Simulation of Ground-Water Flow at the U.S. Naval Air Station, Jacksonville, Florida, with an Evaluation of Changes to Ground-Water Movement Caused by Proposed Remedial Designs at Operable Unit 1

By J. Hal Davis, Michael Planert, and William J. Andrews

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CONVERSION FACTORS, VERTICAL DATUM, ABBREVIATIONS, AND ACRONYMS

Multiply	By	To obtain
inch (in.)	2.54	centimeter
inches per year (in/yr)	2.54	centimeters per year
foot (ft)	0.3048	meter
gallon (gal)	0.003785	cubic meter
gallon (gal)	3.785	liter
mile (mi)	1.609	kilometer

Equations for temperature conversion between degrees Celsius (°C) and degrees Fahrenheit (°F):

$$°C = 5/9\ (°F - 32)$$
$$°F = (9/5\ °C) + 32$$

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929-- a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Additional Abbreviations

in/yr = inches per year
ft/d = feet per day
gal/min = gallons per minute
Mgal/d = million gallons per day
ft^3/s = feet cubed per second

Acronyms

OU1	Operable Unit 1
OU2	Operable Unit 2
OU3	Operable Unit 3
USGS	U.S. Geological Survey
MODFLOW	USGS Modular Three-Dimensional Finite-Difference Ground-Water Flow Model
MODPATH	USGS Flow-Path simulation program
NAS	Naval Air Station, Jacksonville, Florida
RI/FS	Remedial Investigation/Feasibility Study
USGS	U.S. Geological Survey

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ABSTRACT

The U.S. Navy has been concerned about the movement, to the neighboring St. Johns River, of organic compounds and metals occurring in ground water in the shallow surficial aquifer at the Naval Air Station, Jacksonville, Fla. (referred to as NAS). In 1992, the U.S. Navy requested the U.S. Geological Survey to simulate advective ground-water flow in the surficial aquifer at NAS to assess the direction and rates of ground-water flow from areas with documented contamination.

Three Operable Units have been identified that require a Remedial Investigation/Feasibility Study. Operable Unit 1 (OU1) is located in the south-central part of NAS and was used for the disposal of household and sanitary waste, liquid industrial waste (oil and solvents), demolition and construction debris, and includes one area that was formerly used to store electric transformers that contained PCBs. Operable Unit 2 (OU2) is located in the northern part of NAS and has principally been used for fire-fighting training, sewage treatment, and sewage sludge disposal. Operable Unit 3 (OU3) is located in the eastern part of NAS, adjacent to the St. Johns River. The OU3 area consists primarily of the Naval Aviation Depot, an industrialized area that generated waste materials such as paint sludges, solvents, battery acids, and aviation fuels.

A surficial aquifer is the uppermost aquifer beneath NAS and is considered to be unconfined. The surficial aquifer consists of a series of Pleistocene- and Holocene-age terraces composed of silty sands deposited during marine transgressions and regressions associated with glacial and interglacial periods. For modeling, the surficial aquifer was represented by a single layer, subdivided into 240 rows and 290 columns of grid cells. Model cells were spaced so that each monitoring well could be placed in an individual cell, thereby allowing comparison of observed heads at each monitoring well to the simulated head in the model cell. Comparison of 127 observed and simulated heads following model calibration showed that all but one simulated head was within the +/- 2.5-ft error criterion.

Remedial measures are currently being assessed by the Navy that will prevent or mitigate the effect of ground-water contamination on areas surrounding OU1. The calibrated model was used to evaluate the effect of various engineering designs on the movement of ground water. The evaluation of each remedial design consisted of (1) modifying the calibrated-model data files to fit the proposed design, (2) simulating ground-water flow with the new design in place to obtain the head distribution and intercell flow rates needed for particle tracking analysis, and (3) seeding the part of the model surrounding OU1 with particles and tracking their movement to determine ground-water flow directions. A total of 11 engineering designs were simulated with the model to test their effect on the ground-water flow system. The designs included modifying existing ditches and drainages, installing a pumping well, and installing vertical barriers.

INTRODUCTION

The Naval Air Station at Jacksonville, Florida (NAS) was placed on the U.S. Environmental Protection Agency's National Priorities List in December 1989 and is participating in the U.S. Department of Defense Installation Restoration Program. This program serves to identify and remediate environmental contamination in compliance with the Comprehensive Environmental Response, Compensation, and Liability Act and the Superfund Amendments and Reauthorization Act of 1980 and 1985, respectively. Officials from Southern Division Naval Facilities Engineering Command (hereafter referred to as the Navy) have been concerned about the movement of organic compounds and metals in ground water at NAS from the surficial aquifer to the neighboring St. Johns River. This report summarizes part of the Remedial Investigation/ Feasibility Study (RI/FS) for NAS.

Three Operable Units (OU1, OU2, and OU3) have been identified as requiring a RI/FS (fig. 1). OU1 is located in the south-central part of NAS (fig. 1), was formerly known as the Old Main Registered Disposal Area, occupies approximately 38 acres, and includes one area formerly used to store electric transformers that contained PCBs (Navy, 1992). Prior to 1942 and the Navy's operation of NAS, the site was a U.S. Army facility. The U.S. Army is reported to have used parts of OU1 for disposal of non-hazardous debris (primarily a vehicle junk yard). Later, the Navy used OU1 for the disposal of household and sanitary waste, liquid industrial waste (oil and solvents), and demolition and construction debris. At one time, these materials were burned in open pits and trenches, and the residues were left in place. After the pits were full of the burned residue, they were covered with soil and the area was graded to conform to the surrounding topography.

OU2, which occupies 164 acres in the northern part of NAS (fig. 1), has principally been used for fire-fighting training, sewage treatment, and sewage sludge disposal (Navy, 1994a). Potential contaminants include aviation fuel and waste oil at the old fire-training area, sewage and waste-water sludge, asbestos, and petroleum products at the sludge disposal areas, and industrial sludge from metal-plating and paint-stripping activities at sludge-drying beds (Navy, 1994a). Activities possibly contributing to ground-water contamination began in the early 1960's and ended in 1993.

OU3 is located in the eastern part of NAS (fig. 1), adjacent to the St. Johns River, and consists primarily of the Naval Aviation Depot (Navy, 1994b). Activities associated with past operations at OU3 include the maintenance and rework of military aircraft and the facility's laundry and dry cleaning operations. Waste materials previously spilled or disposed of at OU3 reportedly include paint sludges, solvents, battery acids, and aviation fuels.

This report documents the development and calibration results of a ground-water flow model of the surficial aquifer underlying NAS. This report also describes the hydrology of the surficial aquifer and related directions of ground-water flow. The calibrated model was used to evaluate likely directions of flow away from possible sources of contamination on NAS, to determine points of discharge from the surficial aquifer, and to evaluate the effect of various remedial engineering designs on the movement of ground water in an area surrounding OU1. These evaluations are described in this report.

DESCRIPTION OF THE STUDY SITE

NAS occupies 5.9 mi^2 in southeastern Duval County, Fla., (fig. 1) and is located approximately 9 mi south of downtown Jacksonville, Fla. NAS is located on the St. Johns River approximately 24 mi upstream from its confluence with the Atlantic Ocean. Bordering NAS are the St. Johns River to the east and northeast, a residential area on the south, U.S. Highway 17 on the west, and the Timmaquana Country Club on the northwest. A residential area is located to the west, between U.S. Highway 17 and the Ortega River.

Climate

The Jacksonville, Fla., area has a humid, subtropical climate with an annual mean temperature of 68°F. The average annual rainfall in Jacksonville from 1971 to 1990 was 52.76 in. (National Weather Service, oral commun., 1992). Most of the annual rainfall in this area occurs in the late spring and early summer (Fairchild, 1972). The distribution of rainfall in the vicinity of Jacksonville is highly variable because the majority of the rainfall in this area comes

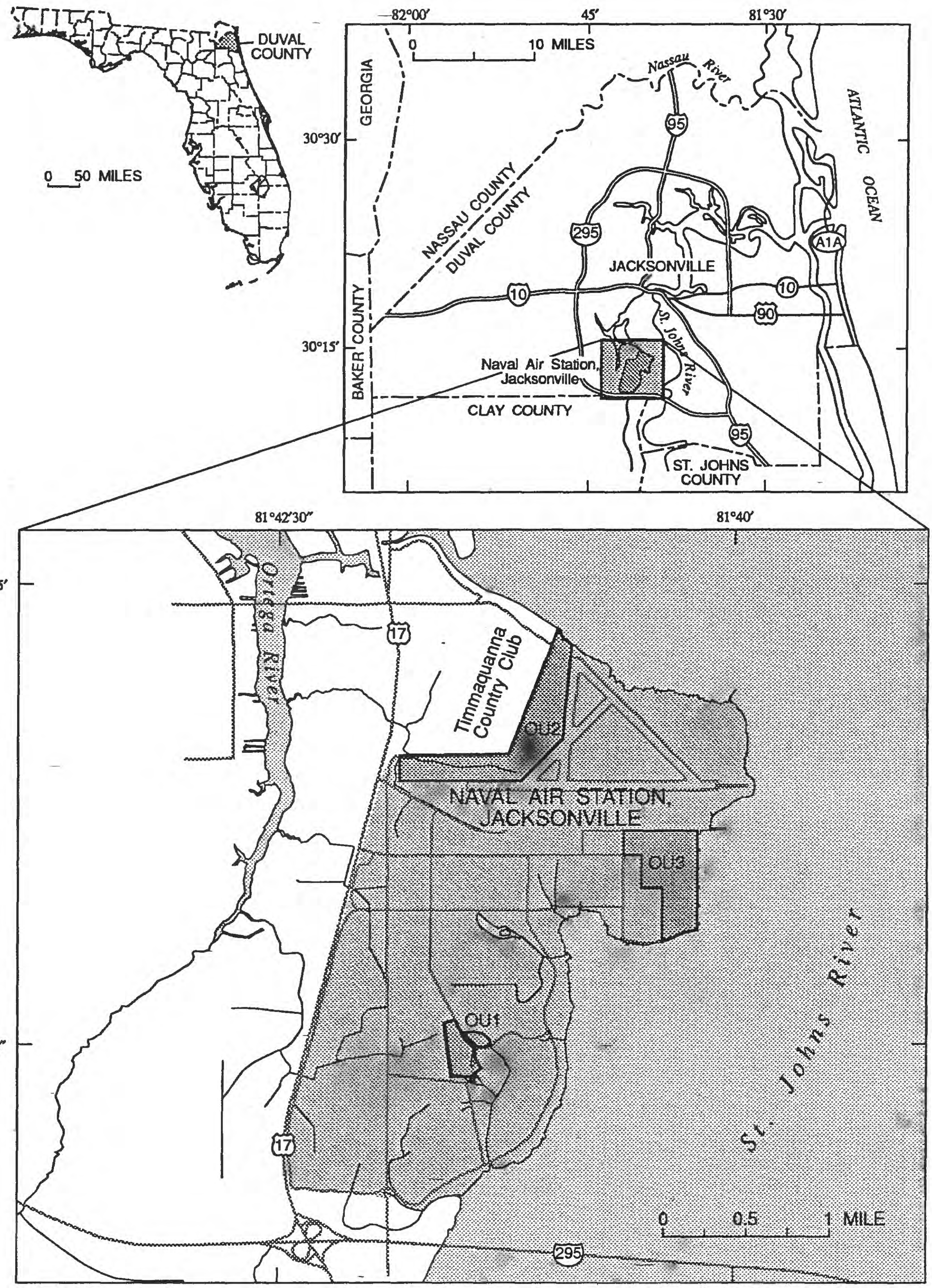


Figure 1. Location of the study area.

from scattered convective thunderstorms during the summer. Winters in the Jacksonville area are mild and dry, with occasional frost from November through February (Fairchild, 1972, p. 4).

Land Use

The area occupied by NAS has been used for military activities since 1909, when the state militia opened a training camp (Kevin Gartland, NAS, written commun., 1993). The camp was the site of the second largest shooting range in the country from 1915-16, and in 1916 an aviation training camp was opened. The site was occupied by as many as 27,000 troops-in-training from 1917-19. The camp was returned to the State of Florida for militia training after World War I and was used for this purpose until 1939, when construction of NAS began at the site (Kevin Gartland, NAS, written commun., 1993). During World War II, NAS was used for cadet and advanced fighter training. The scope of operations at NAS increased after the war, with Fleet Air Wing ELEVEN and its patrol squadron moving to NAS in 1950 and Helicopter Anti-Submarine Wing ONE and its squadrons moving to NAS in 1973.

NAS employed over 15,300 personnel as of 1993, in its role as a master air and industrial station specializing in anti-submarine warfare and aviator training (Kevin Gartland, NAS, written communication, 1993). There were 11 operational squadrons flying P3 "Orion", C12 "Huron", C9 "Skytrain II" aircraft, and SH-3H "Sea King" and SH-60F "Sea Hawk" helicopters at that time. These and other Navy military planes were serviced at NAS. NAS was also the base of Patrol Squadron 30, a training facility for personnel operating P3 aircraft. Support facilities at NAS include an airfield, a maintenance depot, a Naval Hospital, a Naval Supply Center, the Navy Family Service Center, and recreational and residential facilities.

Physiographic Setting

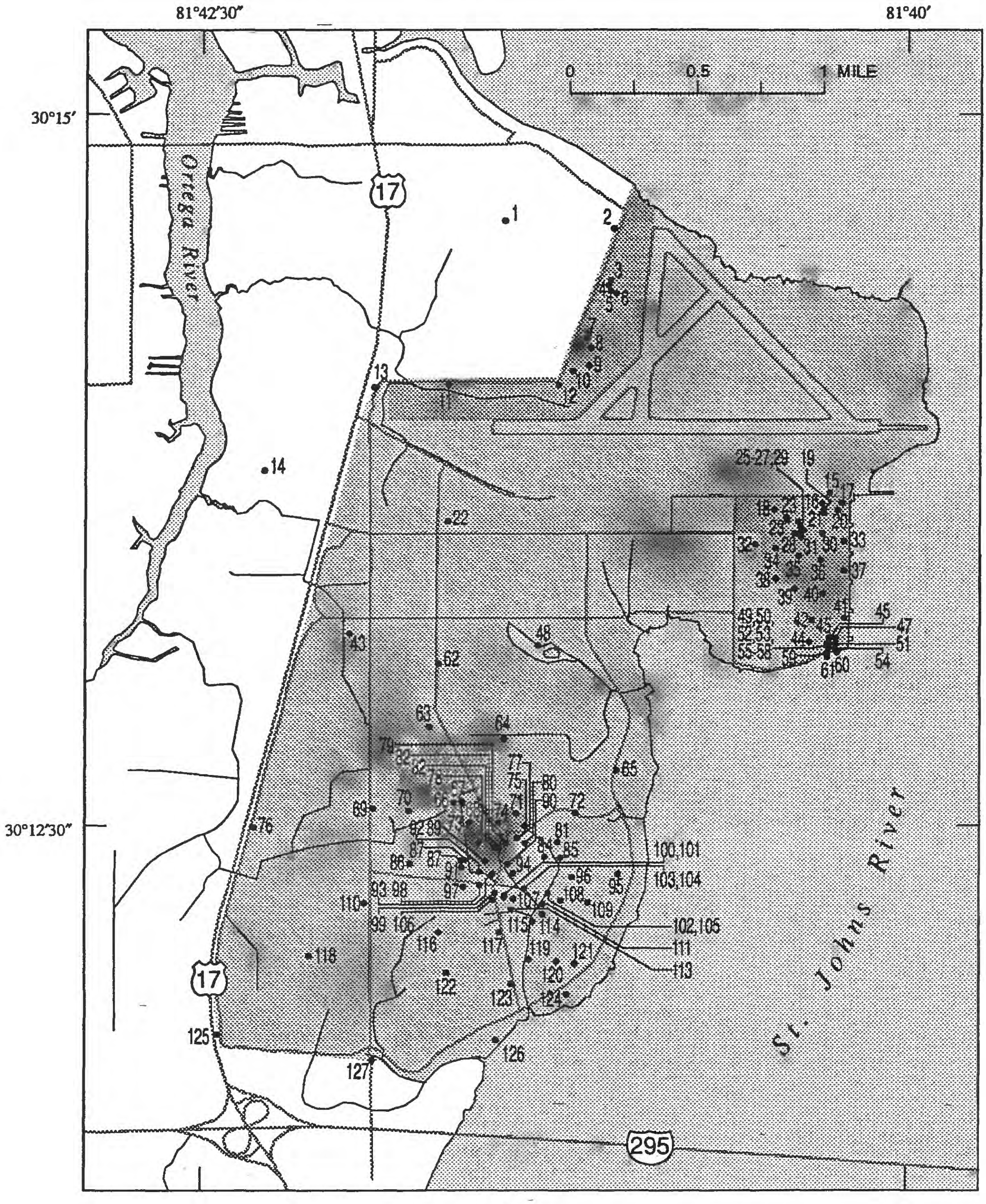
NAS is located in the Dinsmore Plain of the Northern Coastal Strip of the Sea Island District of the Atlantic Coastal Plain (Brooks, 1981). The Dinsmore Plain is characterized by clastic terrace deposits of Pleistocene-to Holocene-age lying between 25 and 30 ft above sea level, oriented parallel to the present shoreline (Brooks, 1981). Stringfield (1966) and other authors have assigned the surficial deposits underlying NAS to the Pamlico Terrace of Mid-Wisconsinan age.

Hydrogeologic Setting

A surficial aquifer contains the water table and consists of a series of Pleistocene- and Holocene-age terraces composed of silty sands deposited during marine transgressions and regressions associated with glacial and interglacial periods (Miller, 1986, p. B39, Stringfield, 1966, p. 68). The Pleistocene and Holocene deposits in the vicinity of NAS consist of about 40 to 95 ft of tan to yellow, medium- to fine-grained, unconsolidated sands with local thin, gray, sandy clay beds, and sporadic ferruginous hardpans and fossil shell fragments (Fairchild, 1972, p. 26). Although the surficial aquifer may be considered a single unit on a "regional" or base-wide scale, the clay beds that occur locally, or in discontinuous lenses, may divide the aquifer into distinct permeable zones. Locally, distinct zones have been identified at OU2 and OU3 where concentrations of resident contaminants and water levels have varied with depth and across clay lenses (Navy, 1994a, 1994b), however, no distinctive base-wide impermeable zones have been identified.

The surficial aquifer is recharged by direct infiltration of precipitation from land surface in highland areas. Fairchild (1972, p. 1) estimated that net recharge to the surficial aquifer in Duval County is about 10 in/yr. Data from stream gaging in the Ortega River basin indicates that there is about 16 in/yr of annual total runoff to local streams, and approximately 36 in/yr that evaporates or transpires from the system (52 in/yr precipitation - 16 in/yr runoff). Surface drainage in Duval County occurs through the St Johns River, a tidally influenced estuary, and its tributaries which also are tidally influenced in their downstream reaches (Fairchild, 1972, p. 9).

