Ground-Water Recharge in Florida--A Pilot Study in Okaloosa, Pasco, and Volusia Counties

By John Vecchioli, C.H. Tibbals, A.D. Duerr, and C.B. Hutchinson

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MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

District Chief
U.S. Geological Survey
Suite 3015
227 North Bronough Street
Tallahassee, Florida 32301

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CONVERSION FACTORS AND ABBREVIATIONS

The inch-pound units used in the text, figures, and tables in this report may be converted to metric (International System) units by the following factors.

Multiply inch-pound unit	By	To obtain metric unit
inch (in.)	25.4	millimeter (mm)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
foot (ft)	0.3048	meter (m)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) as follows:

$$°C = 5/9 \times (°F-32)$$

Sea level: When used in this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a vertical 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.

The metric units used in plates 1, 2, and 3 in this report may be converted to inch-pound units by the following factors:

Multiply metric unit	By	To obtain inch-pound unit
kilometer (km)	0.6214	mile (mi)
meter (m)	3.281	foot (ft)

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ABSTRACT

Protection of ground-water recharge areas against incursions of development is of great interest in Florida, a State whose population depends heavily on ground water and that is experiencing rapid growth. The Florida Legislature is considering implementation of a program to provide favorable tax treatment to owners of high-rate recharge lands that are left in an undeveloped state. Implementation would require delineation of such lands at a scale large enough to be useful to tax assessors. The U.S. Geological Survey undertook a pilot study with the Florida Department of Environmental Regulation to explore the feasibility of mapping high-rate recharge areas at a scale of 1:100,000.

Recharge maps at that scale were compiled for Okaloosa, Pasco, and Volusia Counties. These maps delineate areas of high-rate recharge to the surficial aquifer and to the Upper Floridan aquifer. High-rate recharge was arbitrarily set at 10 or more inches per year. Recharge rates were determined primarily through analysis of streamflow, spring flow, and pumpage data together with knowledge of the ground-water flow system and topographic and soils information. Quantitative mapping of recharge using these techniques may not be possible in some parts of the State, but mapping on a qualitative basis is considered feasible.

INTRODUCTION

Florida's population has grown tremendously in the last few decades--from 2.8 million in 1950 to 11.3 million in 1985. Accompanying the population growth has been a marked increase in ground-water withdrawals and an increased dependency on ground water as the principal source of water supplies. In 1985, slightly more than 4 billion gallons per day of freshwater was withdrawn from Florida's aquifers. Ground water constituted 64 percent of total freshwater withdrawn for all uses in 1985, whereas in 1980, ground water supplied 52 percent of the total freshwater demand (Conover and others, 1989). The dependency on ground water is even greater (72 percent) if withdrawals for thermoelectric power use are excluded from the total. Even more striking is the fact that ground water is the source of drinking water for 91 percent of Florida's population. Obviously, protection of the quantity and quality of Florida's ground-water resources is of vital importance in assuring that future water needs will be met.

As development proceeds in Florida's areas of ground-water recharge, concern heightens over its effects on the quantity and quality of the recharge water. The impervious streets, parking lots, and roofs that are intrinsic to urbanization reduce the area available for rainfall to infiltrate the ground, and, where the precipitation falling on these impervious areas is collected and conveyed by storm sewers to major streams or the sea, less water is available for recharge. In addition, the many human activities associated with urbanization have the potential for degrading the quality of the recharge. Hence, preservation of high-rate recharge areas in their natural or quasi-natural state was the goal of a constitutional amendment, known as the "Bluebelt Amendment," that was overwhelmingly approved by Floridians in a 1988 election. The amendment authorizes favorable tax treatment to owners of land that qualifies as a high-rate recharge area to Florida's ground water and that is left in an undeveloped state.

With the passage of the Bluebelt Amendment, the Florida Legislature is faced with developing legislation for its implementation, the Florida Department of Environmental Regulation with providing the technical basis for the implementation, and local tax assessors with administering the favorable tax treatment for qualifying lands. In order for the legislators, water managers, and tax assessors to communicate effectively with each other and with the interested public on the matter of ground-water recharge, there needs to be a clear understanding of the concept of ground-water recharge and recharge areas. In addition, the practicability of delineating high- rate recharge lands at a scale usable for implementation of the Bluebelt Amendment needs to be demonstrated. Accordingly, the Bluebelt Commission, which was empowered by the Florida Legislature to study the feasibility and effects of implementation of the Bluebelt Amendment, authorized a study to be done by the U.S. Geological Survey, in cooperation with the Florida Department of Environmental Regulation, to evaluate the feasibility of delineating high-rate recharge areas throughout the State. The counties of Okaloosa, Pasco, and Volusia were selected for mapping of high-rate recharge areas to the surficial aquifer and to the Upper Floridan aquifer at a scale of 1:100,000. Results of the pilot study are presented herein.

Purpose and Scope

The purpose of this report is to discuss the ground-water recharge process in reference to hydrologic conditions in Florida and to present results of the mapping of high-rate recharge areas in the three counties selected for study. The concept of ground-water recharge, factors that influence rate of recharge, and methods for determining recharge rates are described. Maps at a scale of 1:100,000 for Okaloosa, Pasco, and Volusia Counties are presented that delineate areas of 10 in/yr (inches per year) or more of recharge to the surficial aquifer and the Upper Floridan aquifer. For purposes of this work, 10 in/yr was the threshold value selected for high-rate recharge by the Bluebelt Commission in its deliberations. The maps also indicate areas of generally no recharge--those areas where ground-water discharges most of the year--and areas of less than 10 in/yr of recharge. Methodologies used to determine recharge rates and delineate the various areas are detailed for each of the counties mapped. Lastly, conclusions are drawn regarding feasibility of the mapping process and reliability of the resulting product.

Previous Work

Information on the spatial variation of ground-water recharge rates in Florida is currently available only for the Floridan aquifer system. Lichtler (1972) mapped in a comparative, qualitative manner the effectiveness of areas for recharge in the east-central Florida region which includes Volusia, Lake, Seminole, Orange, Brevard, Osceola, and Indian River Counties. Tibbals (1975) followed Lichtler's qualitative classification and mapped recharge areas in Seminole County and vicinity, but he also incorporated rates into the classification based on spring discharge and hydrogeology. Stewart (1980) mapped recharge areas and rates to the Floridan statewide at a scale of 1:2,000,000. Stewart's work was largely based on hydrogeology. Recently, numerical modeling of the Floridan aquifer system has provided a more refined quantitative assessment of the spatial distribution of recharge. Aucott (1988) coupled the numerical modeling information with Stewart's earlier map and produced a map showing spatial distribution of recharge rates at a scale of 1:1,000,000.

Acknowledgments

Several Geological Survey personnel furnished invaluable interpretive efforts needed for this study. Wayne C. Bridges determined the base flow of the continuous-record stations in Okaloosa County and vicinity using hydrograph separation techniques. Base flow for the partial-records stations in Okaloosa County and vicinity was estimated by Roger P. Rumenik and J.W. "Trey" Grubbs by correlation with continuous-record stations. Surface-drainage basins were delineated by Donald W. Foose. The authors are grateful for their help.

GROUND-WATER RECHARGE

Ground-water recharge is the replenishment of ground water by downward infiltration of water from rainfall, streams, and other sources (American Society of Civil Engineers, 1987, p. 222). It represents accretions to the zone of saturation (ground-water reservoir), whose upper surface is the water table. Recharge is both the process of accretion and the amount of accretion to ground-water storage and flow.

Recharge occurs naturally as part of the hydrologic cycle. Precipitation over land surface in Florida normally has the following dispositions: interception by the vegetative cover; overland flow to streams, lakes, swamps, and other lowlands; infiltration to the soil zone where part of the water is returned to the atmosphere by evaporation and transpiration by plants, and part infiltrates further to the water table. That part of the precipitation that moves downward to the water table is ground-water recharge, and those areas where accretions to ground water occur are called recharge areas.

Ground-water recharge areas are normally congruent with topographically high land areas and may include virtually all the land except that in stream valleys, lakes, ponds, and swamps. In places where streambeds and lake bottoms lie above the water table and water leaks from the surface-water feature to the water table, these areas, too, are considered recharge areas.

Water that infiltrates to the water table becomes ground water and flows from these recharge areas to discharge areas that are normally in topographically low places such as stream valleys, lakes, swamps and other wetlands, and the sea. Water can also move from one aquifer to another, such as by the downward movement of ground water from the water table through intervening low-permeability material, called confining beds, and eventually into an underlying aquifer. Just as with the water table, both the process and the amount of accretion of ground water to a deeper aquifer are called "recharge." Thus, recharge areas and rates are aquifer specific. For example, in Florida, sinkhole lakes in upland areas commonly function as discharge areas for the shallow surficial aquifer that contains the water table, but these lakes, in turn, may be areas of concentrated recharge to the deeper-lying Floridan aquifer system.

