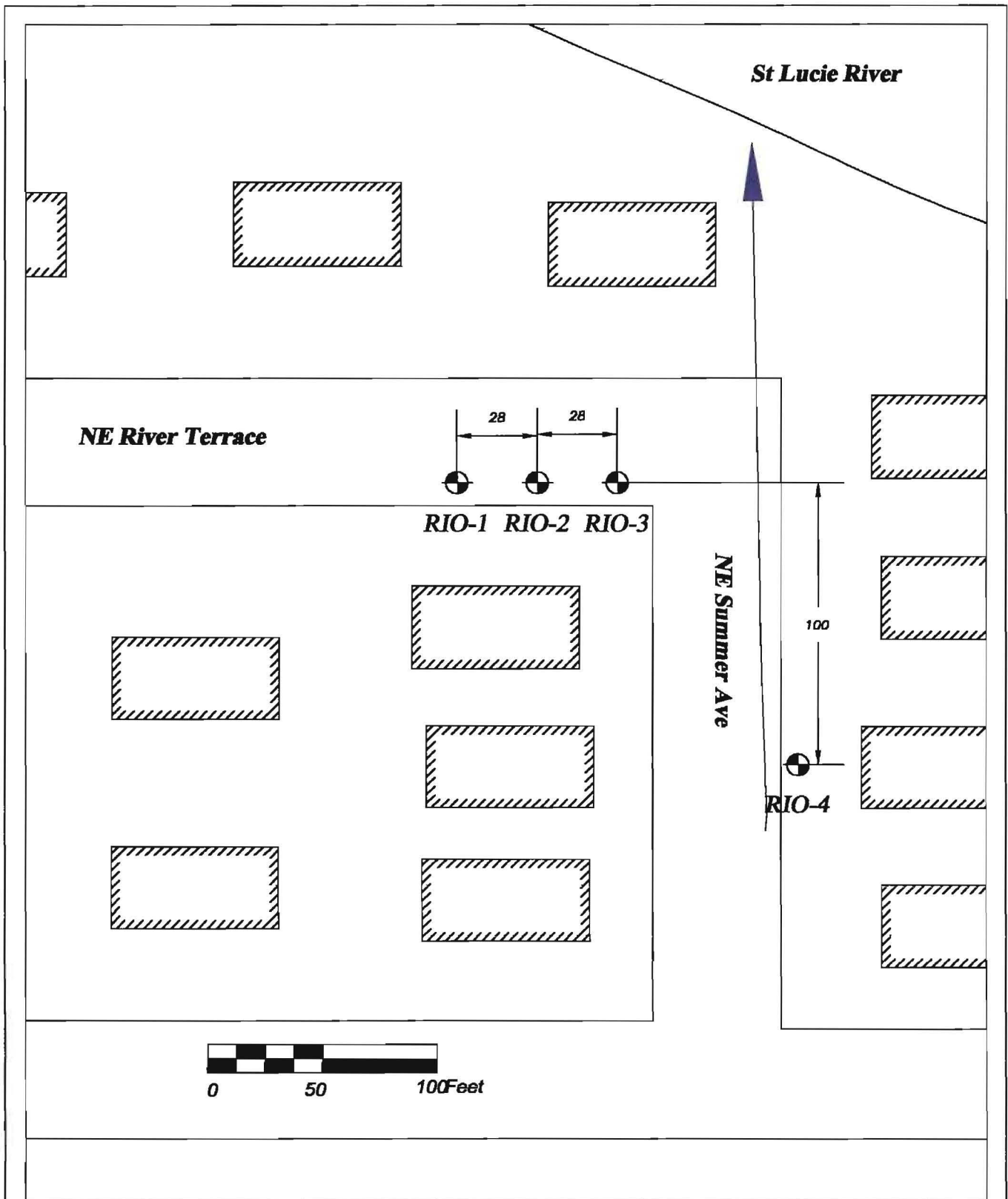
Designed By: JAS

Approved By: JFB

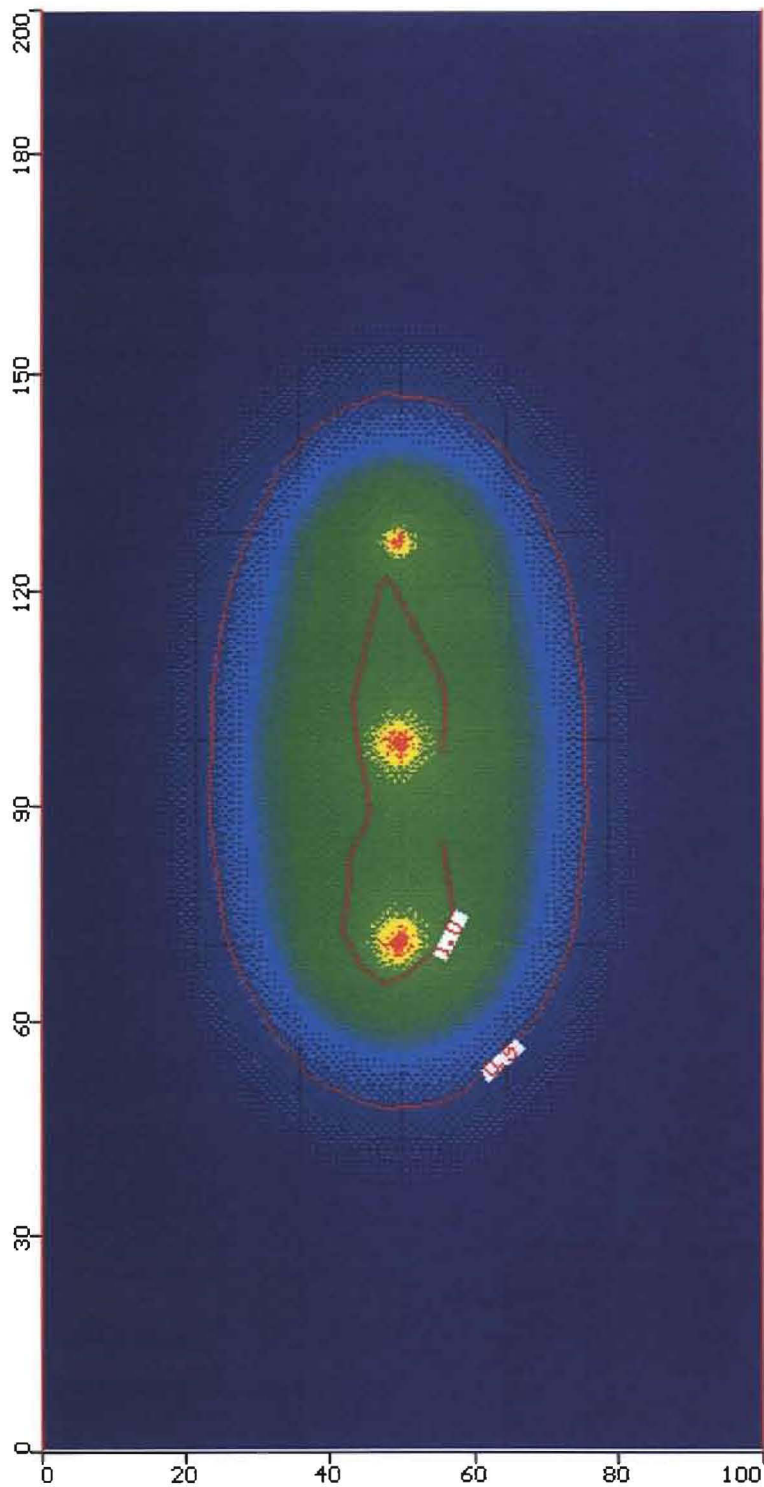
Scale: AS SHOWN

Sheet No: 1 OF 1

Revision Date: 26 January 2000



Legend ⊕ Groundwater Monitoring Well ← Approximate Direction of Groundwater Flow	Horsley & Witten, Inc. Environmental Services Sedant Hill Office Park 90 Route 6A Sandwich, MA 02583 phone: 508.633.6600 fax: 508.633.3150 	Figure 24 Site Map Rio	 NORTH	Date: <u>January 5, 2000</u> Drawn By: <u>JEL</u> Approved By: <u>JFB</u> Scale: <u>1"=50'</u> Sheet No: <u>1 OF 1</u> H&W File No.: <u>a1647dnewrle</u>
--	---	--	--	--



Legend

— Drawdown, in feet

Horsley & Witten, Inc.
Environmental Services

90 Route 6A Sextant Hill
Sandwich, MA 02563
phone: 508-833-6600
fax: 508-833-3150

Figure 24a.
Rio.
Areal Extent of
Drawdown from
Simultaneous Pumping



Date: 12 August 1999
Drawn By: PMT, JAS
Designed By: PMT
Approved By: JFB
Approx. Scale: 1" = 200'
Sheet No: 1 OF 1
Revision Date: 12 August 1999



Legend

-  Capture Zone
-  Monitoring Wells

Horsley & Witten, Inc.
Environmental Services

90 Route 6A Sextant Hill
Sandwich, MA 02563
phone: 508-833-6600
fax: 508-833-3150



Figure 25.

