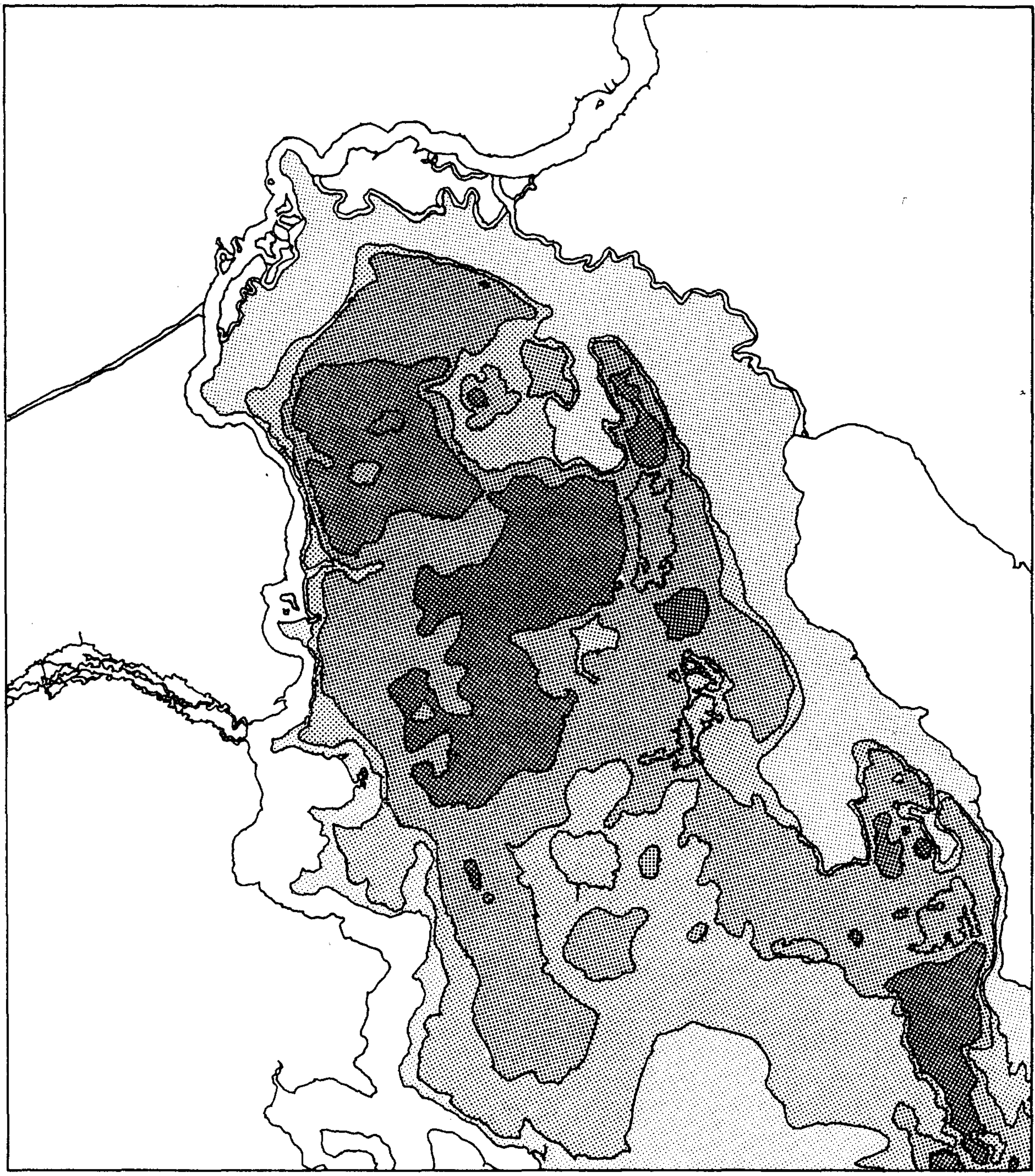
Technical Publication SJ 90-9

Recharge Areas of the Floridan Aquifer in the Crescent City Ridge of Southeast Putnam County, Florida--a Pilot Study



St. Johns River Water Management District

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RECHARGE AREAS OF THE FLORIDAN AQUIFER IN THE CRESCENT CITY RIDGE OF SOUTHEAST PUTNAM COUNTY, FLORIDA-- A PILOT STUDY

by

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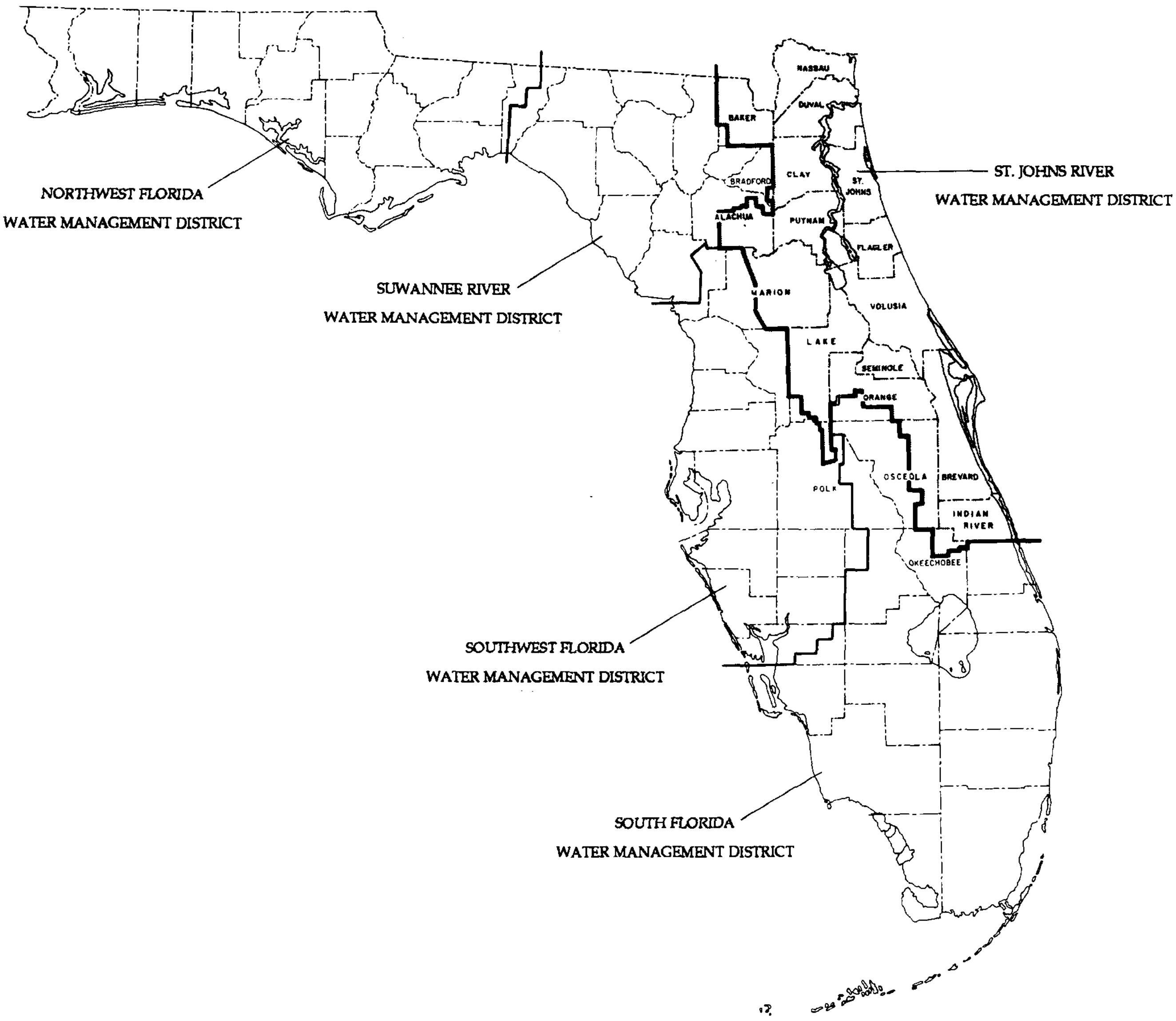

THE ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

The St. Johns River Water Management District (SJRWMD) was created by the Florida Legislature in 1972 to be one of five water management districts in Florida. It includes all or parts of nineteen counties in northeast Florida. The mission of SJRWMD is to manage water resources to insure their continued availability while maximizing environmental and economic benefits. It accomplishes its mission through regulation; applied research; assistance to federal, state, and local governments; operation and maintenance of water control works; and land acquisition and management. Technical reports are published to disseminate information collected by SJRWMD in pursuit of its mission.

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ABSTRACT

The identification of ground water recharge areas is an important part of managing water resources to ensure the future availability of ground water and to protect ground water quality. Amendments to the Florida Water Resources Act (Section 373.0395, Florida Statutes) directed each water management district to designate prime recharge areas as part of the ground water basin resource availability inventory.

A geographic information system (GIS) methodology was used to delineate the recharge areas of the Floridan aquifer in the Crescent City Ridge of southeast Putnam County, Florida. The GIS ARC/INFO software produces high quality hydrologic and geologic map coverages and provides the overlay and analysis functions required for the manipulation of the coverages to produce a map of recharge areas.

The recommended areas of prime ground water recharge, as defined by this report, are the areas within a ground water basin that contribute the greatest volume of water per unit area to the Floridan aquifer. Because of the variability in topography, soil types, underlying geology, and ground water hydrology in the St. Johns River Water Management District, recharge rates defining prime recharge areas may vary from basin to basin in the district.

Rainfall is the source of recharge to the surficial, intermediate, and Floridan aquifers in the study area. The GIS-driven model used in this study to determine recharge rates to the Floridan aquifer is mapped at a contour interval of 2 inches/year (in/yr) based on:

1. the hydraulic pressure difference resulting from the elevation and configuration of the water table and of the potentiometric surface of the Floridan aquifer, and

2. the thickness and vertical hydraulic conductivity of the semi-confining layers, expressed as the leakage coefficient.

The recharge rates are grouped into high (greater than 8 in/yr), moderate (2-8 in/yr), and low recharge (0-2 in/yr). These recommended groups are delineated based on an assessment of:

1. distribution curves plotting the volume of water recharging the Floridan aquifer within the recharge rate contour intervals,
2. the location of the sandy ridges with the highest topographic elevation, and
3. the location of soils with high infiltration potential.

The area-weighted average recharge to the Floridan aquifer in the Crescent City Ridge is 4.53 in/yr. High recharge areas encompass 11,009 acres, or 20 percent of the total recharge area, with 3,206.4 million gallons/year (mgy) of water that could potentially recharge the Floridan aquifer during an average rainfall year. The moderate recharge areas cover 25,140 acres, or 46 percent of the area, with 2,979.0 mgy potentially available as recharge. Low recharge areas encompass 18,091 acres, or 34 percent of the total recharge area, and contribute 491.3 mgy. While the recharge rate per unit area is less in the moderate than in the high recharge areas, the moderate areas encompass more acreage and contribute a significant volume of the total recharge to the Floridan aquifer in the Crescent City Ridge area.

INTRODUCTION

Ground water recharge is vital for providing adequate ground water supplies for future uses and for preserving the quality of ground water resources. Maps of natural ground water recharge areas are important planning tools for the effective management of ground water resources.

Ground water recharge areas were addressed by the Florida Legislature in 1982 with amendments to the Florida Water Resources Act (Chapter 373, Florida Statutes). The amendments directed each water management district to develop a ground water basin resource availability inventory, which included the delineation of prime ground water recharge areas (Section 373.0395, F. S.). Further revisions in 1985 required the publication of a legal notice and public hearing prior to the adoption of a prime ground water recharge area by a water management district (Section 373.0397, F. S.).

As defined by this report, recommended areas of prime ground water recharge to the Floridan aquifer are the areas in a ground water basin that contribute the greatest volume of water per unit area to the Floridan aquifer. Because of the variability in geology and ground water hydrology in the St. Johns River Water Management District (SJRWMD), recharge rates defining prime recharge areas may vary from basin to basin in the district. For the purpose of this study, prime recharge areas are those areas mapped as high recharge areas.

The protection of recharge areas is important for ground water quantity and quality. Ground water recharge sustains natural flow systems, replenishes supplies for all potential users, maintains ambient ground water quality, and protects against upward or lateral saltwater intrusion. Ground water recharge also helps maintain lake levels and stream and spring flow, reduces stormwater runoff and surface flooding, and can reduce sinkhole activity. In addition, recharge areas may require special protection because these areas have a potential for contaminating ground water.

Purpose and Scope

The purpose of this study was to develop a methodology for accurately delineating recharge areas and quantifying the amount of recharge occurring in these areas, and to recommend which of these areas should be designated prime ground water recharge areas to the Floridan aquifer. The delineation of recharge areas was based on the relationships among topography, soils, underlying geology, and ground water hydrology. A geographic information system (GIS) was used to integrate the large amount of data involved in the project.