Ground water that moves from recharge areas and discharges to streams sustains the flow of the streams (base flow), especially during periods of no rainfall. Even though this water is considered as surface runoff from the drainage

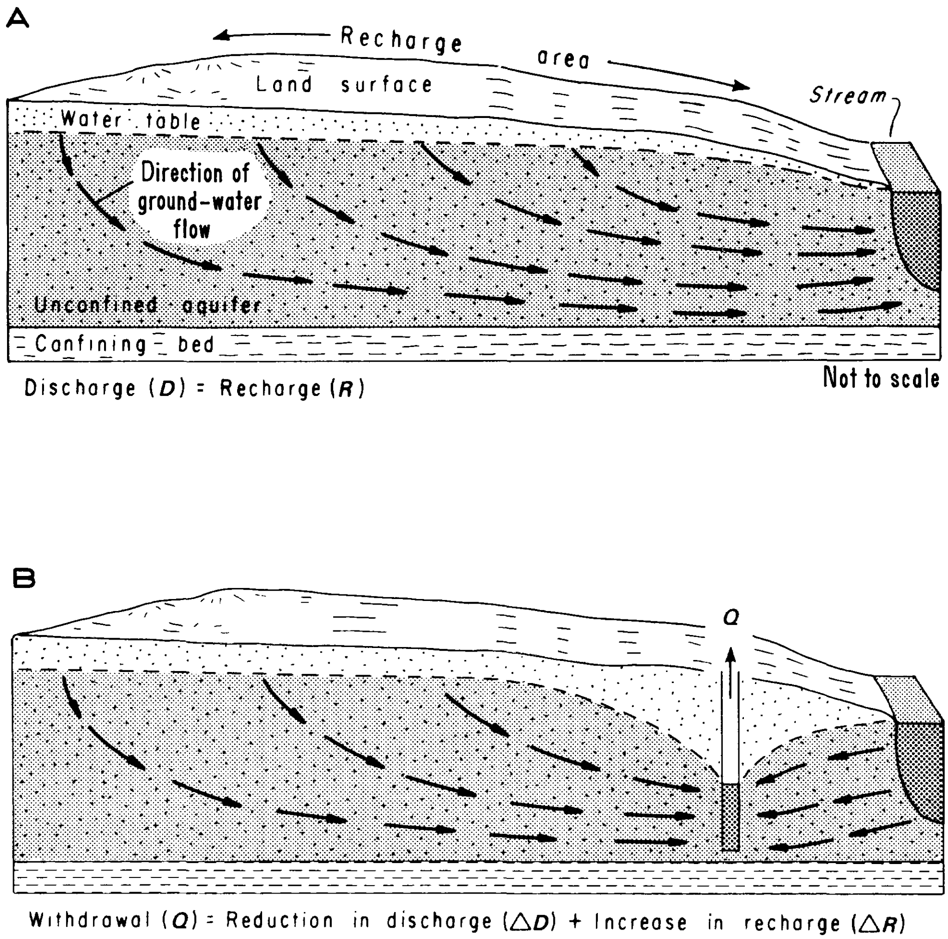

Figure 1. Schematic diagram showing (A) recharge to an unconfined aquifer and discharge from it to a stream under natural conditions, and (B) induced recharge from a stream under ground-water pumping conditions. (Modified from Heath, 1987, p. 33.)

basin, it was ground-water discharge. Under natural conditions, a ground-water system is considered to be in equilibrium if the amount of total recharge is equal to the amount of total discharge. Therefore, if a basin is in an equilibrium condition, then the amount of base flow in streams can be considered as a measure of the amount of ground-water recharge in the basin.

In addition to rainfall and seepage from parts of streams and lakes, other sources that may also contribute to ground-water recharge include: (1) deep percolation of applied irrigation water, (2) effluent from cesspools and septic tank drain fields, (3) leakage from water and sewage conduits, and (4) wastewater discharged to the ground surface. Moreover, the amount of natural recharge can be increased and ground-water flow to surface-water bodies, such as streams and lakes, can be reduced as a result of withdrawal of ground water. In fact, the direction of ground-water flow to a surface- water body can be reversed by nearby pumping wells and water caused to flow from the surface-water body to the aquifer. This phenomenon of induced recharge is pictured in figure 1. Natural recharge can also be augmented by structures provided primarily for the deliberate process of replenishment of ground-water storage; this is called artificial recharge.

Factors That Influence Rate of Recharge

Many factors influence the amount of precipitation that becomes ground-water recharge under natural conditions. They include (1) texture and gradation of surface and near-surface deposits and their vertical permeability, (2) nature and water requirements of the vegetation, (3) frequency, intensity, and volume of rainfall, (4) topography, and (5) temperature (American Society of Civil Engineers, 1987, p. 56).

Well-drained, sandy soils readily absorb rainfall and transmit the infiltrated water downward to the subsoil deposits, whereas heavy clayey soils impede infiltration. Where the subsoil deposits consist of permeable sand and gravel, the infiltrated water percolates rapidly downward to the water table. Fine-grained deposits of clay and silt have low vertical permeability and their presence in the subsurface greatly retards downward percolation of water and commonly results in "perched" saturated conditions above the water table and waterlogged soils during wet periods.

A dense vegetative cover can intercept a large proportion of precipitation and subsequently allow the water to evaporate to the atmosphere. Dense vegetation also returns a major part of the annual rainfall to the atmosphere through the uptake of water from the soil zone by roots and subsequent transpiration by leaves; where vegetation is sparse, losses by evapotranspiration are much less. Plants differ in their water consumption and, thus, transpiration rate depends on the type of vegetation as well as the density of the vegetative cover.

Higher rates of recharge generally result from frequent, moderate rains with long durations that cause soil to exceed its field capacity rather than from infrequent, torrential downpours. Frequent rains enable the soil to stay moist and maintain high hydraulic conductivity, whereas infrequent precipitation events allow the soil to dry out and become less conductive. High rainfall intensities can exceed the infiltration capacity of soil and result in the excess water being rejected and running off as overland flow. Moderate rainfall intensities that do not exceed soil infiltration capacities but maintain the saturation of soil result in maximum recharge rates. Regardless of rainfall intensity, other things being equal, the greater the rainfall, the greater the amount of recharge.

Topography plays a major role in the length of time that rainfall is retained in an area and allowed the opportunity to infiltrate. Flat-lying or gently undulating land allows rainfall to accumulate in many shallow depressions and, thus, the time available for infiltration to occur is at a maximum in such environments. Therefore, even if the storm intensity exceeds the infiltration capacity of the soil, the retention of excess water on the land surface prolongs the infiltration period. This results in more of the rainfall becoming recharge than that which is absorbed by the soil during the actual storm event. Steep slopes cause rainfall to quickly move overland to streams, resulting in minimum time for infiltration.

The viscosity of water varies inversely with temperature and the ability of a soil to transmit water is a function of the viscosity. Therefore, cold, more viscous water moves through the soil less readily than does warm, less viscous water. Obviously, temperature is a much more important factor in northern climates than in Florida, where temperatures are moderate to high throughout most of the year.

Florida is favorably situated with respect to only some of the above factors that influence the rate of recharge. Much of Florida is covered by permeable, sandy soils and sandy subsoil deposits that readily absorb rainfall and transmit it downward to the water table. On the other hand, because of the warm climate and the fact that most of Florida is heavily vegetated, evaporation and transpiration by the vegetative cover consume a large part of the annual precipitation. Evaporation potential is several inches greater in southern Florida than in northern Florida (Visher and Hughes, 1975). Florida's generally flat topography favors recharge, which tends to counterbalance the fact that much of the State's rainfall comes from intense, short-lived storms. The low relief of many parts of the State results in poor drainage, however, as manifested by the extensive wetlands. In these poorly drained areas, the water table is at, or very near, land surface most of the year and there is little capacity for precipitation to be absorbed and stored. Most likely those areas are ground-water discharge areas instead of recharge areas. Lastly, with a mean annual temperature ranging from the upper 60's °F in the northern part to the middle 70's °F in the southern part, viscosity of the water is not a constraining influence on rate of recharge.