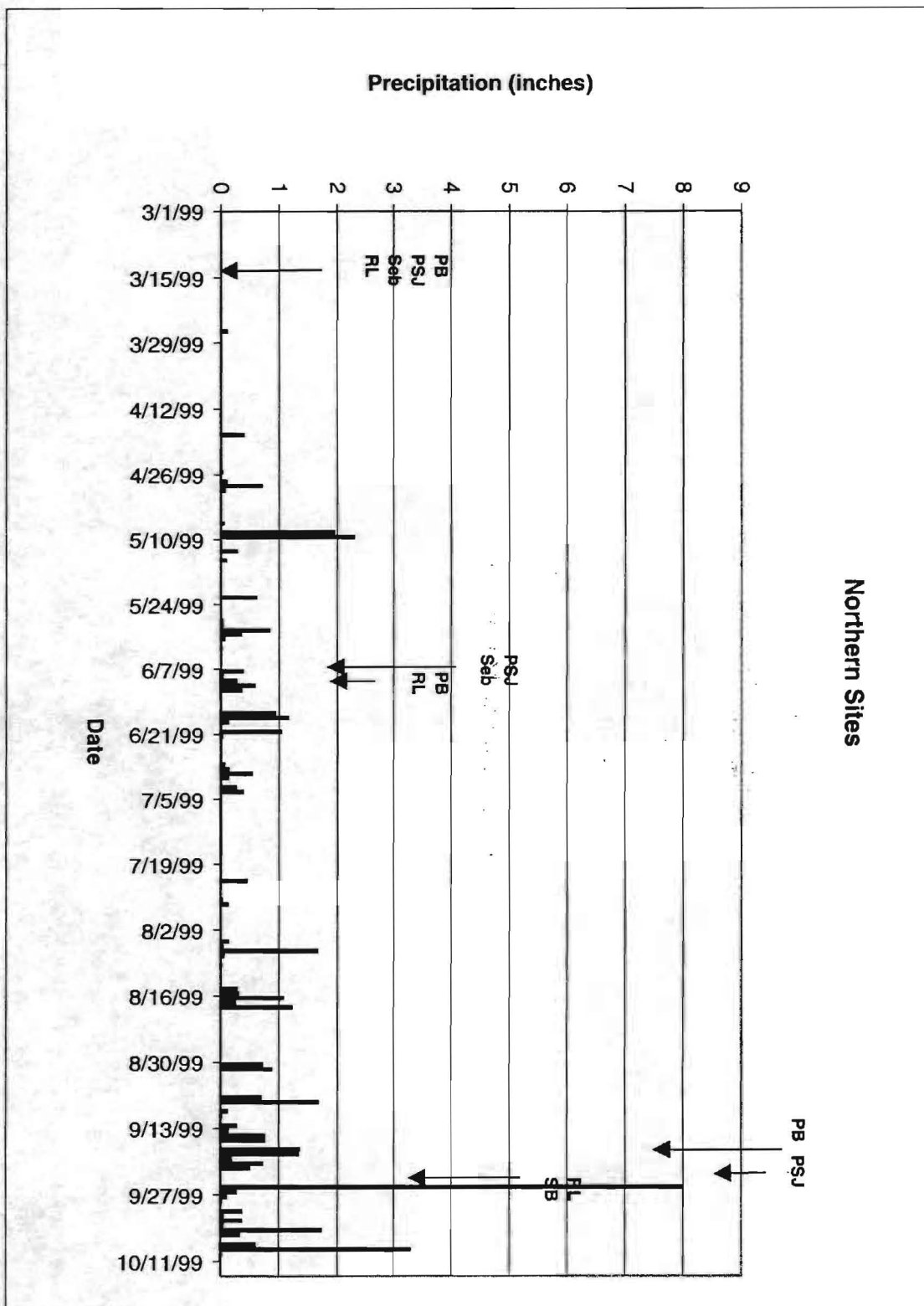
Rio



NORTH

Date: 12 August 1999
 Drawn By: JAS, SW
 Designed By: JAS
 Approved By: JFB
 Approx. Scale: 1" = 200'
 Sheet No: 1 OF 1
 Revision Date: 12 August 1999

Figure 26. Precipitation March through October, 1999 Melbourne Station



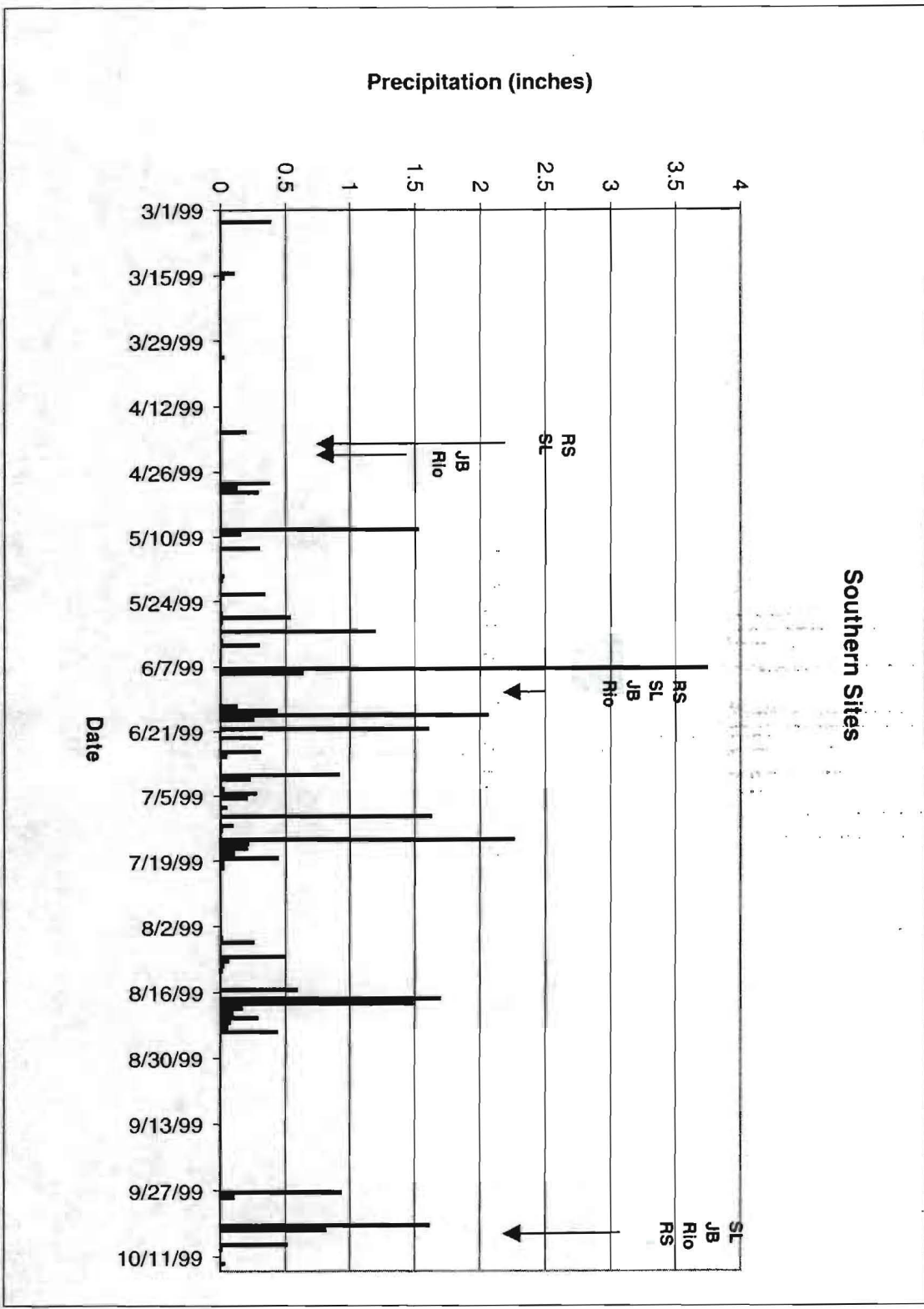


Figure 27. Precipitation March through October, 1999 St. Lucie Station

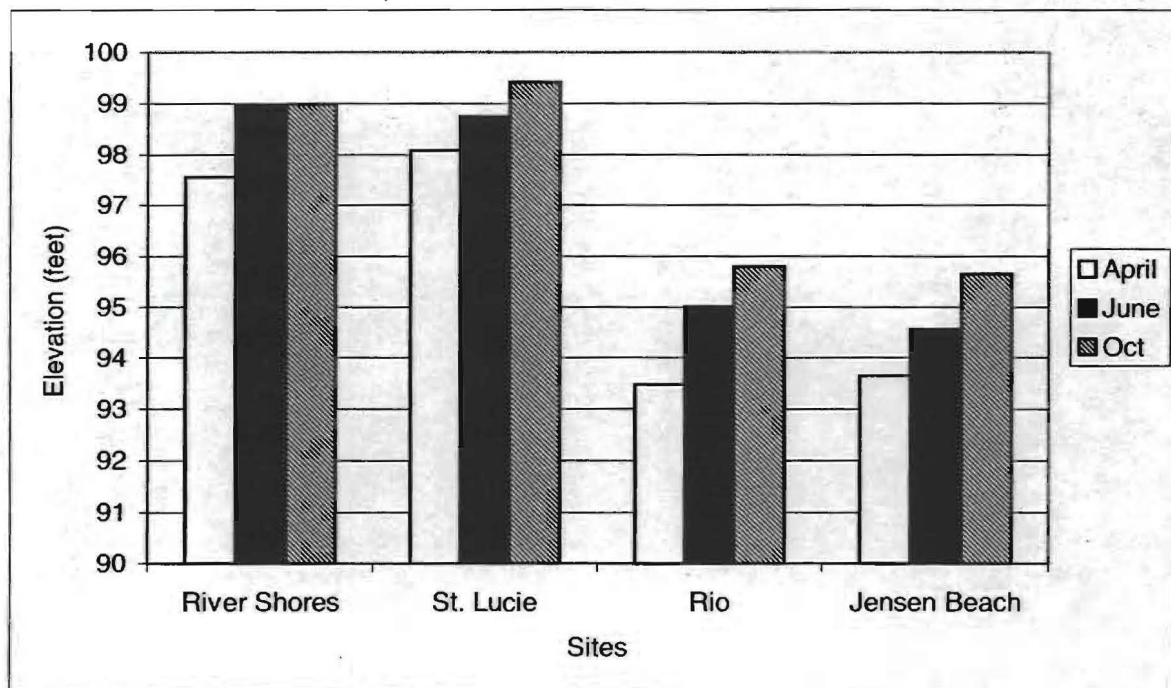
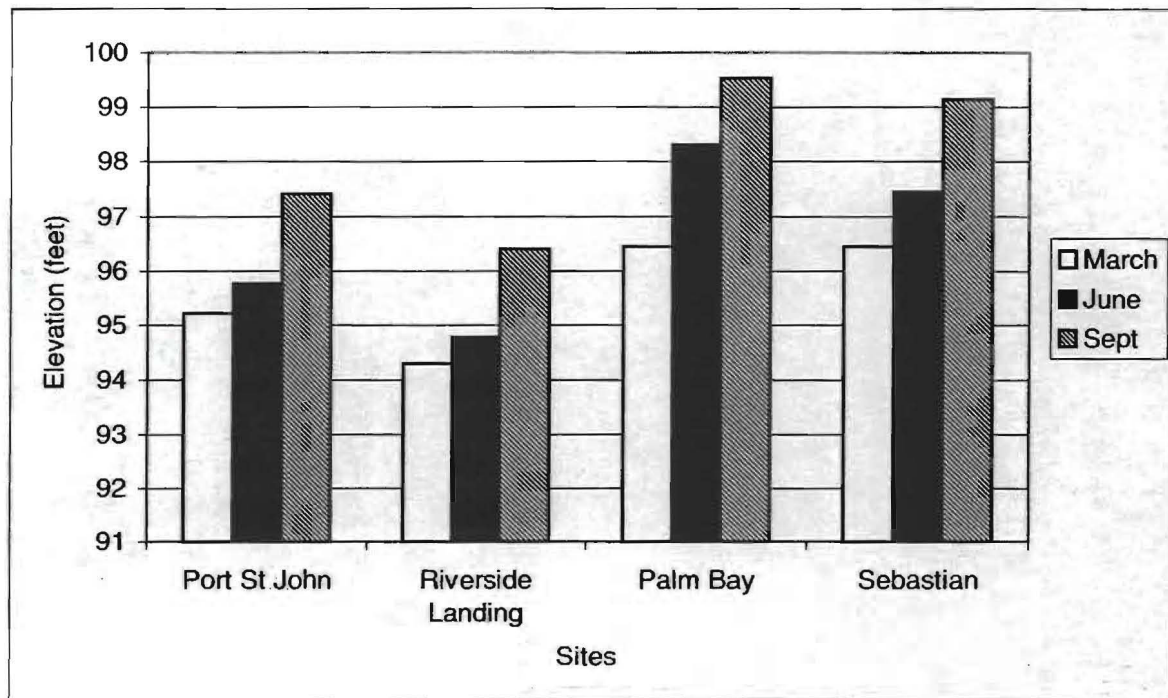