The Crescent City Ridge of southeast Putnam County was chosen as the pilot study area because it is a known recharge area for which data from previous investigations are available. These data, supplemented with new data, provide a good data base to construct the GIS map coverages required to produce a map of recharge areas.

Geographic Information Systems

A geographic information system is a tool for storing, analyzing, and manipulating layers of spatial data in a computer. The primary functions of a GIS for hydrologic investigations are to manage, analyze, manipulate, automate, and display cultural, hydrologic, and geologic data in digital form and use the results for water resource management.

The GIS used by SJRWMD is the ARC/INFO system of the Environmental Systems Research Institute (ESRI). ARC is the GIS program environment that facilitates data conversion, map digitizing and editing, spatial data management, and analytical operations. INFO is the relational database manager for the data used to make the maps (ESRI 1987).

GIS ARC/INFO facilitates the handling of two classes of data: locational data and thematic data. Locational (spatial) data describe the location and topology of points, lines, and area features. Thematic (non-spatial) data describe the characteristics of these features and consist of points, linear features (arcs), and area features (polygons), as well as associated annotation that describes the map attributes (ESRI 1987). Geohydrologic maps are created by relating the locational and thematic attributes of a given area.

ARC/INFO is used to automate the compilation of maps called coverages, each consisting of sets of map features. The advantages of using a GIS to build the map coverages are the accurate integration or manipulation of thematic map layers to create resultant coverages, the speed of data analysis, the objective handling of the data, and data display at the resolution needed by potential users. The GIS can be used for overlaying, gridding, color coding, contouring, constructing fence and block diagrams, generating perspective views, calculating areas and volumes, and zooming in to see details of any area of interest.

The Triangulated Irregular Network (TIN) is the ESRI software used to create, store, manage, and analyze three-dimensional surfaces for ARC/INFO. TIN has two data structures in which map data are analyzed: a triangulated irregular network and a lattice. A triangulated structure is a network of adjacent triangles that connects the data points represented by x,y coordinates and z data values that represent a three-dimensional surface. This TIN data structure includes the topological relationships among neighboring data points, with the points which define each triangle like facets on a surface. A lattice structure is derived from the TIN structure using a set of regularly spaced points, each with an interpolated x,y,z value (ESRI 1987). Contours are drawn from the lattice structure to represent the three-dimensional surface of the data (Figure 1).

The topographic, hydrographic, soils, geologic, or hydrologic coverages created in ARC/INFO can be displayed on screen for review or further manipulation, or produced on paper with a plotter. Quality control was performed for each coverage digitized or generated from the data points and on the resultant coverages produced from the analysis and overlay operations. This process included several iterations of editing, plotting, and checking all aspects of each map.

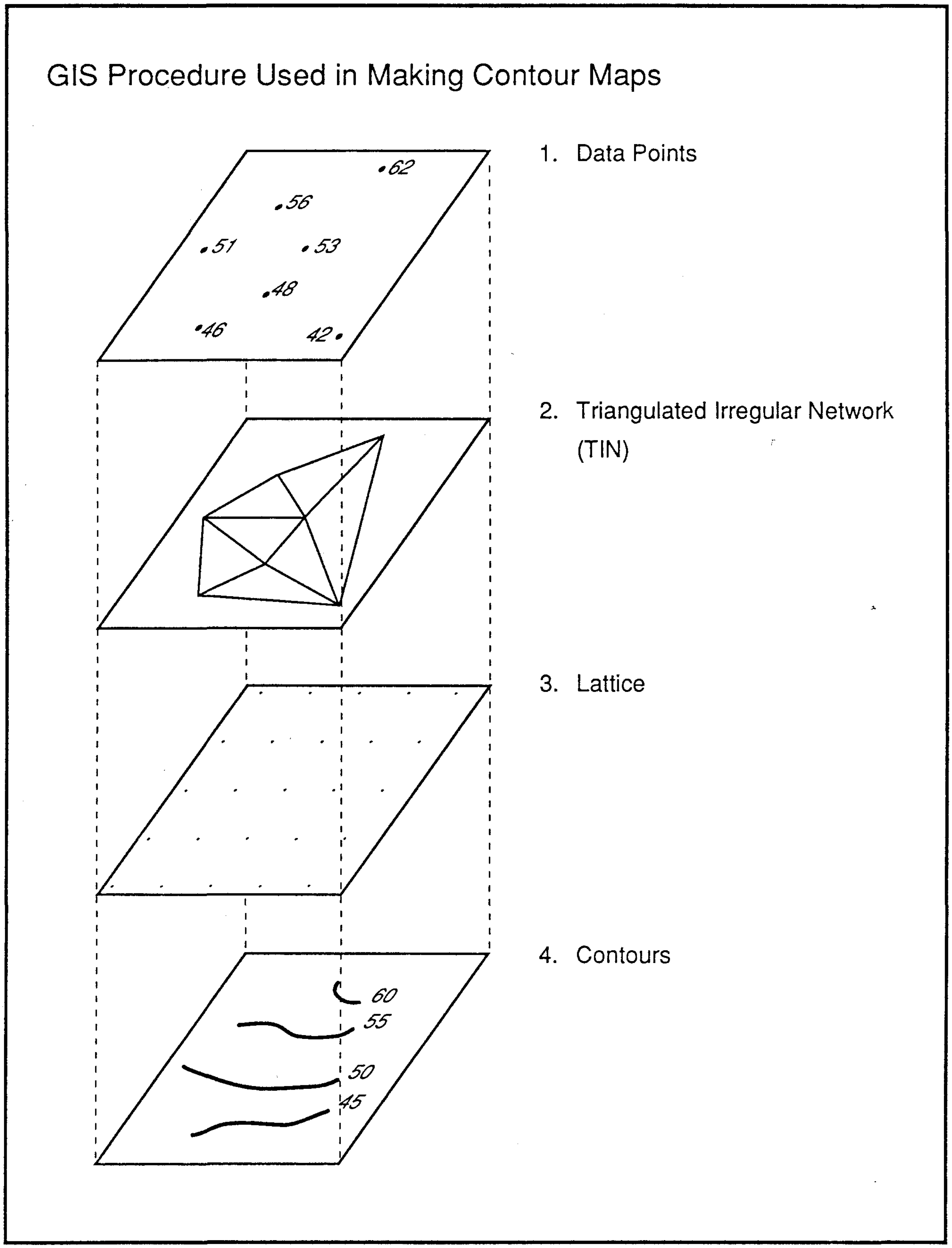

Figure 1. Geographic Information System (GIS) procedure used in making contour maps

The map coverages described in this report were originally produced on hard copy at a scale of 1:48,000, but GIS allows plotting the maps at a scale of 1:24,000 for detailed use with the 7.5 minute USGS quads or page size maps for use as figures in this publication. Explanations of the data sources and how each map coverage was generated are presented in the appropriate sections of this report.

Description of Study Area

The Crescent City Ridge is located in southeast Putnam County and northwest Volusia County in east central peninsular Florida. The study area for this investigation encompasses the part of the Crescent City Ridge within southeast Putnam County (Figure 2). The 112 square mile study area is bounded by Dunns Creek to the north, Crescent Lake to the east, Volusia County to the south, and the St. Johns River to the west (Figure 3). The study area includes parts of the Satsuma, San Mateo, Crescent City, and Welaka 7.5 minute series USGS topographic quadrangle maps (1:24,000 scale).

The topographic contours and hydrography of the four quadrangles were digitized for input into the district's ARC/INFO GIS. The quads were digitized in 5-ft contour intervals and edge-matched to produce one map of the topography of the study area. The topographic map presented in this report shades 20-ft contour intervals (Figure 4) due to scale limitations.

The altitude of the land surface in the study area ranges from near mean sea level (msl) along the St. Johns River, Dunns Creek, and Crescent Lake to approximately 120 ft above msl in the sandy ridges. The topography is characterized by a series of terraces, or step-like surfaces of increasing elevation, which are the result of wave erosion and deposition during the advance and retreat of sea level during the ice ages of Pleistocene time. These marine terraces have been dissected by varying degrees of erosion and are capped by thin surficial sands. The terraces, as described by Cooke (1945) and Healy (1975), are the Silver Bluff (0-10 ft in elevation), Pamlico (10-25 ft), Talbot (25-42 ft), Penholloway (42-70 ft), Wicomico (70-100 ft), and Sunderland (100-170 ft).