Methods of Determining Recharge Rates

Various methods have been used to determine rates of ground-water recharge. Some involve direct measurements of the quantity of water infiltrating at specific sites, whereas others involve measurements of water quantity emanating from a spring or river drainage basin. Still others involve the measurement of water temperature or specific chemical constituents. Recharge rates can also be calculated from hydrologic budgets or from hydraulic analysis of ground-water flow. Hydrogeologic judgment must be used to assess the applicable method(s) for a particular area and the results generated. No one particular method is necessarily superior to the others, but the most appropriate method for calculating recharge may be dictated by hydrologic conditions, available information, and purpose of the determination of recharge. Use of more than one approach may provide greater confidence in the determined recharge rates. The various methodologies are not assembled in any single reference source, but current texts on ground-water hydrology, such as Bouwer (1978), Freeze and Cherry (1979), and Fetter (1988) each describe some of the techniques, as does an older work by Meinzer (1949).

One of the most widely employed methods, especially in the humid eastern United States, involves analysis of streamflow data to determine base flow, which commonly is derived largely from ground-water discharge. Assuming there is no long-term change in the amount of ground water in storage, then ground-water discharge, as measured by the base flow of a stream, equals the amount of ground-water recharge over the basin area contributing the base flow. Other discharge from the ground water reservoir, such as withdrawals by wells or evapotranspiration from the water table, may need to be considered also in estimating recharge. Spring flow is another form of ground-water discharge that can also be used to estimate recharge similarly to the use of base flow. However, although base flow and spring flow are direct measurements of water quantity, the volume so measured is apportioned subjectively over the drainage basin using hydrogeologic judgment and taking into account topography, soils, hydrogeology, and other pertinent factors.

The absence of surface drainage from a topographic basin or the reduction in flow as a stream traverses an area can also be used to estimate recharge. Such conditions are especially prevalent in the karstic environment of Florida. In the former case, the amount of recharge is commonly calculated as the residual of precipitation minus evapotranspiration. In the latter case, measurements of flow in various stream reaches can indicate directly the "loss" of water from the channel and thus the amount of recharge contributed by the stream.

DELINEATION OF RECHARGE IN SELECTED AREAS

In this section, the delineation of recharge in the pilot study areas of Okaloosa, Pasco, and Volusia Counties is described. Information on the respective hydrogeology and methodology used to determine recharge rates is presented for each county.

Okaloosa County

Hydrogeology

Hydrogeologic units in Okaloosa County of interest to this study include, in order of increasing depth below land surface, the sand-and-gravel aquifer, the intermediate confining unit, and the Upper Floridan aquifer.

The sand-and-gravel aquifer occurs throughout Okaloosa County. According to Trapp and others (1977, p. 38), it consists chiefly of very fine to very coarse quartz sand with lenses and stringers of gravel and clay. Because the sand-and-gravel aquifer is the surficial aquifer and contiguous with the land surface, ground water in it is unconfined and the aquifer is recharged directly by rainfall. Trapp and others (1977, p. 38) reported the saturated thickness of this aquifer to range from 15 to 400 feet with the greatest thickness occurring in southwestern Okaloosa County.

Underlying the sand-and-gravel aquifer everywhere in Okaloosa County is the intermediate confining unit, previously called the Pensacola Clay confining bed (Trapp and others, 1977, p. 42). It consists of very dense clay that serves to confine the water in the underlying Upper Floridan aquifer and greatly restricts leakage (recharge) to the Upper Floridan aquifer from the sand-and-gravel aquifer. In Okaloosa County, it varies in thickness from about 50 feet in the northwestern corner of the county to about 35 feet at the coast (Miller, 1986, pl. 25).

The Upper Floridan aquifer lies beneath the intermediate confining unit. The Upper Floridan aquifer, the middle confining unit, and the Lower Floridan aquifer together comprise the Floridan aquifer system. In northern Okaloosa County, the middle confining unit is absent (Trapp and others 1977, p. 46) and the Upper and Lower Floridan aquifers are not separated but regarded collectively as the Upper Floridan aquifer. The Upper Floridan aquifer consists mostly of limestone and dolomite. The aquifer thickens from north to south; it is about 200-feet thick at the northern county boundary and about 400-feet thick at the coast (Miller, 1986, pl. 28). In Okaloosa County, the Upper Floridan aquifer is recharged mainly by water leaking through the overlying intermediate confining unit wherever the water table in the surficial aquifer is higher than the potentiometric surface of the Upper Floridan.

Ground-water withdrawals in Okaloosa County in 1985 were almost entirely from the Upper Floridan aquifer; only 1.53 Mgal/d (million gallons per day) were withdrawn from the sand-and-gravel aquifer, all for private domestic use, as compared to 26.14 Mgal/d withdrawn from the Upper Floridan aquifer (R.L. Marella, U.S. Geological Survey, written commun., 1990). The following table lists 1985 withdrawals by use for the two aquifers, in million gallons per day.

Use	Upper Floridan aquifer	Sand-and-gravel aquifer
Public supply	17.36	0.00
Domestic	.66	1.53
Commercial-industrial	5.82	.00
Agricultural irrigation	2.30	.00
Total	26.14	1.53

Recharge Rates

Recharge to the sand-and-gravel aquifer in Okaloosa County was determined from base-flow analysis. Streamflow data from 9 daily-record sites and 25 partial-record sites in Okaloosa County and adjacent areas were analyzed to determine base flow (fig. 2). Because there is very little surface storage in the county by way of lakes and wetlands to support base flow, virtually all of the base flow can be attributed to ground-water discharge, which is equal to ground-water recharge if there is no long-term change in storage. Base flow for the daily-record sites, each of which had at least 10 years of record, was determined by hydrograph separation techniques using a computer program developed by White and Sloto (in press). Partial-record sites were correlated with one of the daily-record sites nearby, and base flow for the partial-record site was estimated from the base flow of the corresponding index site. The base flows determined from the hydrograph separation technique ranged from 14.3 in/yr to 50.7 in/yr (tables 1 and 2) which indicate that the average recharge throughout Okaloosa County is more than 10 in/yr.

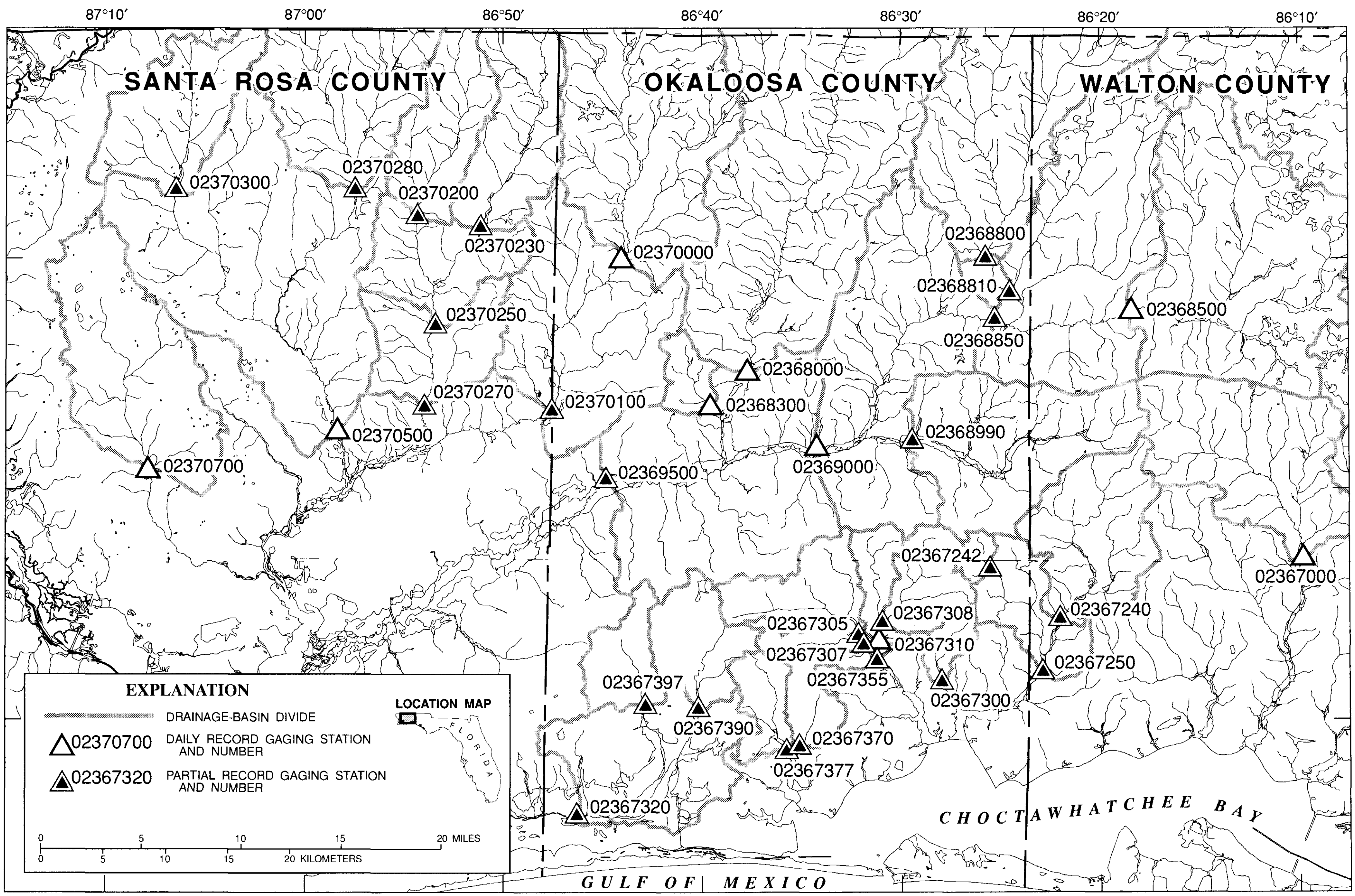

Figure 2. Location of streamflow record sites and respective drainage basins in and around Okaloosa County for which base flow was determined.