Figure 28. Groundwater Elevations at Each Site During Field Sampling

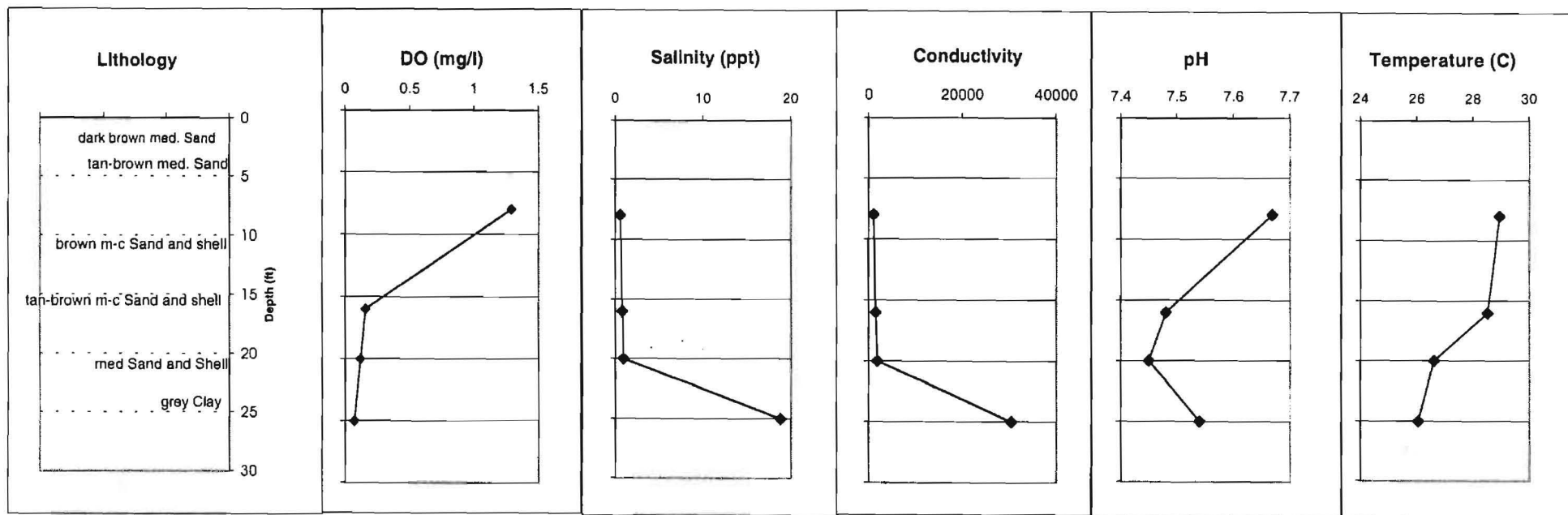


Figure 29. In-situ Depth Profiles Riverside Landing - October

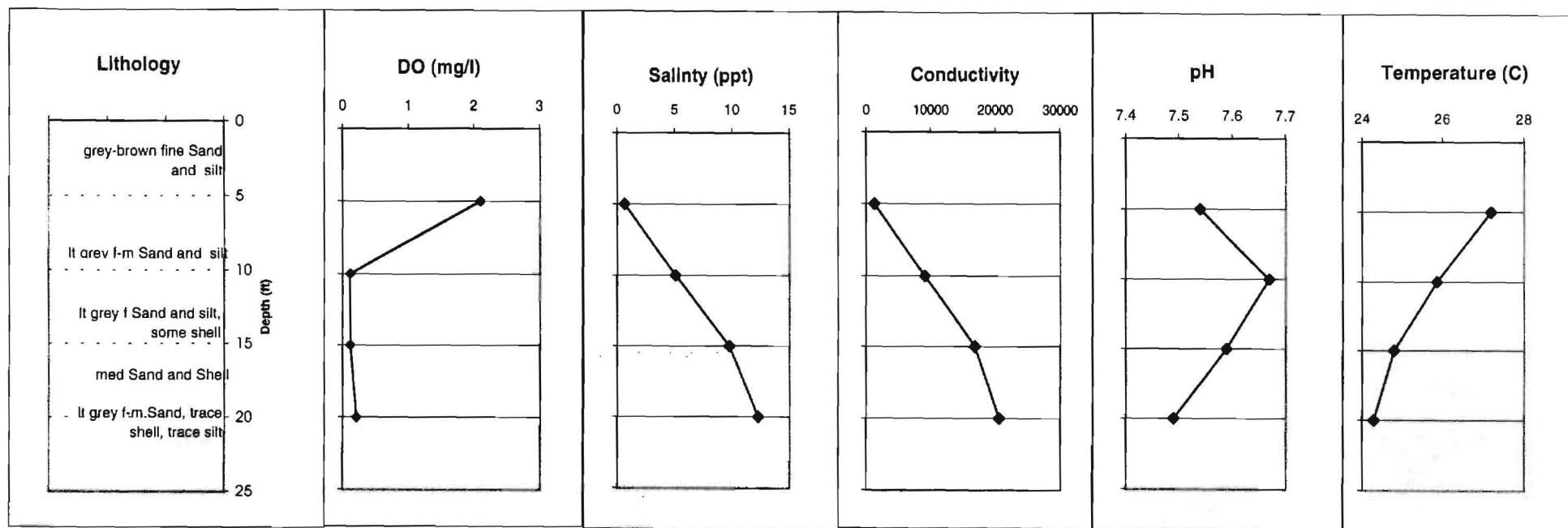


Figure 30. In-Situ Depth Profiles River Shores Site - October

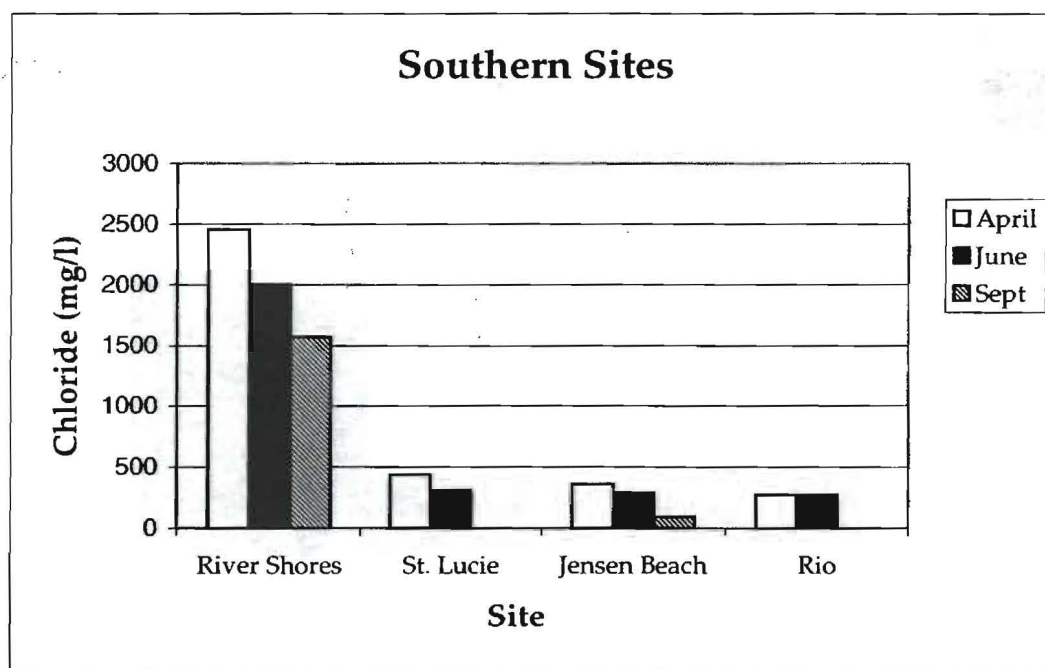
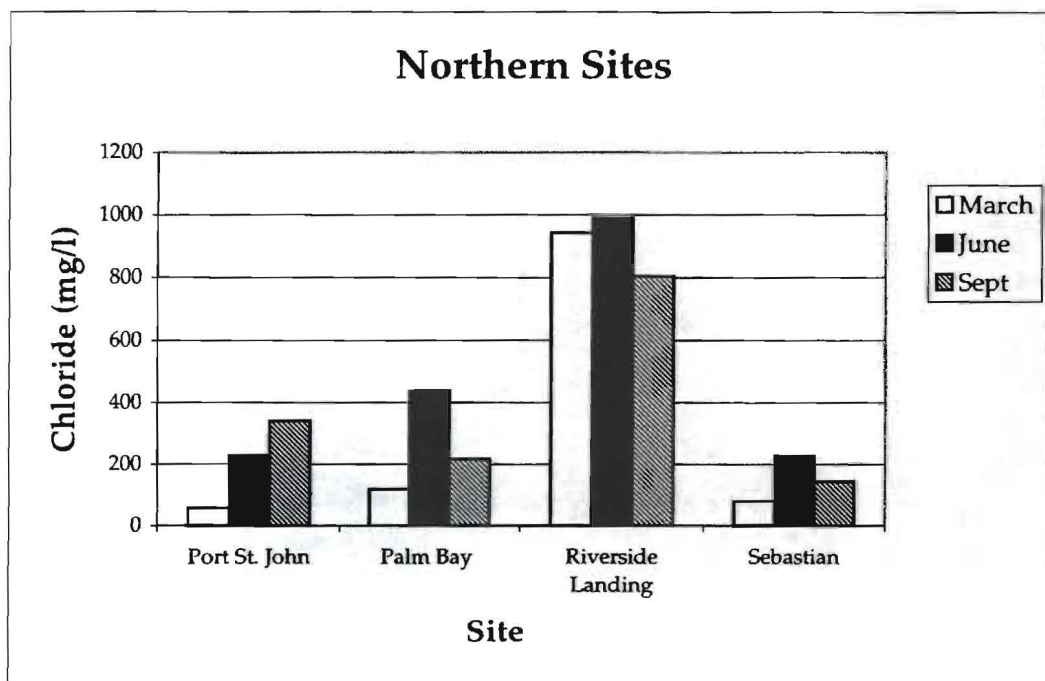