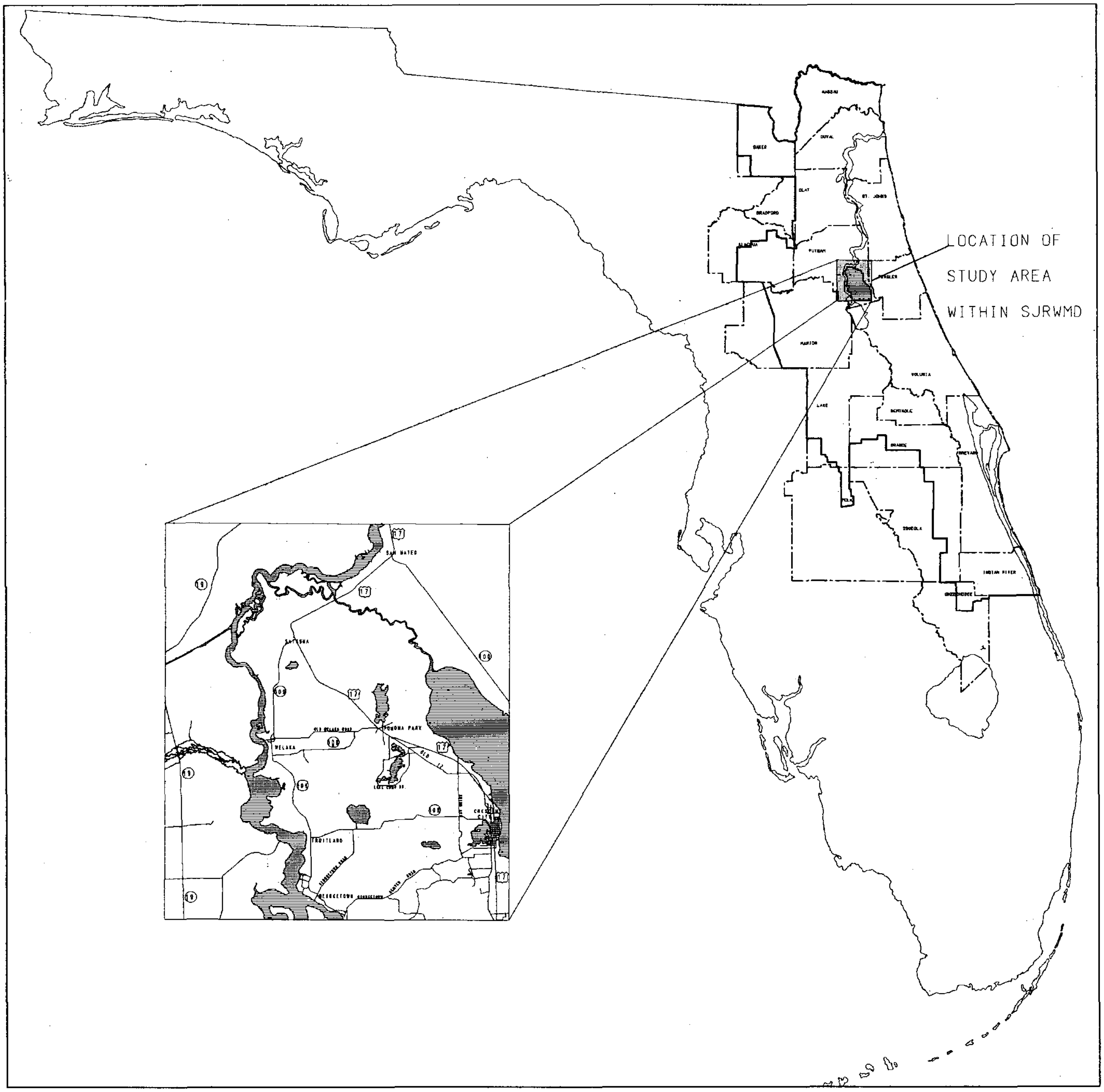

Figure 2. Location of the study area

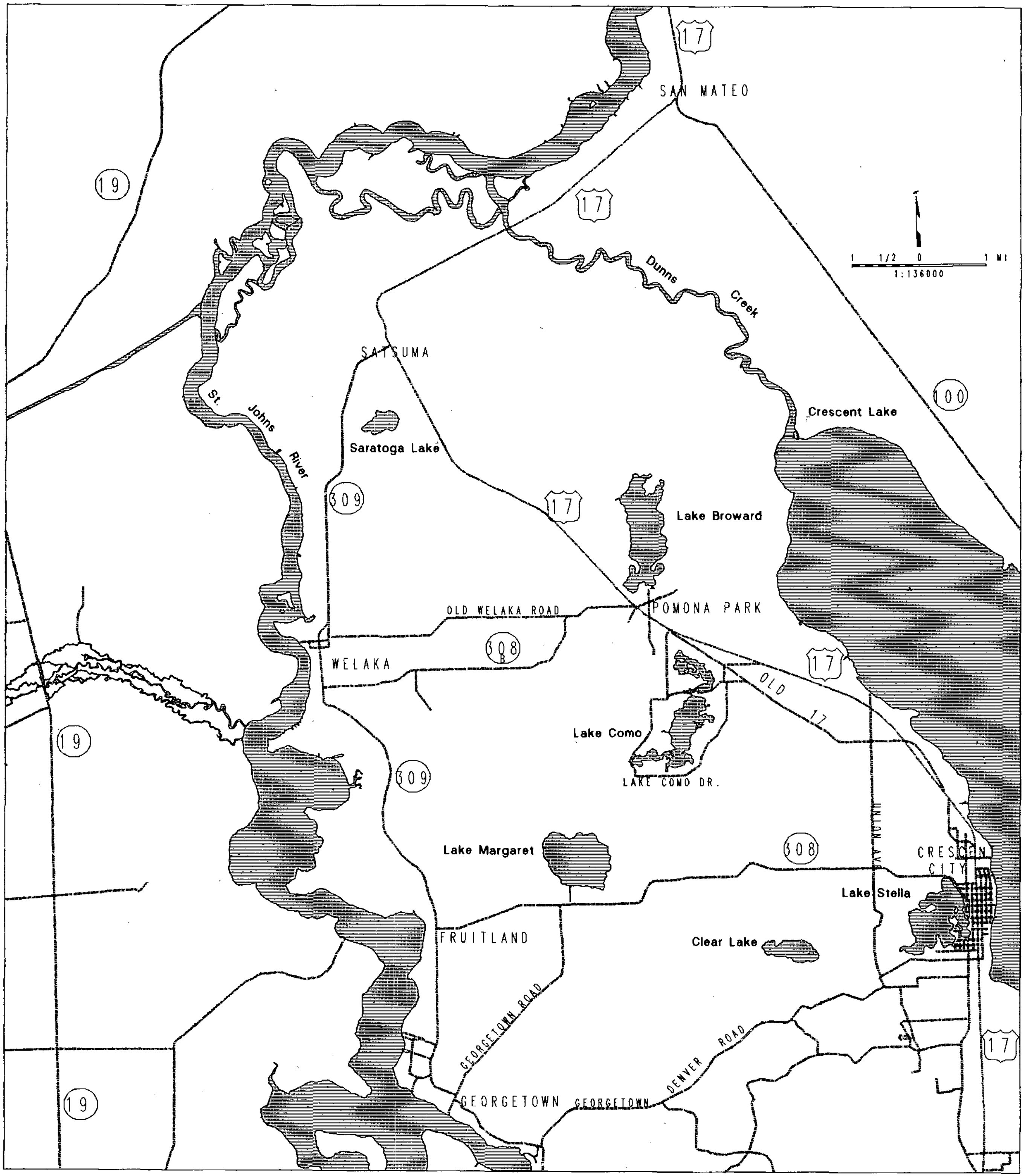

Figure 3. Base map of the study area

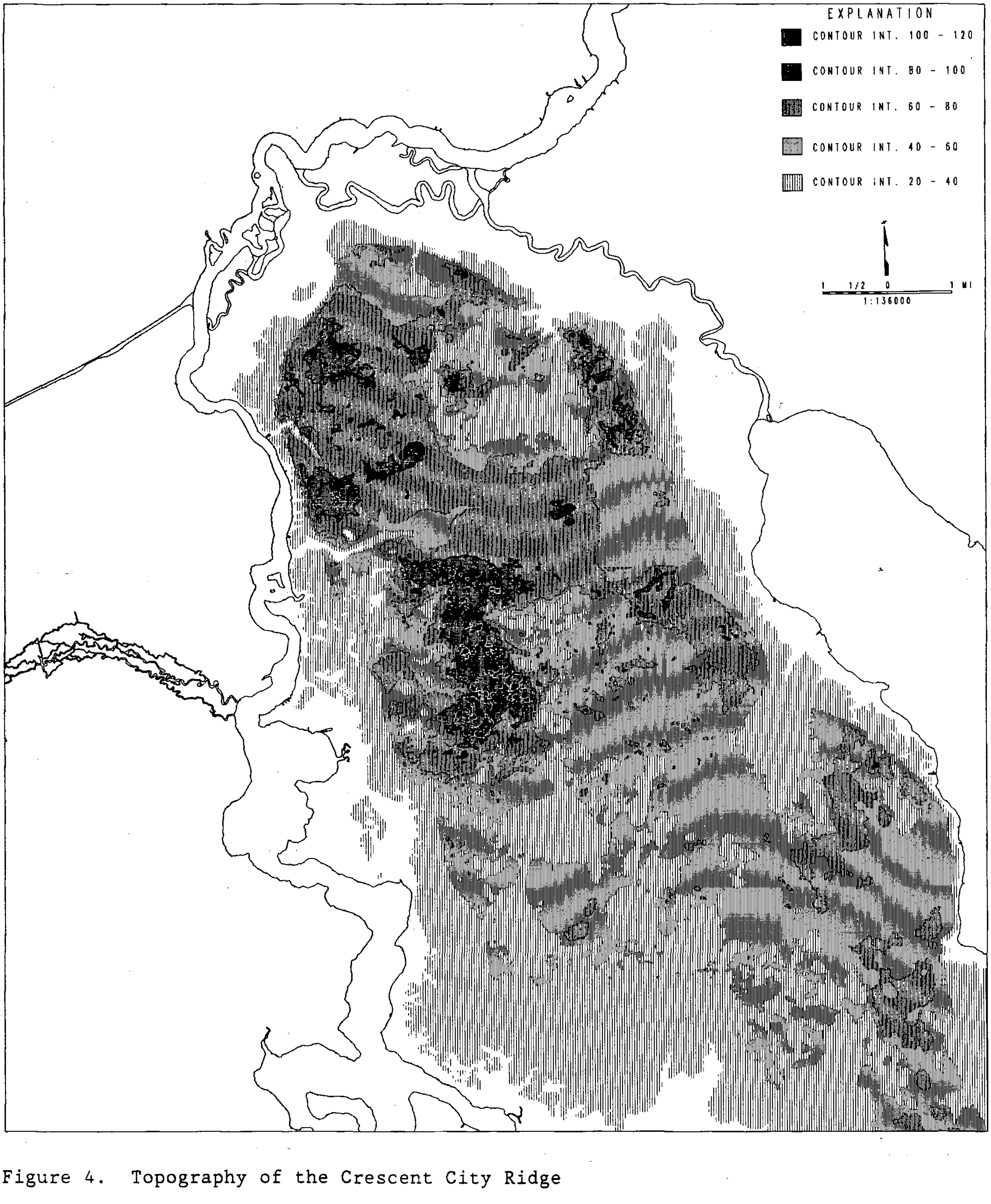

Figure 4. Topography of the Crescent City Ridge

The Crescent City Ridge also exhibits karst topographic features resulting from the dissolution of the underlying limestone formations. Such areas are characterized by high local relief, a lack of surface drainage features, subsurface drainage, sinkholes, sinkhole-related lakes, and springs. Due to the lack of surface drainage in the upland sandy ridges, almost all of the precipitation falling in these areas is either lost to evapotranspiration or drains downward through the permeable soils or sinkholes. The hydrography of the Crescent City Ridge detailing the rivers, lakes, and wetlands is depicted in Figure 5.

The climate of the study area is humid subtropical, with a mean annual temperature of 71 degrees Fahrenheit and an average rainfall of 53 in/yr. Most of the rainfall is due to convective thunder showers from June through September. The winters are mild and drier, with most rainfall due to frontal activity. Seasonal variations in rainfall and temperature influence surface runoff, evapotranspiration, soil moisture content, and seepage to the water table.

The major part of the rainfall is continually returned to the atmosphere by the process of evaporation and transpiration of the water that is captured by plants, the land surface, the unsaturated soil zone, and the water table. Evapotranspiration in central Florida is generally estimated at approximately 70 percent of rainfall (Rutledge 1982). Evapotranspiration in the study area was estimated to be approximately 35 in/yr by Ross and Munch (1980). In the sandy upland areas, evapotranspiration may be below the average for the area and runoff may be virtually nonexistent. This is due to the lack of surface drainage features, the high infiltration characteristics of the soils, the high permeability of the surficial sediments, and the water table at considerable depth below land surface. Actual evapotranspiration depends on rainfall, humidity, vegetation, soil type, and depth to the water table. Where surface drainage features have developed, some of the rainfall runs off the land surface into nearby lakes, rivers, and streams, especially during periods of heavy rainfall. The remainder of the rainfall infiltrates through the soil zone and into the ground water flow regimes.

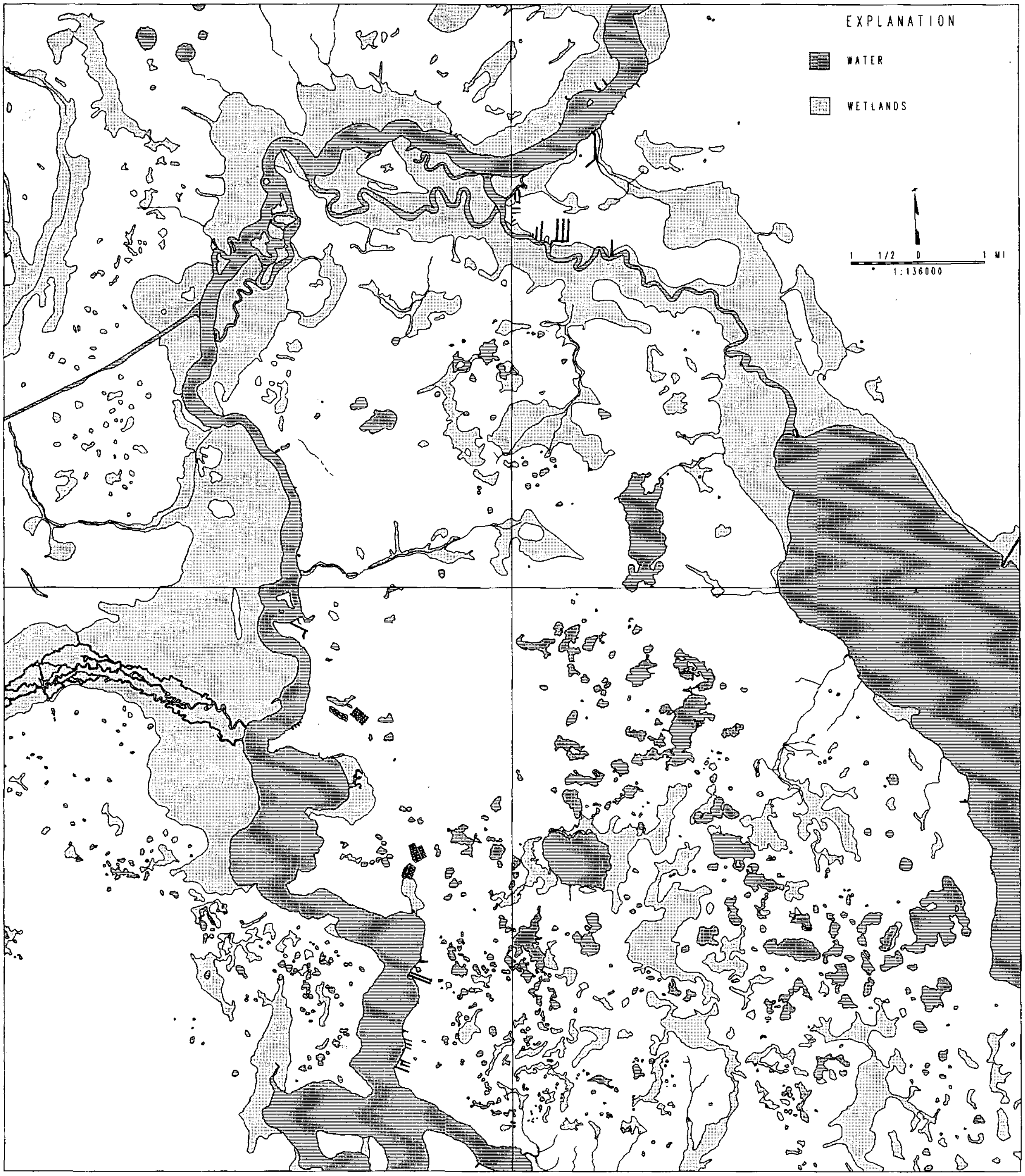

Figure 5. Hydrography of the Crescent City Ridge

Previous Investigations

A review of the literature provides several references which describe the geohydrology and ground water recharge processes in Florida. Additional detailed information on the geomorphology, geology, hydrology, and recharge of the study area and the surrounding region can be found in the references listed in the bibliography.

The geology and the ground water resources of Flagler, Putnam, and St. Johns counties were studied by Bermes, Leve, and Tarver (1963). Bentley (1977) performed aquifer test analyses on the Floridan aquifer in the region. Munch, Ripy, and Johnson (1979) investigated the water levels and water quality of irrigation wells in the three county area.