Water-table altitudes and thickness of the surficial aquifer were determined from the monitoring well data collected at NAS. Prior to this study, wells were located at possible sources of contamination and did not provide sufficient coverage to assess ground-water flow over the entire station. After an inventory of wells was reviewed, locations of new wells needed to fill gaps in the data coverage were identified and 58 additional wells were drilled (fig. 2 and table 1). Measurements of water levels in monitoring wells were



EXPLANATION

	NAVAL AIR STATION, JACKSONVILLE	———	CREEKS, DITCHES, AND SHORELINE
	OPERABLE UNITS	• 127	WELL WITH NUMBER

Figure 2. Location of wells at Naval Air Station, Jacksonville.

le 1. Data for wells at Naval Air Station, Jacksonville, Fla.

o data; Shallow well, exact depth is unknown]

ap number	Site number	Altitude of Top of Casing	Well depth, in feet	Altitude of water level in well on November 18, 1993, in feet
1	PZ-7	19.97	--	12.52
2	PZ-8	15.38	--	7.47
3	PZ-9	18.69	--	11.52
4	PZ-10	19.13	--	11.51
5	PZ-11	19.19	--	11.53
6	PZ-12	19.55	--	12.15
7	PZ-5	25.14	--	18.60
8	PZ-4	23.16	--	17.40
9	PZ-3	21.64	--	15.88
10	PZ-2	21.78	--	17.08
11	PZ-6	19.13	--	11.14
12	PZ-1	19.15	--	16.30
13	MW-37	15.94	14.00	10.10
14	MW-35	11.86	20.00	6.20
15	NARF-17	12.15	17.37	5.98
16	NARF-16	9.04	14.40	2.62
17	NARF-18	8.12	15.50	1.91
18	PZO24	9.04	14.00	3.25
19	MW-2	7.61	13.29	2.91
20	MW-1	6.56	13.46	2.35
21	MW-3	8.32	12.97	2.91
22	MW-41	25.54	16.00	18.94
23	MW-3	9.71	13.47	3.89
24	MW-2	9.41	13.48	3.77
25	NARF-14	9.04	15.01	3.18
26	MW-5	9.25	13.57	3.27
27	MW-4	8.22	13.00	3.41
28	MW-4	9.88	13.49	4.22
29	MW-6	8.49	14.09	3.36
30	PZO14	8.50	14.00	3.66
31	MW-7	8.72	11.45	3.43
32	PZO26	10.86	13.50	5.07
33	PZOO4	5.64	14.00	2.60
34	MW-1	9.99	13.00	5.57
35	PZO19	9.15	14.00	3.62
36	PZOO6	8.19	14.50	4.75
37	PZO10	5.90	14.00	4.58
38	PZO21	9.99	13.00	4.91
39	PZO17	10.77	14.00	4.22
40	PZO12	9.22	15.00	2.98
41	PZOO1	3.99	13.00	1.47
42	PZOO8	9.40	16.00	3.61
43	MW-43	19.79	16.00	13.62
44	NARF-B1	11.65	16.50	3.01
45	JAX873-3-3	9.12	14.74	1.89
46	JAX873-3-2	9.16	15.13	1.82
47	JAX873-6	7.34	12.60	1.52
48	MW-47	20.99	14.50	15.38
49	JAX873-1-3	8.11	14.29	1.77
50	JAX873-1	7.59	12.82	2.73
51	JAX873-4	8.16	13.15	1.75
52	JAX873-1-1	8.46	--	1.79
53	JAX973-1-4	8.96	15.18	1.80
54	JAX873-7	7.63	12.16	1.61
55	JAX873-2	7.60	12.92	1.77
56	JAX873-3	8.32	13.36	1.68
57	JAX873-11	8.99	13.80	1.72
58	JAX873-8	7.56	11.52	1.55
59	JAX873-9	8.60	13.36	1.63
60	JAX873-10	6.79	12.57	1.51
61	NARF-4	8.96	13.01	1.57
62	MW-45	27.45	16.00	22.50
63	MW-51	28.00	14.50	23.36
64	MW-52	27.76	16.00	19.61
65	MW-54	17.99	16.50	11.09

Table 1. Data for wells at Naval Air Station, Jacksonville, Fla.--Continued

[--, no data; Shallow well, exact depth is unknown]

Map number	Site number	Altitude of Top of Casing	Well depth, in feet	Altitude of water level in well on November 18, 1993, in feet
66	MW-5	28.62	18.00	23.30
67	PZ-1	29.44	13.00	22.50
68	PZ-2	29.02	13.00	22.20
69	MW-55	27.61	14.00	22.81
70	MW-57	25.20	14.00	21.80
71	MW-87	25.32	13.00	21.45
72	MW-58	20.83	16.50	14.09
73	MW-10	28.01	13.00	23.07
74	MW-7	27.76	12.50	22.03
75	MW-89	24.99	13.00	21.06
76	MW-39	23.92	14.00	19.02
77	MW-11	29.96	13.50	21.33
78	MW-30	36.67	17.50	23.76
79	MW-16	29.87	13.50	22.33
80	MW-93	23.87	13.00	19.87
81	MW-91	22.03	13.00	15.56
82	PZ-4	32.51	13.00	22.25
83	PZ-3	34.92	15.00	22.53
84	MW-95	21.21	13.00	14.70
85	MW-61	20.05	16.50	14.00
86	MW-60	27.67	14.00	22.77
87	PZ-8	31.11	14.50	22.94
88	PZ-7	27.02	12.00	22.21
89	MW-32	34.04	17.50	22.60
90	MW-21	28.85	14.50	20.85
91	MW-3	27.64	13.00	22.32
92	MW-33	34.53	16.50	22.79
93	MW-27	30.53	14.50	21.92
94	MW-17	25.78	14.50	18.90
95	MW-62	22.57	16.50	12.38
96	MW-115	19.59	13.00	12.55
97	MW-1	29.61	13.00	23.76
98	MW-111	29.10	13.00	22.38
99	MW-26	27.38	14.50	18.04
100	MW-20	19.33	13.50	14.91
101	MW-19	16.93	24.50	14.53
102	MW-67	14.74	14.00	9.18
103	PZ-5	24.84	14.00	14.85
104	PZ-6	24.31	14.00	15.13
105	MW-100	14.73	21.50	10.29
106	MW-24	26.91	14.50	18.76
107	MW-23	23.50	14.50	14.38
108	MW-103	19.27	13.00	12.76
109	MW-68	21.45	16.00	13.73
110	MW-63	27.66	14.50	23.31
111	MW-102	15.33	21.30	9.90
112	MW-101	15.44	13.00	9.44
113	MW-109	21.40	13.00	14.53
114	MW-105	17.73	13.00	11.29
115	MW-107	13.58	13.00	8.40
116	MW-65	28.47	14.50	24.35
117	MW-66	22.18	16.00	14.62
118	MW-73	28.74	14.50	24.27
119	MW-70	13.92	14.00	7.98
120	MW-71	20.11	18.00	9.82
121	MW-72	20.72	22.00	6.28
122	MW-75	27.39	14.50	20.51
123	MW-76	12.63	14.50	7.28
124	MW-77	14.12	14.00	8.67
125	MW-78	27.09	16.50	22.89
126	MW-82	12.52	13.50	6.15
127	MW-80	18.32	12.50	11.60

made on November 18, 1993. Standard current-flowmeter measurements of streamflows were made on December 3, 1992, and November 18, 1993, (a water-table map is shown in fig. 3 and stream discharges are shown in fig. 4); at these times, all net gains in streamflow between measuring points could be attributed to ground-water discharge. Measurements at sites 5 and 6 were significantly higher during the November 18, 1993, round of measurements than the December 3, 1992, round; the difference is attributed to surface runoff from irrigation at the golf course, which was occurring at sites 5 and 6 during the second measurement period. These measurements are not considered to be representative of ground-water seepage. An average value of 5 ft/d for hydraulic conductivity was determined from slug tests performed for the Navy at monitoring wells (Navy, 1992).

The water table ranges in altitude from about 1 ft to 24 ft above sea level (fig. 3). Ground-water flow in the surficial aquifer is generally from areas of high topography to areas of low topography and is controlled to the west, north, and east by the St. Johns and Ortega Rivers, whose stages are at sea level. South of NAS, ground-water flow is controlled by a ground-water divide that trends north-south; flow from this divide moves east to the St. Johns River and west to the Ortega River. The direction of ground-water flow is somewhat coincident with Interstate I-295. Near the St. Johns River, water levels in the surficial aquifer are higher than the stage of the river, indicating that upward flow of ground water from the aquifer to the river is restricted, probably due to the sediments that are present in the bed of the St. Johns River. Only small vertical gradients have been recorded in well pairs further away from the river, indicating there is little vertical resistance to ground-water flow in the surficial aquifer away from the river. There are several surface-water drainages on NAS that have an influence on the shape of the water table (fig. 3). Depth to the water table from land surface ranges from 0 to about 5 ft at NAS.

The base of the surficial aquifer coincides with the top of the Hawthorn Group, the altitude of which is variable (fig. 5). The formations of the Hawthorn Group consist mainly of dark-gray and olive-green sandy to silty clay, clayey sand, clay, and sandy limestone, all of which contain moderate to large amounts of black phosphatic sand, granules, and pebbles (Fairchild, 1972, p. 21). The Hawthorn Group occurs at depths ranging from approximately 10 to 75 ft below sea level in the vicinity of NAS (Scott, 1988, p. 16, Leve, 1978). Approximately 300 ft of the Hawthorn Group confines the underlying Upper Floridan aquifer (Scott, 1988, p. 17) which consists of approximately 350 ft of carbonate rocks of the Ocala Limestone and the Avon Park Formation of Eocene age (Miller, 1986, pl. 28).

The Upper Floridan aquifer beneath Duval County is very transmissive (Bush and Johnston, 1988) and contains good-quality water. Therefore, it is the principal aquifer tapped for municipal and industrial uses in Duval County. Ground-water withdrawals from wells tapping the Upper Floridan aquifer in Duval County were approximately 144 Mgal/d in 1990 (Marella, 1993). Most recharge to the Upper Floridan aquifer underlying Duval County occurs in southwestern Clay and eastern Alachua Counties where the aquifer is unconfined (Fairchild, 1977, p.1). The head of the Upper Floridan aquifer throughout Duval County averaged about 30 ft above sea level in 1991 (Sumner and others, 1992). Thus, the head of this aquifer is approximately 15 ft higher than average head in the surficial aquifer at NAS. The potential for ground-water movement between the aquifers is upward from the Upper Floridan aquifer to the surficial aquifer.

Hydrologic Conditions

The hydrologic system at NAS is controlled by rainfall. When rainfall reaches the ground, it can evaporate from the land surface, discharge to surface-water bodies by overland flow, or infiltrate into the ground. When rainfall infiltrates into the ground, it can remain in the pores of the unsaturated soil, can be return to the atmosphere by plants through transpiration, or move downward to enter the surficial aquifer. The amount of rainfall that enters the surficial aquifer is termed "net recharge." The process of recharging the aquifer is intermittent as recharge rates vary according to antecedent conditions and periods of rainfall and nonrainfall. Local streamflows generally increase during and immediately after these periods of rainfall, primarily from surface runoff and heads in the surficial aquifer rise. However, the hydrologic system begins to drain soon after the rainfall stops. Streamflows decrease, sharply at first, then at a gradually decreasing rate as surface runoff decreases to zero; an increasing percentage of total streamflow is then derived from ground-water discharge. Heads in the aquifer also

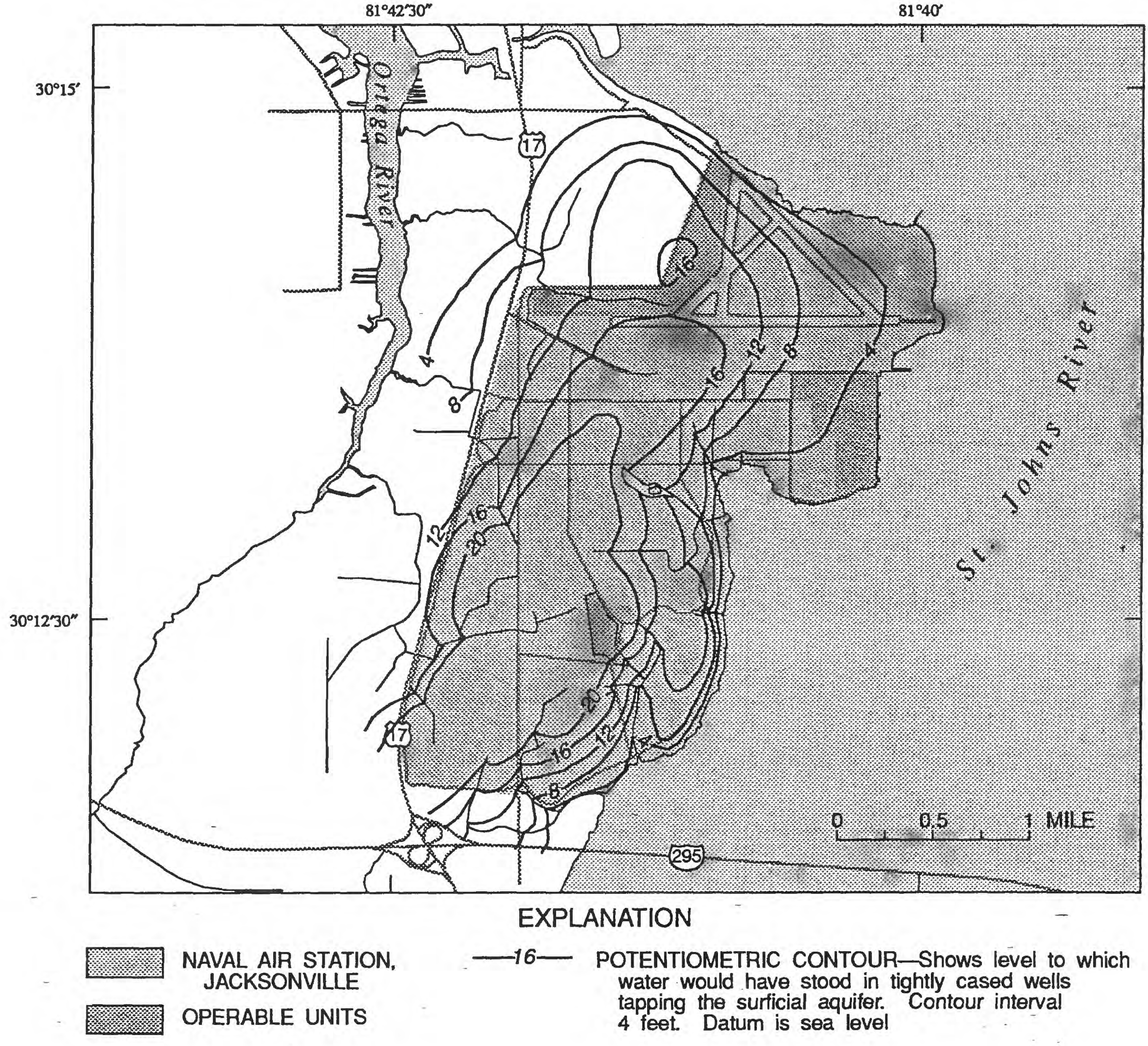
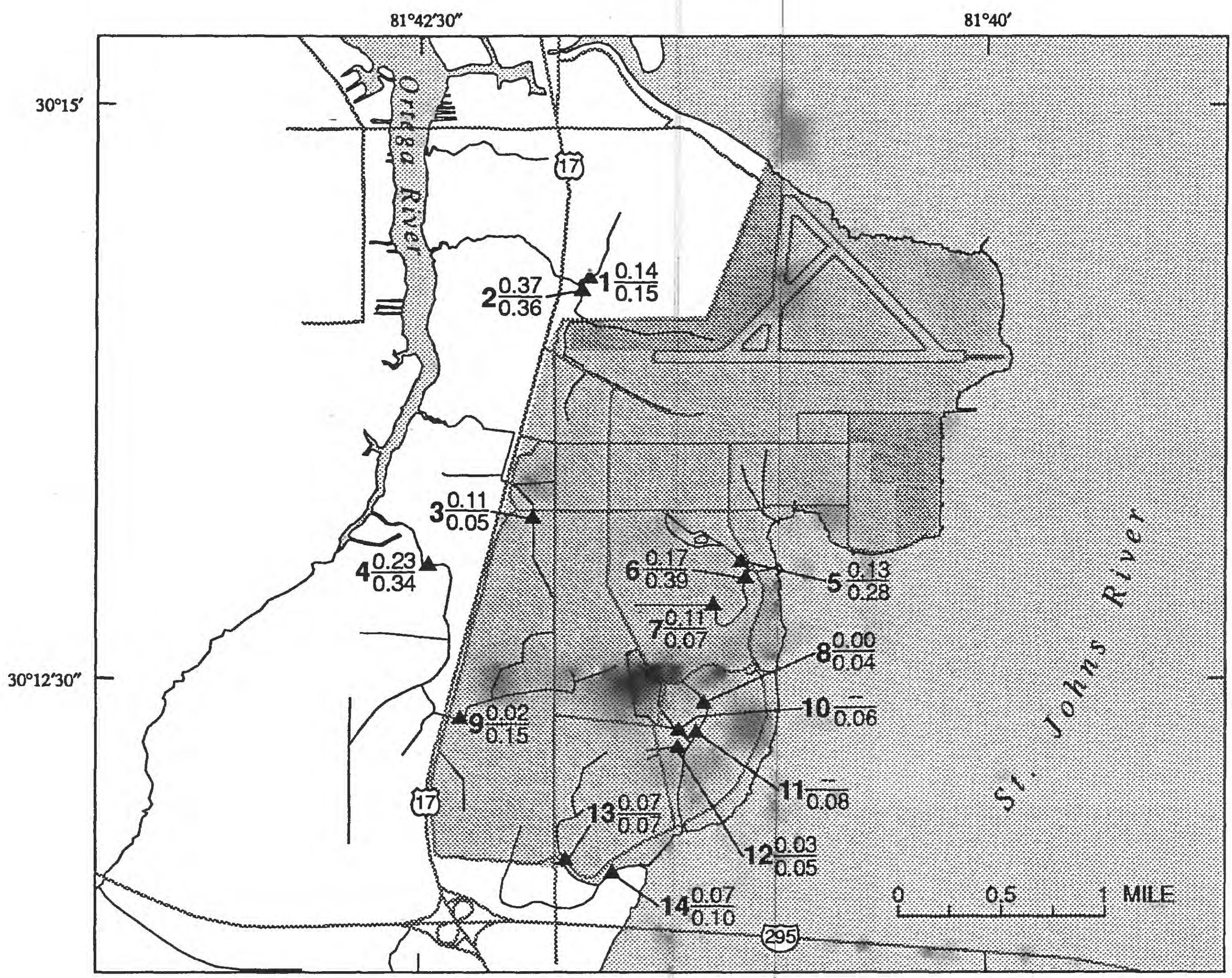


Figure 3. Potentiometric surface for the surficial aquifer, November 18, 1993.

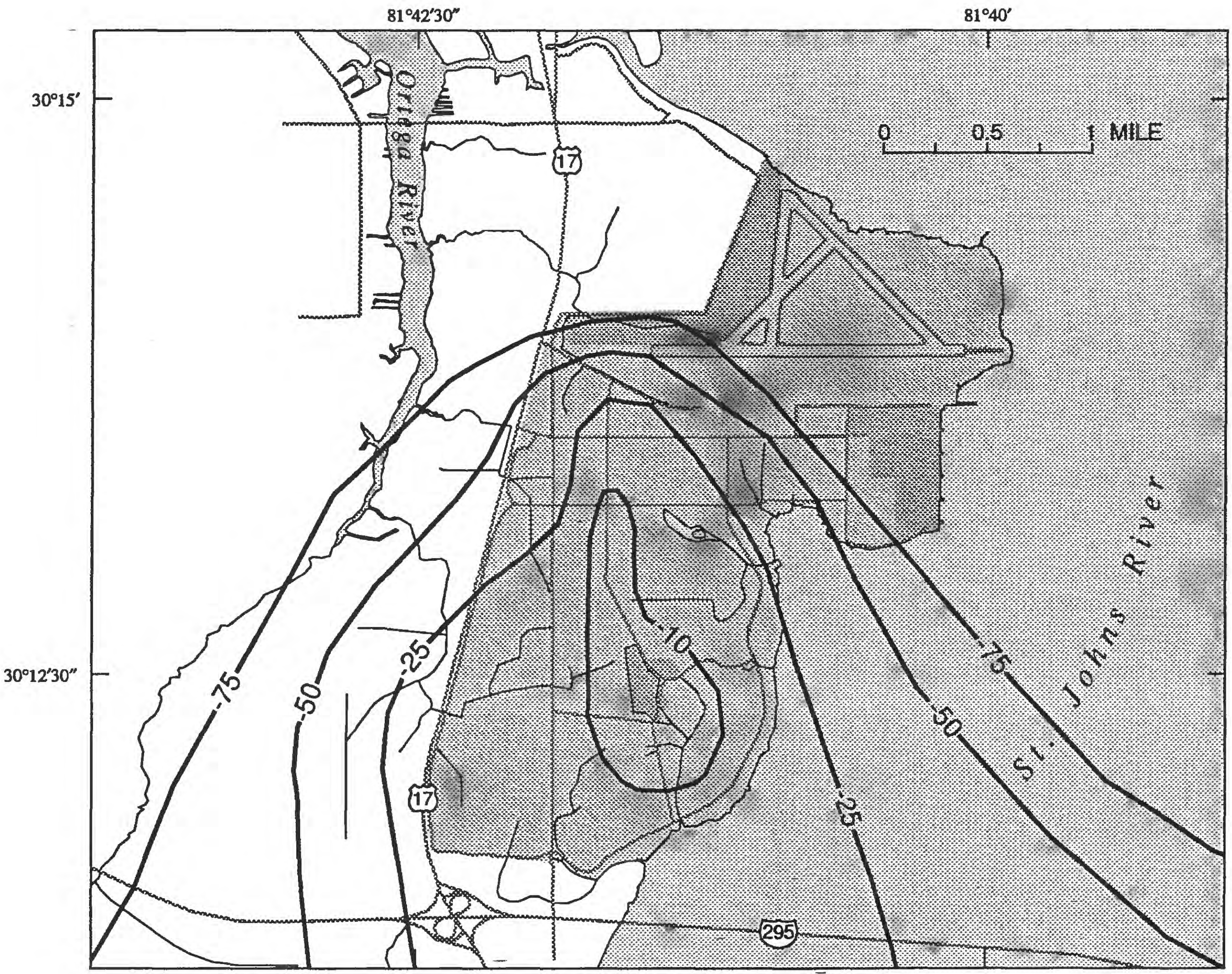


EXPLANATION

- NAVAL AIR STATION, JACKSONVILLE
- OPERABLE UNITS
- ▲14 0.07/0.10 STREAM FLOW MEASUREMENT SITE AND NUMBER—Bold number is site number, upper value is net gain calculation for December 3, 1992 measurement, lower value is net gain calculation for November 18, 1993 measurement. Values in cubic feet per second

NOTE: "--" indicates no measurement taken

Figure 4. Net gain for creeks draining the Naval Air Station, Jacksonville, Florida, December 3, 1992 and November 18, 1993.



EXPLANATION

—-75— STRUCTURE CONTOUR—Shows elevation of the top of the Hawthorn Group. Contour interval 15 and 25 feet. Datum is sea level

Figure 5. Structural surface of the Hawthorn Group.

begin to decline following the termination of rainfall but at a much reduced rate compared to the rate of streamflow decrease. This process is a continuous cycle and changes in the hydrologic system can be affected by seasonal changes, as well as yearly changes in climatic conditions.