Table 1. Base flow at daily-record streamflow sites having at least 10 years of record in Okaloosa County and adjacent areas
[OWDC, Office of Water Data Coordination; mi^2, square mile; ft^3/s, cubic foot per second; in/yr, inch per year]

Site number	Station name	Latitude	Longitude	County code	Hydrologic unit (OWDC)	Drainage area (mi^2)	Base flow ft^3/s	Base flow in/yr	Average flow ft^3/s	Average flow in/yr
02367000	Alaqua Creek near De Funiak Springs	30 37 00	086 09 50	131	03140102	65.6	116	24.0	170	35.2
02367310	Juniper Crk at State Hwy. 85 near Niceville	30 33 26	086 31 10	091	03140102	27.6	80.7	39.7	89.7	44.1
02368000	Yellow River at Milligan	30 45 10	086 37 45	091	03140103	624	708	15.4	1,150	25.0
02368300	Baggett Creek near Milligan	30 43 40	086 39 35	091	03140103	7.80	17.9	31.1	21.5	37.4
02368500	Shoal River near Mossy Head	30 47 45	086 18 25	131	03140103	123	166	18.3	243	26.8
02369000	Shoal River near Crestview	30 41 50	086 34 15	091	03140103	474	737	21.1	1,080	31.1
02370000	Blackwater River near Baker	30 50 00	086 44 05	091	03140104	205	216	14.3	343	22.7
02370500	Big Coldwater Creek near Milton	30 42 30	086 58 20	113	03140104	237	377	21.6	543	31.1
02370700	Pond Creek near Milton	30 40 50	087 07 55	113	03140104	58.7	63.8	14.7	79.6	18.4

Table 2. Partial-record streamflow sites in Okaloosa County and adjacent areas where base flow was determined by correlation procedures
[OWDC, Office of Water Data Coordination; mi^2, square mile; ft^3/s, cubic foot per second; in/yr, inch per year]

Site number	Station name	Latitude	Longitude	County code	Hydrologic unit (OWDC)	Drainage area (mi^2)	Base flow ft^3/s	Base flow in/yr	Index Station Site number	Index Station Base flow (in/yr)
02367240	Rocky Creek near Portland	30 34 23	086 22 01	131	03140102	42.4	90.2	29.4	02367310	39.7
02367242	Little Rocky Creek near Niceville	30 36 34	086 25 31	091	03140102	3.85	11.8	41.6	02367310	39.7
02367250	Rocky Creek near Niceville	30 32 07	086 22 55	131	03140102	67.0	163	33.0	02367310	39.7
02367300	Swift Creek near Niceville	30 31 40	086 28 00	091	03140102	5.96	17	38.7	02367310	39.7
02367305	Turkey Creek near Niceville	30 33 43	086 32 10	091	03140102	22.7	79.3	47.4	02367310	39.7
02367307	Turkey Creek at SR 123 near Niceville	30 33 15	086 31 55	091	03140102	30.1	100	45.2	02367310	39.7
02367308	Tenmile Creek near Valparaiso	30 34 12	086 31 00	091	03140102	16.8	44	35.5	02368300	31.1
02367320	East Bay River near Wynnehaven Beach	30 25 53	086 46 20	091	03140105	62.0	230	50.3	02367310	39.7
02367355	Turkey Creek at Govt RR near Niceville	30 32 35	086 31 15	091	03140102	60.8	227	50.7	02367310	39.7
02367370	Garnier Creek at Longwood	30 28 49	086 35 07	091	03140102	9.42	22	31.7	02367310	39.7
02367377	Lightwood Knot Creek at Longwood	30 28 41	086 35 46	091	03140102	11.8	44	50.6	02367310	39.7
02367390	Turtle Creek near Ocean City	30 30 31	086 40 13	091	03140105	22.3	51.2	31.2	02367310	39.7
02367397	Live Oak Creek near Florosa	30 30 39	086 42 53	091	03140105	16.2	63.7	53.4	02367310	39.7
02368800	Pond Creek near Dorcas	30 50 02	086 25 43	091	03140103	94.8	97.6	14.0	02368000	15.4
02368810	Pond Creek at Dorcas	30 48 36	086 24 29	091	03140103	96.5	79.8	11.2	02368000	15.4
02368850	Shoal River at Dorcas	30 47 27	086 25 14	091	03140103	319	350	14.9	02368500	18.3
02368990	Titi Creek near Crestview	30 42 05	086 29 28	091	03140103	62.9	134	28.9	02367000	24.0
02369500	Yellow River near Holt	30 40 25	086 44 50	091	03140103	1210	1820	20.4	02369000	21.1
02370100	Blackwater River near Holt	30 43 26	086 47 34	113	03140104	276	342	16.8	02370000	14.3
02370200	Big Juniper Creek near Munson	30 51 50	086 54 20	113	03140104	36.0	39.2	14.8	02370000	14.3
02370230	Sweetwater Creek near Munson	30 51 20	086 51 06	113	03140104	45.0	55.6	16.8	02370200	14.8
02370250	Big Juniper Creek near Spring Hill	30 47 06	086 53 28	113	03140104	113	155	18.6	02370500	21.6
02370270	Big Juniper Creek near Harold	30 43 36	086 53 58	113	03140104	142	181	17.3	02370500	21.6
02370280	East Fork Big Coldwater Creek near Munson	30 52 56	086 57 28	113	03140104	64.0	65.6	13.9	02370500	21.6
02370300	West Fork Big Coldwater at Cobbtown	30 53 00	087 06 30	113	03140104	39.5	49.1	16.9	02370500	21.6

Stream-valley floors having discernible breadth on 1:100,000-scale maps were delineated on the basis of break in topographic slope. These areas, together with all the undelineated narrower stream channel areas are considered to be areas of discharge for the sand-and-gravel aquifer where little to no recharge occurs. Swamp and coastal wetland areas were also delineated and designated as areas of little to no recharge.

The description and distribution of soil types in Okaloosa County (J.D. Overing, U.S. Soil Conservation Service, written commun., 1990) were then examined. Areas dominated by soils having poor drainage characteristics were delineated and found to be congruent with the above-mentioned stream-valley floors, swamps, and coastal wetlands. All other parts of the county are dominated by soils that are moderately well to excessively drained.

Lacking any further definitive information, the entire county, except for the stream-valley floors, swamps, and coastal wetland areas, was judged to have 10 in/yr or more of recharge to the water table in the sand-and-gravel aquifer. The judgment is based on the fact that all of the widely scattered streamflow sites for which base flow was determined had base flow exceeding 10 in/yr and all of the soil types, except for those dominating lowland areas, had good drainage characteristics.

Recharge to the Upper Floridan aquifer is less than 5 in/yr everywhere in Okaloosa County, according to the recently completed modeling study by Maslia and Hayes (1988, pl. 8). Therefore, for purposes of this study, only areas of generally zero recharge, or discharge areas, were delineated. This was done by first digitizing the 1985 potentiometric-surface map (Rosenau and Meadows, 1986), rescaling it to 1:100,000, and converting the contours to read in meters. Lacking actual measurements of water-table altitude, stream altitudes determined from the metric 1:100,000 topographic base map were used as surrogates of the lowest water-table position in the respective locales. More than 1,000 points where topographic contours crossed the stream network were digitized and compared to the digitized potentiometric-surface map for the Upper Floridan aquifer and a head-difference map was generated. The head-difference map was used to delineate areas where the potentiometric surface of the Upper Floridan was higher than the stream altitude--areas where no recharge occurs.