Ross and Munch (1980) investigated the potentiometric high of the Floridan aquifer in the Crescent City Ridge using aquifer tests, flow net analysis, water budget analysis, and water quality. Their water budget analysis estimated that recharge in the area averaged 5 in/yr. Rutledge (1982) described the hydrology of the Floridan aquifer in northwest Volusia County and estimated recharge rates to average 3 in/yr, with rates up to 20 in/yr in the ridge areas. Tibbals (1981 and in press) modelled the flow regime and described the hydrology of the Floridan aquifer in east-central Florida and identified the ridge areas as having the highest rates of recharge. Bush and Johnston (1988) provided information on the hydrologic characteristics of the Floridan aquifer, including leakage, as part of the Regional Aquifer System Analysis. Leakage coefficients were estimated to be 2.3×10^{-4} (feet/day)/foot ((ft/day)/ft) for semi-confined areas such as the Crescent City Ridge, with recharge rates averaging 5 in/yr for the entire Floridan aquifer system.

While several authors have investigated ground water recharge in areas throughout the state, the lack of detailed maps of recharge areas illustrates the complexity of the problem. Strangland (1973) presented an overview of ground water recharge in Florida. Tibbals (1978) studied the effects of paved surfaces on ground water recharge to the Floridan aquifer in east-central Florida. Phelps (1978) discussed methods of estimating recharge to the Floridan aquifer in northeast Florida, including the closed contour method, water budget analysis, and calculations of leakage through confining beds.

Lichtler (1972) mapped effective, moderately effective, poor, and very poor recharge areas in east central Florida. Tibbals (1975) mapped areas of recharge to the Floridan aquifer in Seminole County. His map delineated the most effective recharge areas (10-21 in/yr), moderately effective areas (3-10 in/yr), poor recharge areas (0-3 in/yr), and areas of very poor recharge. Stewart (1980) provided a generalized statewide recharge map of areas with high (10-20 in/yr), low to moderate (2-10 in/yr), very low (less than 2 in/yr), and no recharge to the Floridan aquifer. Phelps (1984) mapped areas of high, low to moderate, and no recharge to the Floridan aquifer in SJRWMD. Aucott (1988) mapped generalized areas of recharge to and discharge from the Floridan aquifer for Florida.

GEOHYDROLOGIC FRAMEWORK

The geohydrologic units in southeast Putnam County are the surficial aquifer, the semi-confining layers and intermediate aquifers, and the Floridan aquifer system (Figure 6). More information about the geologic history and the hydrology of the area can be found in Bermes, Leve, and Tarver (1963) and Ross and Munch (1980).

Surficial Aquifer

The surficial sediments are composed of Holocene and Pleistocene sand, clayey sand, and clay, with some shell locally, and Pliocene sand, shell, and clay deposits. The surficial aquifers are composed of sand and shell layers of varying thickness that extend from land surface down to the uppermost areally extensive and less permeable clay layer. These unconfined surficial aquifers supply small to moderate amounts of water to screened wells, widely used for lawn and garden irrigation. The surficial aquifer system is recharged primarily by rainfall and also by upward movement of water from underlying aquifers. Water leaves the system through evapotranspiration; seepage to lakes, streams, and wetlands; leakage to underlying aquifers; and pumpage from wells.

The lithology, texture, and thickness of the surficial deposits can vary laterally and vertically. The unconsolidated to poorly consolidated sediments generally grade from sand to clayey sand to clay, and the shell beds may have a matrix of sand and/or clay. The clay layers can vary in extent, thickness, and permeability, and thus do not significantly retard the downward movement of water. The surficial sediments generally range from 40 to 60 ft thick and may be over 90 ft thick in some areas of higher elevation in the sandy ridges (Bermes, Leve, and Tarver 1963; Pirkle 1971).

SYSTEM	SERIES	STRATIGRAPHIC UNIT	GENERAL LITHOLOGY	GEOHYDROLOGIC UNITS
Quaternary	Holocene Pleistocene	Surficial sands, terrace deposits	Sand, clayey sand, and clay, with some shell locally	Surficial aquifer
Tertiary	Pliocene	Undifferentiated deposits	Sand, clay, and shell	Semi-confining layers and intermediate aquifers
	Miocene	Hawthorn Group	Clay, silt, sand, dolomite, and limestone, phosphatic	
	Eocene	Ocala Limestone	Limestone and dolomitic limestone	Floridan aquifer
		Avon Park Limestone	Limestone and dolomite	
		Lake City Limestone	Limestone and dolomite	

Figure 6. Geohydrologic framework

Semi-Confining Layers and Intermediate Aquifers

The semi-confining layers and intermediate aquifers consist of the phosphatic sand, silt, clay, dolomite, and limestone of the Hawthorn Group of Miocene age (Scott 1988). The confined intermediate aquifer units are composed of thin, discontinuous layers or lenses of sand, shell, or limestone, and yield moderate amounts of water to domestic supply wells. The limestones in the lower part of the Hawthorn may be hydraulically connected to the Floridan aquifer. The intermediate aquifer units are recharged from the overlying surficial aquifer or the underlying Floridan aquifer, depending on hydraulic pressure relationships and the degree of confinement of aquifer units.

The clays within the Hawthorn Group act as semi-confining layers and retard the vertical movement of water among the surficial, intermediate, and Floridan aquifers. The elevation of the top of the semi-confining layers in the area ranges from 70 ft below to 20 ft above msl, with the highest elevations near the center of the study area (Figure 7). The map is based on 60 data points obtained from the SJRWMD geophysical data base, the Florida Geological Survey (FGS) well log data base, and existing publications (Appendix A). The data values were contoured using the TIN surface modelling software. The semi-confining layers range in thickness from 10 ft in the southern part of the area to 80 ft in the northwest part of the study area (Figure 8). The thickness map was generated by subtracting the TIN lattice representing the top of the Ocala limestone (see next section) from the TIN lattice representing the top of the semi-confining layers. Contours depicting the thickness of the semi-confining layers are drawn from the resultant lattice.

The Hawthorn Group is a complexly interbedded and highly variable sequence, and the lack of existing hydrologic data on the semi-confining layers results in difficulty in predicting the downward movement of water through the layers and into the Floridan aquifer. Areas of high permeability within the confining layers were reported in observation wells drilled by Ross and Munch (1980). Sinkholes which breach the confining layers may be filled with more permeable material and increase the amount of

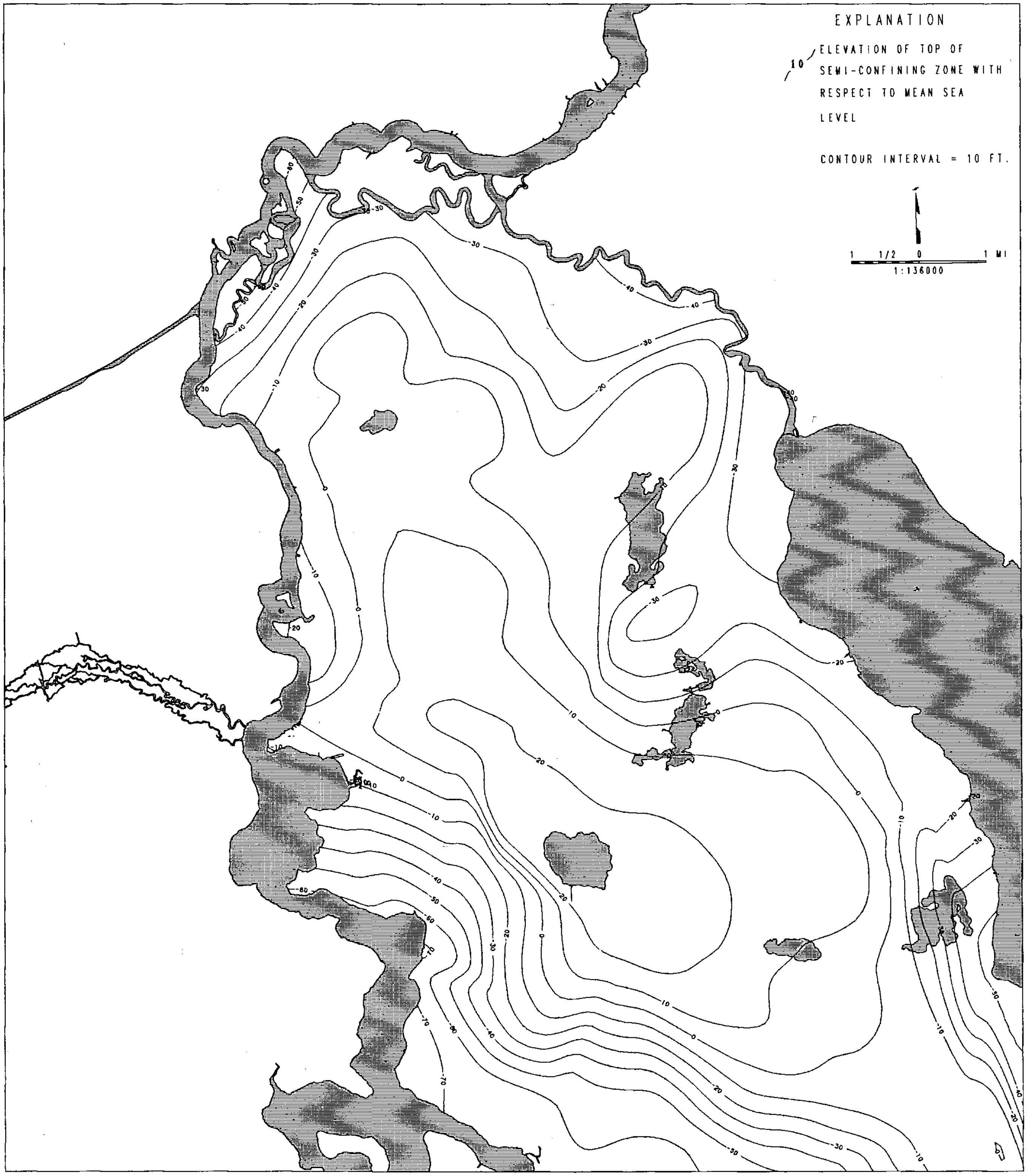

Figure 7. Elevation of the top of the semi-confining layers

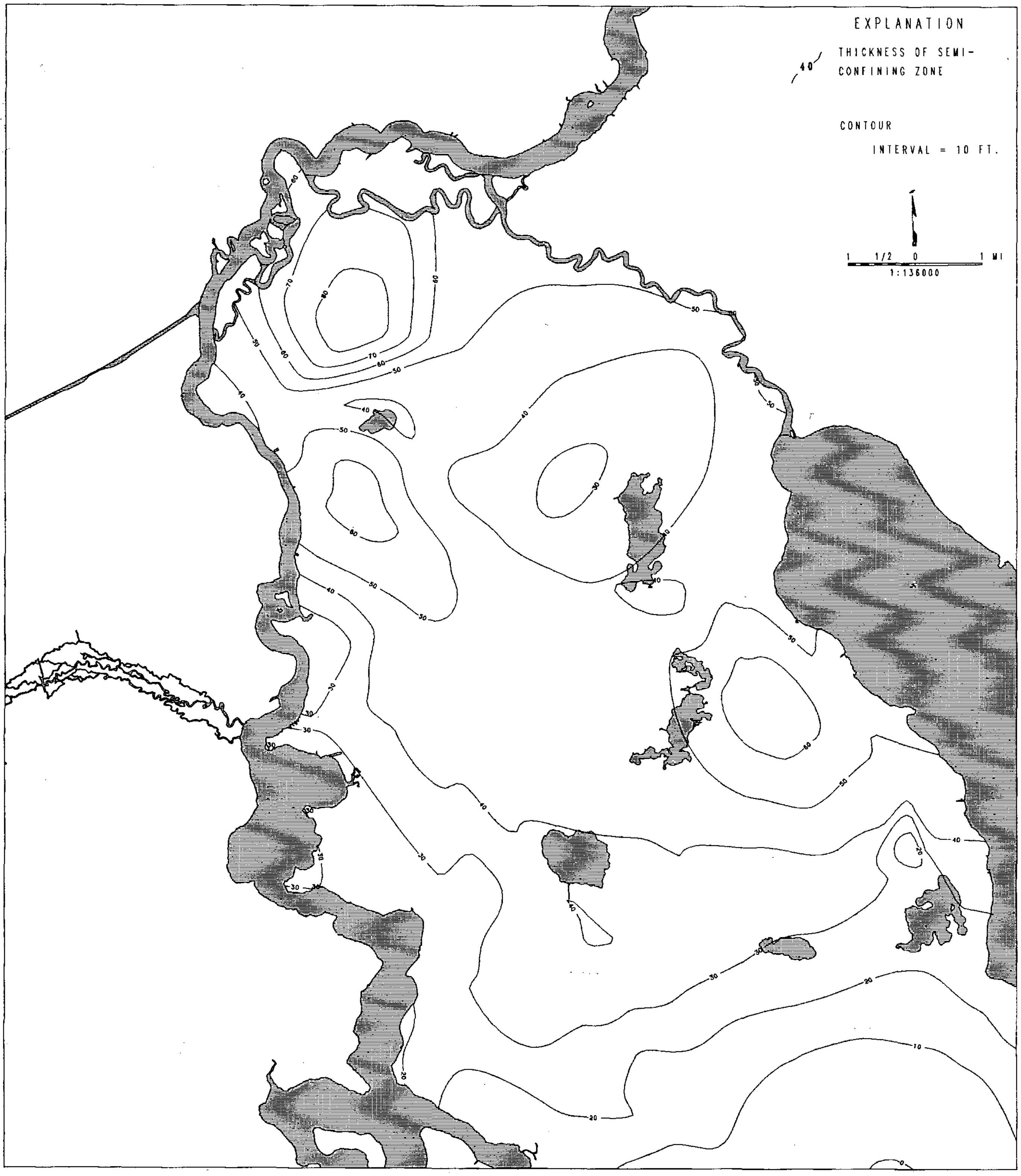

Figure 8. Thickness of the semi-confining layers

water that can move from the surficial to the Floridan aquifer, or the sinkholes may be filled with peat, which retards the downward movement of water. Sinkholes in the study area are generally formed where soluble material in the underlying limestone has been removed by solution, causing the overlying surficial sediments to collapse, and forming sinkhole depressions at the surface.