The term "dynamic equilibrium" has been used to describe hydrologic systems that are not overly stressed and where storage changes are small compared to long-term net recharge. The concept of dynamic equilibrium accounts for changes in ground-water levels and rates of streamflow due to seasonal and yearly changes in rainfall and evapotranspiration, but requires that, over a long term of many years, rates of recharge and discharge and the altitude of the water table consistently range about a mean or average value. This concept is applied to evaluate systems that, on the short term, may be continually changing but, over the long term, approximate equilibrium or steady-state conditions. Long-term hydrologic data for similar hydrologic systems in similar areas can be used to evaluate the dynamic equilibrium of hydrologic systems where long-term measurements are available in one basin but not the other.

To evaluate long-term ground-water conditions for the surficial aquifer at NAS, the range in water levels that occurs throughout the year must be defined. No long-term water-level measurements exist for NAS and periodic base-wide water-level measurements were not possible prior to November 18, 1993, when the drilling of 58 monitor wells was completed. Monthly base-wide water-level measurements were obtained from November 1993 through July 1994, and stopped when funding ended. Figure 6 shows the water-level data and the monthly rainfall totals collected for the period of May 6, 1993, through July 14, 1994. Water levels in wells on NAS fluctuated during the year with a maximum range of about 2.6 ft at higher elevations of the water table (Well 89). At mid elevations of the water table, the range in water levels is about 1.8 ft (Well 107). At lower elevations of the water table, the range in water levels is about 0.4 ft (Well 31). This range may reflect a maximum change for the surficial aquifer because of the high level rainfall (18 in.) that occurred from May through July, 1994. Although water-level measurements are not available for June through September 1993, the large amount of rainfall that occurred during this period, relative to the annual mean, caused water levels to rise from June to October. The November and December measurements indicate a decline in water levels in response to the relatively small amounts of rainfall for those months. Water-level fluctuations in wells completed in the surficial aquifer on NAS appear synchronous, indicating that water-level gradients are stable throughout much of the year. Relatively constant conditions occur because the surficial aquifer is unconfined and storativity values are high. Thus, relatively large quantities of recharge to, and discharge from the aquifer are necessary to substantially change water levels. Figure 6 shows that in May of both years the water levels in wells 31, 89, and 107 are similar, even though rainfall during the period of June 1992 to May 1993 totaled 54.54 in. and rainfall during June 1993 to May 1994 period totaled 49.24 in.

Baseflow probably is the major component of total streamflow. A study in Okaloosa County, Fla. (Vecchioli and others, 1990), evaluated the baseflow contribution at several long-term gaging stations. Figure 7 shows the percentage of baseflow computed during this study compared to average daily streamflow for 9 basins. For basins under 60 mi^2, the percentage of baseflow contribution to average total streamflow is about 80 to 90 percent, while for basins above 60 mi^2, the percentage of baseflow contribution to average total streamflow is between 60 to 70 percent. Therefore, discharge measurements obtained at NAS during even relatively short periods of streamflow recession probably represent entirely baseflow. Because of the large component contribution of baseflow to total streamflow, discharges measured during long-term average or near average annual streamflow conditions probably approximate average baseflow conditions.

Two surface-water stations (fig. 8) in Duval County, the Ortega River and Big Davis Creek, were selected as indicators of steady-state flow conditions on NAS, based on drainage areas less than 60 mi^2 (30.9 and 13.6 mi^2, respectively). The average daily discharge of the Ortega River at Jacksonville, Fla., from 1965 through 1993 is 36.8 ft^3/s (U.S. Geological Survey, 1994, p.153). Figure 9a shows the discharge at this station from October 6, 1993 through December 5, 1993. The data show that on November 18, 1993, the discharge of Ortega River was close to the long-term average-daily discharge and that the effects of the recent rainfall event had begun to dissipate. The discharge on November 18 was 28 ft^3/s which is 76 percent of the long-term average-daily discharge.

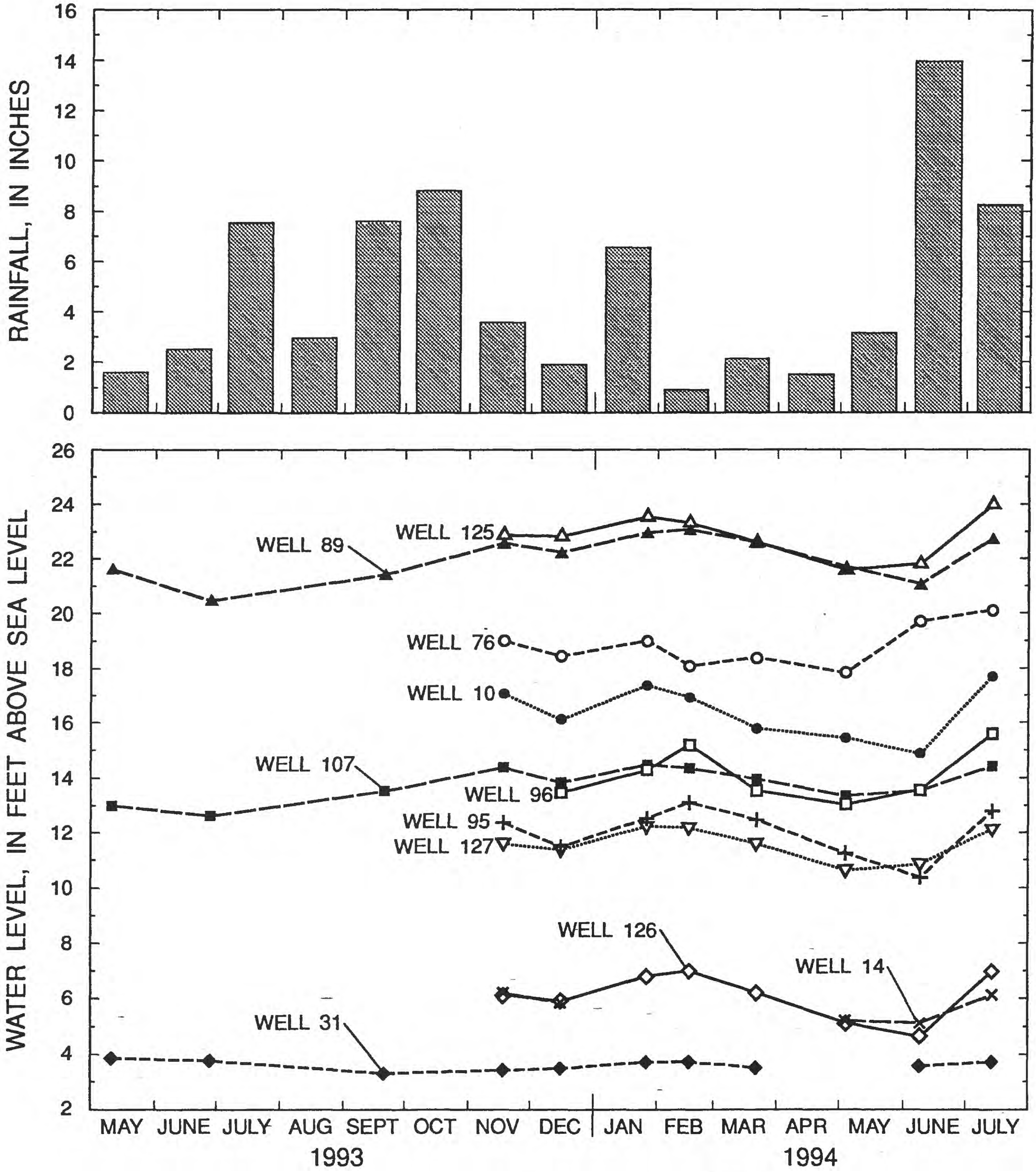


Figure 6. Water-level measurements for monitoring wells at the Naval Air Station and monthly rainfall from May, 1993 to July, 1994.

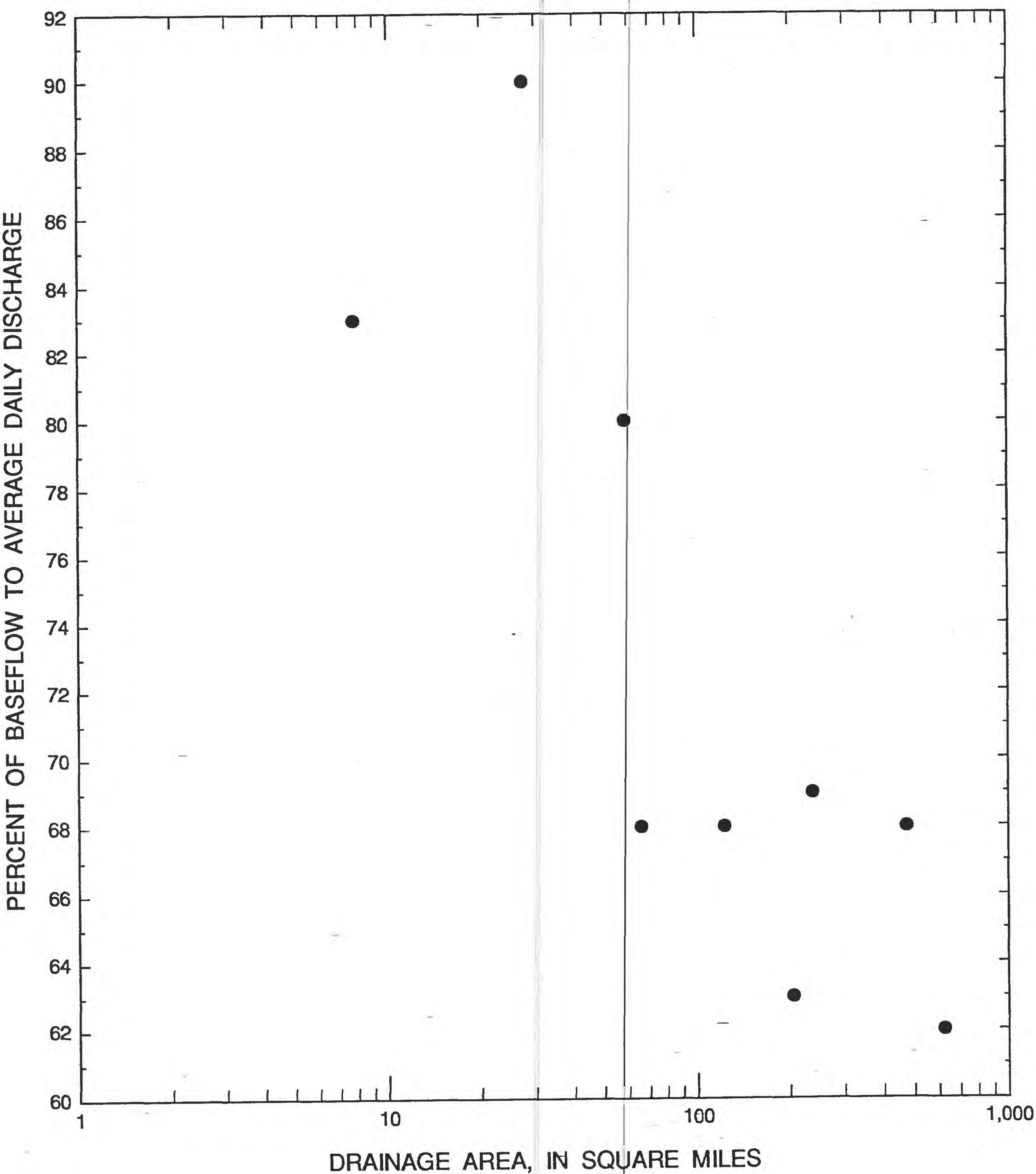


Figure 7. Percentage of baseflow to average flow for nine basins in Okaloosa County.

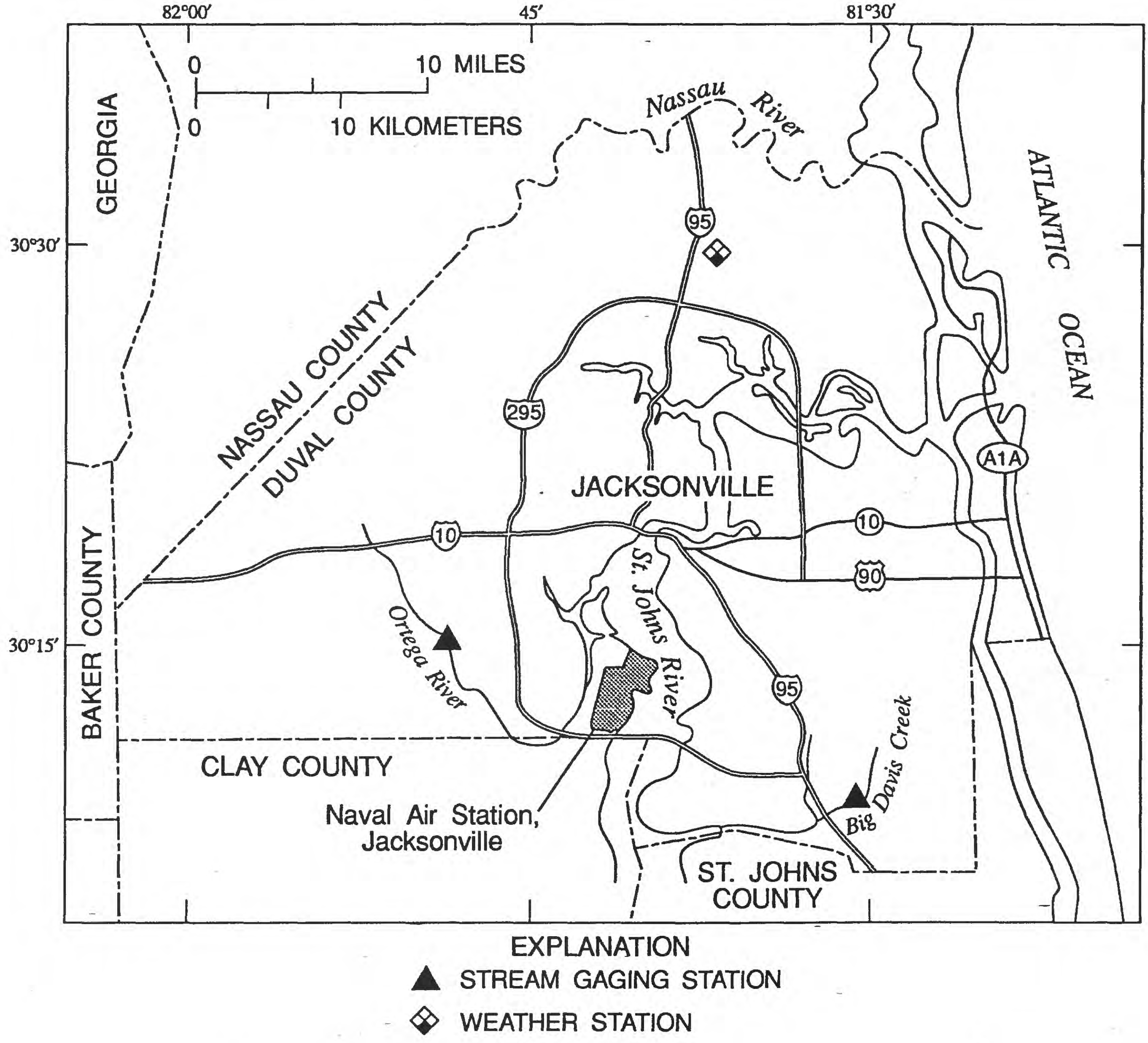


Figure 8. Location of two stream-gaging stations in Duval County.

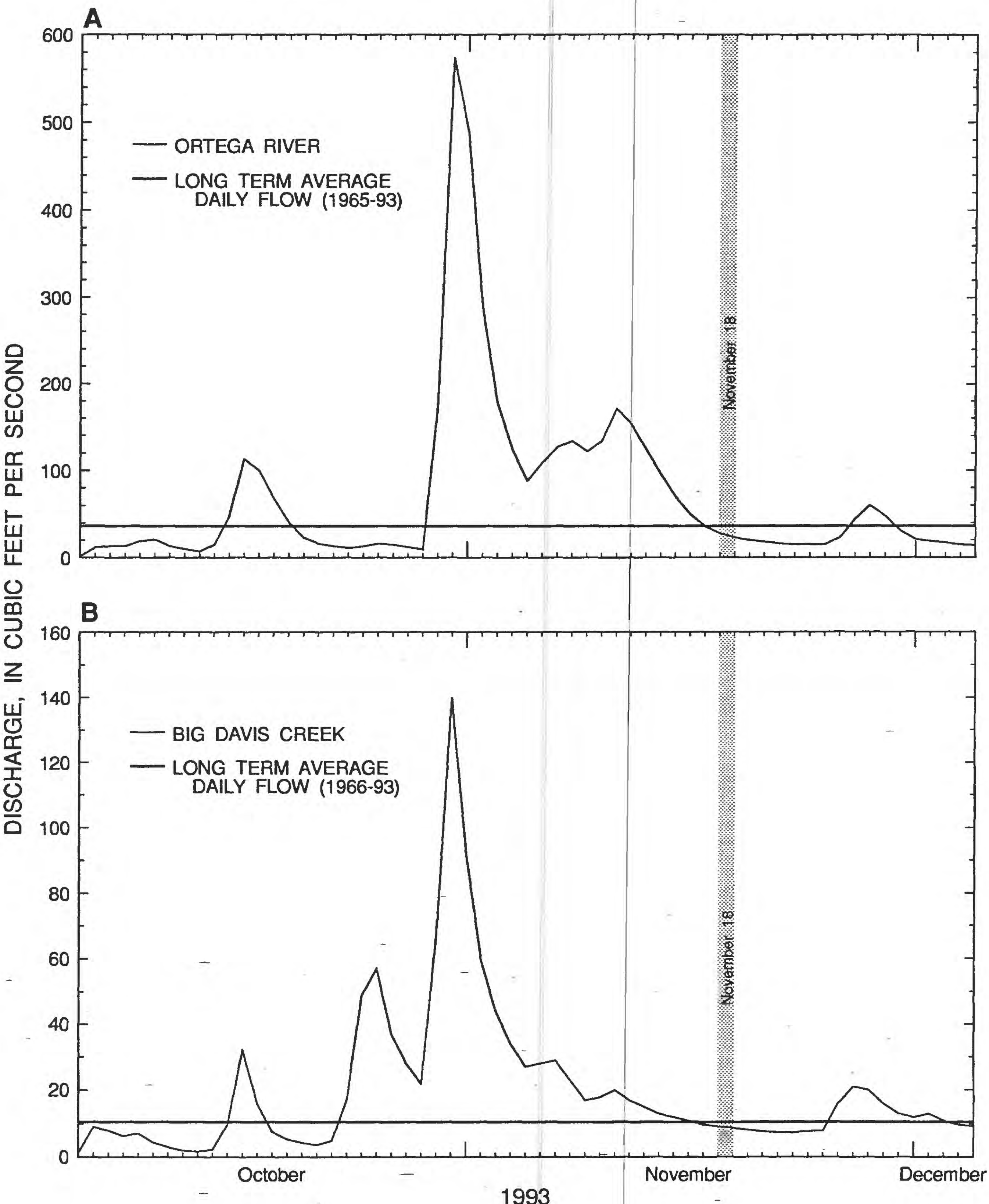


Figure 9. Daily stream discharge from October 6, 1993 to December 5, 1993 for (A) Ortega River and (B) Big Davis Creek.

The average-daily discharge of Big Davis Creek at Bayard, Fla., from 1966 through 1993 is 10.6 ft^3/s (U.S. Geological Survey, 1994, p. 152). Figure 9b shows the discharge at this station from October 6, 1993, through December 5, 1993. The discharge data show that on November 18, 1993, the discharge of Big Davis Creek was close to the long-term average-daily discharge and that the effects of the recent rainfall had dissipated. The discharge on November 18 was 9.2 ft^3/s which is 87 percent of the long-term average-daily discharge. Although drainage areas for the gaging stations on Ortega River and Big Davis Creek are considerably larger than the drainage areas for creeks on NAS, the near-average conditions of flow at the gaged stations indicates that stream-discharge measurements obtained at NAS during November 18, 1993, represented not only baseflow but approximate long-term average baseflow.

SIMULATION OF GROUND-WATER FLOW

Simulations of ground-water flow in the surficial aquifer were made using the USGS Modular Three-Dimensional Finite-Difference Ground-Water Flow Model (MODFLOW) as described in McDonald and Harbaugh (1988). Directions and rates of ground-water flow in the aquifer were simulated using the USGS program MODPATH, as described in Pollock (1989).

Model Construction

For modeling, the surficial aquifer was represented by a single layer, divided into 240 rows and 290 columns of cells (fig. 10). Model cells are 100 by 100 ft, representing a volume of aquifer which extends vertically downward to the top the Hawthorn Group. At the model scale, the cell spacing of 100 ft allowed each monitoring well to be located in an individual cell, thereby facilitating comparisons of observed heads at monitoring wells to simulated heads at the model cell. Each parameter assigned to a model cell is assumed to be constant and equal to the average value of that property throughout the entire areal and vertical extent of the cell.