On the basis of the average recharge rates calculated from hydrograph separation, interpretation of soil characteristics, topographic conditions, water-level altitudes, and computer simulated leakage to the Upper Floridan aquifer, a map showing the recharge conditions in Okaloosa County was constructed.

The recharge map (pl. 1) indicates large areas where recharge to the water table in the sand-and-gravel aquifer is 10 in/yr or greater. Doubtlessly, within the areas mapped as 10 in/yr or greater there are places where recharge is less, but on the basis of the information available and at the scale of this mapping effort, it is not possible to distinguish them from areas of higher-rate recharge which, when combined, yield an average recharge rate that exceeds 10 in/yr. Within areas delineated as 0 to 10 in/yr recharge to the sand-and-gravel aquifer, recharge probably is minimal. Because of the shallow depths to the water table in these lowland areas, storage for acceptance of recharge is limited and evapotranspiration rates are high.

Where the recharge map shows recharge to the Upper Floridan aquifer to be zero, these are areas of artesian flow. Before withdrawals of ground water from the Upper Floridan began, all of southern Okaloosa County was an area of artesian flow and no recharge to the Upper Floridan aquifer occurred there. Withdrawals from the Upper Floridan aquifer, concentrated along the coast at Fort Walton Beach, have drawn down the potentiometric surface to below land surface throughout southern Okaloosa County so that, currently, artesian flow occurs only in the deeply incised stream valley areas in the northern part of the county. Although recharge to the Upper Floridan aquifer occurs now through most of Okaloosa County, recharge rates are low, probably less than 5 in/yr (Maslia and Hayes, 1988, pl. 8) because of the confinement of the Upper Floridan aquifer by clay beds of the overlying intermediate confining unit.

Pasco County

Hydrogeology

In Pasco County, the hydrogeologic system consists of a thick sequence of carbonate rocks overlain by clastic deposits. Hydrogeologic units of interest to this study are the surficial aquifer, the intermediate confining unit, and the Upper Floridan aquifer.

Surficial deposits, comprised predominantly of sand and clay, occur throughout most of the county. These deposits range in thickness from 0 to about 100 feet and have an average thickness of about 25 feet. Where these deposits have sufficient saturated thickness to supply water to wells, they comprise the surficial aquifer. The surficial aquifer is recharged directly by precipitation.

The intermediate confining unit underlies the surficial aquifer and overlies the Upper Floridan aquifer throughout most of the county. It consists predominantly of clay but also contains some sand, marl, calcareous sandstone, and limestone. Its thickness ranges from 0 to more than 100 feet (Fretwell, 1988). In some parts of the county, the intermediate confining unit is breached by sinkholes that permit rapid percolation of water from the surficial aquifer to the Upper Floridan aquifer.

The Floridan aquifer system underlies either the intermediate confining unit or, in its absence, the surficial aquifer. The Floridan aquifer system is subdivided into the Upper and Lower Floridan aquifers that are separated by a middle confining unit. In Pasco County, the freshwater-bearing part of the Floridan aquifer system is limited to the Upper Floridan aquifer. The top of the Upper Floridan aquifer is at land surface near the northern coast but is more than 100 feet below land surface in the Brooksville ridge area in western Pasco County. Thickness of the Upper Floridan aquifer ranges from less than 700 feet in the north-central part of the county to about 1,050 feet in the southwestern part of the county (Miller, 1986, pl. 28).

The Upper Floridan aquifer generally is unconfined in the northwestern part of the county and semiconfined throughout the rest of the county. Its potentiometric surface changes slightly between wet and dry seasons. Ground-water recharge to the Upper Floridan aquifer occurs as direct infiltration of precipitation where the aquifer is unconfined or as leakage through the intermediate confining unit where it is semiconfined. Ground-water flow in the county generally is westward toward the Gulf of Mexico and southward toward Hillsborough County, although some flow is northward out of the county toward springs in Hernando County (Fretwell, 1988).

Outflow from the Upper Floridan aquifer occurs as point discharges at pumping wells and at springs along the rivers and near the coast. Discharge also occurs over broad areas by diffuse upward leakage in swamps adjacent to streams and coastal marshes.

About 126 Mgal/d of fresh ground water was withdrawn from the Upper Floridan aquifer in Pasco County in 1985 (R.L. Marella, U.S. Geological Survey, written commun., 1988). The surficial aquifer supplied less than 1 Mgal/d of ground water, mainly for lawn irrigation. Water withdrawn, in million gallons per day, from the Upper Floridan aquifer by use category, is summarized below:

Public supply	75.44
Irrigation	22.42
Commercial-industrial self-supplied	19.91
Domestic self-supplied	8.25
Total	126.02

Recharge Rates

Estimates of ground-water recharge in Pasco County were arrived at through a combination of streamflow analysis, water-budget calculations, ground-water flow system analysis, head data analysis, and analyses of topographic and soils information. The methodology employed is discussed below.

Head data for the surficial and Upper Floridan aquifers were retrieved from an existing ground-water flow model (Fretwell, 1988) with a grid spacing of 1 mi^2 (square mile). Differences between the water table in the surficial aquifer and the potentiometric surface of the Upper Floridan aquifer for 1977 were calculated and plotted at a scale of 1:100,000. From the head differences, areas where the potentiometric surface of the Upper Floridan aquifer was higher than the water table were delineated as areas of zero recharge to the Upper Floridan aquifer. These areas commonly are areas of artesian flow and generally coincide with topographically low wetland areas.

Leakage rates to the Upper Floridan aquifer calculated by the aforementioned ground-water flow model were displayed at a 1:100,000 scale and the distribution of leakage was used as a guide to likely areas of high-rate recharge. Comparison of the leakage distribution with topography indicated that internally drained upland areas were areas of high-rate recharge--a not unexpected qualitative relation. However, because model-derived leakage rates are the result of assignment of a nonunique set of flow system variables for large areas in the model, they may or may not accurately represent recharge locally. Independent verification of recharge is highly desirable and was done by analyzing the flow of Cypress Creek in relation to the ground-water flow system in the Upper Floridan aquifer. The Cypress Creek drainage basin upstream from the gage at Worthington Gardens encompasses an area of 117 mi^2 in central Pasco County that consists largely of upland internally drained areas and low-lying wetland areas (fig. 3). Superposition of the potentiometric surface of the Upper Floridan aquifer on the drainage basin indicates that the subbasin between the gage at San Antonio and the gage at Worthington Gardens is roughly coincident with a "ground-water" basin defined by the potentiometric contours. The subbasin boundaries on the north, west, and east generally coincide with potentiometric-surface highs (flow divides) and on the south, ground-water flow is captured by Cypress Creek. Lateral ground-water inflow and outflow are considered to be negligible for this "closed" subbasin. Therefore, the ground-water budget for the subbasin is:

$$\text{Recharge} = \text{Base flow} + \text{Pumpage}$$

This budget does not account for evapotranspiration in the broad 22-mi^2 swamp area of the subbasin where ground water discharges from the Upper Floridan aquifer by upward leakage. However, evapotranspiration discharge from the ground-water system is probably negligible because potential evaporation in this area is about 45 in/yr and rainfall within the swamp (53 in/yr), more than balances the potential evapotranspiration demand.

During the period from October 1973 through September 1989, the average annual discharge of Cypress Creek at San Antonio was 18.9 ft^3/s (cubic feet per second) (4.59 in/yr over the 56-mi^2 drainage area above the gage), and at Worthington Gardens was 52.8 ft^3/s (6.13 in/yr over the 117-mi^2 drainage area above the gage). The discharge for the 61-mi^2 drainage area between the San Antonio and Worthington Gardens gages was 7.54 in/yr. If there were no surface runoff, and all the gain in flow of Cypress Creek was derived from recharge in the upland areas between San Antonio and Worthington Gardens, the equivalent maximum possible recharge rate would have been 11.79 in/yr over an upland area of 39 mi^2. Figure 4 shows a hydrograph based on the Worthington Gardens gage for a near-average water year (1976), which had streamflow of 51.5 ft^3/s (6.00 in/yr over the drainage basin). The hydrograph was separated into components of surface runoff and base flow. The base flow segments during the high-flow periods were estimated by projecting rise and recession trends forward and backward in time to arbitrary peaks that lie below the maximum discharge peaks. The calculated average base flow is 41 ft^3/s, which is about 80 percent of the average flow of Cypress Creek during a normal year. Applying this percentage to the maximum possible recharge in the upland area (11.79 in/yr), the base flow component of the recharge equation that would produce 41 ft^3/s is 9.4 in/yr. Rainfall recorded at St. Leo, 3 miles northeast of the subbasin, was 48.3 inches during water year 1976 compared to the normal (for 1951-80) of 53.9 inches. By direct proportionality (53.9/48.3), the base flow component of the recharge equation adjusted for normal rainfall conditions is thus 10.5 in/yr.