Floridan Aquifer

The Floridan aquifer is the principal source of fresh ground water in SJRWMD and is capable of supplying large quantities of water to wells. Floridan wells derive water from the fissures and cavities created by the dissolution of limestone. The Floridan aquifer is confined by the clays of the Hawthorn Group in the study area, and water levels in tightly cased wells will rise above the top of the Floridan aquifer limestone.

The sequence of relatively homogeneous and permeable marine limestones that comprise the Floridan aquifer acts as a single hydrologic unit. The Floridan aquifer system consists of the Ocala, Avon Park, and Lake City limestones and dolomites of Eocene age. The elevation of the top of the Ocala limestone, or the top of the upper Floridan aquifer, ranges from 120 to 20 ft below msl in the study area (Figure 9). The TIN software was used to generate the contours from 61 data values obtained from SJRWMD geophysical data, FGS well log data, and from existing publications (Appendix A). The eroded and irregular nature of the limestone's surface is not obvious in the generalized contour map.

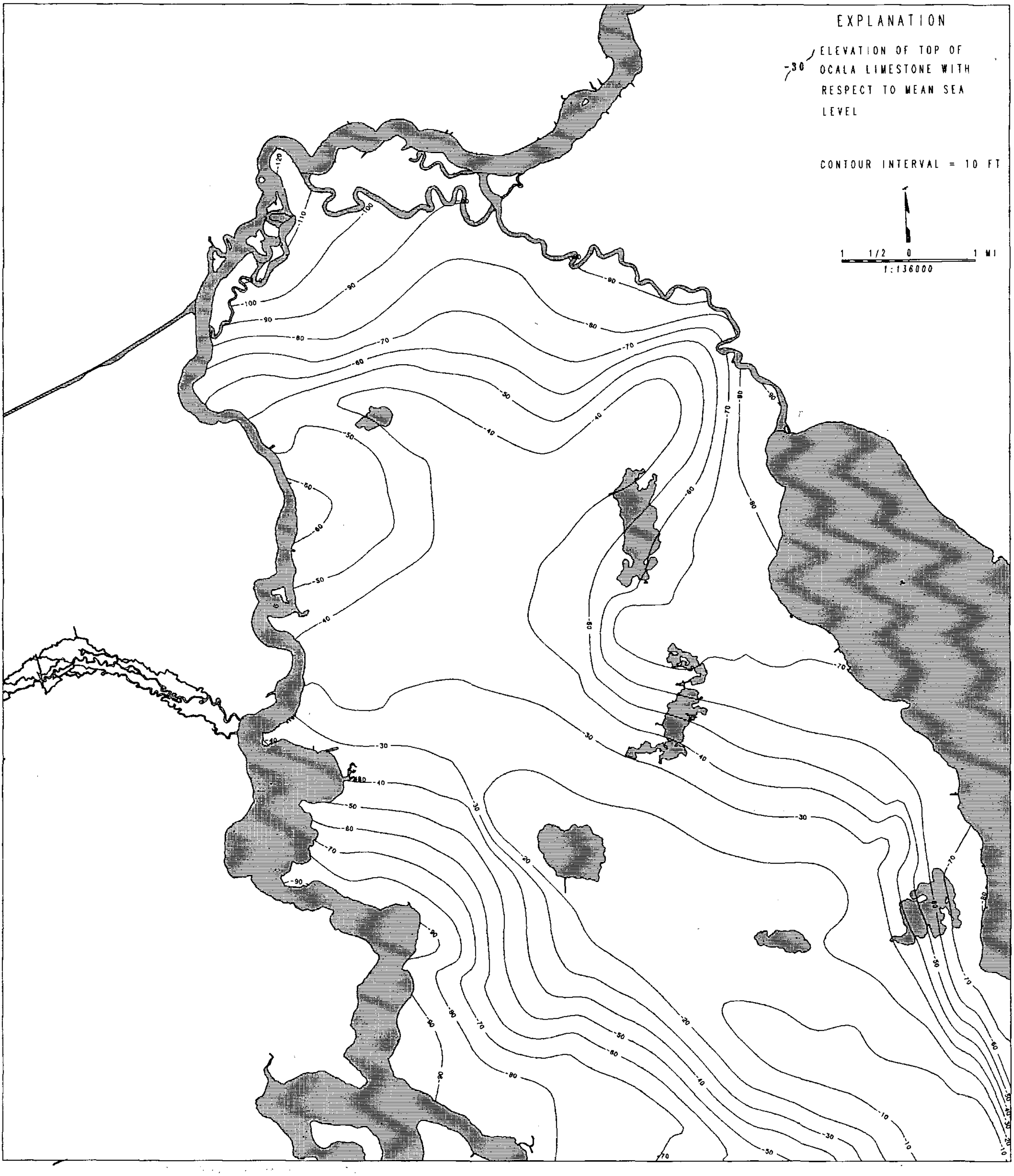

Figure 9. Elevation of the top of the Ocala limestone

GROUND WATER RECHARGE

Ground water recharge is the addition of water to the saturated zone and the downward movement of the water into aquifer systems. The U. S. Environmental Protection Agency (1986) defines a recharge area as an area of land beneath which there is a net annual transfer of water downward through the unsaturated zone into the regional ground water flow regime.

Nearly all of the water recharging the Floridan aquifer in SJRWMD is derived from rainfall in the district. Rainfall percolating downward from land surface to the Floridan aquifer must move through the unsaturated soil zone, the surficial aquifer, and the semi-confining layers to recharge the Floridan aquifer. The amount of water stored in the aquifer systems is determined by a balance between recharge, evapotranspiration, runoff, leakage to or from adjacent aquifers, natural discharge, and withdrawals from water wells. The movement of water through sinkholes or lakes of probable sinkhole origin that breach the semi-confining layer can be a significant conduit for recharge, depending on the degree of hydraulic connection to the Floridan aquifer.

Recharge rates are usually expressed in terms of volume per unit of time, such as inches/year (in/yr). In addition to inches/year of recharge, this report also presents the area (acres) and the volume of water (million gallons/year, mgy) which could potentially recharge the Floridan aquifer within each inches/year recharge contour interval. The recharge rate contours are grouped into high, moderate, and low recharge areas.

Movement of Water in the Soil Zone

Water from precipitation or irrigation will run off the land surface into lakes or streams or infiltrate into the ground depending on the surface drainage features, soil properties, vegetation, and land use practices. The earth materials through which infiltrating water moves may be subdivided into zones depending on the relative proportion of open spaces in the soil, sediment, or porous rock occupied by water.

All pores and open spaces are completely filled with water in the zone of saturation, or the ground water zone. The open spaces in the unsaturated zone, or the zone of aeration, contain water and gases (mostly air and water vapor). The unsaturated zone consists of the soil moisture zone, the intermediate or vadose water zone, and the capillary fringe. Moisture in the unsaturated zone varies depending on the frequency, duration, and intensity of precipitation, temperature and humidity, topography, land use practices, and the physical properties of the soil as modified by vegetation and animal organisms.

Infiltration is the flow or movement of a fluid through the pores and open spaces of a soil, sediment, or rock. A soil's infiltration rate describes its ability to absorb and transmit water and is determined by a soil's physical properties and landscape position. The percentage of a soil or sediment that is occupied by pore spaces is its porosity. The size and shape of the pore spaces and the degree to which the spaces are interconnected determines the permeability and hydraulic conductivity of a soil, sediment, or porous rock (Bates and Jackson 1980).

Data from the U. S. Department of Agriculture's Soil Conservation Service are used to describe the soil infiltration potential of the soil associations mapped in the Crescent City Ridge. These data describe the physical properties of a soil up to a maximum depth of approximately 80 in. A soil association's subsoil texture, subsoil permeability, subsoil drainage, surface slope, and surface runoff provide information on a soil's infiltration capacity and its ability to transmit water to the water table and the ground water flow systems. These parameters for the soil associations of the Crescent City Ridge are described in Appendix B and are used to group the soil associations into soils with high, moderate, or low soil infiltration potential (Figure 10).

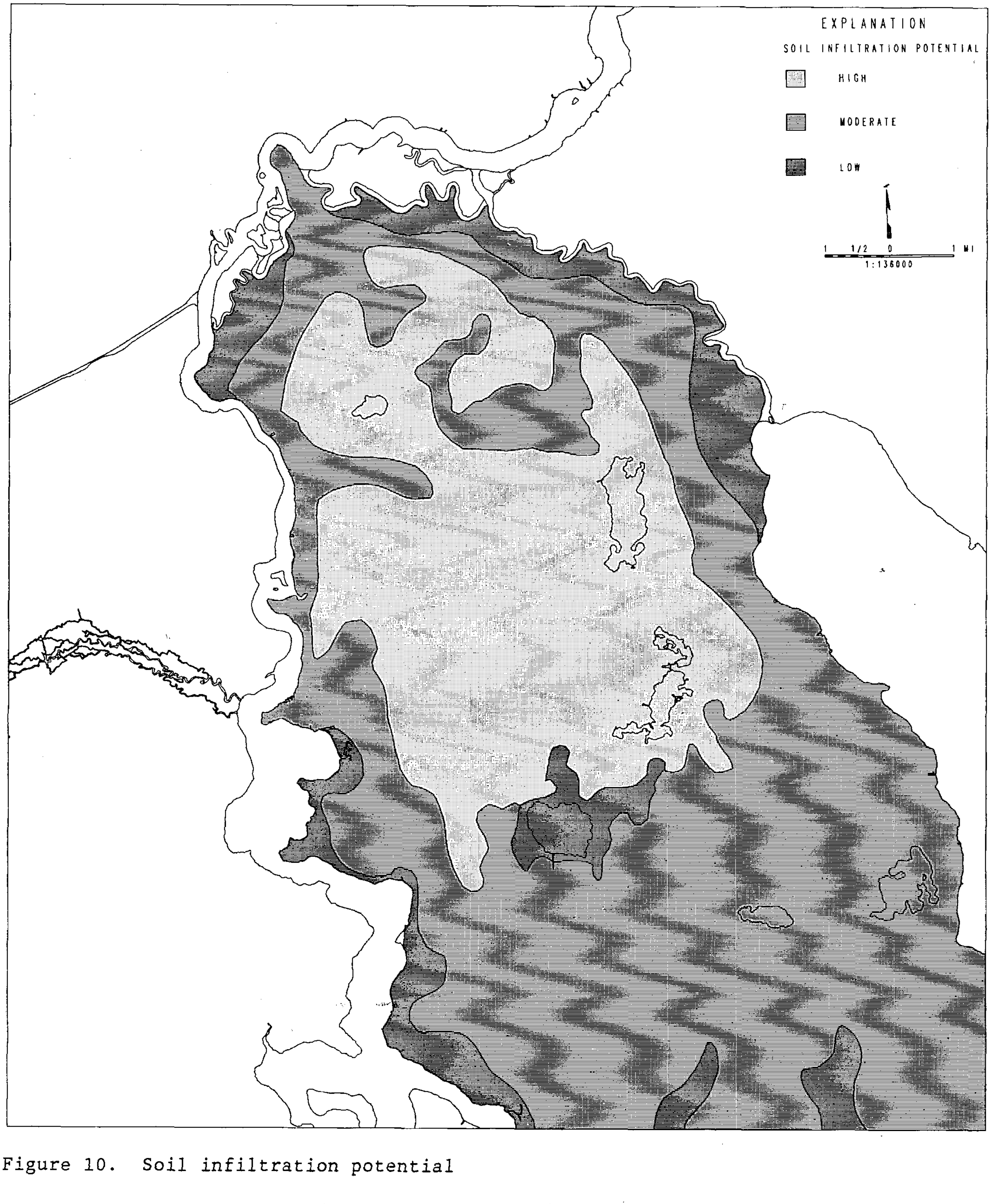

Figure 10. Soil infiltration potential

The map of soil infiltration potential is used to confirm the mapped distribution of recharge areas. Soils having high infiltration potential occupy the sand ridges and consist of deep, well drained to excessively drained sands with rapid permeability and low runoff potential (Astatula and Candler-Apopka soils). Soils that have high infiltration potential readily allow water to percolate to deeper ground water regimes. Moderate infiltration rates are characterized by moderately well drained to poorly drained sandy to loamy soils. These soils generally occupy the flatwoods and have moderately slow to moderately rapid permeability and moderate runoff potential (Tavares-Myakka-Basinger, Pomello-Satelite-Immokalee, Pomello-Myakka, and Myakka-Wauchula-Placid soils). Soils having low infiltration potential occupy lowlands or border surface water bodies and consist of poorly drained, organic clays, silts, and loams that are subject to frequent flooding (freshwater swamp soils).