Figure 31. Average Chloride Concentrations in Surficial Aquifer

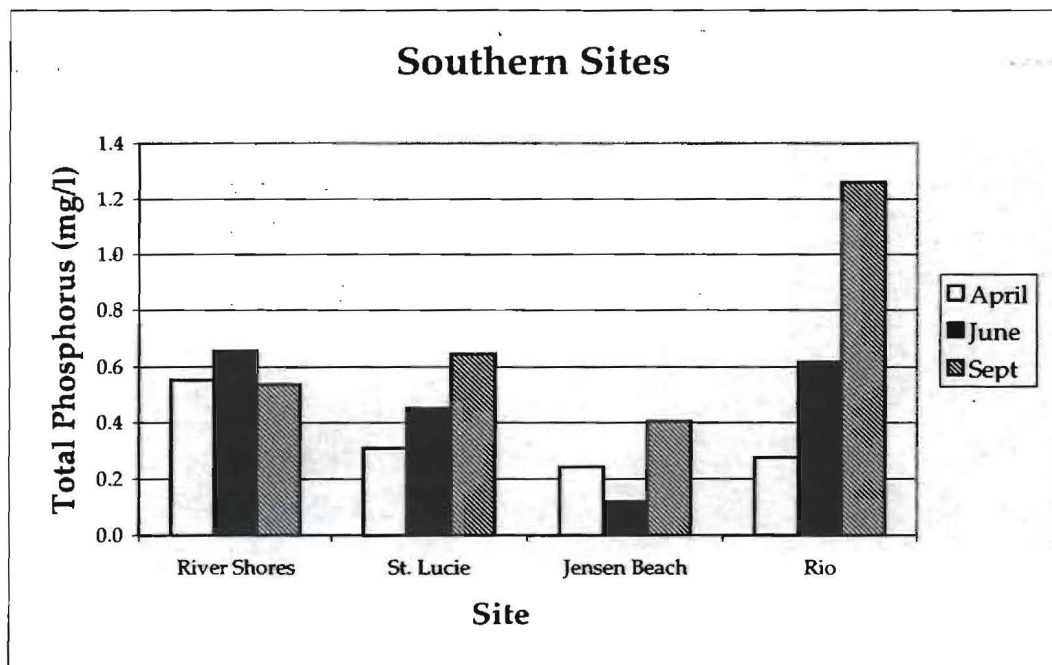
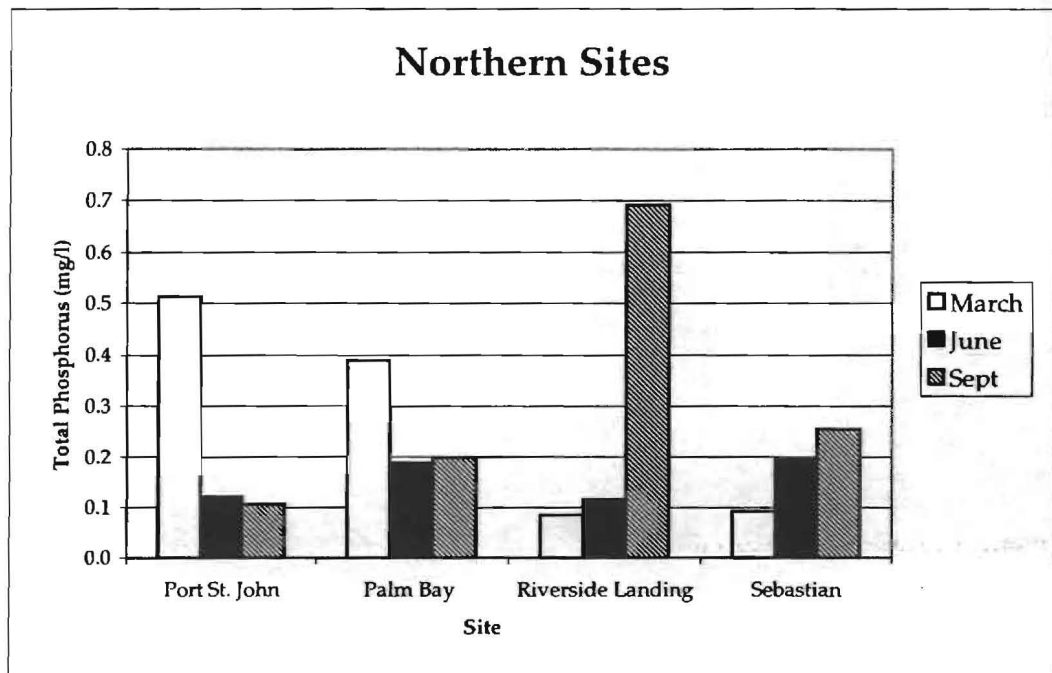


Figure 32. Average Total Phosphorus Concentrations in Surficial Aquifer

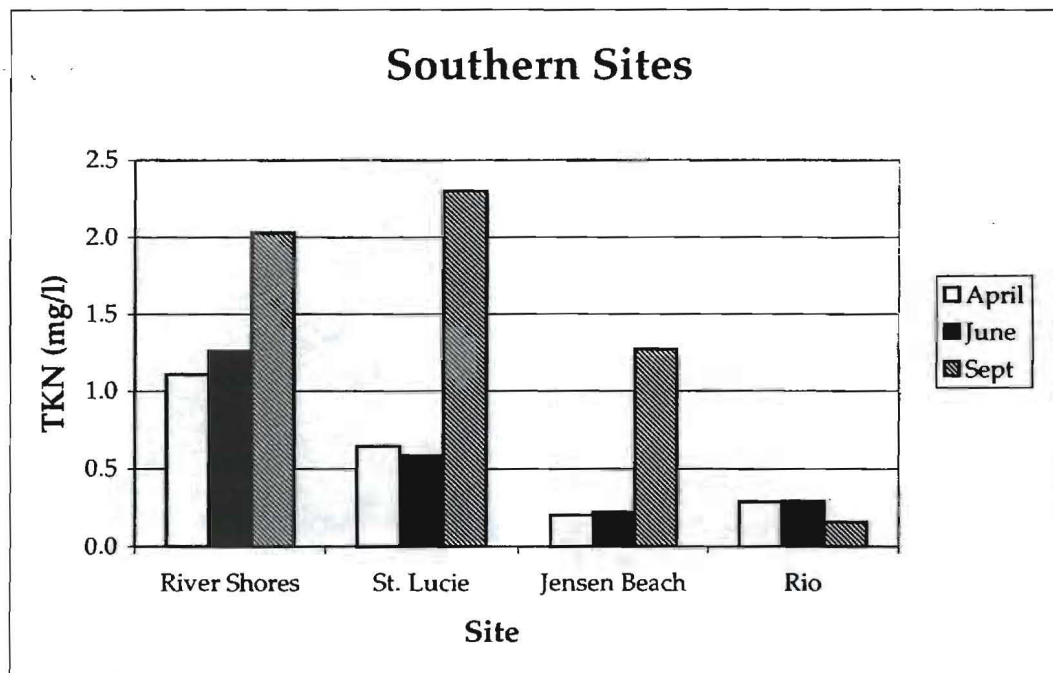
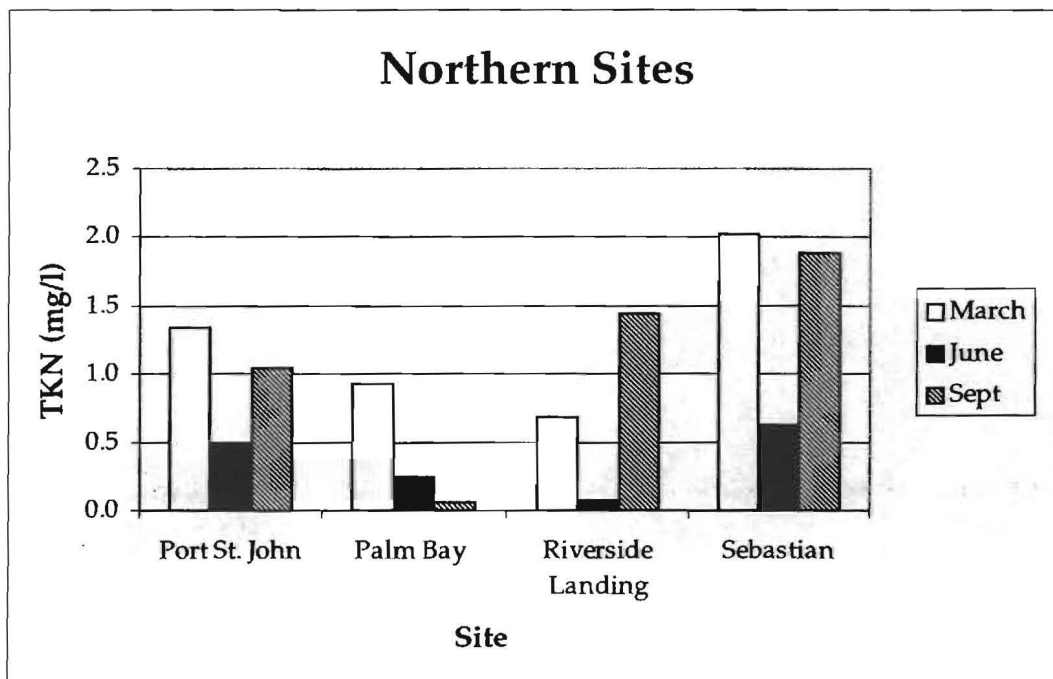