Model simulation has demonstrated that pumpage from the Cypress Creek well field is derived from recharge within approximately a 123-mi^2 area when pumping is at the permitted rate of 30 Mgal/d (Hutchinson, 1984, p. 160). Because the well field is centered in the subbasin, direct proportionality can be applied to estimate that, when pumping is less than about 5 Mgal/d, the pumped water is derived wholly from recharge within the subbasin. The well field began operating in April 1976 (fig. 4). The average monthly pumping rate varied from 0.81 Mgal/d to 9.25 Mgal/d, between April and September 1976, and the average pumping rate for the

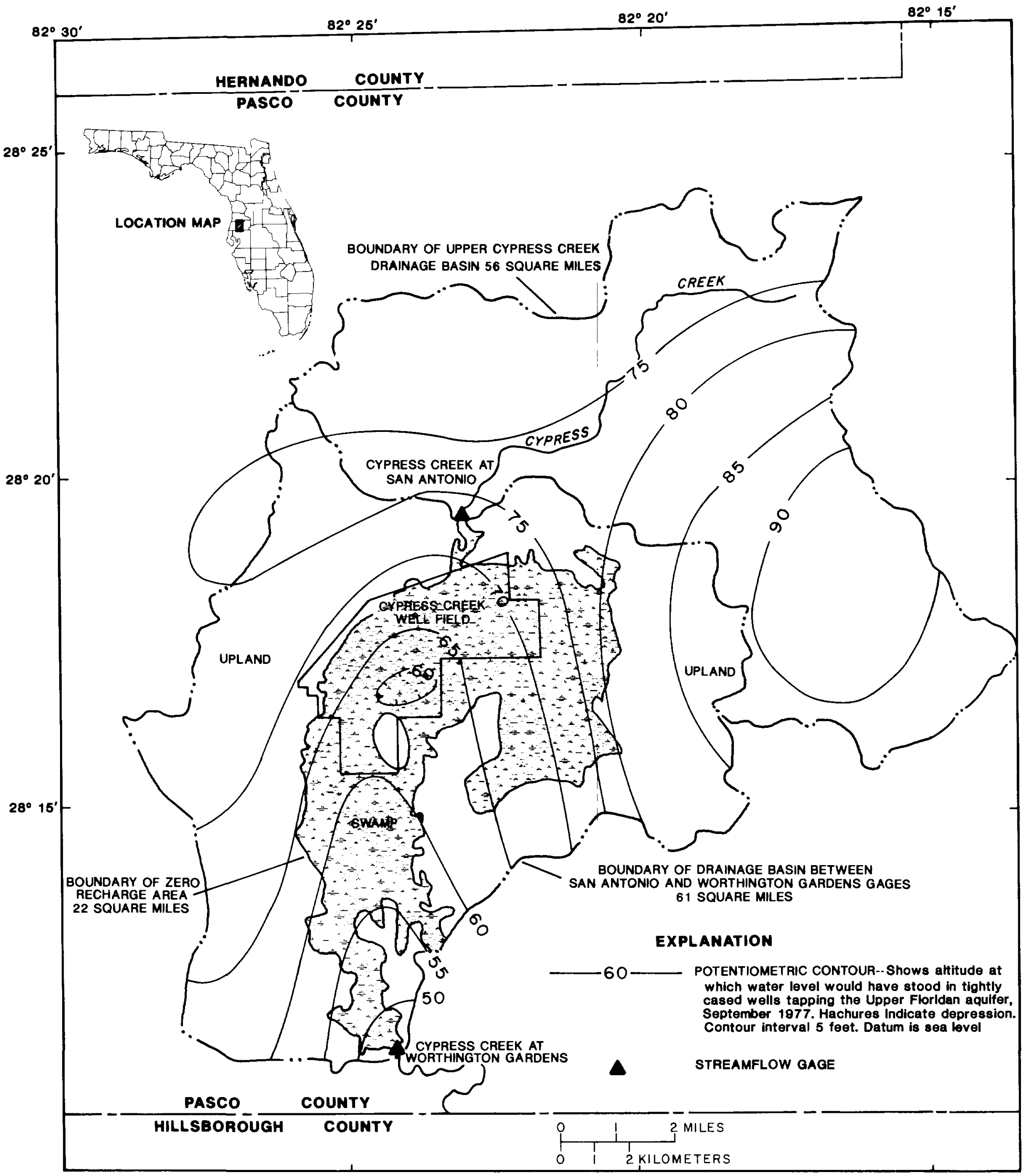

Figure 3. Boundary and hydrologic features of the Cypress Creek drainage basin above Worthington Gardens.

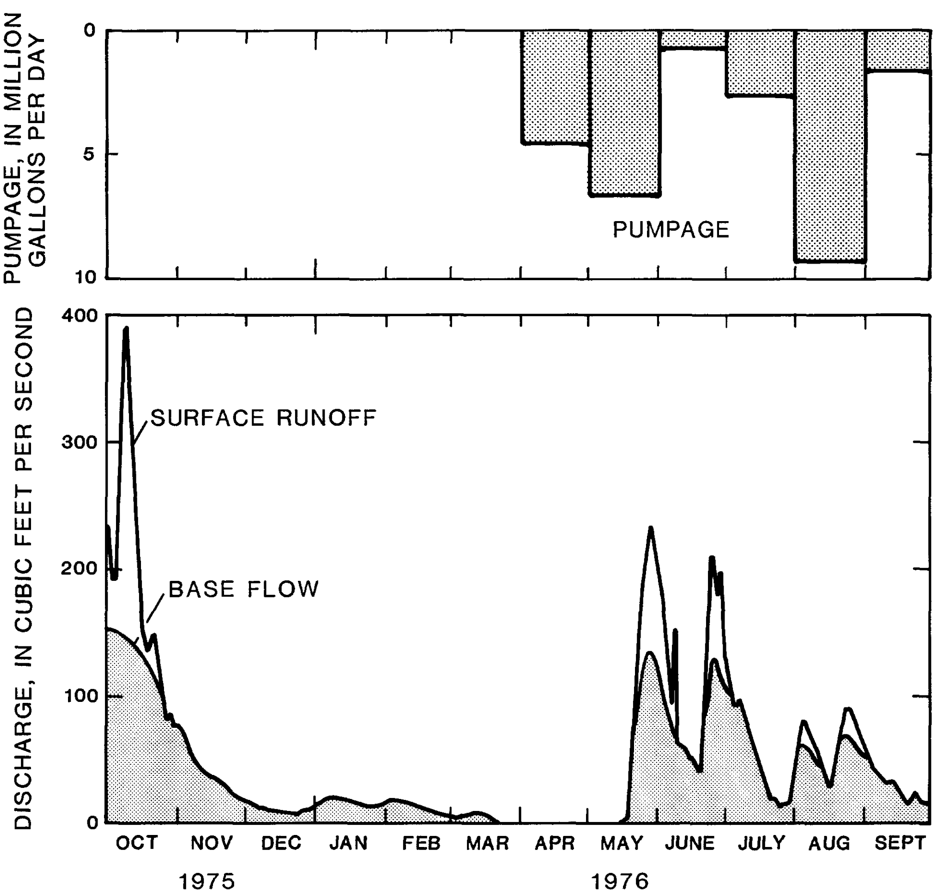

Figure 4. Graph showing mean daily discharge and base flow of Cypress Creek at Worthington Gardens, and pumping rate of Cypress Creek well field.

water year was 2.15 Mgal/d. If pumpage is balanced by recharge in the upland area, the pumpage component of the recharge equation is 1.2 in/yr.

Substituting adjusted base flow and pumpage components into the equation:

Recharge = Base flow + Pumpage

Recharge = 10.5 inches + 1.2 inches = 11.7 inches.

Thus, recharge to the Upper Floridan aquifer in the upland areas of the Cypress Creek drainage subbasin between the San Antonio and Worthington Gardens gages averages 11.7 in/yr. This rate is similar to that estimated using a ground-water flow model which indicated significant leakage (recharge) in forty-three 1-mi^2 grid blocks with an average leakage of 11.6 in/yr. The model simulation represented 1977, a year when rainfall was 10 percent below normal, the flow of Cypress Creek at Worthington Gardens averaged 20 ft^3/s, and pumpage from the Cypress Creek well field averaged 9.8 Mgal/d.