Water Table Elevation

The surficial aquifer is most suitable as a source of recharge in the upland ridge areas where the depth to the water table and the thickness of the unsaturated zone is greatest. In these areas the surficial aquifer has the greatest capacity for storing infiltrating rainfall which could potentially recharge the Floridan aquifer. The ridges support a higher water table and the increased hydraulic pressure results in greater potential leakage from the surficial deposits to the Floridan aquifer. In addition, a greater depth to the water table also reduces the loss of water to evapotranspiration. In areas of lower topographic elevation, the surficial aquifer has less capacity for storing infiltrating water and potential recharge is lost to runoff and evapotranspiration.

The water table of the surficial aquifer is the surface at which pore water pressure equals atmospheric pressure in the unconfined surficial sediments. The elevation of the water table is indicated by the level at which water stands in an auger hole or a shallow well. The hydraulic pressure at any point on the water table is equal to the elevation of the water table at that point. The water table has the same general shape as the topography, although water table relief is not as great as topographic relief.

Maps of the water table in the surficial aquifer and the potentiometric surface of the Floridan aquifer are required to map the hydraulic pressure (or head) difference between the two aquifers. The water table in the Crescent City Ridge was mapped from water level measurements taken from 76 auger holes drilled in September 1988 (Figure 11). Water table measurements were taken in September 1988 to coincide with the measurements of potentiometric levels in the Floridan. Auger holes were drilled at benchmark sites from geodetic surveys or other sites of known topographic elevation to determine the elevation of the water table in reference to mean sea level.

The land surface elevations and the water table measurements with respect to mean sea level were statistically analyzed with the Minitab statistical software (Arnold 1981). The graph of land surface elevation versus water table elevation resulted in 90 percent linear correlation. The water table measurements from the auger holes, the regression equation relating land surface elevation to the water table, and the location of lakes and streams were used to interpolate the water table contours in the study area (Appendix C). The water table contours were then digitized into a GIS line coverage for further analysis.

The elevation of the water table ranges from a high of more than 70 ft above msl in the sand ridges in the west central and northwest part of the study area to less than 10 ft above msl along the perimeter of the area. The water table is near land surface in topographically low areas, wetlands, or near a lake's shore, and at greater depths in the upland, sandy ridges.

Leakage Through the Semi-Confining Layers

The clays of the semi-confining layers retard the flow of water between the surficial, the intermediate, and the Floridan aquifers. The confining clays, generally of the Hawthorn Group, vary in thickness and areal extent, resulting in variability in vertical hydraulic conductivity and leakage to the Floridan aquifer. The hydraulic conductivity is a measure of the ease with which water will pass through a porous earth material, and is determined by the size and shape of the pore spaces and the degree of

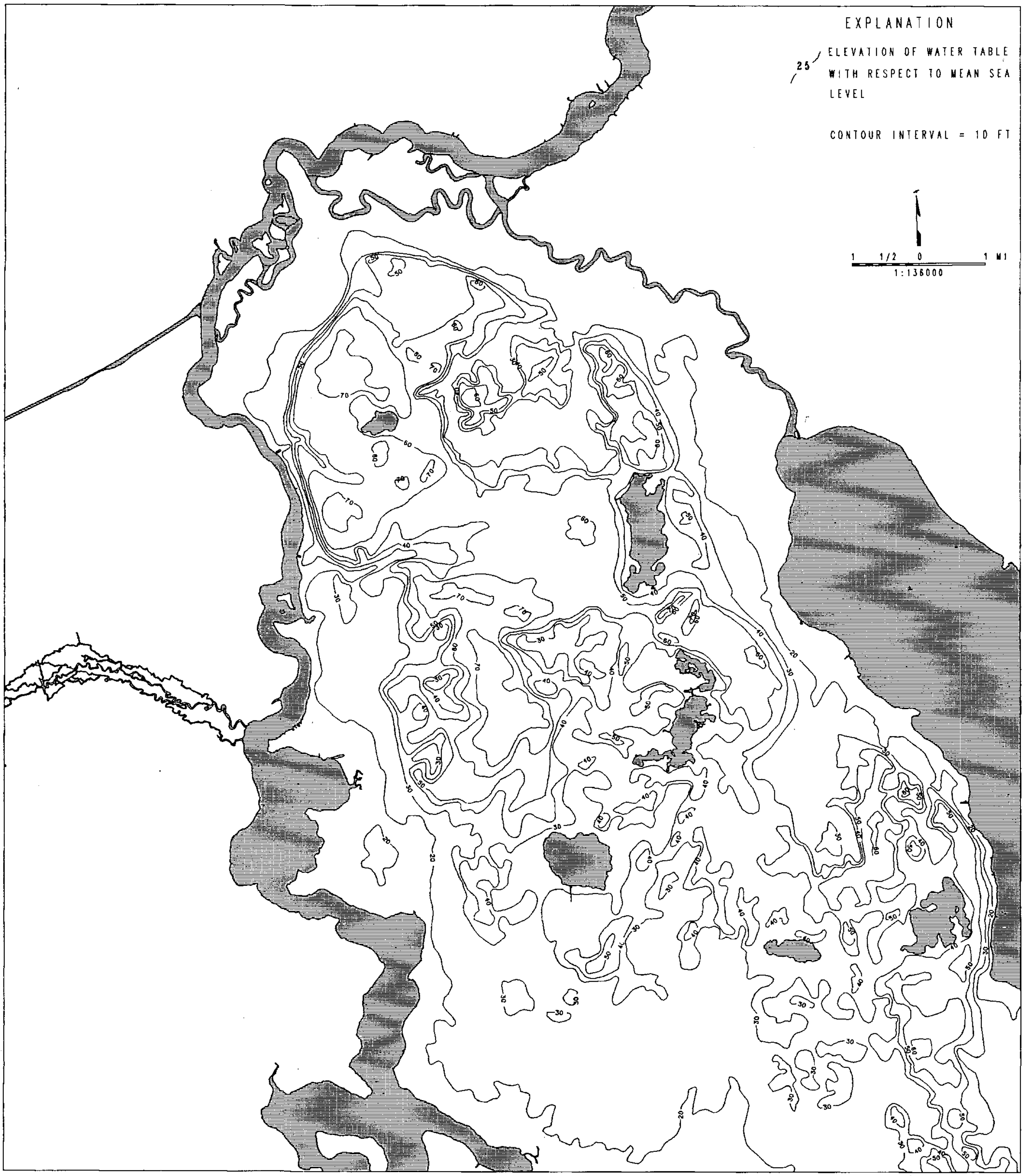

Figure 11. Elevation of the water table, September 1988

interconnection. Hydraulic conductivity is defined as the quantity of water that will flow through a unit cross-sectional area of a porous material per unit of time under a unit hydraulic gradient (Bates and Jackson 1980).

The complex and highly variable lithology, thickness, and integrity of the semi-confining layers results in difficulty in predicting the vertical movement of water and quantifying leakage coefficient values. The leakage coefficient refers to the amount of water that flows to (or from) the Floridan aquifer from (or to) the surficial aquifer. The amount of water moving through the semi-confining layers can be estimated by determining the vertical hydraulic conductivity and the thickness of the clays, as expressed by the leakage coefficient.

$$\text{Leakage coefficient} = \frac{\text{Vertical hydraulic conductivity of semi-confining layers}}{\text{Thickness of semi-confining layers}}$$

Where the overlying semi-confining materials are thick and relatively impermeable, the downward movement of water is inhibited. Where the semi-confining layers are thin, more permeable, or breached by sinkholes, the downward movement of water is greatly increased.

Other investigators, such as Bush and Johnston (1988), reported model simulated leakage coefficients of 2.3×10^{-4} (ft/day)/ft in semi-confined areas. Ryder (1985) reported leakage coefficients ranging from 1.0×10^{-7} to 7.0×10^{-4} (ft/day)/ft in southwest Florida and Duerr, Hunn, Lewelling, and Trommer (1988) reported values of 1.0×10^{-7} to 7.0×10^{-5} (ft/day)/ft in west central Florida. Large variations in vertical hydraulic conductivity and leakage coefficients can occur within the semi-confining layers from site to site, as reported by Bermes, Leve, and Tarver (1963), Knochenmus and Beard (1971), and McGurk, Bond, and Mehan (1989).

The rate of leakage, or recharge, through the semi-confining layers is controlled by the leakage coefficient and the hydraulic pressure difference between the surficial and Floridan aquifers. Values for recharge are highest in areas where the hydraulic pressure difference between the surficial and Floridan aquifers is the highest and where the leakage coefficient is the greatest. The equations representing these relationships are:

$$\text{Recharge} = \text{Leakage coefficient} \times \text{Hydraulic pressure difference}$$

$$\text{Leakage coefficient} = \frac{\text{Vertical hydraulic conductivity of semi-confining layers}}{\text{Thickness of semi-confining layers}}$$

$$\text{Hydraulic pressure difference} = \text{Elevation of water table} - \text{Elevation of potentiometric surface of Floridan aquifer}$$

Recharge to the Floridan Aquifer

The magnitude and direction of the hydraulic gradient, or the hydraulic pressure difference, between the water table in the surficial aquifer and the potentiometric surface of the upper Floridan aquifer is a primary factor determining recharge to the Floridan. The hydraulic pressure difference determines upward or downward leakage through the semi-confining layers.

The potential movement of water from the surficial aquifer to the Floridan aquifer is greatest in the higher topographic elevations of the sandy ridges where the water table is at sufficient depth to allow for the storage of infiltrating water. These areas allow a greater potential hydraulic pressure difference between the surficial and Floridan aquifers due to a rise in the water table during a rainfall event.

The potentiometric surface of an aquifer is the level to which water will rise in tightly cased wells. Water levels in approximately 800 wells in the Floridan potentiometric network are measured in May and September of each year. The September 1988 potentiometric surface of the upper Floridan aquifer in the Crescent City Ridge (Figure 12 and Appendix D) was mapped using water level measurements from the USGS-SJRWMD Floridan aquifer semiannual monitoring well network. The data values for September 1988 were contoured with the ARC/INFO and TIN software. This process revealed two potentiometric highs in the study area: one of