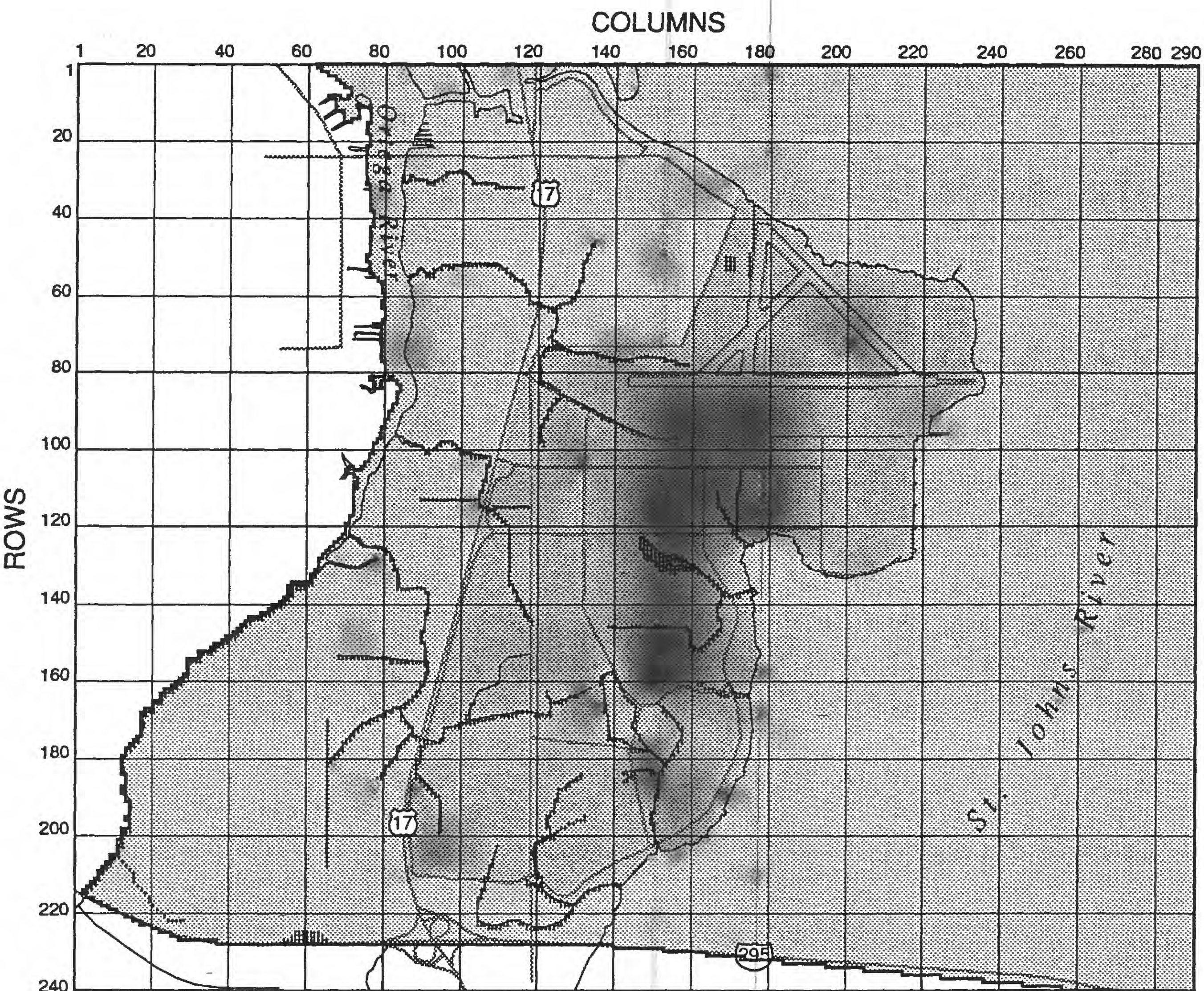
Boundary and Initial Conditions

The St. Johns and Ortega Rivers (fig. 10) are the endpoints of flow in the surficial aquifer and were used in this simulation as the north, east, and west ground-water boundaries of the ground-water model. River cells surrounded the study area to the east, north, and west, and the river stages were set to an altitude of sea level. These cells allow ground water to leak upward from the surficial aquifer to the simulated rivers.

In addition to the St. Johns and Ortega Rivers, several small creeks and ditches drain water from the surficial aquifer. The location of the river cells that correspond to these drains are shown in figure 10. Assigned stages for the creeks were estimated from topographic maps showing 2.5 ft contour intervals of land surface. Equal altitudes were assigned to the stages and stream bottoms so that the cells simulating the creeks would drain water from, but not leak water to, the surficial aquifer. The altitude of the stage of the ditch at OU1 was set to 22 feet and the ditch bottom was set to 21 feet, allowing the cells that simulate the ditch to drain water from or leak water to the aquifer. This allowed for the simulation of ground-water movement into the ditch at the northern end of OU1 and out of the ditch at the southeastern end.

The initial riverbed hydraulic conductivity used to calculate the riverbed conductance was 5 ft/d, which assumes a ratio of 1/1 for horizontal to vertical hydraulic conductivity. Other parameters used to calculate initial riverbed conductances were a riverbed thickness of 1 ft, and the area that the creek occupied within the cell. The area used to calculate conductance for the cells representing the St. Johns River was equal to the total area of the model cell, while the area used for the smaller creeks was a small percentage of the model cell area.

The southern boundary was modeled as a no-flow boundary. In this region, a ground-water divide trends north-south and ground-water flow moves east-west from this divide and the flow direction is somewhat coincident with Interstate I-295. The base of the aquifer was modeled as a no-flow boundary because of the large contrast in hydraulic conductivity between the surficial aquifer and sediments of the Hawthorn Group which should restrict any appreciable vertical flow to or from the surficial aquifer. The altitude of the base of the model coincides with the top of the Hawthorn Group.



EXPLANATION

NAVAL AIR STATION, JACKSONVILLE

ACTIVE MODEL GRID

MODEL CELLS IN WHICH CREEKS OR DITCHES ARE SIMULATED

0 0.5 1 MILE

Figure 10. Location and orientation of finite-difference grid and modeled area.

The rate of net recharge to the surficial aquifer was initially estimated at 7 in/yr based on the discharge measurements made for the small streams on NAS. Paved areas, such as the runways and industrial park, were modeled with negligible recharge. Initial hydraulic conductivity for the surficial aquifer was 5 ft/d determined from slug tests performed for the Navy at numerous well sites on NAS (Navy, 1992).

Model Calibration

The calibration strategy was to simulate long-term average-annual conditions at NAS. The long-term average conditions are assumed to be at steady-state and to be approximated by water-level and streamflow measurements made on November 18, 1993. The flow model was calibrated by matching simulated heads with measured water levels at wells and by comparing simulated leakage into river cells with streamflow measurements made in the field. The criterion for acceptable head matching was +/- 2.5 ft which was equal to the accuracy of the topographic coverage. The USGS program ZONEBUDGET (Harbaugh, 1990) was used to calculate streamflows for specified stream reaches representing the locations where streamflow measurements were made. The criterion for comparing simulated and measured net gains in streamflow was +/- 20 percent and represents the error associated with the discharge measurements in the small streams.

Several adjustments were made to the initial model values during calibration. The hydraulic conductivity of the surficial aquifer was increased to 7.5 ft/d from 5 ft/d to better simulate measured heads and gradients in the aquifer. Net recharge was modified from a constant rate for all model cells which receive recharge, to a variable rate pattern (fig. 11) such that: (1) net recharge was reduced in areas where the water table was within 2 ft of land surface and therefore susceptible to higher rates of rejected recharge, and (2) net recharge was increased to model cells representing areas where irrigation was prominent, such as golf courses and the housing area. Net recharge rates ranged from 0.005 in/yr for the paved areas to 12 and 13 in/yr for the golf courses and housing area.

The simulated heads, illustrated as a potentiometric surface, of the surficial aquifer are presented in figure 12. The final calibrated comparison between observed and simulated water levels resulted in 126 of 127 water levels (99 percent) being within the +/- 2.5 ft criterion and these results are shown in figure 13. If the model simulated water-levels had matched the measured values exactly, then all the points would lie on the 45° line. Only one simulated water level exceeded the error criterion. The simulated head in this well was six feet above the measured value; however, simulated heads for nearby wells did match within the +/- 2.5 ft criteria. The reason for the poor match in this well could not be determined. Eighty-four of the 127 simulated water levels (66 percent) were within +/- 1.0 ft of the measured values.

The simulated net streamflow gains are shown in figure 14 and listed in table 2. All of the simulated values for the stream reaches were within the error criteria of +/- 20 percent of the measured values, except for sites 5, 6, and 8. As discussed previously the streamflows for sites 5 and 6 were affected by surface runoff from irrigation. Site 8 had a high percentage error because the flow rates compared were so low (0.03 ft^3/s and 0.04 ft^3/s for measured and simulated values, respectively), even though the actual difference between the two values was only 0.01 ft^3/s. The sum of the measured net streamflow gains equaled 1.52 ft^3/s (excluding sites 5 and 6) while the simulated discharges to the equivalent river cells equaled 1.50 ft^3/s, giving an error of -1% for the overall comparison of simulated and measured streamflows. For this comparison, it is important to note that modeled stream reaches could not act as sources of water to the aquifer, for reasons discussed earlier, and the inflows to the aquifer from the ditches at OU1 equaled the outflows.

Sensitivity Analysis

Sensitivity tests were made to assess the response of the calibrated model to a change in one input parameter while other data were unchanged from the calibrated model. Sensitivity tests were made for the input parameters hydraulic conductivity, recharge, and riverbed conductance; the effect of each test was judged by (1) determining the number of simulated heads that were within +/- 2.5 ft of the measured values, and (2) comparing the simulated stream discharge gains to the measured values. The results of the sensitivity analysis are tabulated in table 3.

Model simulations were sensitive to changes in horizontal hydraulic conductivity. A decrease in conductivity of 50 percent, from the calibrated value caused the number of simulated heads that exceeded

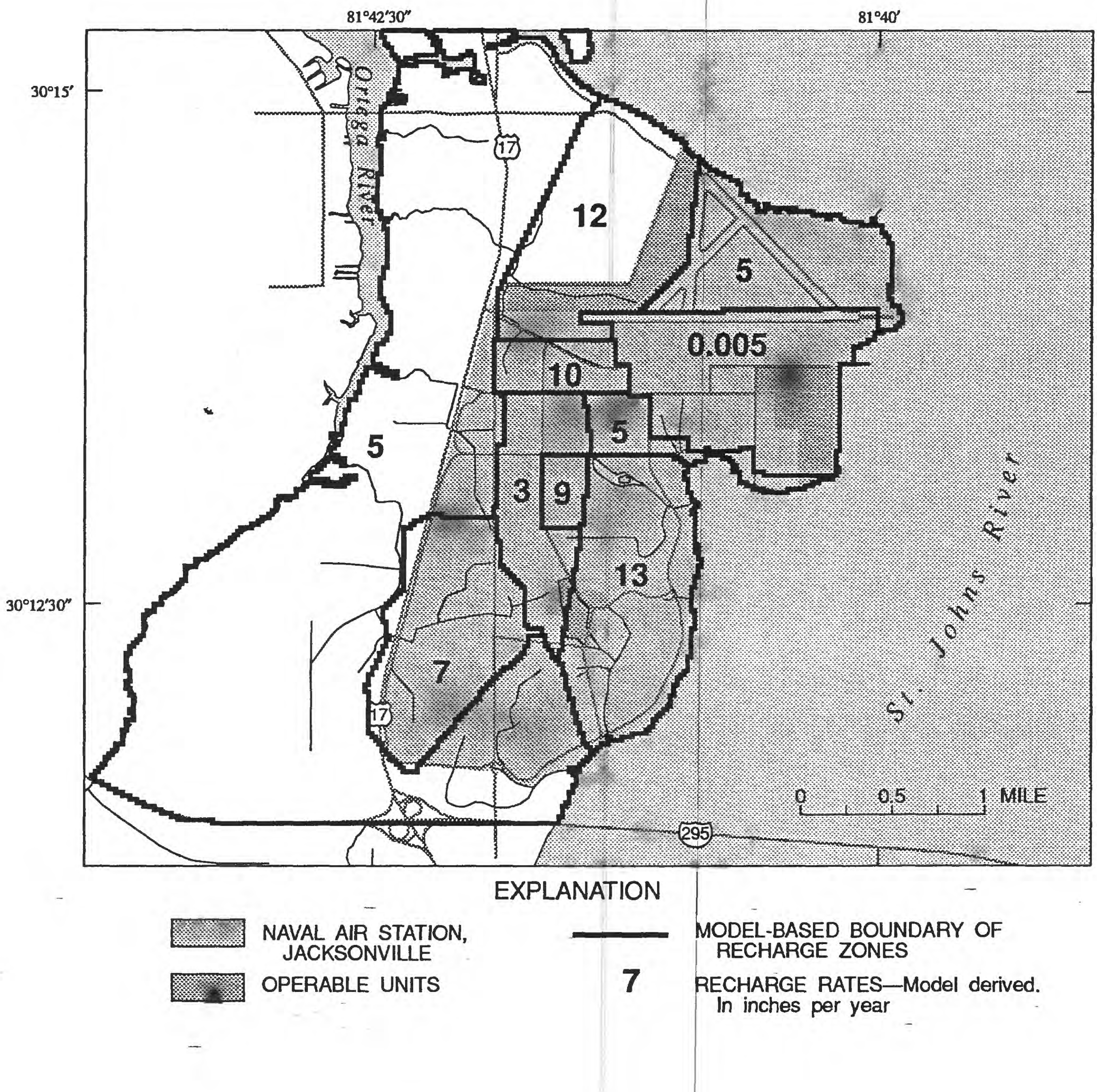
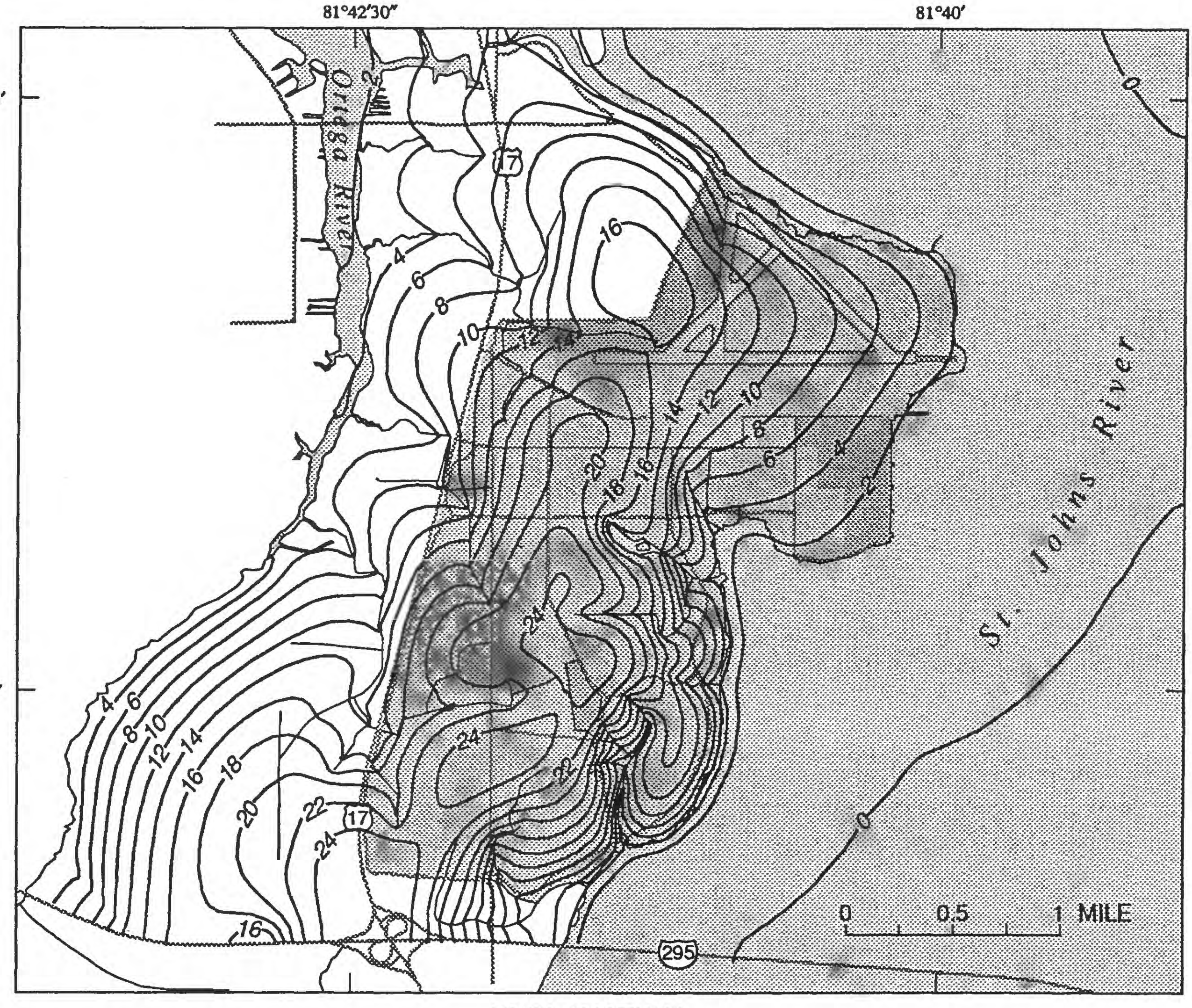


Figure 11. Model derived distribution of recharge rates for the surficial aquifer.



EXPLANATION

NAVAL AIR STATION, JACKSONVILLE

OPERABLE UNITS

—16— SIMULATED POTENTIOMETRIC CONTOUR—Shows level to which water would have stood in tightly cased wells tapping the surficial aquifer. Contour interval 2 feet. Datum is sea level

Figure 12. Simulated potentiometric surface of the surficial aquifer.