The distribution of recharge is probably not uniform over the upland areas. Lakes with leaky bottoms, such as those in the western upland area, probably concentrate recharge. The absence of well-defined surface drainage in upland areas not containing lakes indicates that, on the average, recharge is high throughout the uplands. Since 1979, the Cypress Creek well field has been pumped at its permitted capacity of 30 Mgal/d, resulting in a 14-mile diameter cone of depression that captures 4 in/yr of water from the Cypress Creek basin and adjacent drainage basins. The pumping has increased downward leakage (induced recharge) to the Upper Floridan aquifer and reduced upward leakage to the swamp areas.

The analysis of base flow and pumpage indicates that the uplands within the subbasin recharge the Upper Floridan aquifer at an average rate of more than 10 in/yr. Recharge is probably greatest in the internally drained uplands at higher altitudes and somewhat less in the lower-lying areas with ill-defined surface drainage that border the wetlands. On this basis, all upland internally drained areas in Pasco County are delineated on plate 2 as high-rate recharge to both the surficial aquifer and the Upper Floridan aquifer. Where recharge by downward leakage to the Upper Floridan aquifer exceeds 10 in/yr, recharge to the overlying surficial aquifer (the source of the leakage) must also exceed 10 in/yr. All other areas have lesser recharge rates to both aquifers and where the head in the Upper Floridan aquifer is above the water table, recharge to the Upper Floridan there is zero.

Volusia County

Hydrogeology

The topography of Volusia County reflects two physiographic regimes: karst ridges and level terraces. The karst areas are characterized by the relatively high, undulating well-drained sandhills of the De Land Ridge in west Volusia. Those karst areas contain numerous sinkhole lakes and closed depressions. The level terraces are characterized by flat topography and numerous elongated, coast-parallel swamps separated by poorly drained flatwoods.

Surface drainage in Volusia County is poorly developed. There is virtually no surface-drainage system in the closed-basin karst areas of the De Land Ridge because almost all the rainfall that is not lost to evapotranspiration, a minimum of 30 in/yr (Tibbals, 1978, p. 8), infiltrates the deep, well-drained soils and ultimately enters the ground-water flow system. The surface-drainage network in the level terraces is poorly developed because there is little gradient to move the water toward the surface streams. Streams are not deeply incised and there are usually one or more extended periods of zero flow in most streams during most years. Surface runoff from the terraces averages about 12 in/yr. In those areas, water stands at or near land surface throughout most of the year; therefore, evapotranspiration rates are relatively high--probably on the order of about 38 to 45 in/yr (Tibbals, 1978, p. 8).

The uppermost aquifer in Volusia County is the surficial aquifer. It is comprised of unconsolidated fine- to medium-grained quartz sand, sandy silt and clay and, locally, small amounts of shell. The thickness of the surficial aquifer generally ranges from 20 to 50 feet but can be as much as 100 feet in the karst sandhills of the De Land Ridge. The water table in the surficial aquifer generally is several feet, or even several tens of feet, below land surface in the higher karst areas. In the level terraces, the water table is at or near land surface throughout much of the year. The surficial aquifer is recharged directly by local rainfall.

The surficial aquifer generally yields less than about 20 gal/min (gallons per minute) of water to wells and thus is used mostly for lawn and garden irrigation and for air conditioning cooling water. The surficial aquifer is used for domestic drinking water supplies only locally where poor water quality precludes the use of the Floridan aquifer system and where public supplies are not available.

The surficial aquifer is underlain by unconsolidated deposits of fine sand, calcareous silty clay, and shell that collectively comprise the intermediate confining unit. These deposits generally are less permeable than the overlying surficial aquifer and retard movement of water between the surficial aquifer and the underlying Floridan aquifer system. These deposits are not extensively used as a source of water because well yields typically are low but, locally, discontinuous lenses of coarse sand and shell yield usable quantities of water to wells.

The Floridan aquifer system in Volusia County is comprised of consolidated limestones and dolomitic limestones. It occurs at depths of about 100 to 125 feet under the De Land Ridge, 75 feet in the level terraces of central Volusia, and 100 feet along the east coast. The freshwater thickness of the Floridan is about 1,000 to 1,200 feet in central Volusia and diminishes in all directions to the extent that brackish water occurs in the Floridan everywhere on the periphery of the county except to the north toward Flagler County.

The Floridan aquifer system in Volusia County and in much of east-central Florida can be separated on the basis of permeability and well yields into three more or less distinct units: Upper Floridan aquifer, middle semiconfining unit, and Lower Floridan aquifer. It should be noted that the middle semiconfining unit is fairly permeable and does not hydraulically isolate the Upper and Lower Floridan. In fact, water in the Lower Floridan is derived from water that has previously recharged the Upper Floridan and that has leaked through the middle semiconfining unit.

Recharge to the Upper Floridan aquifer in Volusia County is derived from downward leakage from the overlying surficial aquifer where the water table in the surficial aquifer is above the potentiometric surface of the Upper Floridan. Much of this water discharges to artesian springs, such as Blue Springs and Ponce De Leon Springs, as will be discussed later. The Floridan aquifer system is capable of yielding large quantities of water to wells. Well yields of 1,000 gal/min are not uncommon.

Ground-water withdrawals in Volusia County in 1985 were almost entirely from the Floridan aquifer system. Of the 79 Mgal/d pumped, 76 Mgal/d was from the Floridan and included all of the ground water pumped for public supply (R.L. Marella, U.S. Geological Survey, written commun., 1990) Distribution of withdrawals by use, in million gallons per day, is as follows:

Use	Floridan aquifer system	Surficial aquifer	Intermediate confining unit
Public supply	36.40	0.00	0.00
Domestic	3.72	1.60	.00
Commercial-industrial	.64	.00	.00
Agricultural irrigation	35.09	.47	1.00
Thermoelectric power generation	.16	.00	.00
Total	76.01	2.07	1.00

Recharge Rates

Separate methodologies were used to evaluate Upper Floridan aquifer recharge rates in the De Land Ridge areas of western Volusia County and in the level terrace areas of central and eastern Volusia County. In western Volusia County, recharge rates were determined using analyses of ground-water flows to Blue Springs and to Ponce De Leon Springs and analyses of soil types. In central and eastern Volusia County, recharge rates were estimated using analyses of rainfall and runoff for gaged surface-water basins.

Recharge to the Upper Floridan aquifer in Volusia County must first pass through the surficial aquifer; therefore, high-rate Upper Floridan aquifer recharge areas are congruent with surficial aquifer high-rate recharge areas. In other than high-rate Upper Floridan aquifer recharge areas, high-rate surficial aquifer recharge areas were determined using analyses of soil types.

Upper Floridan Aquifer--Western Volusia County

The May 1985 Upper Floridan aquifer potentiometric-surface map (Schiner and Hayes, 1985) was digitized, converted to 1-meter contour intervals, rescaled and plotted at 1:100,000 scale, and transferred to the Daytona Beach, Orlando, New Smyrna Beach, and Titusville 1:100,000 scale U.S. Geological Survey topographic quadrangle maps. Areas of artesian flow were delineated by determining where the altitude of the potentiometric surface was higher than that of the land surface. The areas of artesian flow are, by definition, discharge areas where recharge is zero. Outside of areas of artesian flow, the Upper Floridan is considered to receive recharge. The next step was to quantify the rates at which Upper Floridan aquifer recharge occurs and that was done by analyzing the flow and ground-water basins of selected springs.

Ground-water basins for Blue Springs (2 miles west of Orange City) and Ponce De Leon Springs were delineated using the potentiometric-surface map previously transferred to the topographic quadrangles. The gross surface areas of those basins were determined (table 3), internally drained parts of the basins were delineated based on topography, and the surface areas of those internally drained areas were determined. Also measured were the extents of areas of artesian flow within the respective basins; artesian-flow areas are considered to be noncontributing areas in terms of recharge that would ultimately discharge at the springs.

The long-term average discharge rates of the springs were computed from existing flow-measurement data. Those rates were converted into net unit area minimum Upper Floridan aquifer recharge rates by subtracting the areas of artesian flow from the gross area of each ground-water basin and dividing the long-term discharge rate by that area. Net unit area maximum rates were obtained by dividing the long-term average discharge of the springs by the area of the internally drained parts of the ground-water basins (table 3). For Blue Springs, the minimum recharge rate is about 10 in/yr and the maximum recharge rate is about 18 in/yr. For Ponce De Leon Springs, the minimum recharge rate is about 6 in/yr and the maximum recharge rate is about 18 in/yr. In the Blue Springs and Ponce De Leon Springs ground-water basins, the actual high-rate Upper Floridan aquifer recharge areas are, thus, smaller in areal extent than merely the "nondischarge areas" but are larger than the areas that are shown as internally drained.