Figure 33. Average TKN Concentrations in Surficial Aquifer

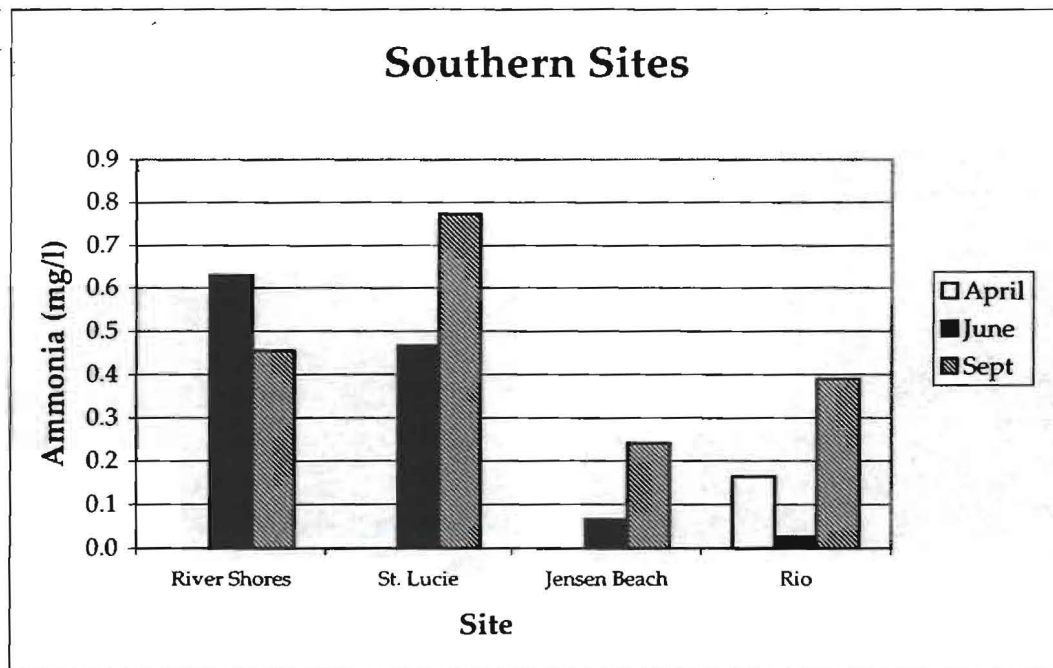
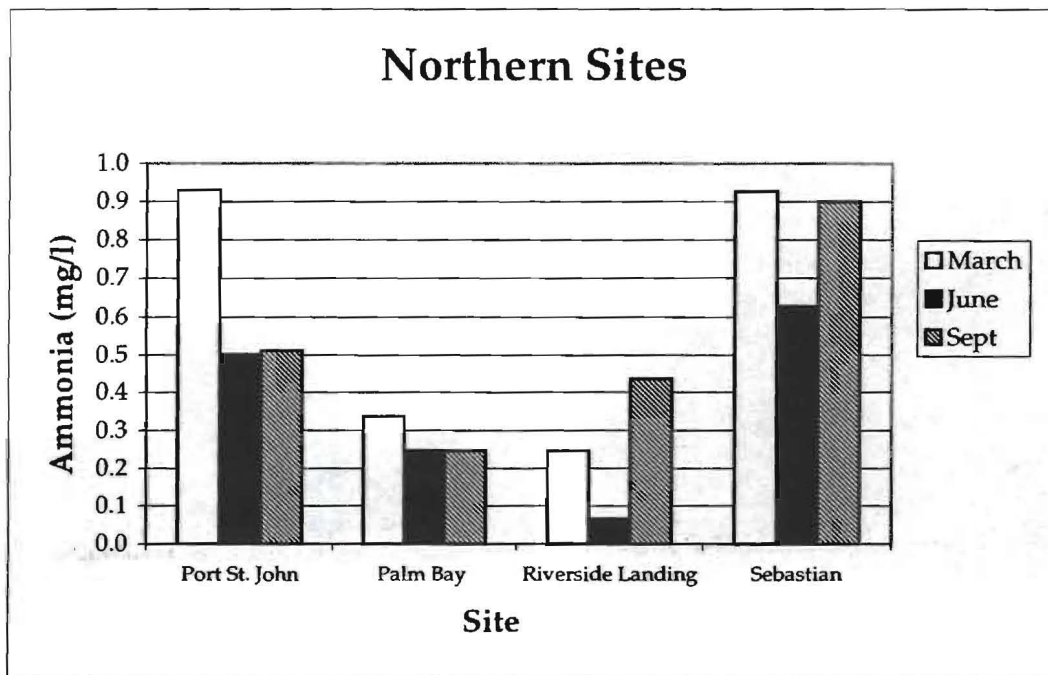


Figure 34. Average Ammonia Concentrations in Surficial Aquifer

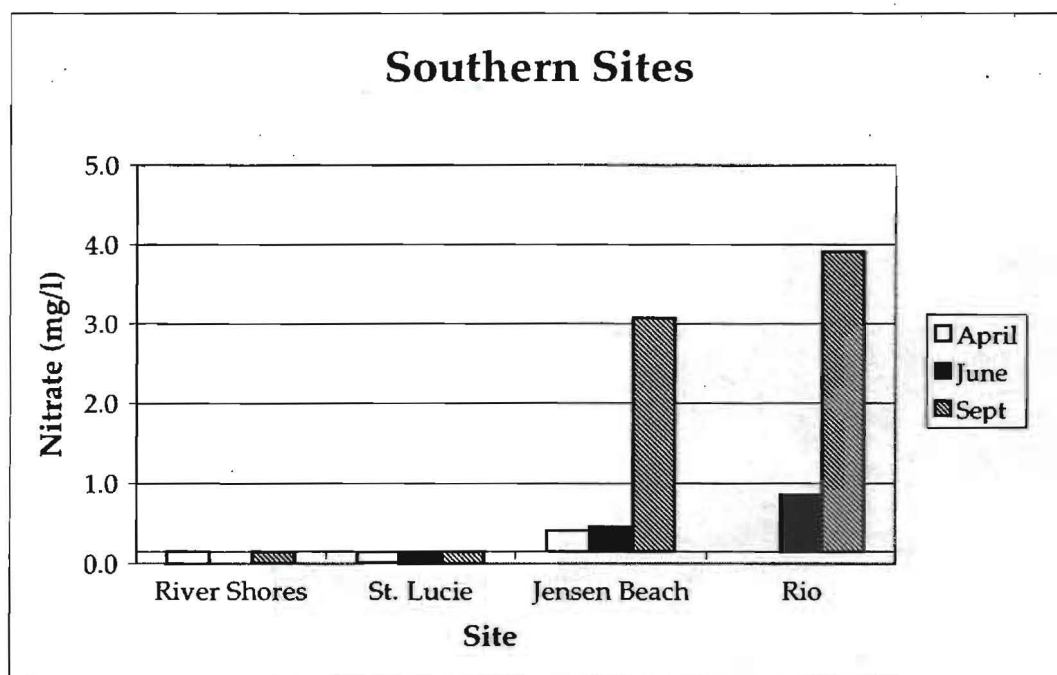
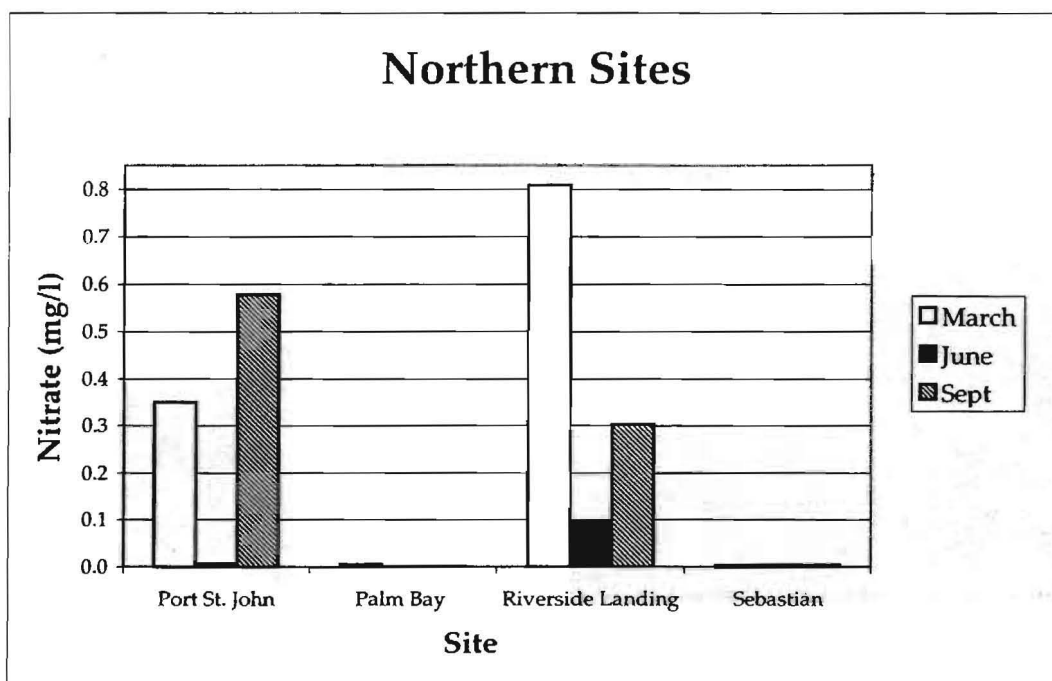


Figure 35. Average Nitrate Concentrations in Surficial Aquifer

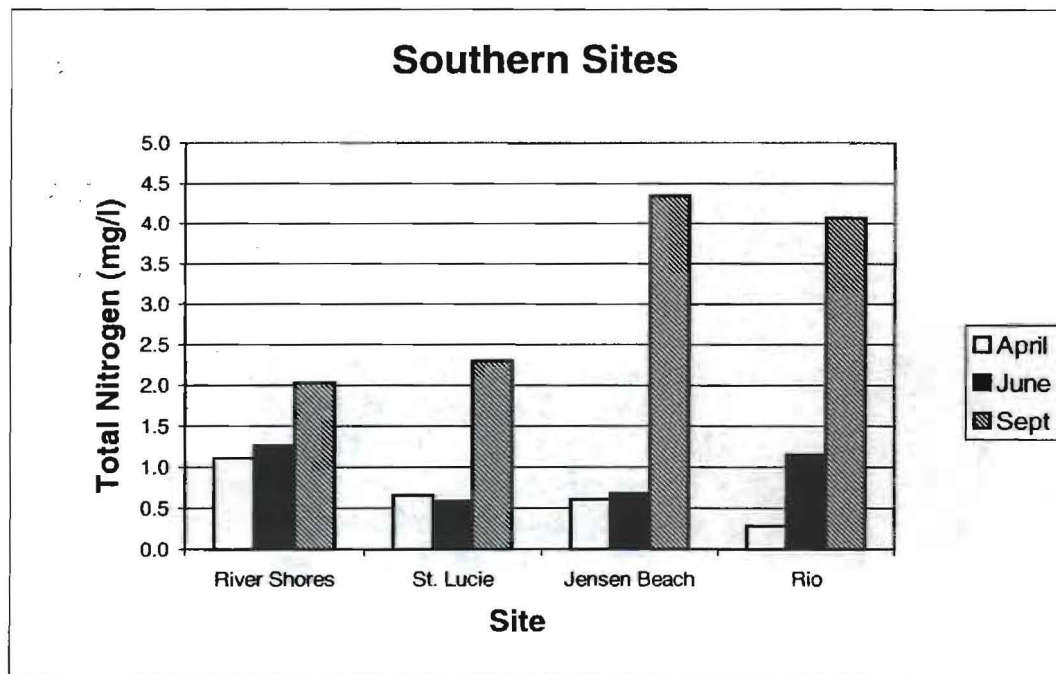
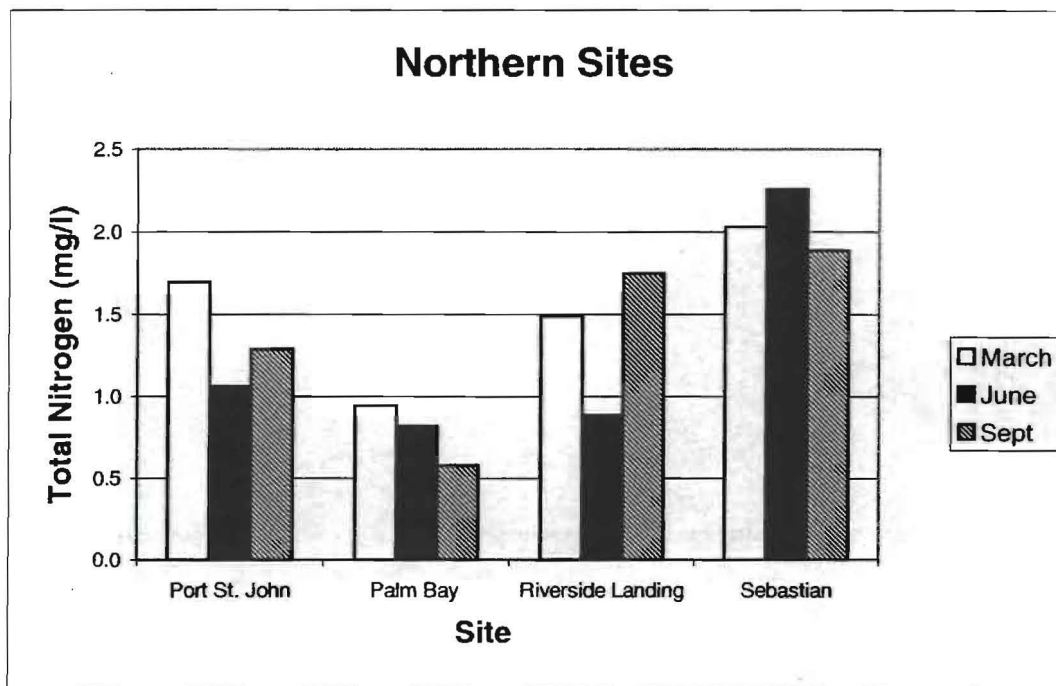