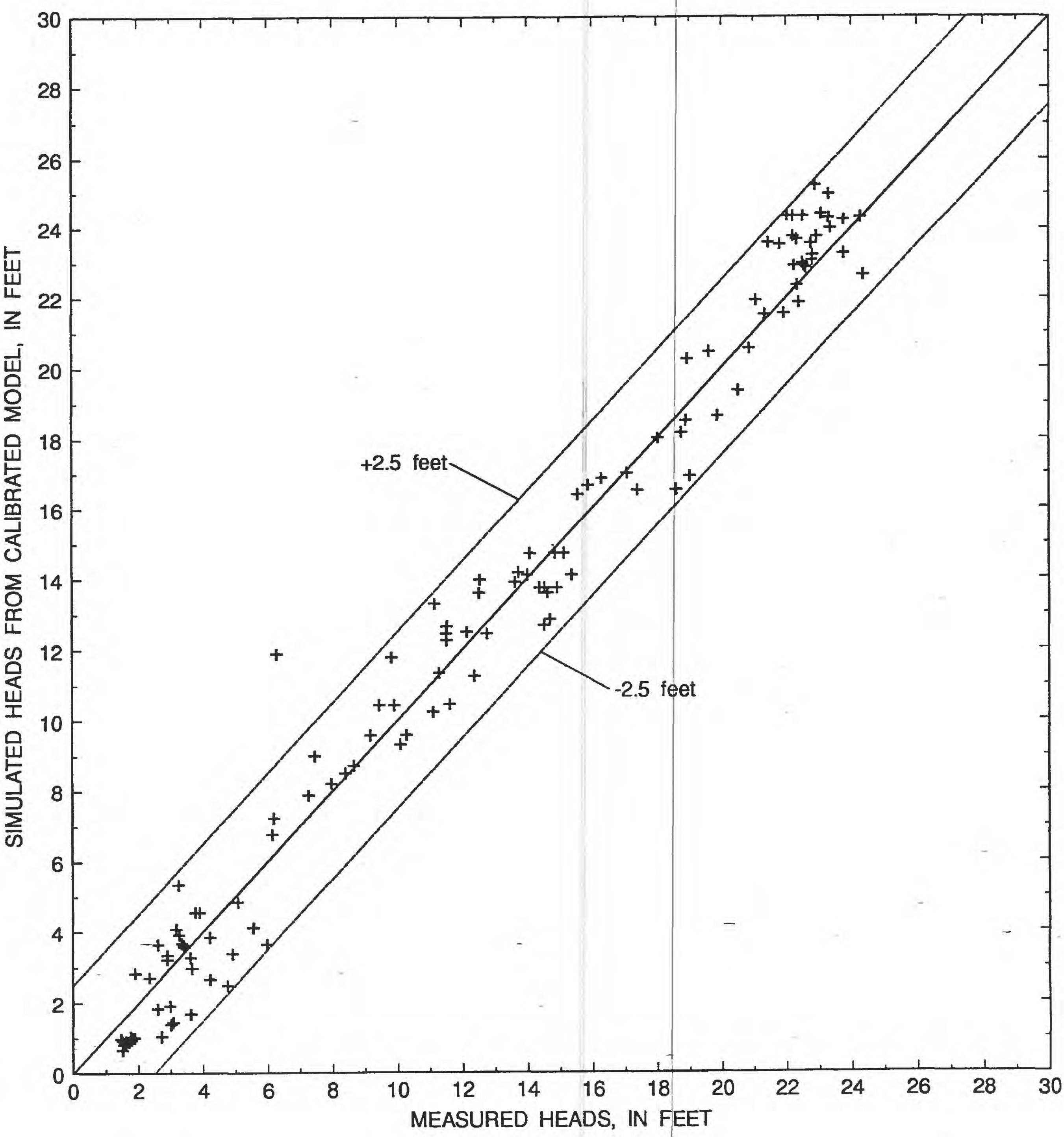


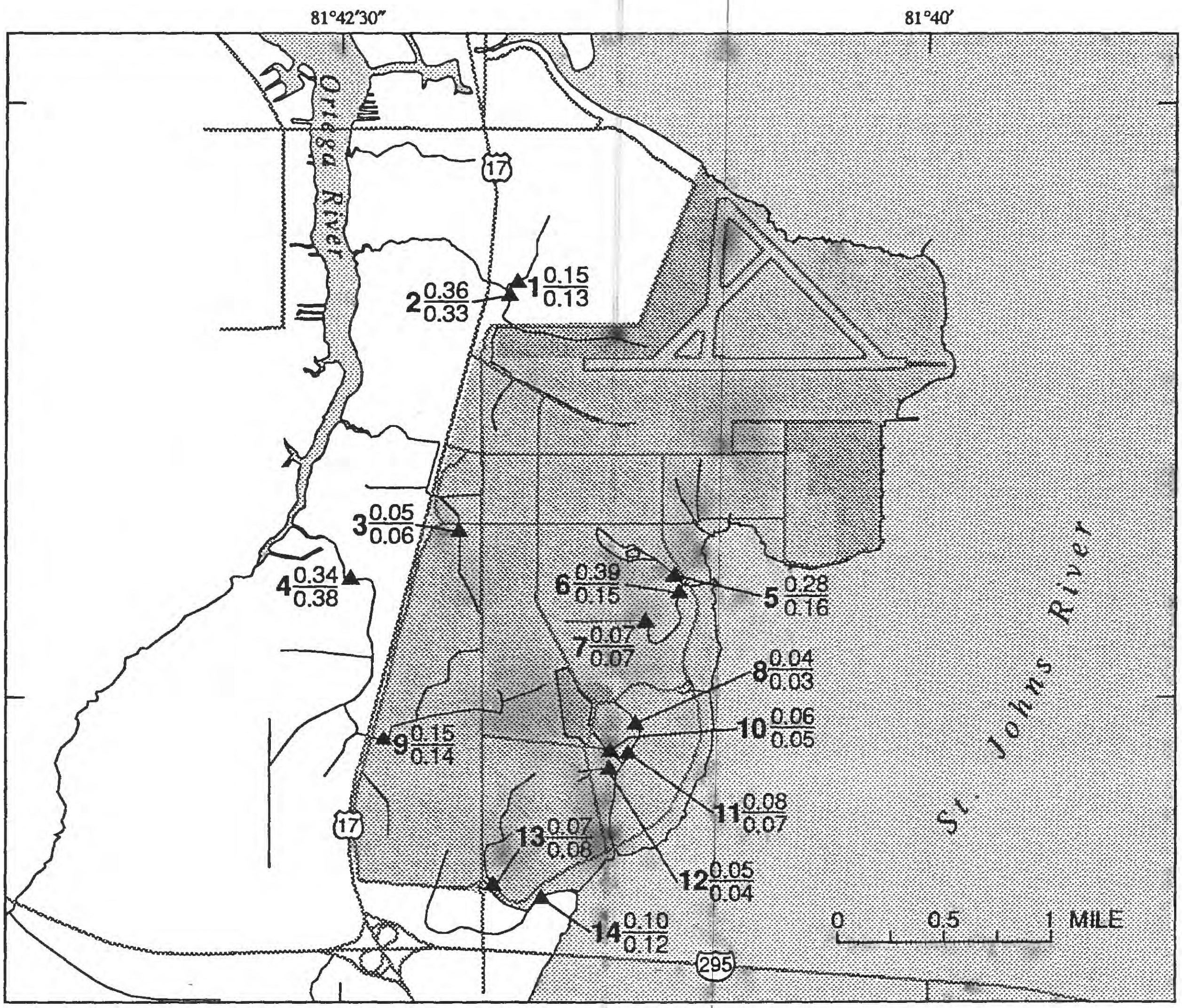
Figure 13. Comparison of measured and simulated heads.

T

Table 2. Summary of measured stream discharges on November 18, 1993, and simulated stream discharges

[Discharge values are in cubic feet per second]

Site number	Measured discharge	Simulated discharge	Percent difference
1	0.15	0.13	-13
2	0.36	0.33	-8
3	0.05	0.06	20
4	0.34	0.38	12
5	0.28	0.16	-42
6	0.39	0.15	-62
7	0.07	0.07	0
8	0.04	0.03	-25
9	0.15	0.14	-7
10	0.06	0.05	-17
11	0.08	0.07	-13
12	0.05	0.04	-20
13	0.07	0.08	14
14	0.10	0.12	20



EXPLANATION

NAVAL AIR STATION, JACKSONVILLE

OPERABLE UNITS

▲14 0.10/0.12 STREAM FLOW MEASUREMENT SITE AND NUMBER—Bold number is site number, upper value is net gain calculation for November 18, 1993 measurement, lower value is simulated net gain. Values in cubic feet per second

Figure 14. Comparison of measured net gains in streamflow and simulated net gains, November 18, 1993.

Table 3. Summary of model sensitivity analyses

[H.C. is the hydraulic conductivity for the surficial aquifer; * indicates parameter is multiplied by the number to the right; Recharge is the recharge rate for the surficial aquifer. Riverbed is the riverbed conductance for simulated river cells]

Parameter changed	Number of cells where calculated head minus measured head exceeded 2.5 feet	Percent difference in measured river gain from model predicted river gain													
		Site number													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Calibrated	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans. * .05	40	23	27	33	17	6	20	43	0	0	14	-20	0	25	10
Trans. * 1.5	8	-15	-24	-33	-15	0	-13	-40	0	10	-21	0	0	0	-5
Recharge * 0.5	28	-69	-73	-83	-63	-50	-67	-71	-67	-40	-71	-40	-50	-63	-50
Recharge * 1.5	34	69	76	83	69	56	67	85	33	-50	64	40	50	88	55
Riverbed * 0.5	17	0	0	0	4	0	0	0	0	0	0	-20	0	25	-5
Riverbed * 1.5	5	0	0	0	0	6	0	0	0	10	0	0	0	0	0

the error criteria to increase from 1 to 40 (table 3). Simulated river discharges varied significantly from the measured net streamflow gains (table 3). An increase in horizontal hydraulic conductivity of 50 percent caused the number of simulated heads exceeding the error criterion to increase from 1 to 8, indicating that model simulations are more sensitive to decreases than increases in horizontal hydraulic conductivity.

The model was sensitive to changes in net recharge. A decrease in net recharge of 50 percent caused the number of simulated heads that exceeded the error criterion to increase from 1 to 28. Changes in simulated river discharges were also significant compared to the measured values. A 50 percent increase in net recharge caused the number of computed heads exceeding the error criterion to increase from 1 to 34. The model was particularly sensitive to changes in net recharge, especially the river discharges, because recharge was the only source of water to the model.

The model was least sensitive to changes in riverbed conductance. A decrease in riverbed conductance of 50 percent caused the number of simulated heads exceeding the error criterion to increase from 1 to 17. However, simulated river discharges, were not significantly different from the measured values. An increase in riverbed conductance of 50 percent caused the number of simulated heads exceeding the error criterion to increase from 1 to 5 with virtually no change in simulated river discharges.

Flow Path Analysis

The direction of ground-water flow was determined using the USGS program MODPATH (Pollock, 1989). This program uses the head distribution and intercell flow rates, computed by MODFLOW, to compute ground-water flow directions. The program requires particle-starting locations to be specified, then the particles are tracked backward to areas of recharge or forward to areas of discharge, depending on the options selected.

Base-wide flow paths are shown in figure 15. Particles were placed in every fifth model cell and tracked forward. The pathlines show the movement of ground water toward areas of discharge such as the Ortega River, St. Johns River, or the small creeks that drain the interior of the study area. The ground-water divides (highland areas) are evident by the blank areas where the pathlines diverge. There appear to be several major ground-water drainage areas as defined by the model, and each of the Operable Units occurs in a separate ground-water drainage area. Ground-water discharge to the St. Johns River and lower reach of the Ortega River occurs as widespread upward leakage through the low permeability riverbed sediments. Most particle pathlines, indicating ground-water discharge to the St. Johns River, terminate relatively near the shoreline. While most ground-water discharge to the St. Johns River does occurs near the shoreline, the model simulation indicates that upward leakage persists fairly far offshore, as evidenced by the few particle pathlines that move extended distance offshore (fig. 15) and by the location of the zero contour (fig. 12) that indicates an upward ground-water gradient out to this point. Particle pathlines near the northern half of OU2 move to the northeast where ground water discharges to the St Johns River. A ground-water divide is present in the middle of the Timmaquanna Country Club and ground-water moves from the divide toward OU2. Particle pathlines show that OU3 overlies the middle and end of northwest-to-southeast ground-water flow that discharges to the St. Johns River. Particle pathlines show that OU1 overlies a ground-water high and ground water flows outward from the site in all directions. However, the principle direction of flow is to the southeast where ground water discharges into small creeks.

EVALUATION OF REMEDIAL DESIGN MEASURES AT OU1

Remedial design measures are being assessed by the Navy that will prevent or mitigate the movement of contaminated ground water from OU1 to surface waters. The calibrated model was used to evaluate the effects of various engineering designs on the movement of ground water at and near OU1. The evaluation of each design consisted of (1) modifying the calibrated model to simulate the proposed design, (2) simulating the design to obtain the head distribution and intercell flow rates needed for particle-tracking analysis, (3) seeding the area of the model near OU1 with particles and tracking their movement to determine ground-water flow directions, and (4) simulating the rate of seepage into nearby streams. Each of the remedial designs and the results of the respective model evaluation are discussed below.

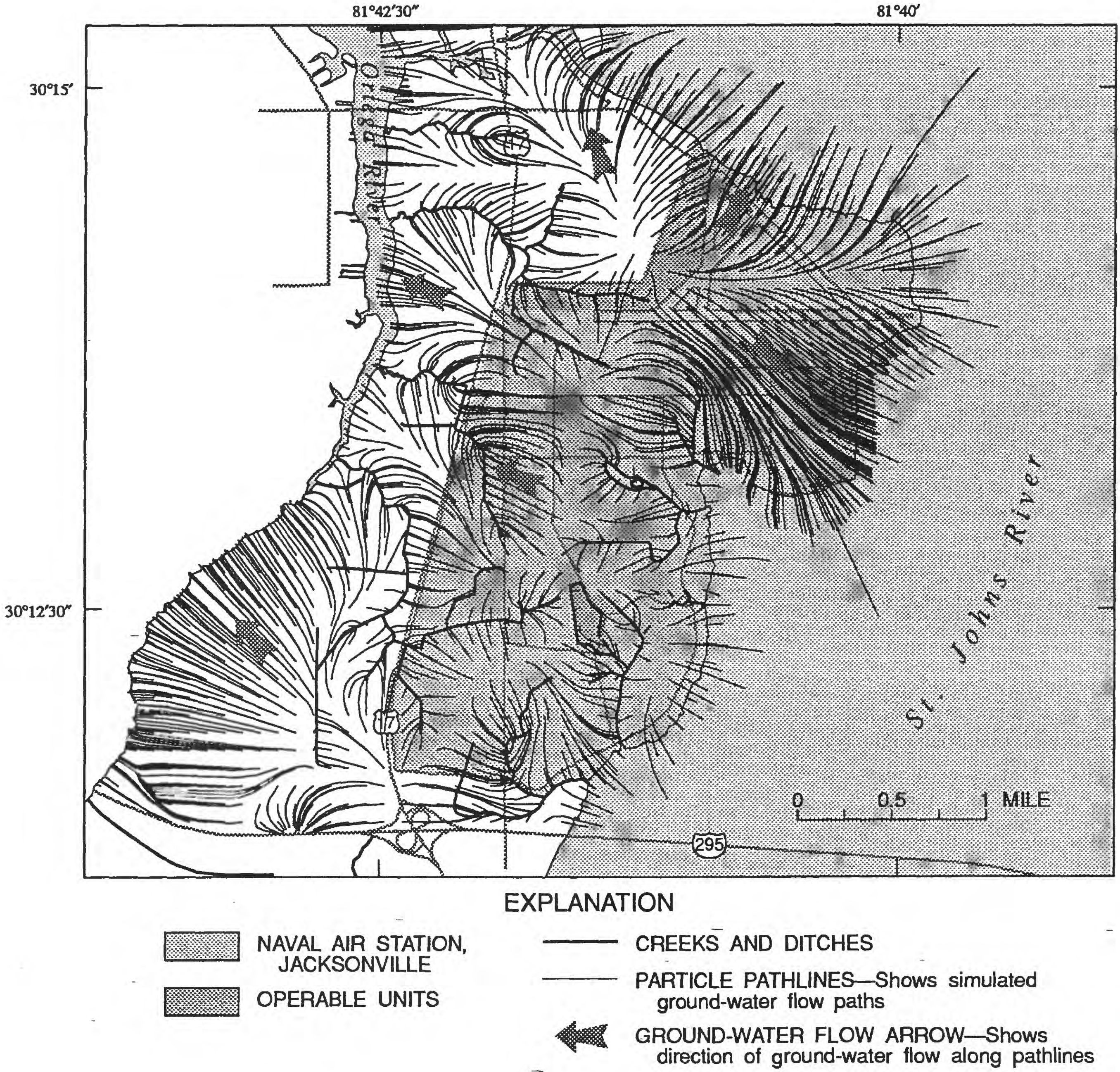


Figure 15. Particle pathlines at the Jacksonville Naval Air Station, representing simulated ground-water flow directions.

Figure 16 shows OU1 and the surrounding area. For clarity, only the area immediately surrounding OU1 is shown in this and subsequent figures. The important features shown are the extent of the old landfill area of OU1, the free product recovery trenches, the extent of dissolved contamination based on total organic volatile compounds (provided by the Navy), the OU1 ditches installed to drain ground water and free product but later blocked with earthen dams, and the locations of two streamflow simulation sites where the rate of seepage was summed to determine the net gain in streamflow. Although figures 15 through 28 show only the area immediately around OU1, model simulations were conducted using the full base-wide model.

Eleven remedial designs were evaluated by model simulation and each design's related effects on ground-water flow are discussed separately. Every design simulation had two features in common: (1) the old landfill part of OU1 was capped to prevent recharge, and (2) two free-product recovery trenches were simulated with the water level in the trenches maintained at 10 feet above sea level (approximately 15 feet below land surface). The capped area was simulated by setting the recharge rate at respective cells to zero in the model. The rate of seepage into the creeks east and south of OU1 was determined for each design. This seepage rate represents the flow of ground water that would need to be treated if unacceptable levels of contamination were present in the water. Some designs included a vertical barrier to prevent ground-water flow in certain directions. These were simulated by assigning a zero hydraulic conductivity to appropriate model cells. Table 4 is a summary of all the designs simulated.

The ground-water flow directions simulated for the site by the calibrated model (fig. 17) provide a standard for comparison and are used to evaluate the effect of the remedial designs. The net gain in streamflow at simulation sites 1 and 2 was 0.13 ft^3/s and 0.11 ft^3/s, respectively, for the calibrated model.

The effect of just the free product recovery trenches on ground-water flow was simulated and, as shown in figure 18, the trenches have a localized effect only on the northern half of the flow system at OU1. The net gain in streamflow at simulation sites 1 and 2 was 0.10 ft^3/s and 0.10 ft^3/s, respectively, and the simulated flow of ground water to the free product recovery trenches was 0.05 ft^3/s. Because the free product recovery trenches were installed during preparation of this report, no measured flow rates to the trenches were available for comparison with the simulated values.

Containment of Contamination on Site

Design 1

Remedial design 1 consists of the simulation of a very low-permeability vertical barrier to surround the old landfill part of OU1 and contain contaminated ground water. The vertical barrier would extend down to the low-permeability Hawthorn Group sediments. To determine the effect of this design on ground-water flow, the calibrated model was modified by setting the hydraulic conductivity of model cells representing the old landfill area to zero. The results of the particle tracking analysis related to design 1 are shown in figure 19. Compared to the calibrated simulation, the location of the ground-water divide to the north moved further north. The net gain in streamflow at simulation sites 1 and 2 was 0.09 ft3/s and 0.09 ft^3/s, respectively, and the simulated flow of ground water to the free product recovery trenches was 0.04 ft^3/s.

Ground Water Drainage From Site by Existing Ditches

Design 2

For design 2, the existing ditches would be used to drain ground water from the site and surrounding areas. The ditches were originally installed to recover free product; later, earthen dams were installed to block the ditches at the southern end of the site. The dams now prevent the ditches from directly draining ground water away from OU1. For this design, the dams would be removed to again allow the ditches to drain water. The exact depth of the bottom of the ditches is not known; however for simulation purposes, the bottom and stage altitudes were specified at 17 feet. The simulated ground-water flow paths for this design are shown in figure 20. The major change between design 2 and calibrated flow conditions is the movement of ground water through OU1, with the west free-product trenches collecting ground water from the northern part of OU1. The net gain in streamflow at simulation sites 1 and 2 was 0.10 ft^3/s and 0.10 ft^3/s, respectively, and the simulated flow of ground water to the free product recovery trenches was 0.05 ft^3/s.

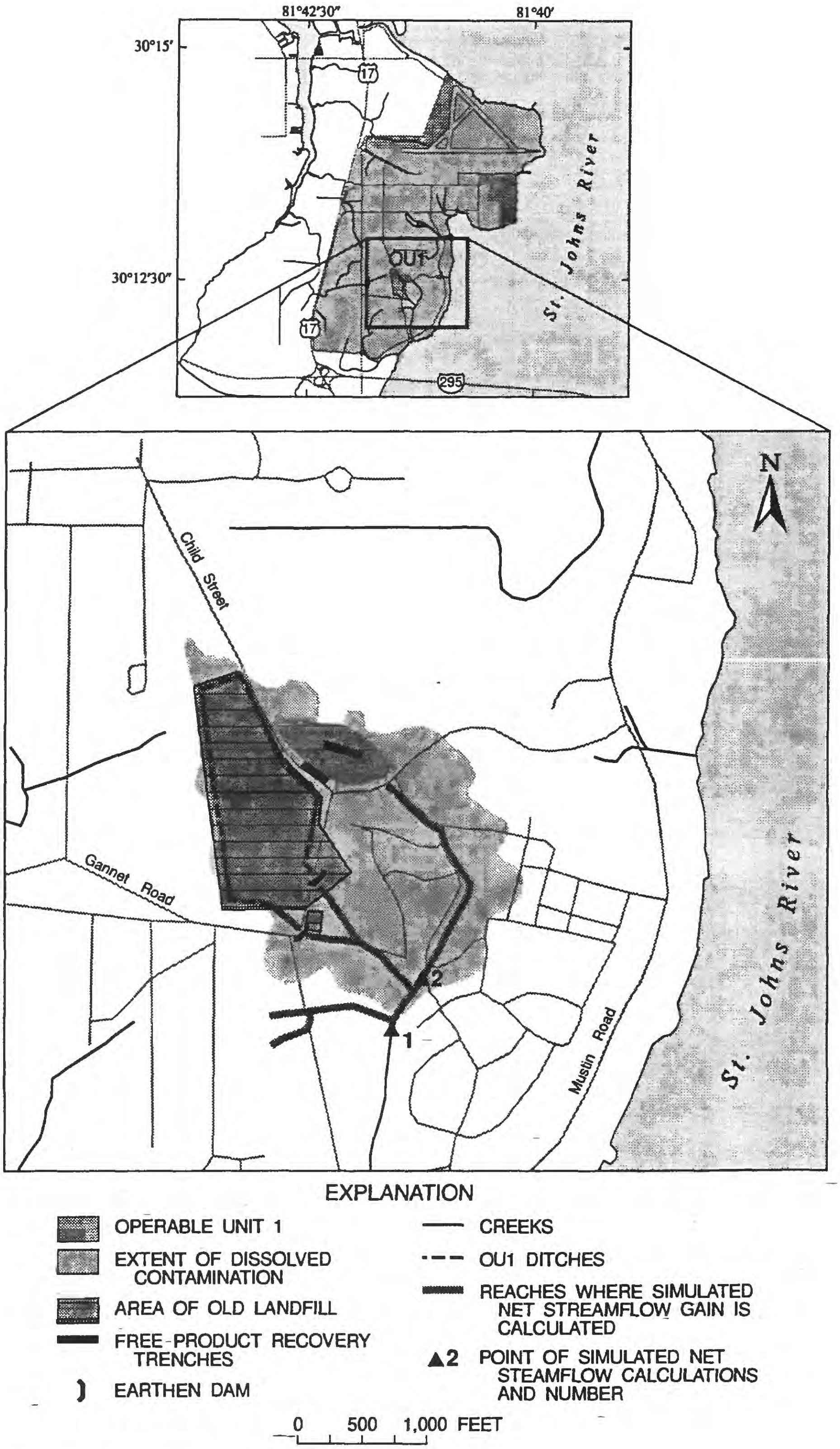
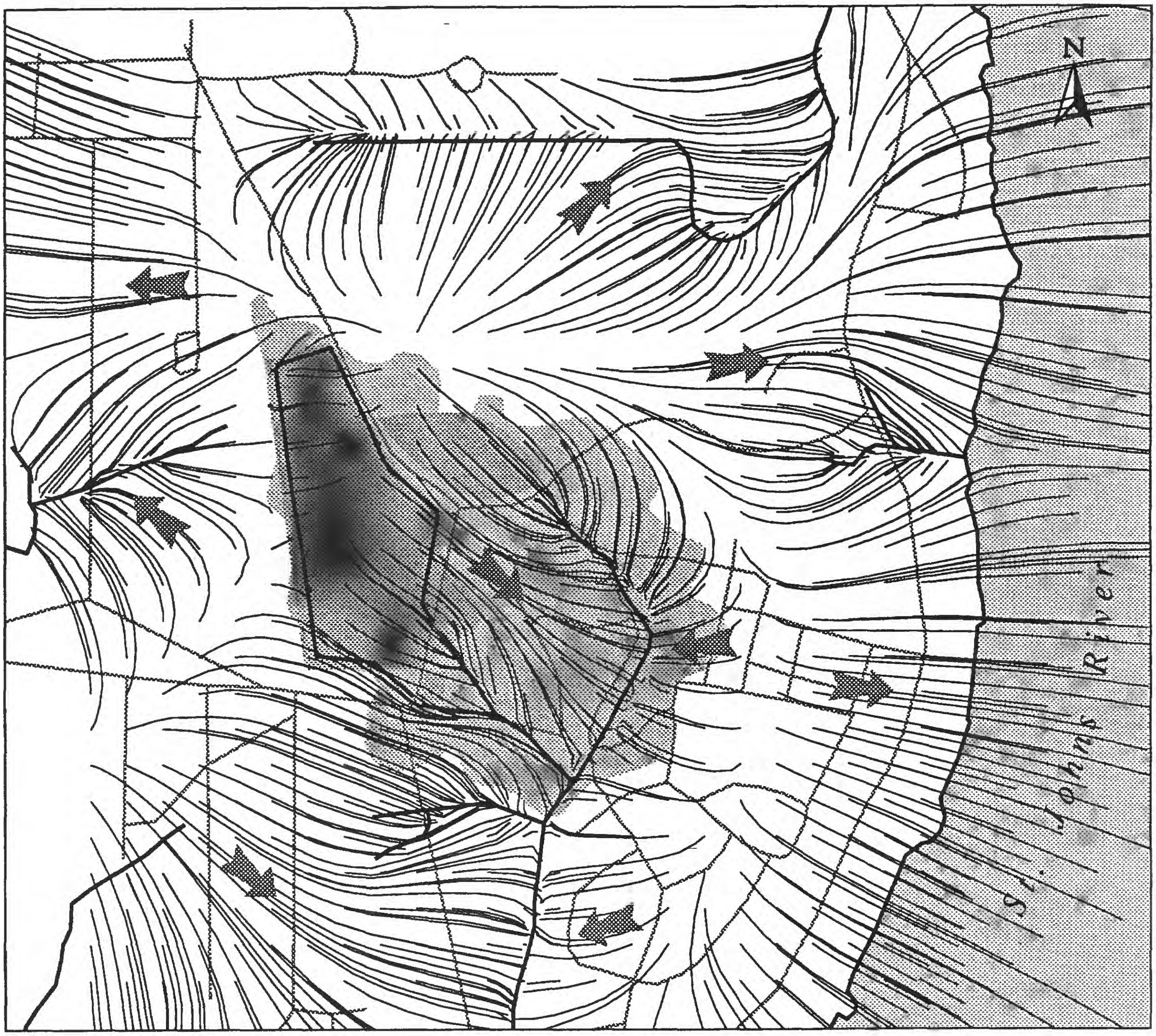