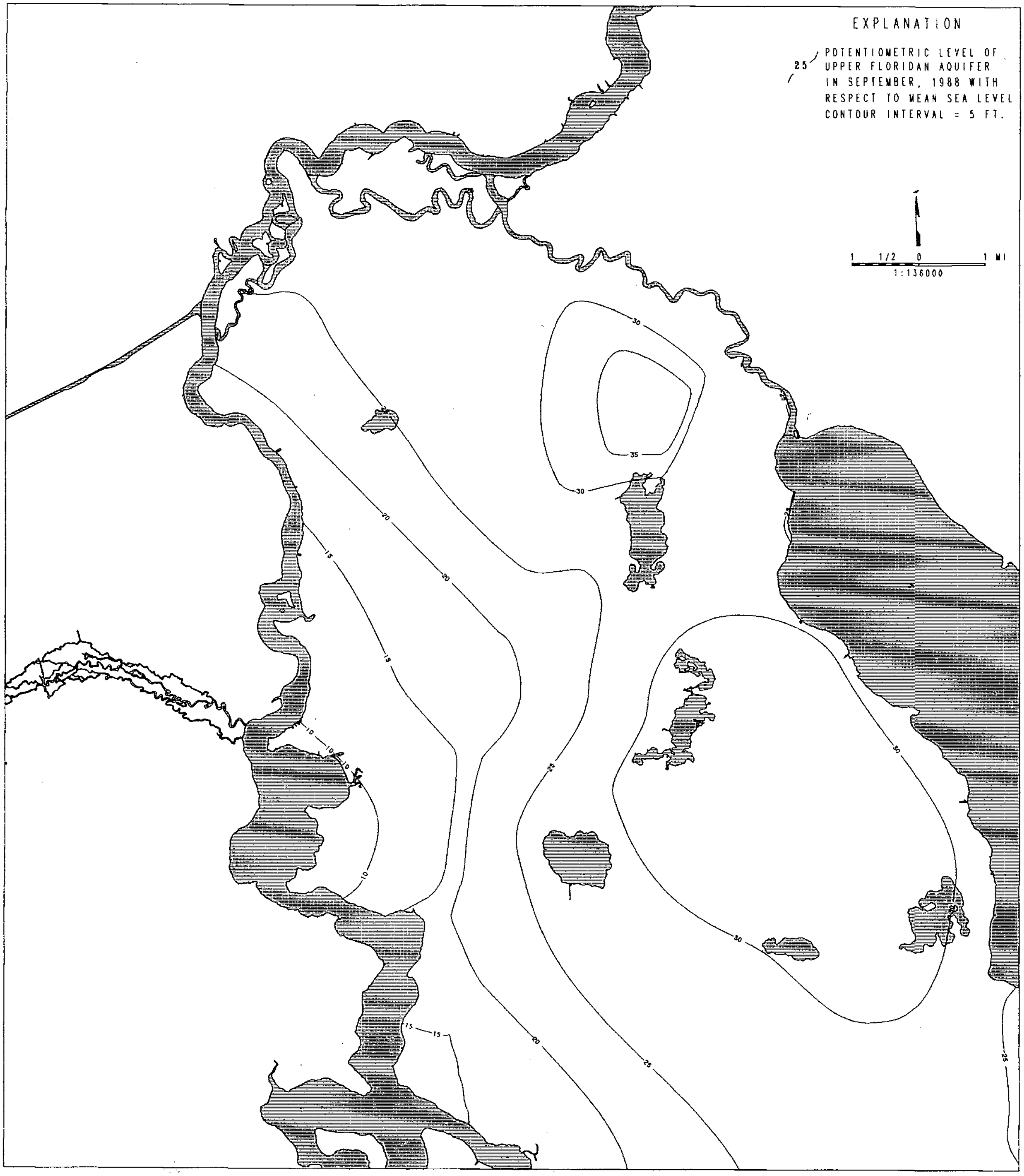

Figure 12. Potentiometric surface of the upper Floridan aquifer, September 1988

approximately 35 ft north of Pomona Park and a broad high of about 30 ft to the west of Crescent City. The general direction of ground water movement is away from the potentiometric highs toward Crescent Lake to the east, the St. Johns River to the west, and Dunns Creek to the north.

A positive hydraulic pressure difference between the water table and the potentiometric surface of the Floridan aquifer produces downward leakage and potential recharge to the Floridan aquifer. As an example, a continuous record of the water levels for a surficial aquifer well (P-0409) and a Floridan aquifer well (P-0408) located on Highway 308B between Welaka and Pomona Park shows that the hydraulic pressure difference between the surficial and Floridan aquifer fluctuates between approximately 45 and 55 ft (Figure 13). In other areas where the Floridan potentiometric surface is higher than the water table, leakage is upward from the Floridan to the surficial aquifer.

In order to establish the hydraulic pressure (head) relationship between the surficial and Floridan aquifers over the entire study area, ARC/INFO and TIN were used to subtract the lattice representing the Floridan potentiometric surface from the lattice representing the water table map. The resultant map depicting this hydraulic pressure difference during September 1988 is shown in Figure 14. Positive hydraulic pressure differences of up to 50 ft occur at the higher elevations of the sand ridges.

Negative pressure differences, or areas where no recharge to the Floridan can occur, are located primarily in low-lying areas along the St. Johns River, Dunns Creek, and Crescent Lake. The areas where leakage is upward from the Floridan to the surficial aquifer define the discharge areas of the Floridan aquifer.

In some areas the hydraulic gradient between the surficial and Floridan aquifers can change direction seasonally from upward in the dry season to downward during the wet season when the water table is at higher elevations. In addition, water level declines in the Floridan from intense pumping may increase the potential for recharge by lowering the Floridan potentiometric surface and increasing the hydraulic gradient between the surficial and Floridan aquifers.

The amount of water that can recharge the Floridan aquifer depends not only on the amount of water infiltrating

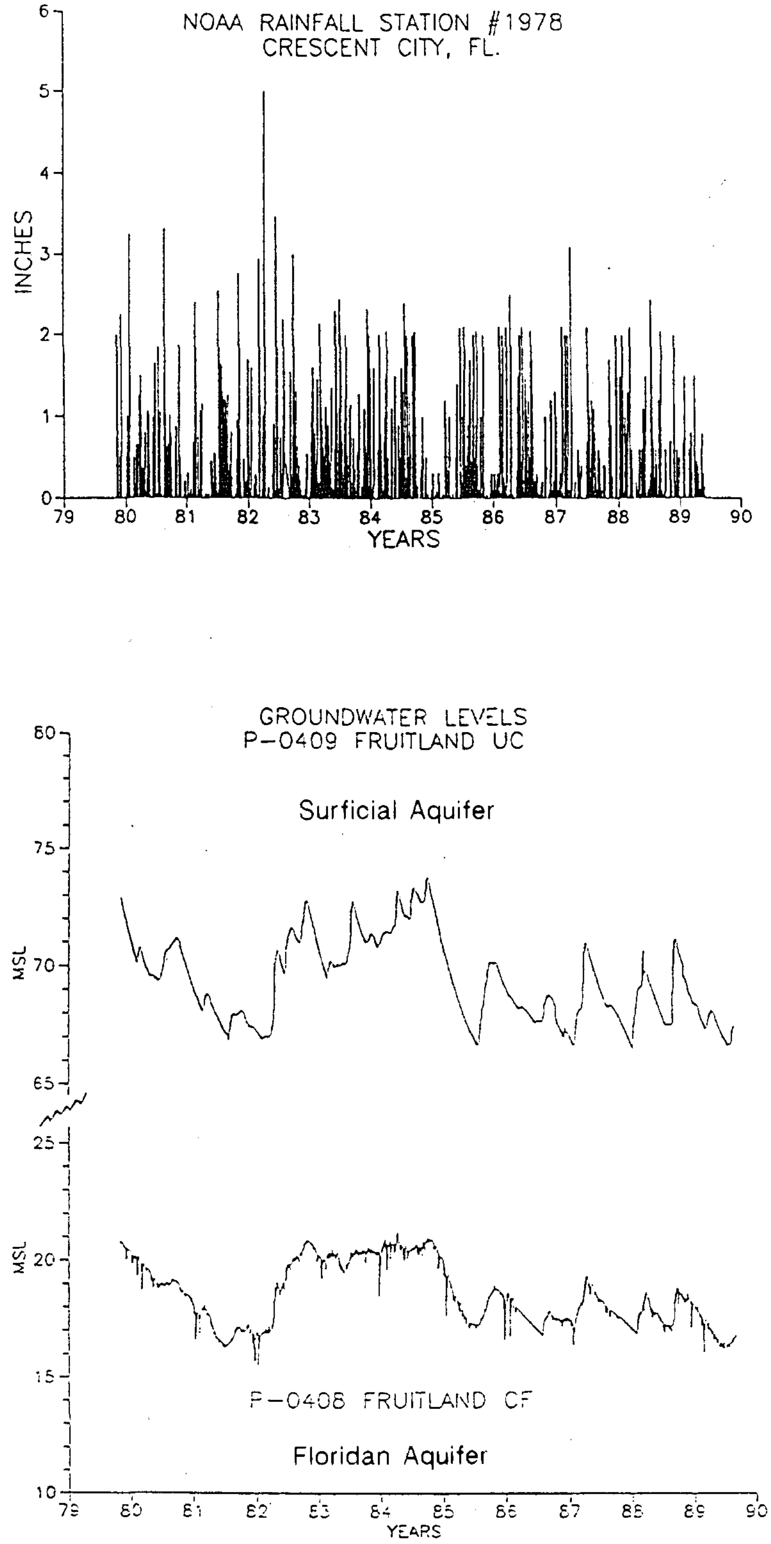

Figure 13. Rainfall data and hydrographs of surficial and Floridan aquifer wells in the Crescent City Ridge

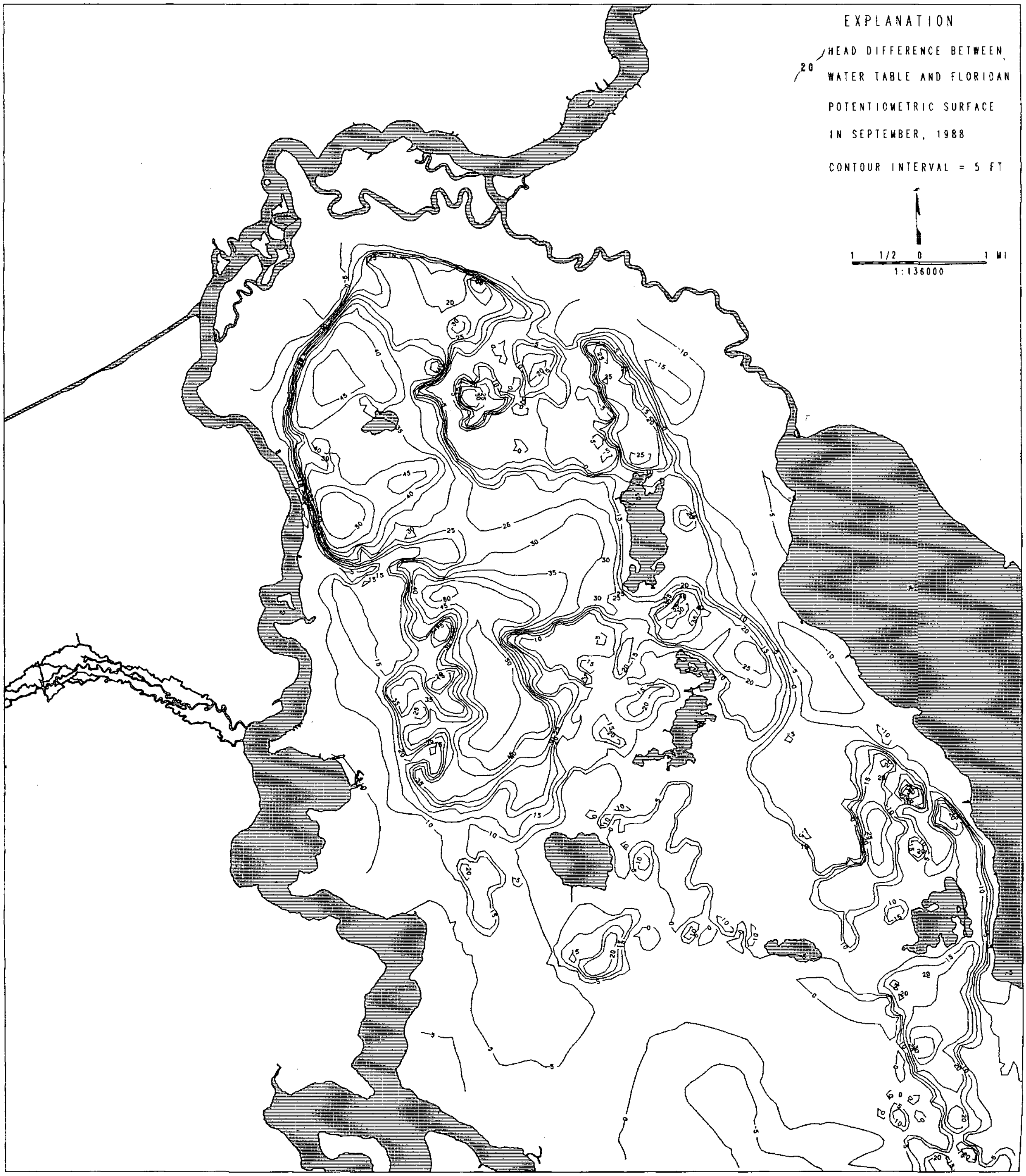

Figure 14. Hydraulic pressure (head) difference between the water table and the Floridan potentiometric surface, September 1988

in the upland, sandy ridge areas, but also on the ability of the overlying sediments and the Floridan aquifer limestone to transmit water (transmissivity) away from the recharge areas and into the regional ground water flow patterns. If the transmissivity of the Floridan limestone is low, water will back up and result in delayed or rejected recharge.

ASSESSMENT AND DELINEATION OF RECHARGE RATES

Rainfall is the source of recharge to the aquifer systems in the study area. The quantity of water potentially available for recharge to the Floridan aquifer depends on the amount that percolates to the surficial aquifer after losses to evapotranspiration, runoff, and lateral subsurface seepage. In an average year with 53 in of rainfall, the normal losses to evapotranspiration, runoff, and lateral seepage are estimated to be approximately 35-40 in/yr. Therefore, on the average, a maximum of 18 in/yr is potentially available for aquifer recharge.

The GIS-driven model used in this study to determine recharge rates to the Floridan aquifer depends on:

1. the hydraulic pressure difference resulting from the elevation and configuration of the water table and of the potentiometric surface of the Floridan aquifer, and
2. the thickness and vertical hydraulic conductivity of the semi-confining layers, expressed as the leakage coefficient.