Figure 36. Average Total Nitrogen Concentrations in Surficial Aquifer

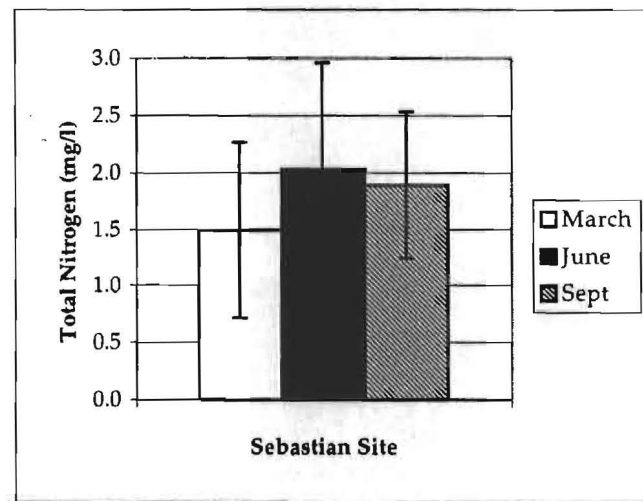
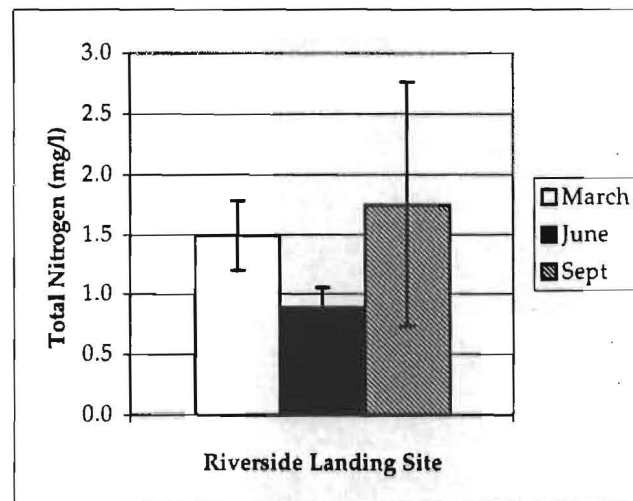
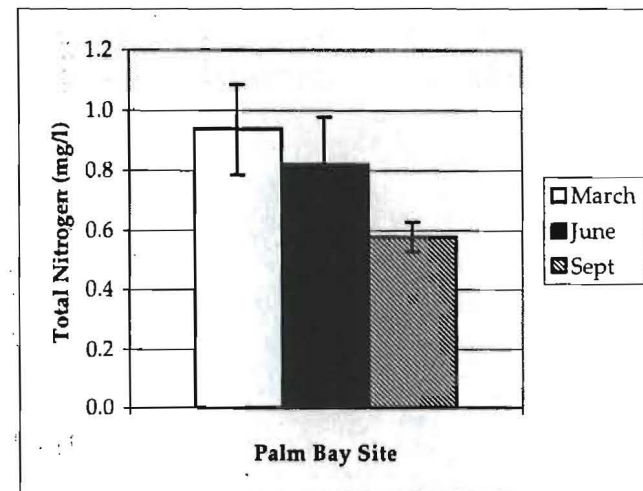
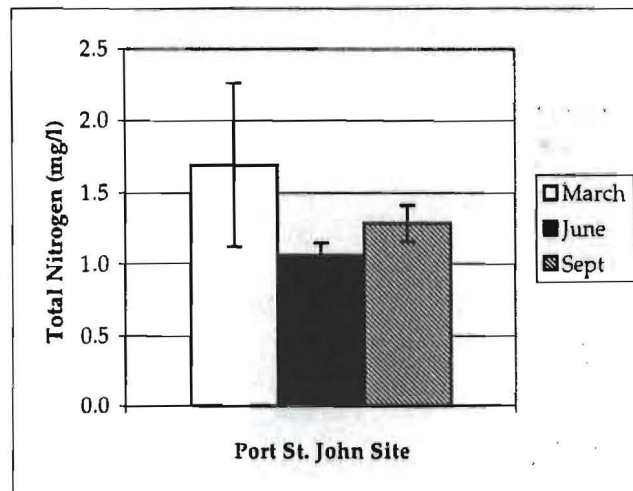


Figure 37. Average Total Nitrogen Varying Seasonally, Northern Sites

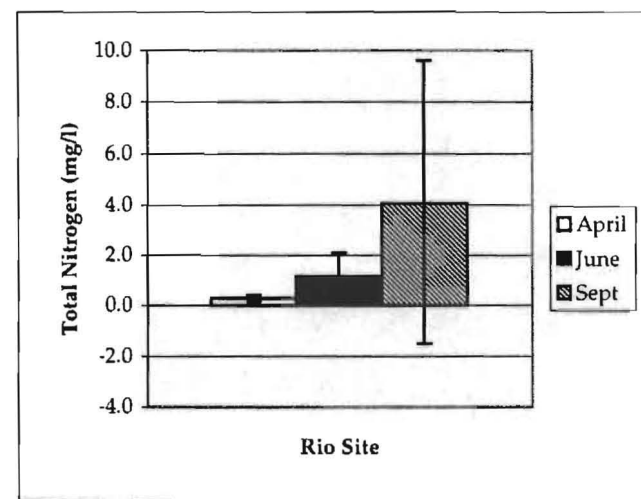
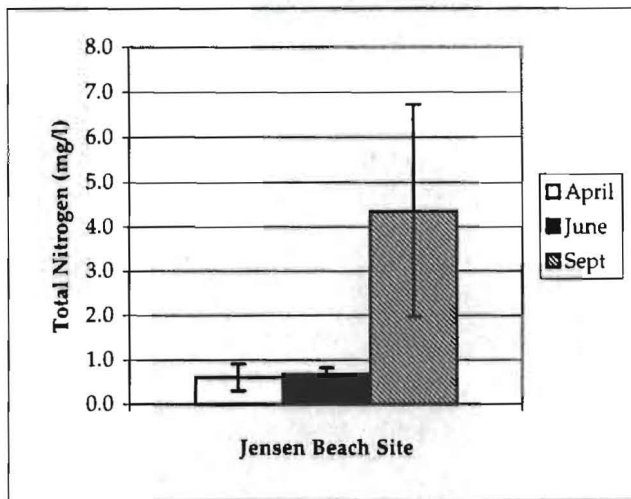
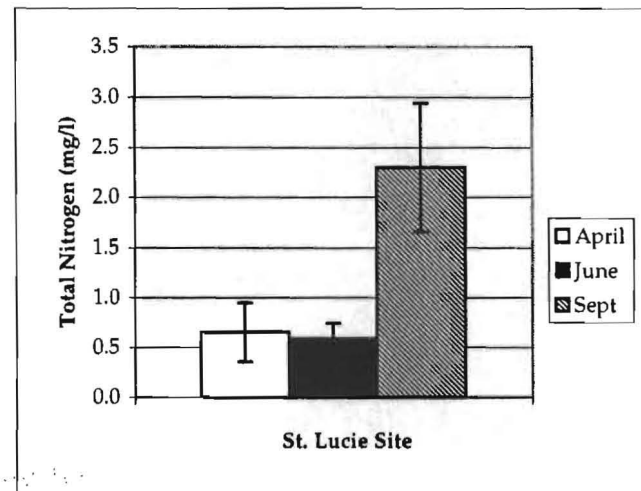
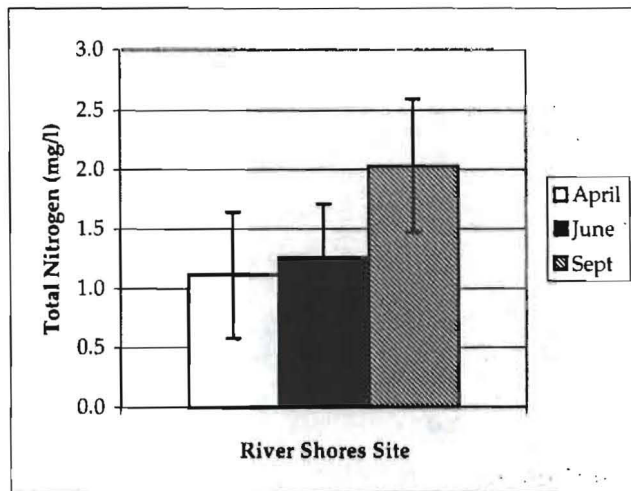