Figure 16. Salient features at Operable Unit 1.

Table 4. Summary of simulated net gains in creeks east and south of Operable Unit 1 and related remedial design features

[Discharge values in cubic feet per second; na, not applicable; *, net gain for simulation site 1 not included in net gain for simulation site 2]

Simulation	Net gain instreamflow at simulation site 1	Net gain in streamflow at simulation site 2*	Ground-water discharge to free product recovery trenches	Imper-meable cap	Free product trenches installed	Vertical barrier around old landfill	Earthern dams removed	Vertical barrier along ground-water divides	Creek east of OU1 deepened and pumped	New ditch installed at OU1	Vertical barrier west of OU1	Pumping well	Ditches at OU1 filled
calibrated model	0.13	0.11	na										
trenches only	0.10	0.10	0.05		x								
Design 1	0.09	0.09	0.04	x	x	x							
Design 2	0.10	0.10	0.05	x	x		x						
Design 3	0.11	0.09	0.04	x	x		x	x					
Design 4	0.12	0.14	0.04	x	x		x		x				
Design 5	0.09	0.12	0.03	x	x		x	x	x				
Design 6	0.20	0.07	0.02	x	x		x			x			
Design 7	0.19	0.07	0.02	x	x		x			x		x	
Design 8	0.13	0.07	0.02	x	x	x	x			x			
Design 9	0.15	0.07	0.02	x	x		x			x	x		
Design 10	0.13	0.10	0.04	x	x								x
Design 11	0.18	0.07	0.03	x	x					x			x

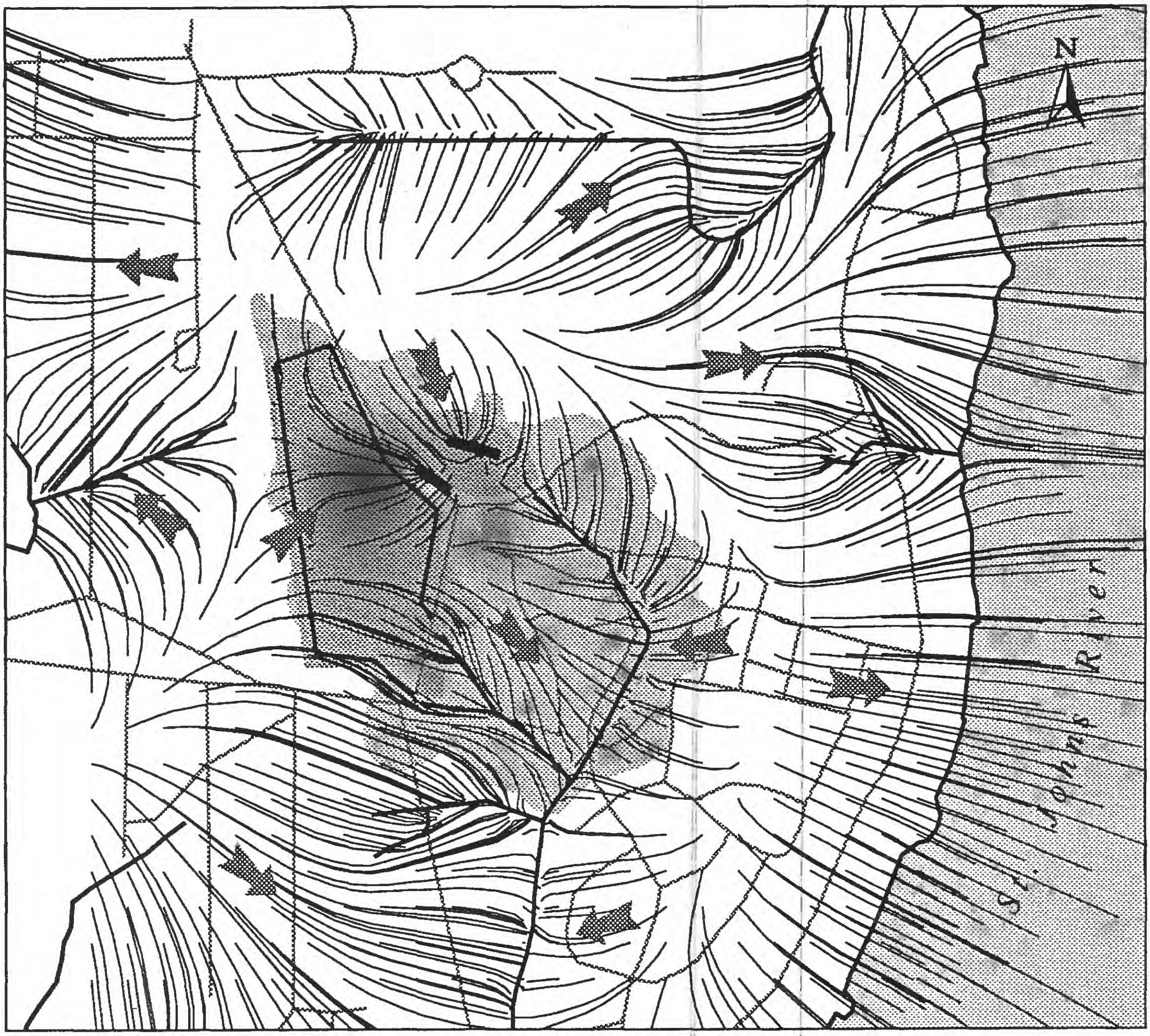


EXPLANATION

- OPERABLE UNIT 1
- EXTENT OF DISSOLVED CONTAMINATION
- CREEK, DITCH, OR SHORELINE
- PARTICLE PATHLINES—Shows simulated ground-water flow path
- GROUND-WATER FLOW ARROW—Shows direction of ground-water flow along pathlines

0 500 1,000 FEET

Figure 17. Particle pathlines at Operable Unit 1, representing simulated ground-water flow directions.



EXPLANATION

OPERABLE UNIT 1

EXTENT OF DISSOLVED CONTAMINATION

FREE PRODUCT RECOVERY TRENCH

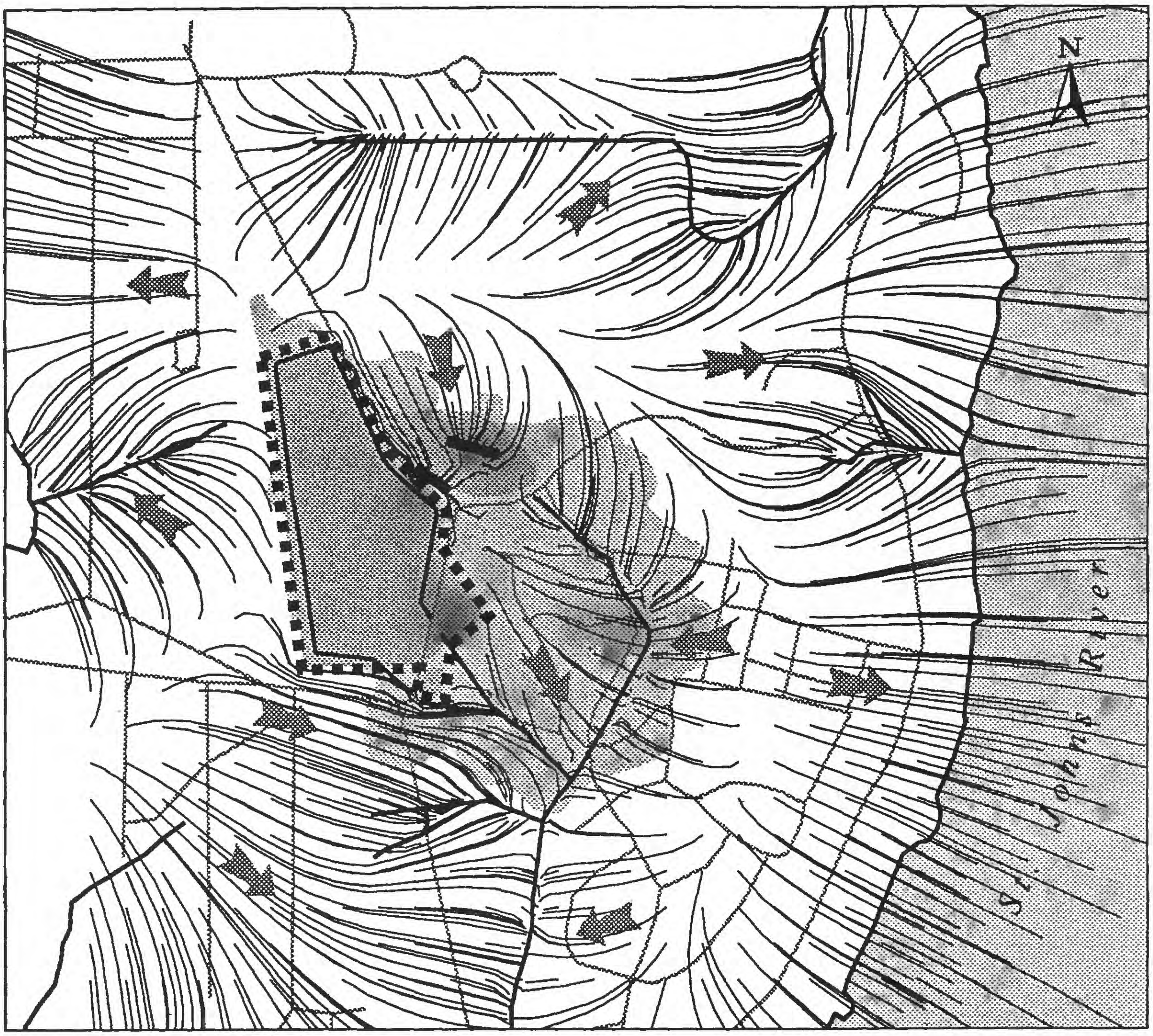
CREEK, DITCH, OR SHORELINE

PARTICLE PATHLINES—Shows simulated ground-water flow path

GROUND-WATER FLOW ARROW—Shows direction of ground-water flow along pathlines

0 500 1,000 FEET

Figure 18. Particle pathlines representing simulated ground-water flow at Operable Unit 1 after installation of free product recovery trenches.

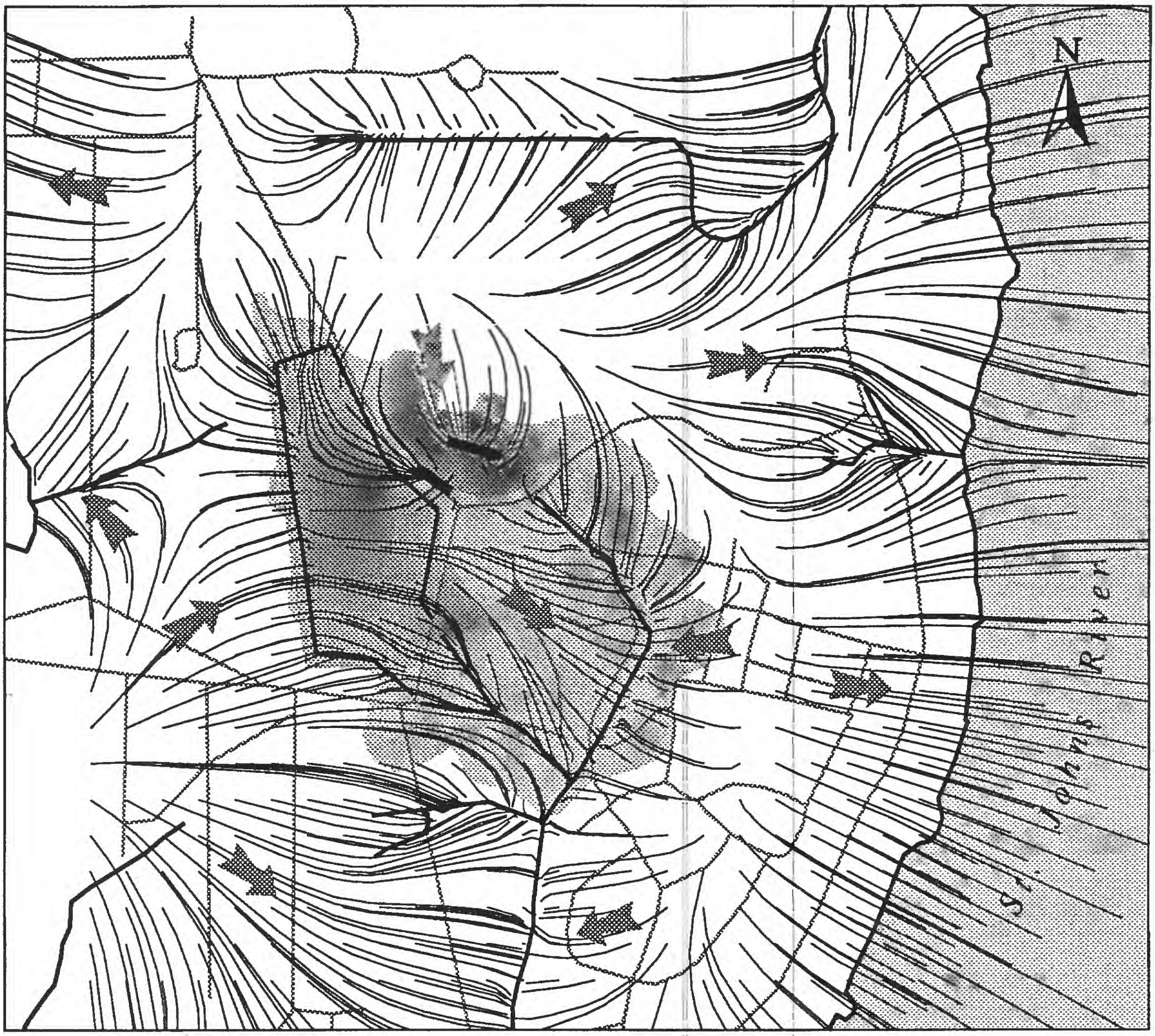


EXPLANATION

- OPERABLE UNIT 1
- EXTENT OF DISSOLVED CONTAMINATION
- FREE PRODUCT RECOVERY TRENCH
- CREEK, DITCH, OR SHORELINE
- PARTICLE PATHLINES—Shows simulated ground-water flow path
- VERTICAL BARRIER
- GROUND-WATER FLOW ARROW—Shows direction of ground-water flow along pathlines

0 500 1,000 FEET

Figure 19. Particle pathlines representing simulated ground-water flow directions at Operable Unit 1 for design 1.



EXPLANATION

OPERABLE UNIT 1

EXTENT OF DISSOLVED CONTAMINATION

FREE PRODUCT RECOVERY TRENCH

CREEK, DITCH, OR SHORELINE

PARTICLE PATHLINES—Shows simulated ground-water flow path

GROUND-WATER FLOW ARROW—Shows direction of ground-water flow along pathlines

0 500 1,000 FEET

Figure 20. Particle pathlines representing simulated ground-water flow directions at Operable Unit 1 for design 2.

Design 3

Design 3 was modified from design 2 to include a vertical barrier installed along the ground-water divides delineated by the calibrated model, and located to the north, east and south of the site. The simulated ground-water flow directions related to design 3 are shown in figure 21. The installation of the vertical barrier had very little effect on the ground-water flow directions. The net gain in streamflow at simulation sites 1 and 2 was 0.11 ft^3/s and 0.09 ft^3/s, respectively, and the simulated flow of ground water to the free product recovery trenches was 0.04 ft^3/s.

Increasing Natural Drainage by Deepening Creek Near OU1

Design 4

For design 4, the natural ground-water drainage would be increased by deepening a part of the creek immediately east of OU1 by about 10 feet and the earthen dams would be removed. To maintain a stage near the creek bottom in the deepened section of the creek, it would require pumping, because the modeled creek bottom would be below the water level in the St. Johns River. The simulated ground-water flow directions related to remedial design 4 are shown in figure 22. Ground-water flow now moves through OU1 to be discharged at the deepened creek. The net gain in streamflow at simulation sites 1 and 2 were 0.12 ft^3/s and 0.14 ft^3/s, respectively, and the simulated flow of ground water to the free product recovery trenches was 0.04 ft^3/s.

Design 5

Design 5 was modified from design 4 to include the vertical barrier installed along the ground-water divides to the north, east and south of OU1. The simulated ground-water flow directions related to design 5 are shown in figure 23. The installation of the vertical barrier had very little effect on the ground-water flow directions in the vicinity of OU1. The net gain in streamflow at simulation sites 1 and 2 was 0.09 ft^3/s and 0.12 ft^3/s, respectively, and the simulated flow of ground water to the free product recovery trenches was 0.03 ft^3/s. The flows in the creeks were lower compared to design 4 because the vertical barrier forced the ground-water divides to return to the position originally delineated by the calibrated model.

Extending and Deepening Ditch at OU1

Design 6

For design 6, the ditch on the eastern side of OU1 would be deepened and extended to the natural drainage east of OU1 (fig. 24); the remaining ditches would not be modified except by removing the earthen dams. The altitude assigned to the stage of the trench was uniformly graded from 10 ft at the northern end of the trench to 5 ft at the southern end. Using this design, the new deepened ditch would become the major ground-water drain for OU1. The net gain in streamflow at simulation sites 1 and 2 was 0.20 ft^3/s and 0.07 ft^3/s, respectively, and the simulated flow of ground water to the free product recovery trenches was 0.02 ft^3/s.