Soils maps were used to help differentiate high-rate recharge areas within the gross recharge areas. Soils information was obtained from the U.S. Soil Conservation Service (1980) publication "Soil Survey of Volusia County, Florida." Two groups of well-drained soils predominate in the internally drained parts of the Blue Springs and Ponce De Leon Springs ground-water basins: Paola-Orsino soils and Astatula-Tavares soils. Wherever those two soil groups occurred within the basins, those areas were determined to be high-rate recharge areas (pl. 3). Those soil groups also occurred in recharge areas other than just the internally drained areas of the basins. They also occurred in the Pierson and Seville areas of northwestern Volusia County outside the area of the spring basin analysis. The Pierson and Seville areas are topographically and hydrologically similar to the areas within the basins of the springs; therefore, wherever

Table 3. Computation of Upper Floridan aquifer recharge rates in Blue Springs and Ponce De Leon Springs ground-water basins
[ft^3/s, cubic foot per second; mi^2, square mile; in/yr, inch per year]

Site number and spring name	Period of record analyzed	Average discharge (ft^3/s)	Approximate area of spring basin (mi^2)	Approximate noncontributing area (discharge area of artesian flow) (mi^2)	Approximate contributing recharge area (mi^2)	Approximate minimum recharge rate in contributing area (in/yr)	Approximate area of internally drained terrane in spring basin (mi^2)	Approximate maximum recharge rate assuming all recharge occurs in internally drained terrane (in/yr)
022355.00 Blue Springs near Orange City	1932-89 (451 measurements)	160	268	46	228	9.5	121	17.9
022361.10 Ponce de Leon Springs near De Land	1929-89 (137 measurements)	29.3	108	40	68	5.8	21.6	18.4

the Paola-Orsino and Astatula-Tavares soils occurred in the Pierson and Seville areas, those areas were also delineated as high-rate recharge areas.

Upper Floridan Aquifer--Central and Eastern Volusia County

Gaged surface-drainage basins for Little Haw Creek, Middle Haw Creek, Tomoka River, Tiger Bay Canal, Deep Creek (near Osteen), and Spruce Creek were delineated on the Daytona Beach, Orlando, New Smyrna Beach, and Titusville 1:100,000 scale U.S. Geological Survey topographic quadrangle maps. Also delineated were the internally drained areas that are in the springs basins and do not contribute to the above surface drainage. Those spring basin areas were subtracted from the gross drainage basin areas and adjusted unit runoff rates were calculated (table 4).

Using estimated ranges of evapotranspiration (38-45 in/yr) and the average of rainfall at Daytona and De Land for the period of record at each gaging station, ranges of available amounts of Upper Floridan aquifer recharge were determined. The net amount of water available for Upper Floridan aquifer recharge was calculated as rainfall minus runoff minus evapotranspiration. The analysis presumes that Upper Floridan aquifer contribution to runoff of these streams is minimal. For the six surface-water basins analyzed, estimated amounts of water available for Upper Floridan aquifer recharge in contributing parts of the basins range from +5 to -7 in/yr depending on the particular basin. Therefore, it is doubtful that high-rate Floridan aquifer recharge areas of any significant size exist in the contributing areas of the six basins analyzed or in ungaged surface-water basins in similar terranes. The

Table 4. Computation of water available to recharge the Upper Floridan aquifer in selected gaged surface-water drainage basins
[ft^3/s, cubic foot per second; mi^2, square mile; in/yr, inch per year]

Site number and station name	Period of record analyzed (by water[3] year)	Average discharge (ft^3/s)	Gross drainage area (mi^2)	Unadjusted discharge from gross drainage area (in/yr)	Noncontributing drainage area (mi^2)	Net contributing drainage area (mi^2)	Adjusted discharge from net contributing drainage area, Ro (in/yr)	Rainfall[2] during period of record analyzed, P (in/yr)	Estimated[1] range of evapotranspiration, ET (in/yr)	Estimated water available for Upper Floridan aquifer recharge P-Ro-ET
02444.20 Little Haw Creek near Seville	1952-89 (38 years)	83.4	93.0	12.2	17.3	75.7	15.0	53.13	40 to 45	-2 to -7
02443.20 Middle Haw Creek near Korona	1976-89 (14 years)	71.9	78.3	12.5	0	78.3	12.5	52.78	38 to 43	+2 to -3
02475.10 Tomoka River near Holly Hill[4]	1965-89 (25 years)	52.6	76.8	9.3	0	76.8	9.3	51.66	38 to 43	+4 to -1
02474.80 Tiger Bay Canal near Daytona Beach	1979-89 (11 years)	18.7	[5]29.0	8.8	0	29.0	8.8	53.61	40 to 45	+5 to 0
02480.00 Spruce Creek near Samsula	1952-89 (38 years)	31.6	33.4	12.8	0	33.4	12.8	53.13	38 to 43	+2 to -3
02341.00 Deep Creek near Osteen[6]	1965-66 1982-89 (10 years)	110	[5]140	10.7	5.3	[5]135	11.1	52.47	40 to 45	+1 to -4

[1]Range given brackets likely minimum and maximum basinwide average rates for contributing part of basin.
[2]Average rainfall of De Land and Daytona Beach.
[3]Water year is 12-month period from October 1 to September 30.
[4]Includes discharge from Tiger Bay Canal.
[5]Drainage area is approximate.
[6]Includes area drained by Deep Creek Diversion Canal.

noncontributing areas of the surface-water basins are generally in either the Ponce De Leon Springs or Blue Springs ground-water basins and are already delineated as high-rate Upper Floridan aquifer recharge areas (pl. 3).

Surficial Aquifer

As stated previously, surficial aquifer high-rate recharge areas are congruent with high-rate Upper Floridan aquifer recharge areas (pl. 3). Additional high-rate surficial aquifer recharge areas in other than high-rate Upper Floridan recharge areas were determined by delineating the following three groups of well-drained soils: Palm Beach-Paola-Canaveral, Daytona-Paola-Astatula, and Daytona-Satellite-Cassia. These areas were assumed to have recharge characteristics similar to the high-rate areas determined on the basis of the spring-flow analysis.

CONCLUSIONS

This pilot study has demonstrated that mapping of high-rate ground-water recharge areas in Florida at a scale of 1:100,000 can be done when measurements of ground-water discharge are obtainable. These measurements are useful only insofar as the boundaries of the ground-water basin contributing to the discharge can be defined. Ground-water discharge measurements used in this study included stream base flow, spring flow, and pumpage.

Also demonstrated is the fact that procedures for determining recharge rates cannot be rigidly detailed in manual fashion and made applicable universally. Rather, the appropriate steps to follow must be determined by an experienced ground-water hydrologist after the local ground-water flow system and the factors controlling flow are evaluated. Then, and only then, can the available information be analyzed and interpreted in a manner appropriate for arriving at quantitative estimates of recharge that are technically defensible. At best, these arduous efforts can produce maps depicting broad categories of recharge amounts, such as were compiled herein for Okaloosa, Pasco, and Volusia Counties. However, comparable results may not be possible everywhere. Moreover, various recharge rates should be viewed as representing an average of the rates for relatively large areas; within a recharge-rate area there may be places where locally the recharge is greater or less than the average rate shown. Given the existing information, recharge rates cannot be mapped more precisely at the 1:100,000 or larger scale.

Mapping of recharge on a quantitative basis is particularly difficult in areas having extensive wetlands and/or highly controlled surface-water drainage, such as south Florida. Determination of ground-water discharge through base flow analysis in such situations is nearly impossible. A parallel study being conducted in Lee County by the U.S. Geological Survey, in cooperation with the South Florida Water Management District, is trying other approaches to delineate recharge areas and determine rates (R.K. Krulikas, U.S. Geological Survey, oral commun., September 12, 1990).

If recharge areas are mapped in a qualitative rather than quantitative fashion, the task is much easier. Assigning areas to a qualitative ranking such as "poor," "moderate," or "good," requires much less analytical rigor and information than trying to assign them to a specific quantity category. Qualitative mapping can be done comparatively quickly using readily available topographic and soils maps coupled with application of available knowledge on the hydrogeology of an area and ground-water hydrology fundamentals. Moreover, a qualitative ranking approach to mapping recharge might allow for better identification of the relative potential for recharge for local areas.

Finally, it also should be noted that one of the factors involved in mapping of the high-rate recharge areas is identification of where water levels are very near land surface. This condition can be modified locally; if ground water is heavily developed in such areas, water levels undoubtfully will be lowered. Under certain conditions, these present areas of rejected recharge may turn into recharge-receptive areas. In summary, recharge conditions in low-lying areas can be changed if water-level conditions are changed.

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