Figure 38. Average Total Nitrogen Varying Seasonally, Southern Sites

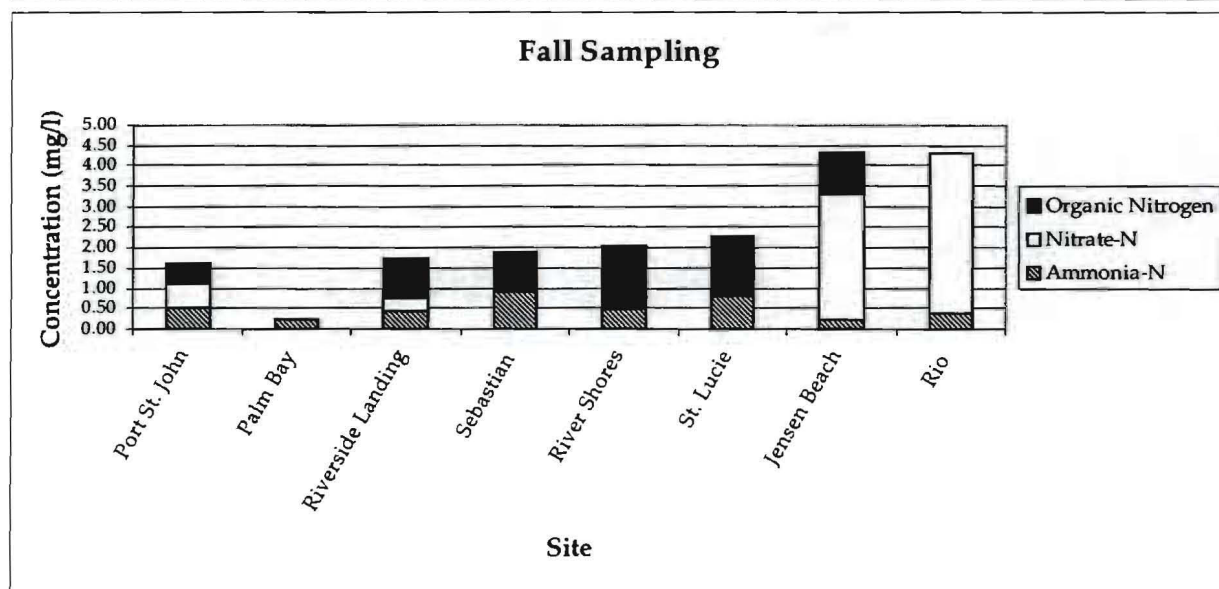
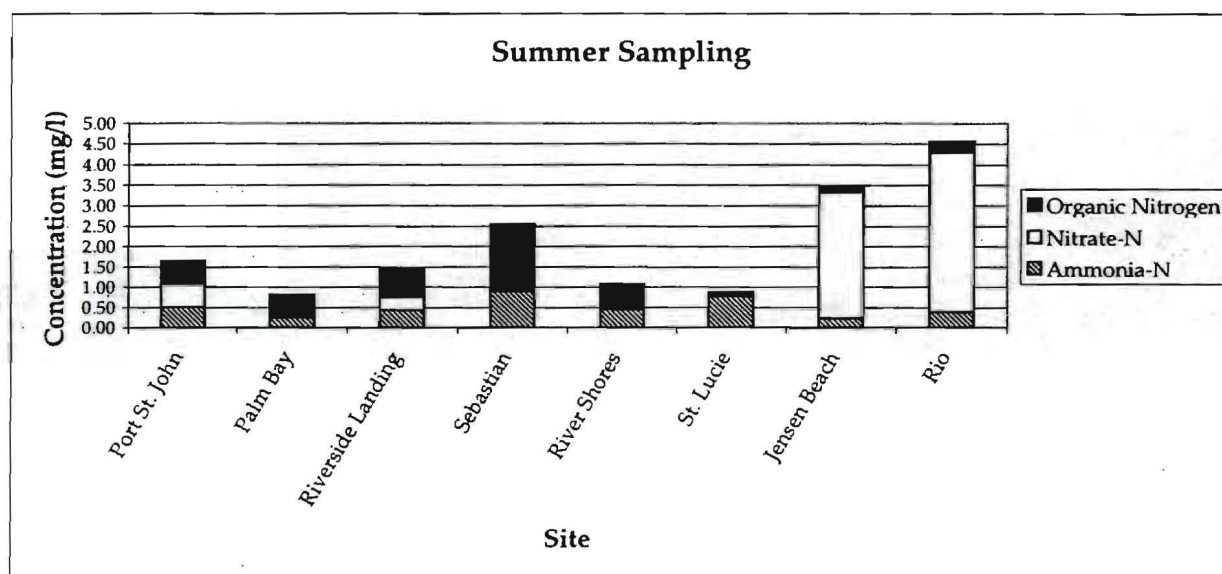
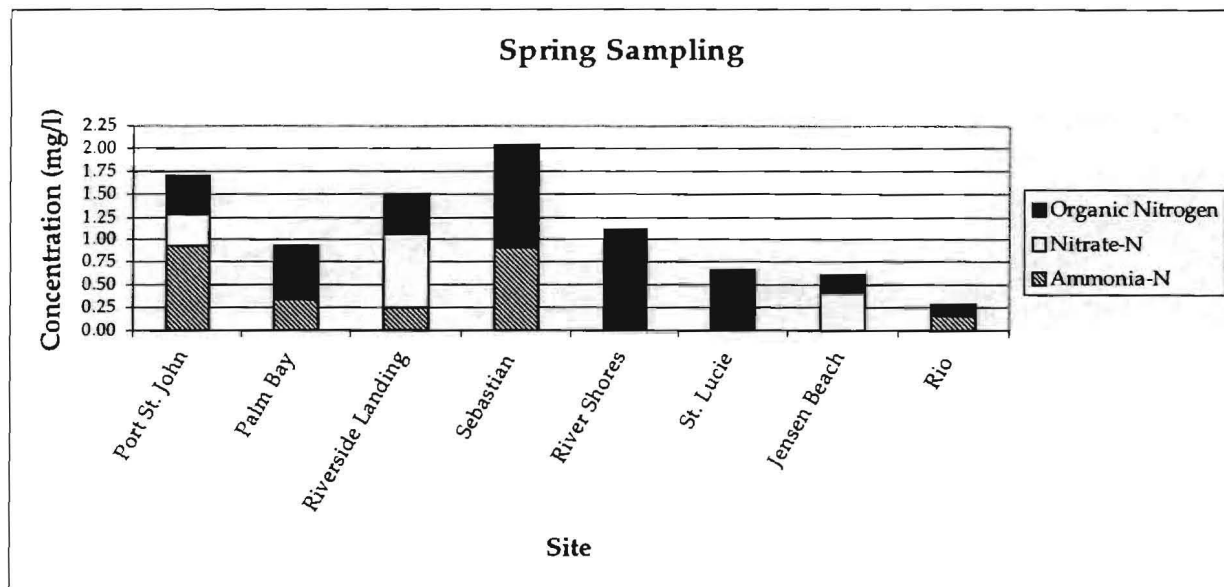


Figure 39. Nitrogen Speciation at Each Site

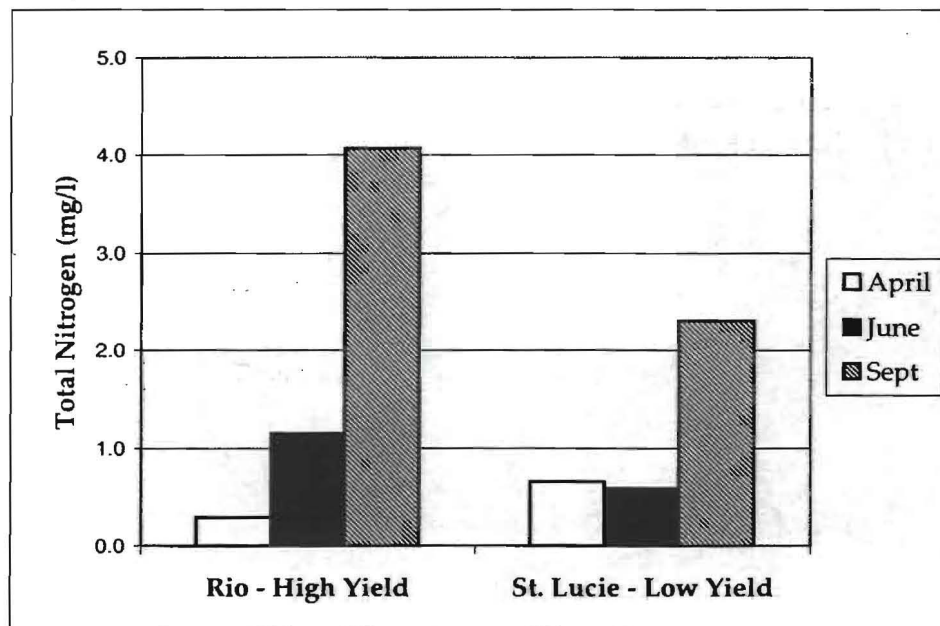
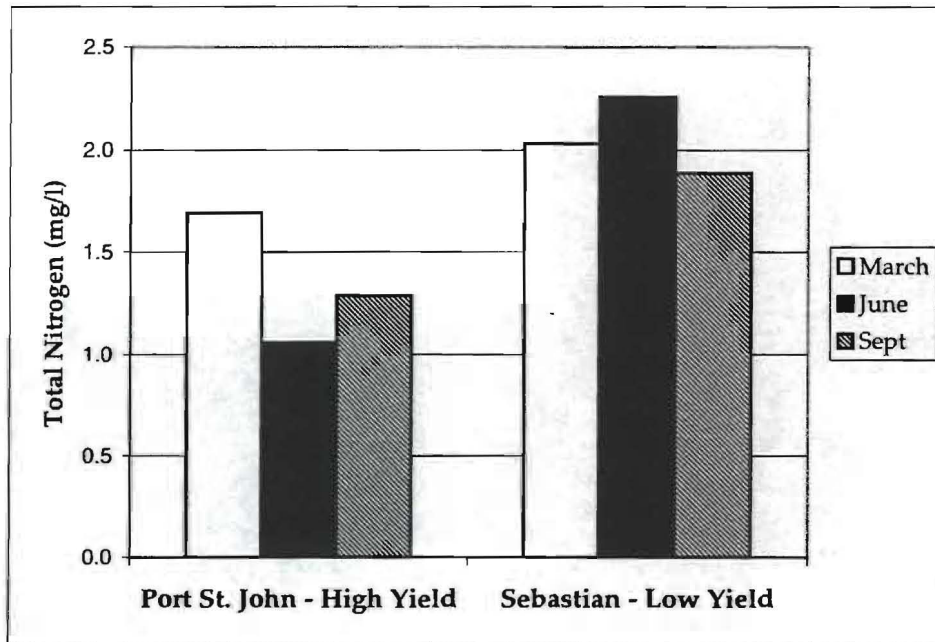


Figure 40. Comparison of Average Total Nitrogen Concentrations in High and Low Yield Wells