Design 7

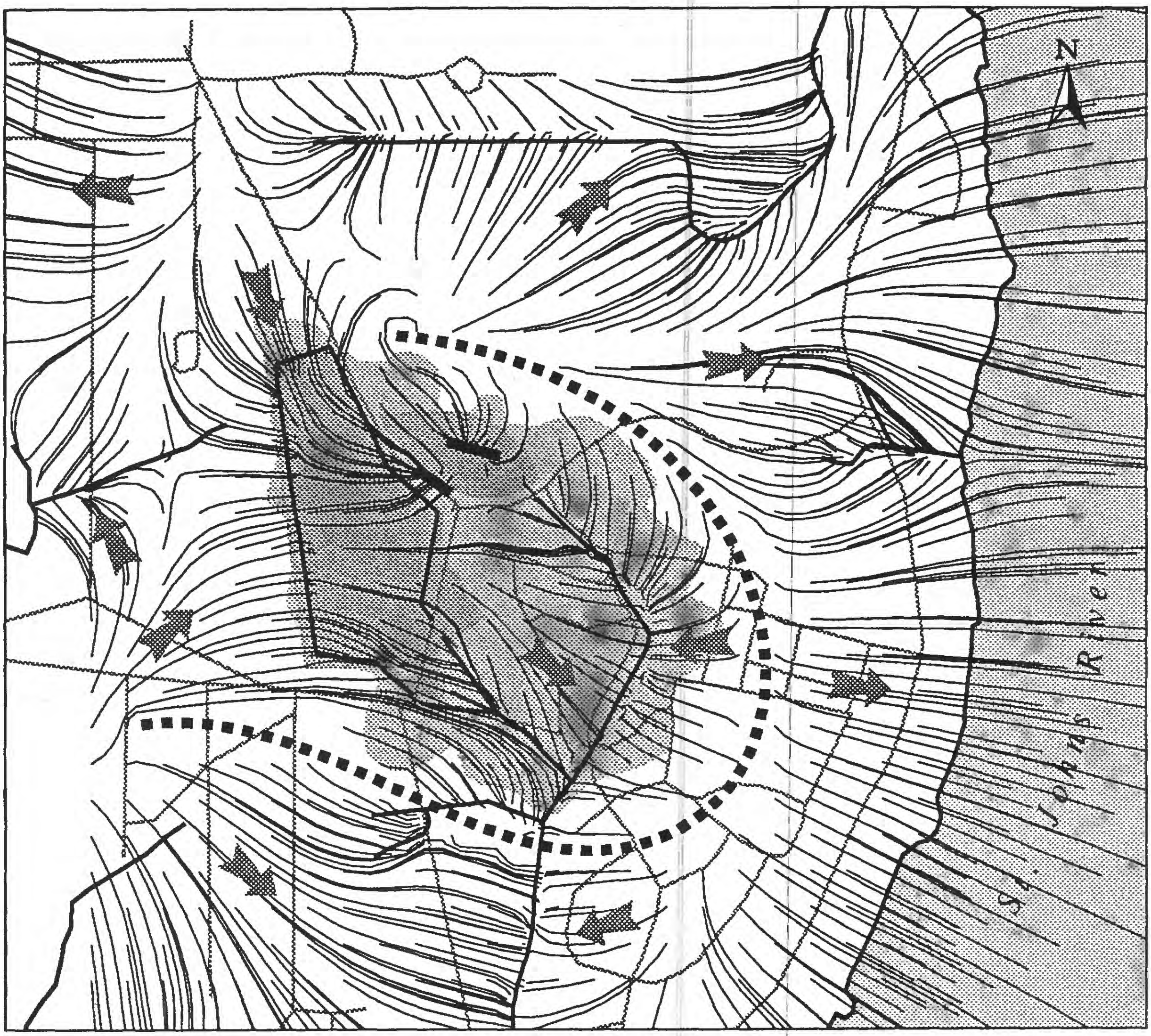
Design 7 is the same as design 6, except that a well is installed east of the new ditch (fig. 25) and pumped at 3 gal/min, the maximum expected sustainable pumping rate. The purpose of the well is to speed recovery of contaminated ground water from beneath a housing area. The net gain in streamflow at simulation sites 1 and 2 was 0.19 ft^3/s and 0.07 ft^3/s, respectively, and the simulated flow of ground water to the free product recovery trenches was 0.02 ft^3/s.

Design 8

Design 8 is the same as design 6, except that a vertical barrier is installed around the old landfill area to contain the leachates within the present landfill (fig. 26). Using this design, ground water flow is diverted from north of OU1 to the deepened trench. The net gain in streamflow at simulation sites 1 and 2 was 0.13 ft^3/s and 0.07 ft^3/s, respectively, and the simulated flow of ground water to the free product recovery trenches was 0.02 ft^3/s.

Design 9

Design 9 is the same as design 6, except that a vertical barrier is installed around the western perimeter of OU1 (fig. 27). Ground water is not drained from areas west of OU1 using this design, but is drained from beneath OU1 to the deepened trench to the east. The net gain in streamflow at simulation sites 1 and 2 was 0.15 ft^3/s and 0.07 ft^3/s, respectively, and the simulated flow of ground water to the free product recovery trenches was 0.02 ft^3/s.

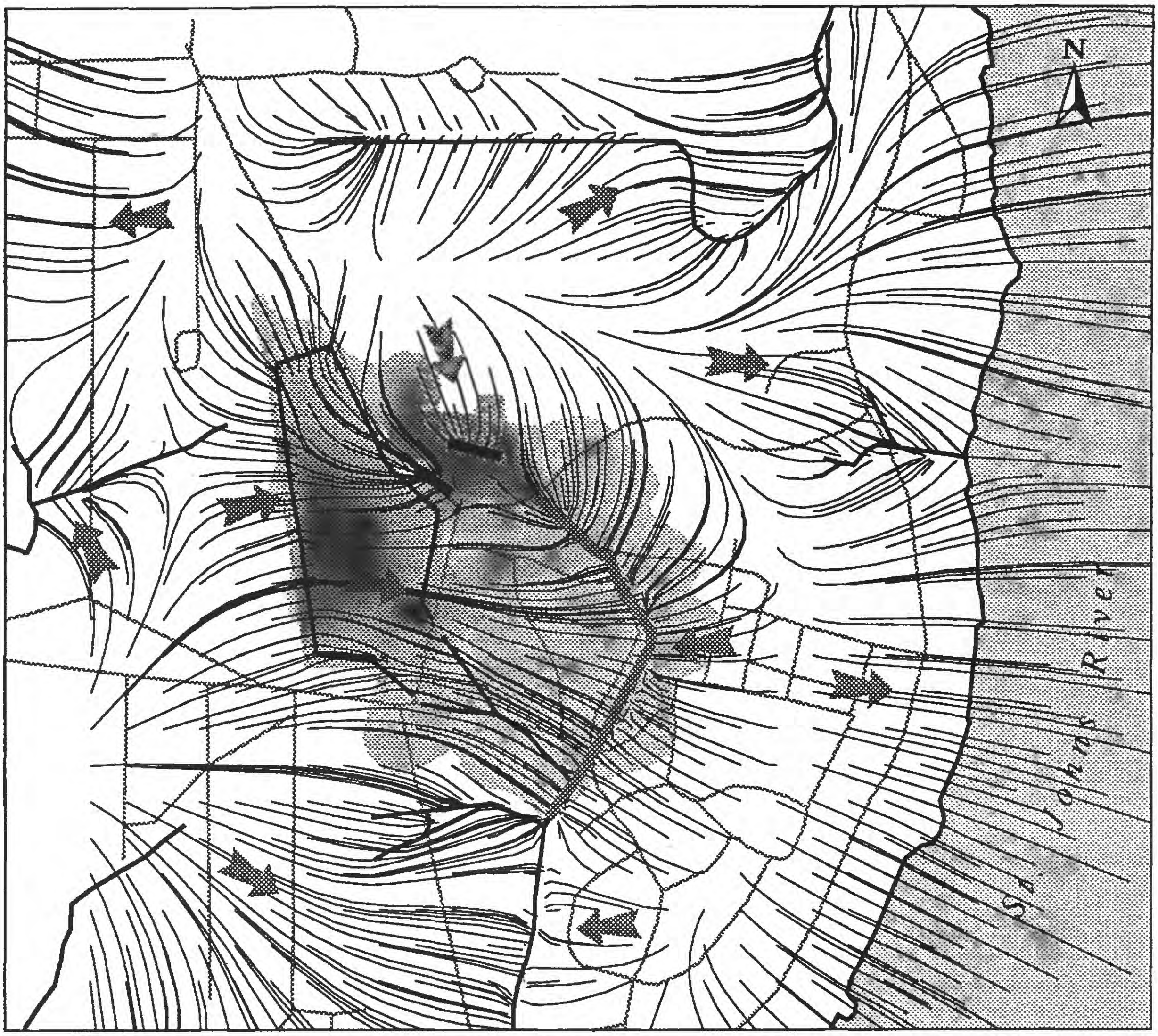


EXPLANATION

- OPERABLE UNIT 1
- EXTENT OF DISSOLVED CONTAMINATION
- FREE PRODUCT RECOVERY TRENCH
- CREEK, DITCH, OR SHORELINE
- PARTICLE PATHLINES—Shows simulated ground-water flow path
- VERTICAL BARRIER
- GROUND-WATER FLOW ARROW—Shows direction of ground-water flow along pathlines

0 500 1,000 FEET

Figure 21. Particle pathlines representing simulated ground-water flow directions at Operable Unit 1 for design 3.



EXPLANATION

- OPERABLE UNIT 1
- EXTENT OF DISSOLVED CONTAMINATION
- FREE PRODUCT RECOVERY TRENCH
- CREEK, DITCH, OR SHORELINE
- PARTICLE PATHLINES—Shows simulated ground-water flow path
- DEEPENED DITCH
- GROUND-WATER FLOW ARROW—Shows direction of ground-water flow along pathlines

0 500 1,000 FEET

Figure 22. Particle pathlines representing simulated ground-water flow directions at Operable Unit 1 for design 4.

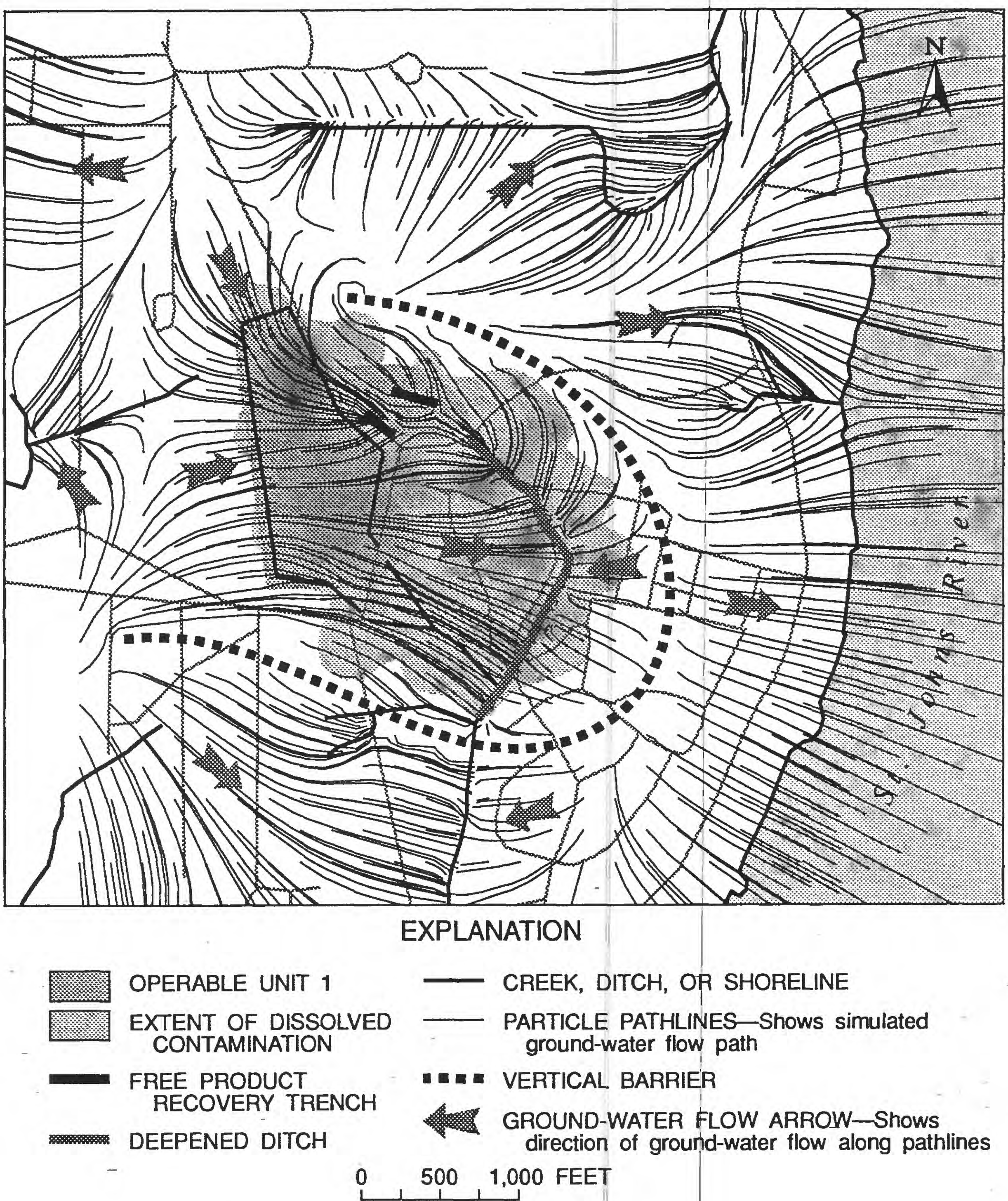
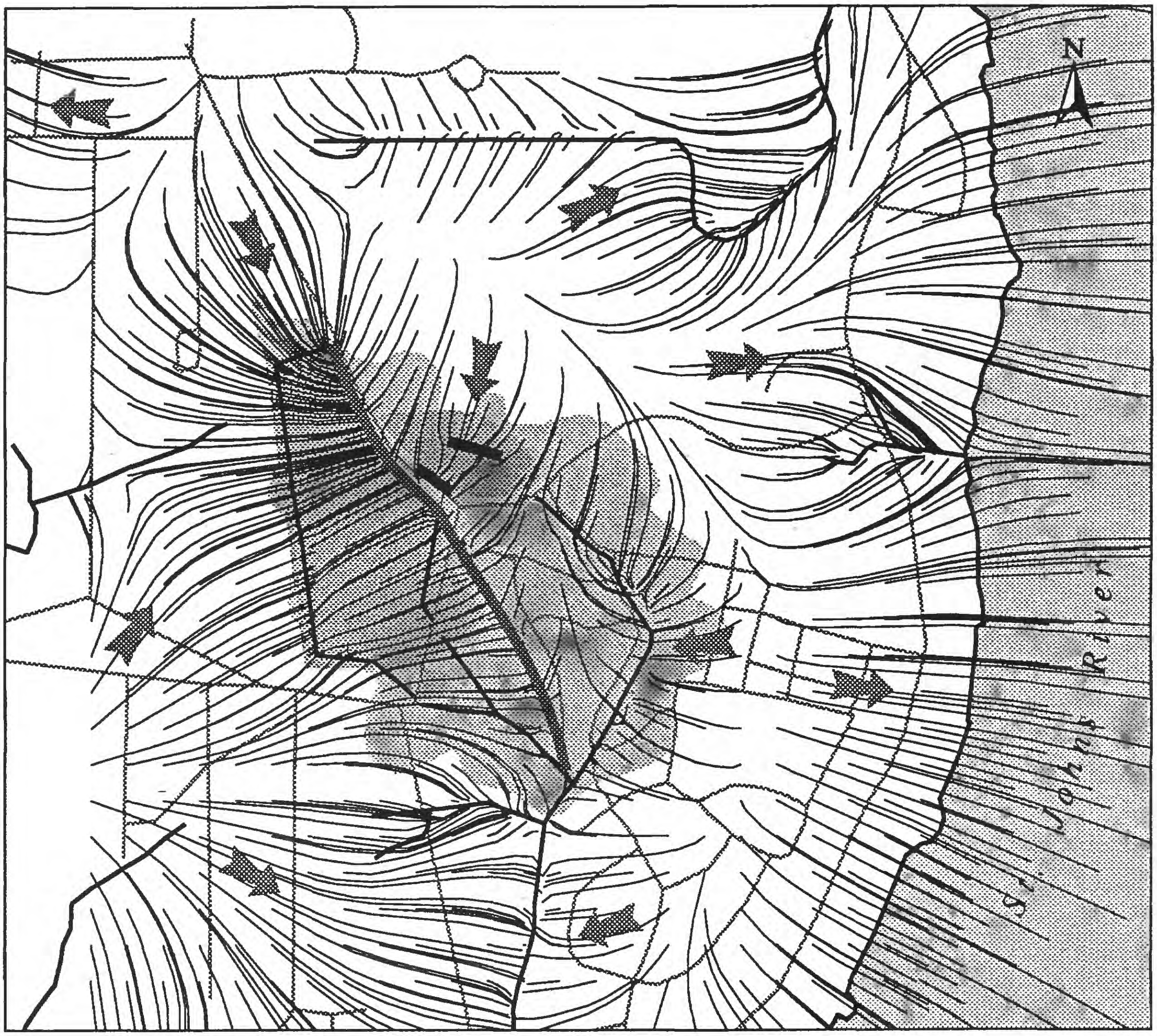


Figure 23. Particle pathlines representing simulated ground-water flow directions at Operable Unit 1 for design 5.



EXPLANATION

OPERABLE UNIT 1

EXTENT OF DISSOLVED CONTAMINATION

FREE PRODUCT RECOVERY TRENCH

CREEK, DITCH, OR SHORELINE

PARTICLE PATHLINES—Shows simulated ground-water flow path

NEW DITCH

GROUND-WATER FLOW ARROW—Shows direction of ground-water flow along pathlines

0 500 1,000 FEET

Figure 24. Particle pathlines representing simulated ground-water flow directions at Operable Unit 1 for design 6.

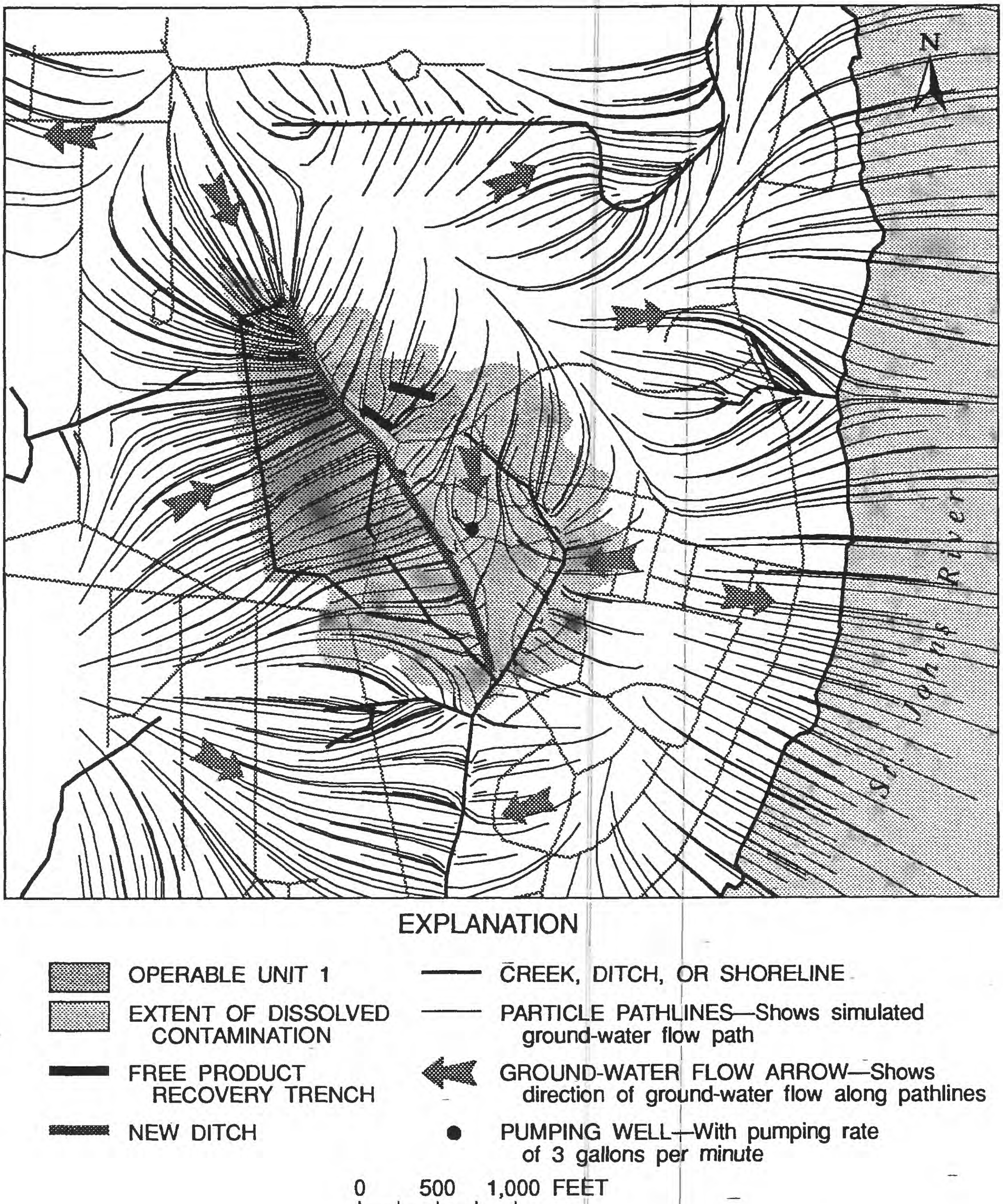
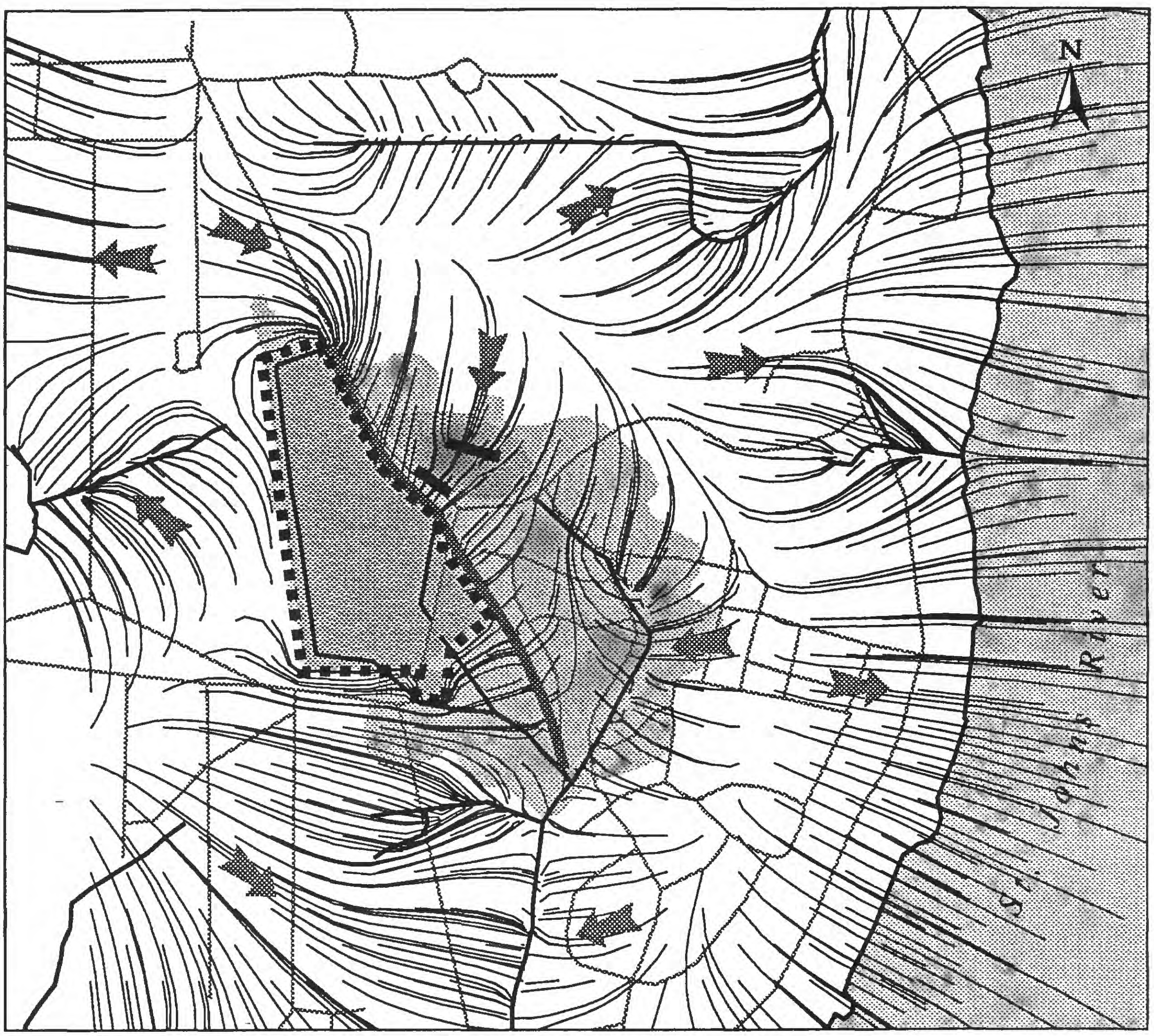


Figure 25. Particle pathlines representing simulated ground-water flow directions at Operable Unit 1 for design 7.



EXPLANATION

- OPERABLE UNIT 1
- EXTENT OF DISSOLVED CONTAMINATION
- FREE PRODUCT RECOVERY TRENCH
- VERTICAL BARRIER
- CREEK, DITCH, OR SHORELINE
- PARTICLE PATHLINES—Shows simulated ground-water flow path
- NEW DITCH
- GROUND-WATER FLOW ARROW—Shows direction of ground-water flow along pathlines

0 500 1,000 FEET

Figure 26. Particle pathlines representing simulated ground-water flow directions at Operable Unit 1 for design 8.

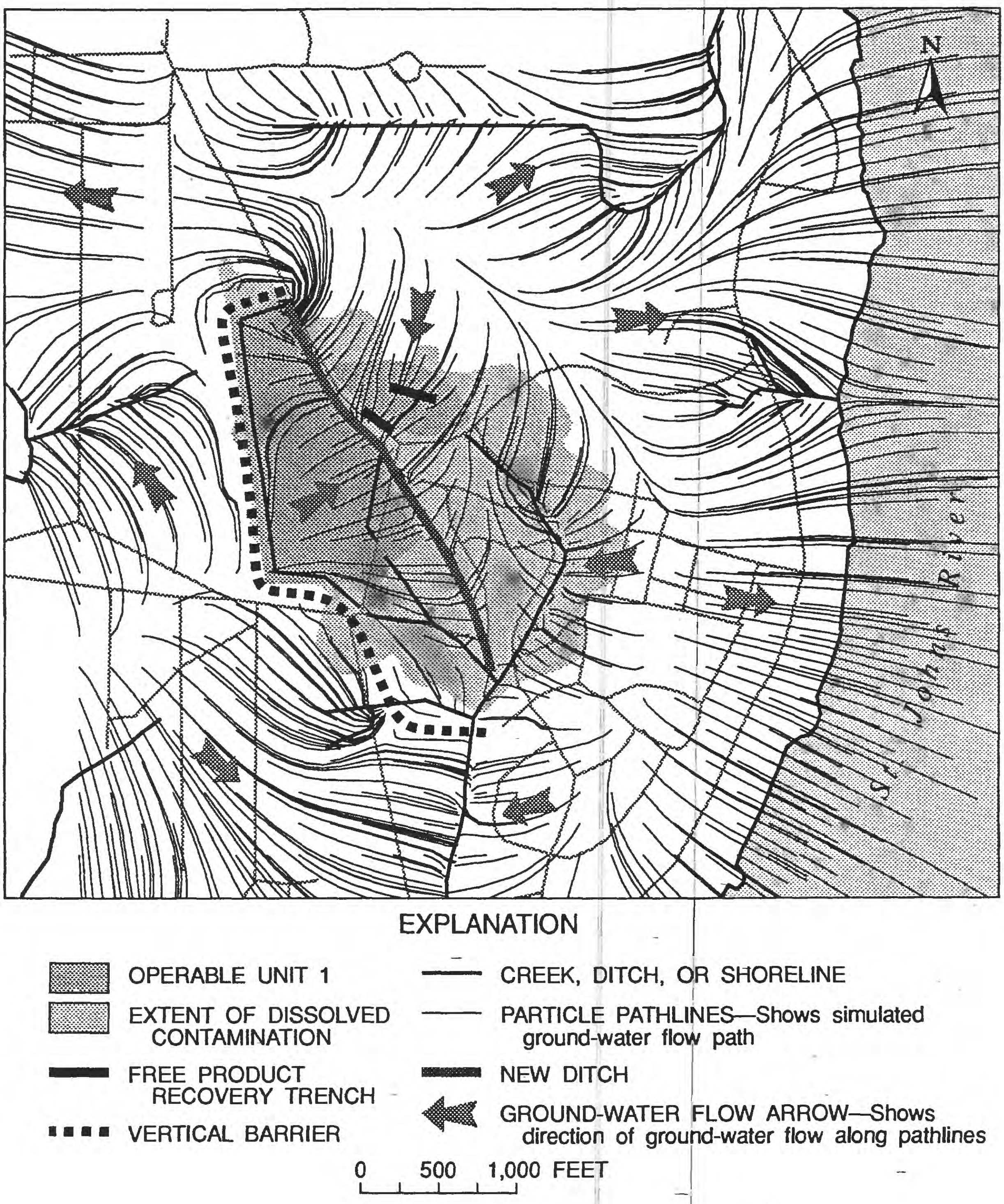


Figure 27. Particle pathlines representing simulated ground-water flow directions at Operable Unit 1 for design 9.

Ditches at OU1 Filled

Design 10

For design 10, the ditches surrounding the old landfill area would be back filled with local materials; these materials were assumed to have a hydraulic conductivity of 7.5 ft/d. As shown in figure 28, ground water moving beneath OU1 discharges to the south and east into the creeks and to the free product recovery trenches. The net gain in streamflow at simulation sites 1 and 2 was 0.13 ft^3/s and 0.10 ft^3/s, respectively, and the simulated flow of ground water to the free product recovery trenches was 0.04 ft^3/s.

Design 11

Design 11 is the same as design 10, except that the ditch on the eastern side of OU1 would be deepened and extended to the natural drainage east of OU1 (fig. 29). The altitude assigned to the ditch bottom at the northern end of the ditch was 10 feet and was graded uniformally to 5 feet at the southern end. Using this design, the deepened trench would become the major ground-water drain for OU1. The net gain in streamflow at simulation sites 1 and 2 were 0.18 ft^3/s and 0.07 ft^3/s, respectively, and the simulated flow of ground water to the free product recovery trenches was 0.03 ft^3/s.

SUMMARY AND CONCLUSIONS

NAS occupies 5.9 mi^2 in southeastern Duval County, Fla., and is located approximately 9 mi south of downtown Jacksonville, Fla. NAS is located on the St. Johns River approximately 24 mi upstream from its confluence with the Atlantic Ocean. The U.S. Navy has been concerned about the movement of contaminated ground water from the surficial aquifer into the St. Johns River and small creeks that feed the St. Johns. In 1992, the U.S. Navy requested the U.S. Geological Survey to simulate advective ground-water flow in the surficial aquifer at NAS so that they could assess the direction and rates of ground-water flow and the migration of contaminants from areas with documented contamination.

Three Operable Units have been identified that require a Remedial Investigation/Feasibility Study. OU1 is located in the south-central part of NAS and contains what was formerly known as the Old Main Registered Disposal Area and an area that was formerly used to store electric transformers that contained PCBs. OU2 is located in the northern part of NAS and has principally been used for fire-fighting training, sewage treatment, and sewage sludge disposal. OU3 is located in the eastern part of NAS, adjacent to the St. Johns River. The OU3 area consists primarily of the Naval Aviation Depot and waste materials of concern are paint sludges, solvents, battery acids, and aviation fuels.

A surficial aquifer is the uppermost aquifer beneath NAS. The surficial aquifer consists of a series of Pleistocene- and Holocene-age terraces composed of silty sands deposited during marine transgressions and regressions associated with glacial and interglacial periods. For modeling, the surficial aquifer was represented by a single layer and divided into 240 rows and 290 columns of grid cells. Model cells were spaced so that each monitoring well could be placed in an individual cell, thereby allowing comparison of observed water levels at each monitoring well to the simulated head in the model cell. The St. Johns River and the Ortega River were used in the simulation as the natural ground-water flow boundaries of the surficial aquifer, because these rivers are be the endpoints for flow in the surficial aquifer. The final calibrated model matched 126 of 127 measured ground-water levels within the +/- 2.5 ft criterion and simulated the total net measured ground-water to surface-water discharge to within 1 percent (1.52 ft^3/s measured to 1.50 ft^3/s simulated).

Based on the results of the modeling and particle tracking analysis, there appears to be several ground-water drainage areas, and each of the Operable Units belong to separate areas. OU2 has ground-water flow that moves from the sewage treatment plant to the northeast where it discharges to the St Johns River. Ground-water flow at OU3 is toward the southeast where flow discharges into the St. Johns River. OU1 is centered at a ground-water high caused by drainage ditches that surrounds the site, and ground water flows outward from the site in all directions. However, the principle direction of flow is to the east and southeast where the ground water discharges into small creeks.

Remedial measures are currently being assessed by the Navy that will prevent or mitigate the effect of ground-water contamination on areas surrounding OU1. The calibrated model was used to evaluate the effect of various engineering designs on the movement of ground water. The evaluation of each design consisted of (1) modifying the calibrated model to simulate the proposed design, (2) simulating the design to obtain the head distribution and intercell flow rates needed for

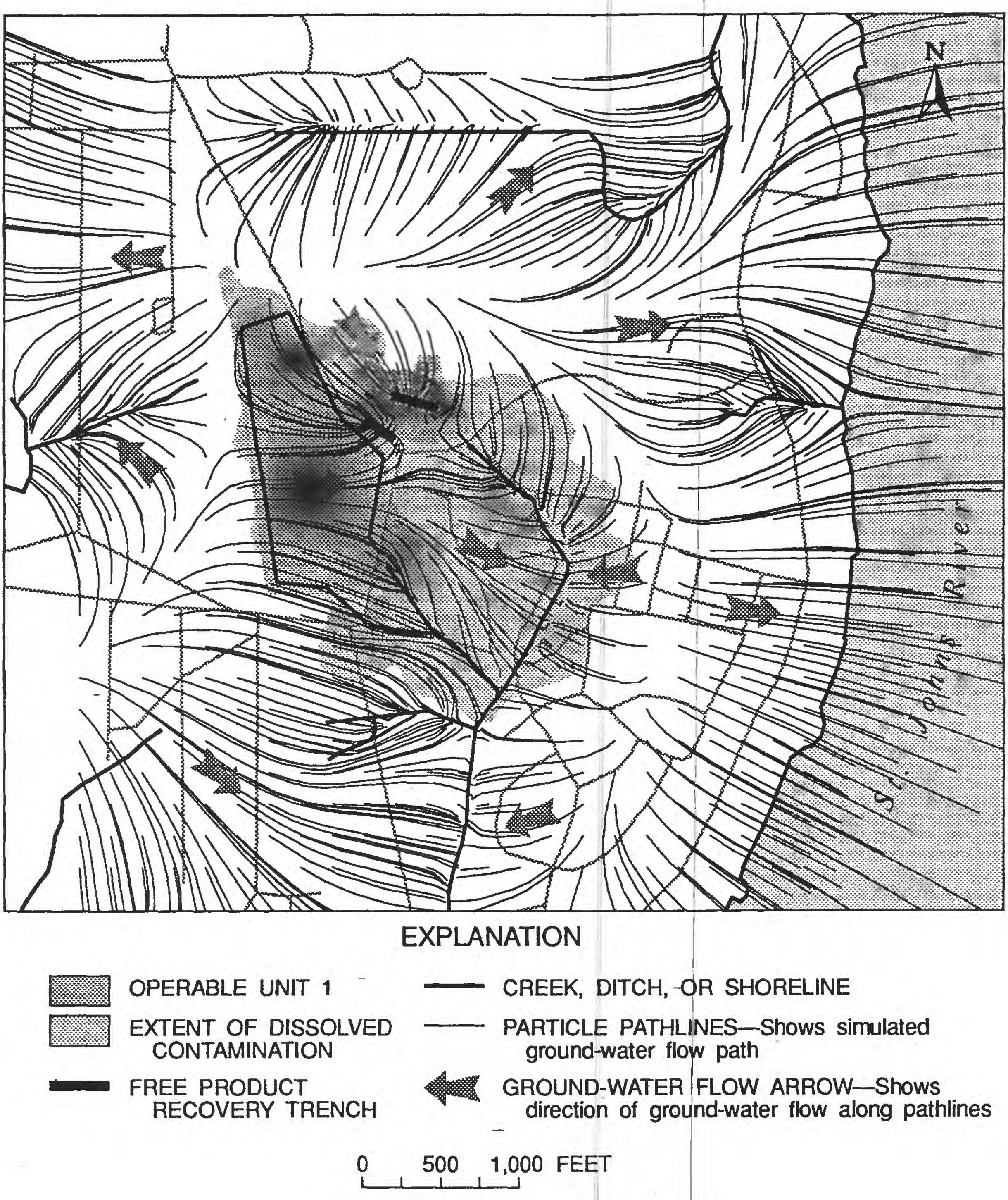


Figure 28. Particle pathlines representing simulated ground-water flow directions at Operable Unit 1 for design 10.

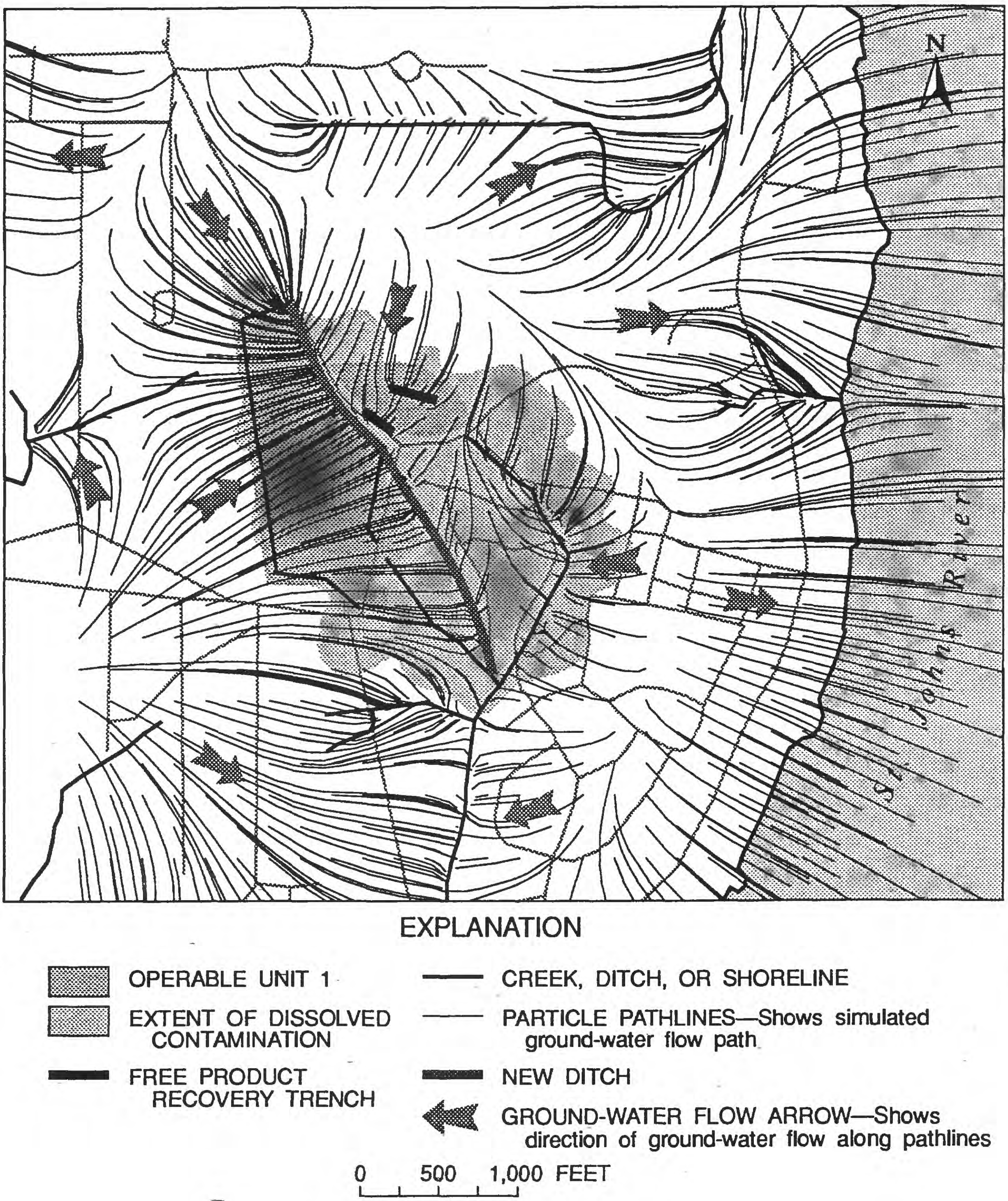


Figure 29. Particle pathlines representing simulated ground-water flow directions at Operable Unit 1 for design 11.

particle tracking analysis, and (3) seeding the part of the model near OU1 with particles and tracking their movement to determine ground-water flow direction. A total of 11 engineering designs were simulated with the model to test their effect on ground-water flow. The designs included modifying existing ditches and drainages, installing a pumping well, and installing vertical barriers.

Remedial design 1 consists of the simulation of a very low-permeability vertical barrier to surround the old landfill part of OU1 and contain contaminated ground water on site. An impermeable cap would be installed for this and all following designs. Design 2 consists of allowing existing ditches to drain ground water from the site and surrounding areas. Design 3 was modified from design 2 to include a vertical barrier installed along the ground-water divides located to the north, east and south of the site. For design 4, the natural ground-water drainage would be increased by deepening a part of the creek immediately east of OU1 by about 10 feet. Design 5 was modified from design 4 to include a vertical barrier, installed along the ground-water divides to the north, east and south of OU1. For design 6, the ditch on the eastern side of OU1 would be deepened and extended to the creek east of OU1. Design 7 is the same as design 6, except that a well is installed east of the new ditch and pumped at 3 gal/min, the maximum expected sustainable pumping rate. Design 8 is the same as design 6, except that a vertical barrier is installed around a part of OU1 to contain the leachates within the old landfill area. Design 9 is the same as design 6, except that a vertical barrier is installed around the western perimeter of OU1. For design 10, the ditches underlying the old landfill area would be back filled. Design 11 is the same as design 10, except that the ditch on the eastern side of OU1 would be deepened and extended to the creek east of OU1.

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