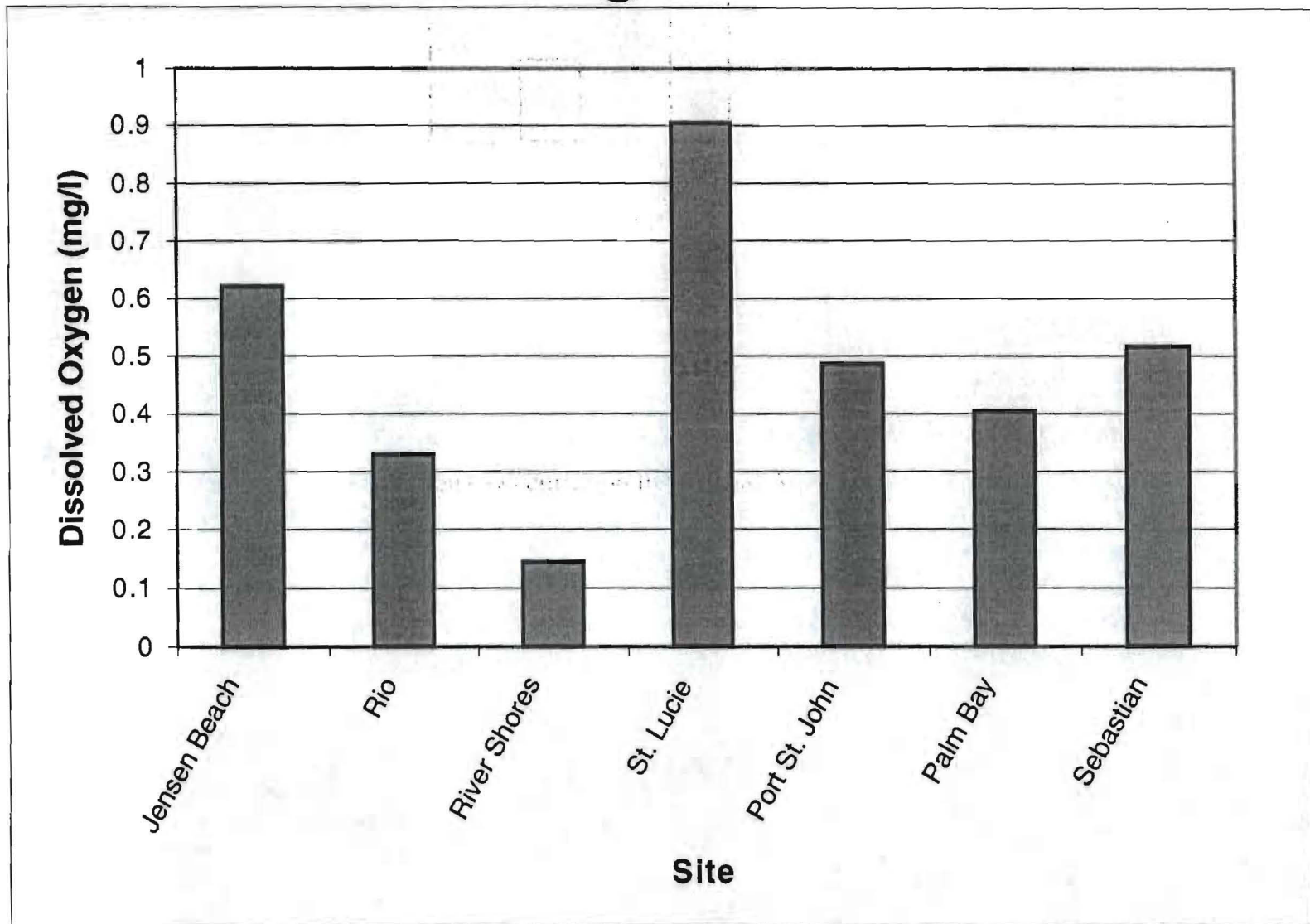


Figure 41. Average Dissolved Oxygen Concentration in Surficial Aquifer

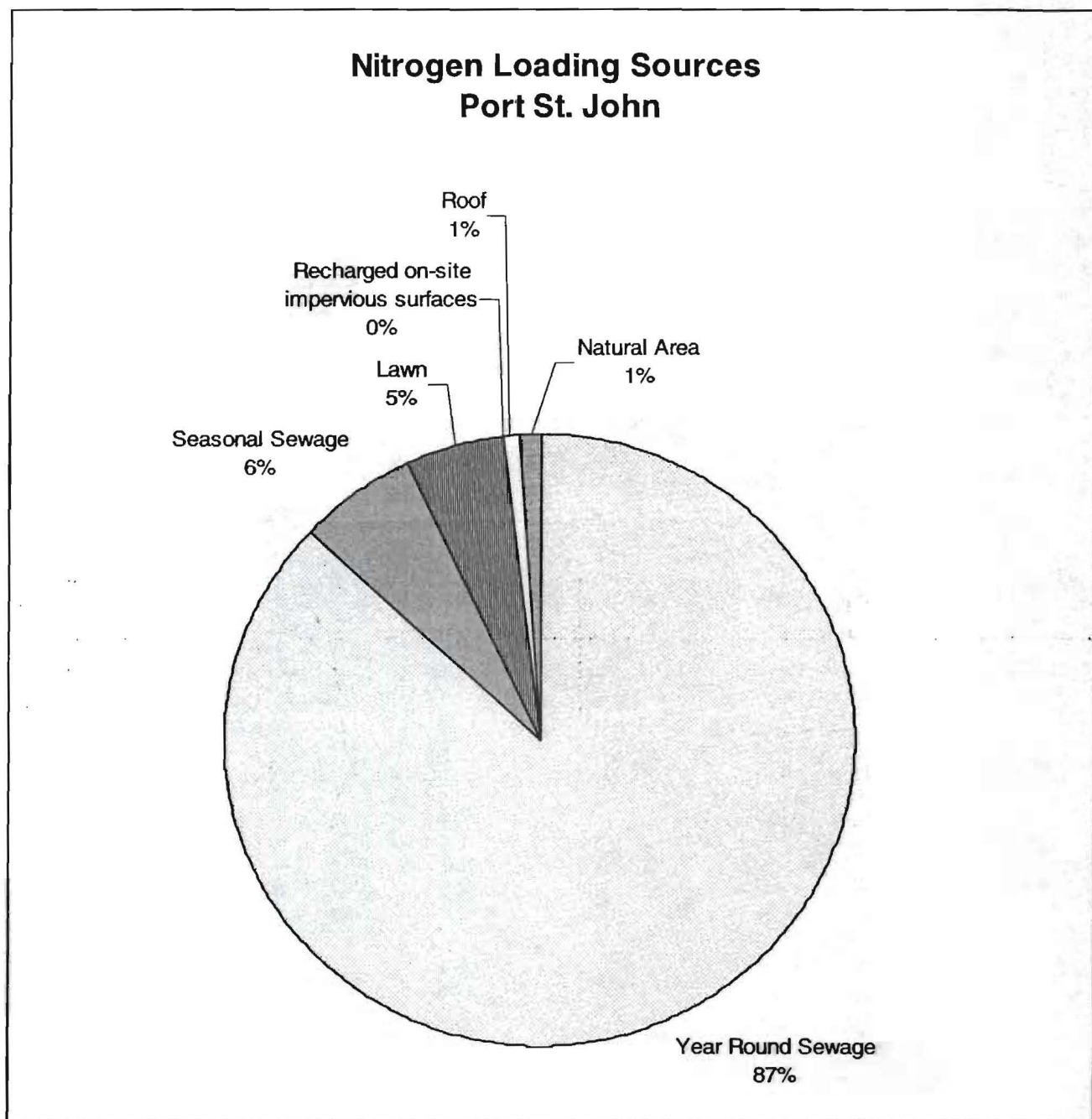
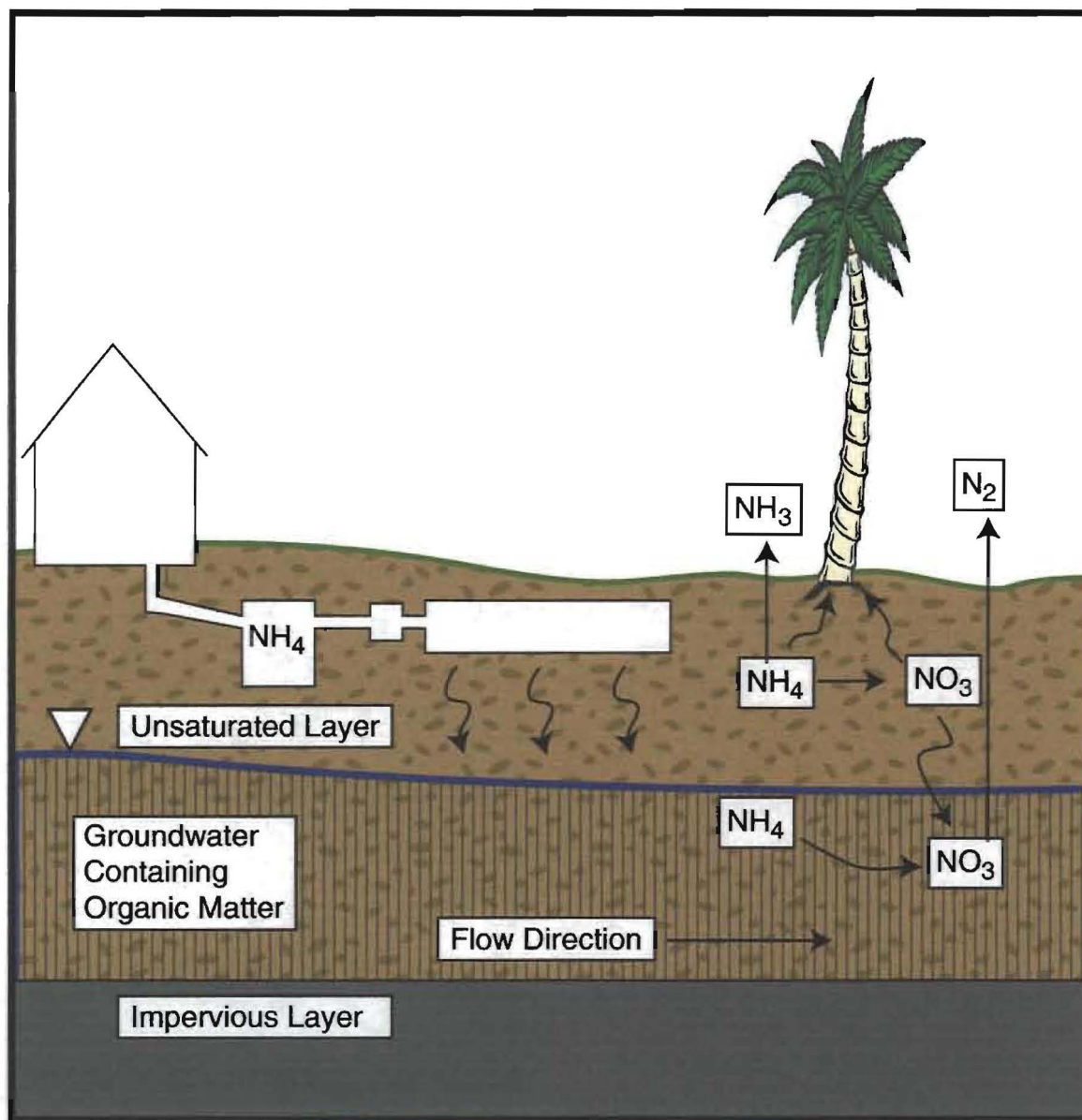


Figure 42. Sources of Nitrogen Loading



Legend

▽ Water Table

Horsley & Witten, Inc.
Environmental Services

90 Route 6A Sextant Hill
Sandwich, MA 02563
phone: 508-833-6600
fax: 508-833-3150



Figure 43.

Nitrogen Transformations



Date: 2 February 2000
 Drawn By: JAS
 Designed By: JAS
 Approved By: JFB, SWH, SW
 Approx. Scale: NA
 Sheet No: 1 OF 1
 Revision Date: 2 February 2000