The map coverages depicting the water table in the surficial aquifer and the potentiometric surface of the Floridan aquifer were analyzed and manipulated to produce the hydraulic pressure difference map. Likewise, the map coverages representing the elevation of the top of the semi-confining layers and the top of the Ocala limestone were subtracted to produce the map of the thickness of the semi-confining layers, a component of the leakage coefficient. Reliable point data were used to generate these required map layers with the GIS software, resulting in a good level of confidence in the resultant map coverages.

The vertical hydraulic conductivity component of the leakage coefficient is more difficult to predict in the study area because of the complexly interbedded and variable sequences of clays, silts, and sands that comprise the semi-confining layers. Two different sources of data were tested to determine an appropriate value for vertical hydraulic conductivity and evaluate the sensitivity of the GIS-driven model to that data.

First, hydraulic conductivities were estimated based on laboratory tests of similar geologic materials (Freeze and Cherry 1979), and then compared to the limited pump test data available for the area. The GIS model was calibrated by varying the value for hydraulic conductivity until the resultant recharge rates contoured in the study area did not exceed the maximum potential recharge of 18 in/yr.

An average hydraulic conductivity value of 2.83×10^{-4} (ft/day)/ft, divided by the varying mapped thickness of the semi-confining layers, produced the most reasonable leakage coefficient values and recharge results when average rainfall, evapotranspiration, and runoff were considered. The resultant leakage coefficient, based on the varying thickness of the semi-confining layers, ranged from 1.0×10^{-5} to 1.0×10^{-4} (ft/day)/ft. This range of leakage coefficients agrees with the leakage values for semi-confined areas reported by Bush and Johnston (1988).

An analysis of the leakage component of the model illustrates that recharge rates are very sensitive to the varying leakage coefficients of the semi-confining layers. However, although the varying leakage coefficient values changed the magnitude of recharge rates, the pattern of contour lines remained the same.

The second source of data used in evaluating leakage coefficients for this study was to use leakage values from a numerical ground water flow model (Tibbals, in press). Leakage coefficient grids (4 x 4 miles) with values ranging from 1.0×10^{-5} to 6.0×10^{-4} (ft/day)/ft were superimposed on the study area. An area-weighted average leakage for each part of the study area covered by a leakage grid was determined and multiplied by the hydraulic pressure difference map coverage. However, the resulting recharge rates were considerably higher than the maximum of 18 in/yr potentially available as recharge. The most probable reasons for the disagreement with expected recharge rates is that the majority of the study area was covered by grids with high leakage coefficients and because of the lack of detail in the 16 square mile grids. Therefore, the modelled leakage grids were not used to determine recharge rates for this study.

The ARC/INFO and TIN software were used for manipulating the coverages to map the recharge rates. The potential recharge to the Floridan aquifer in the Crescent City Ridge was contoured at an interval of 2 in/yr (Figure 15). Distributions of the acreage and the volume of water in million gallons per year (mgy) that could potentially recharge the Floridan aquifer in each 2 in/yr contour interval are listed in Table 1. Graphs of the distributions of the area and volume of water are presented in Figure 16.

The recharge rates are grouped into high (greater than 8 in/yr), moderate (2-8 in/yr), and low recharge (0-2 in/yr). These recommended recharge groups (Figure 17 and Table 1) are delineated based on an assessment of:

1. distribution curves plotting the volume of water recharging the Floridan aquifer within the recharge rate contour intervals,
2. the location of the sandy ridges with the highest topographic elevation, and
3. the location of soils with high infiltration potential.

As defined in this report, areas of high recharge in the Crescent City Ridge are those areas with recharge rates greater than 8 in/yr. However, in other ground water basins the recharge rates in recommended high ground water recharge areas may be greater than or less than 8 in/yr.

High recharge areas with rates greater than 8 in/yr encompass 11,009 acres, or 20 percent of the total recharge area, with 3,206.4 mgy of water that could potentially recharge the Floridan aquifer in a year with average rainfall. Moderate recharge rates of 2-8 in/yr cover 25,140 acres, or 46 percent of the area, with 2,979.0 mgy potentially available as recharge. Low recharge areas with rates from 0-2 in/yr encompass 18,091 acres, or 34 percent of the total recharge area, and contribute 491.3 mgy. Areas of no recharge along the perimeter of the study area encompass 18,911 acres, and were not included in this evaluation.

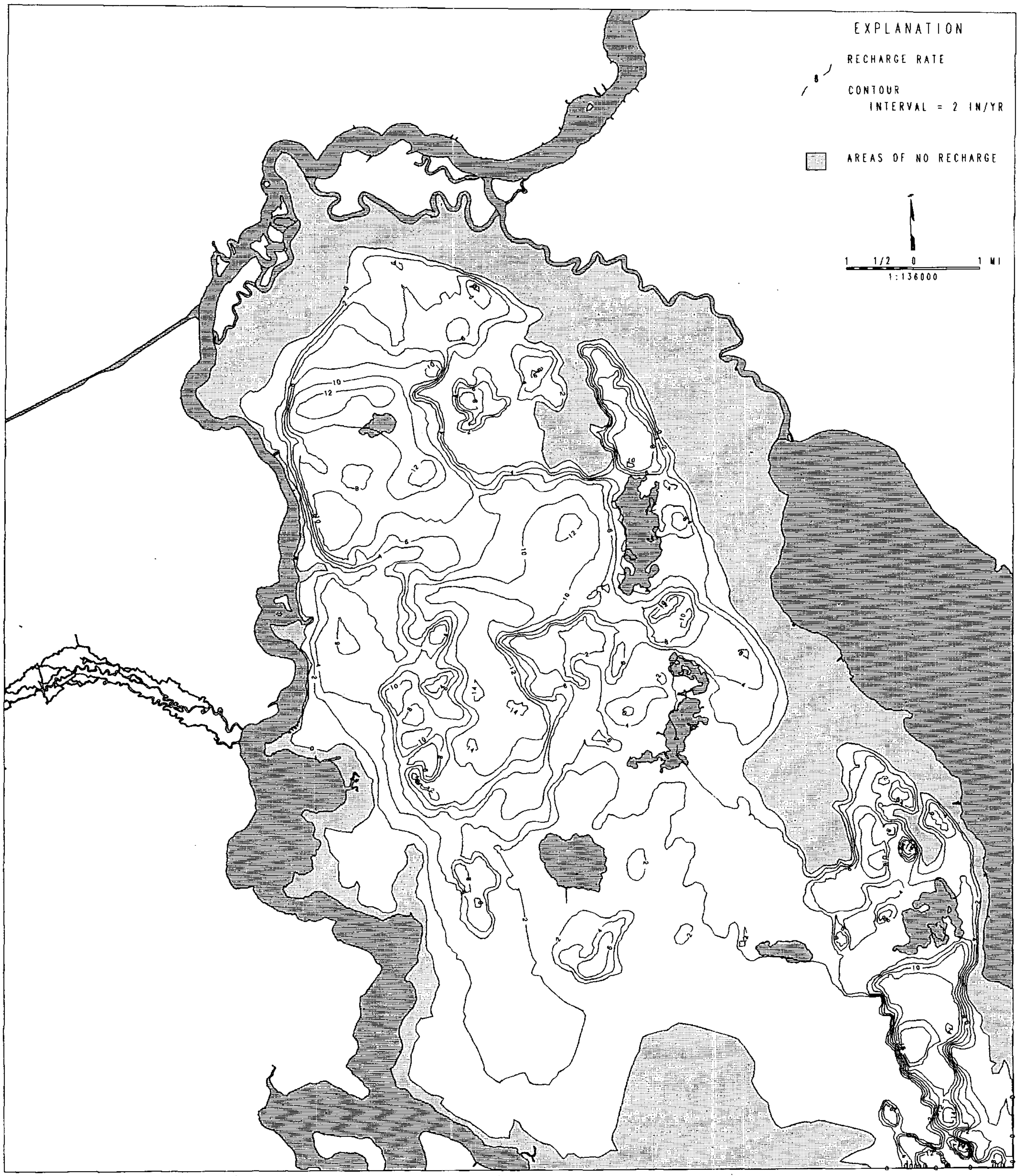

Figure 15. Potential recharge to the Floridan aquifer in the Crescent City Ridge

Table 1. Distributions of the area and volume of water within recharge contour intervals

Recharge Rate (inches/year)	Area (acres)	Volume of Water (acre feet/year)	Volume of Water (million gallons/year)		Recharge Group (inches/year)	Area (acres)	% of Area
0 - 2	18,091	1,507.6	491.3	491.3	Low 0 - 2	18,091	34%
2 - 4	12,817	3,205.3	1,044.1				
4 - 6	7,503	3,126.3	1,018.7	2,979.0	Moderate 2 - 8	25,140	46%
6 - 8	4,802	2,811.7	916.2				
8 - 10	4,716	3,537.0	1,152.5				
10 - 12	3,481	3,190.9	1,039.8				
12 - 14	2,534	2,745.2	894.5	3,206.4	High > 8	11,009	20%
14 - 16	162	202.5	66.0				
> 16	116	164.3	53.6				

Total = 6,677.7 million gallons/year

Area-weighted average recharge rate for Crescent City Ridge = 4.53 inches/year

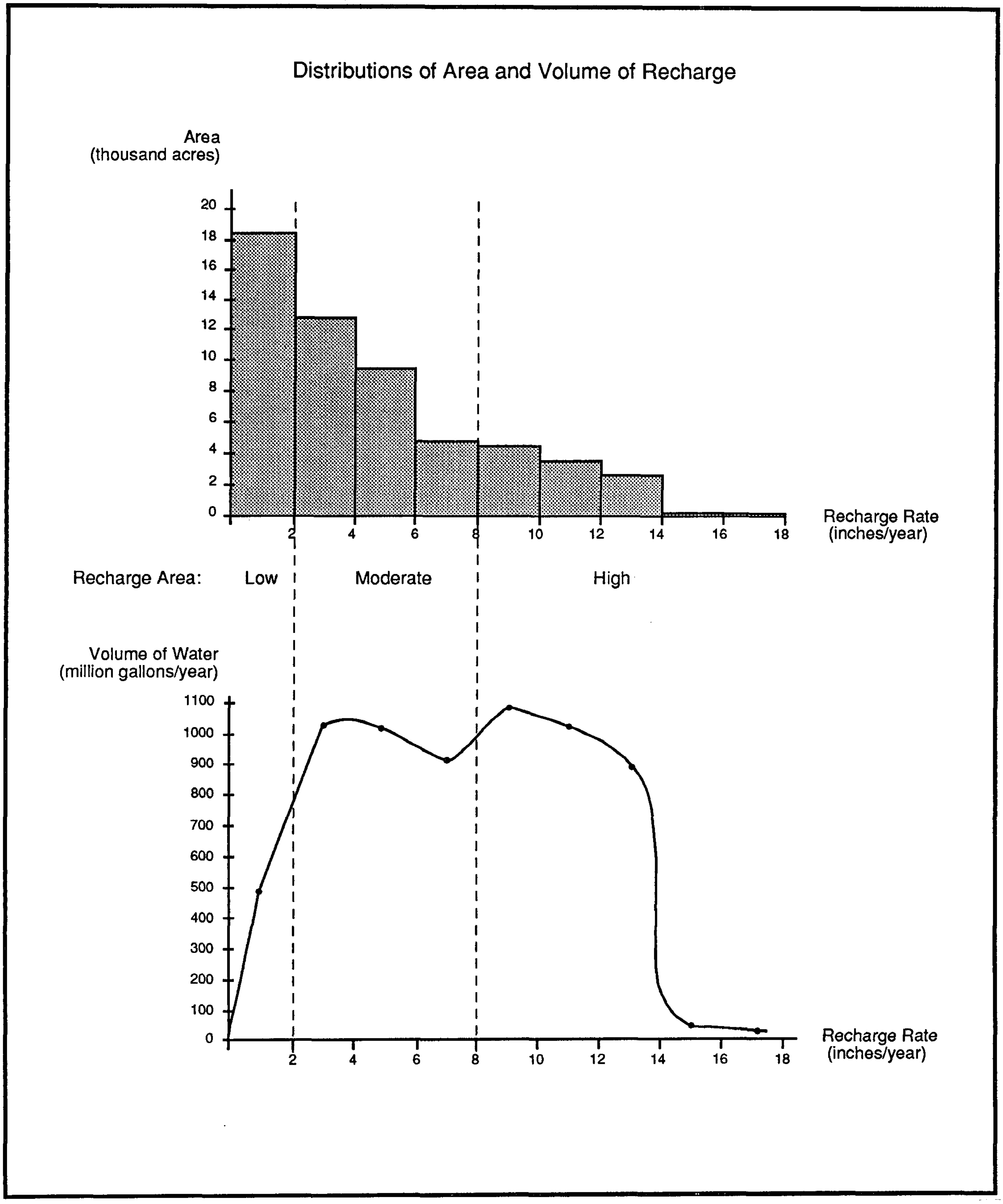

Figure 16. Distribution of area and volume of water recharging the Floridan aquifer for each contour interval in the Crescent City Ridge

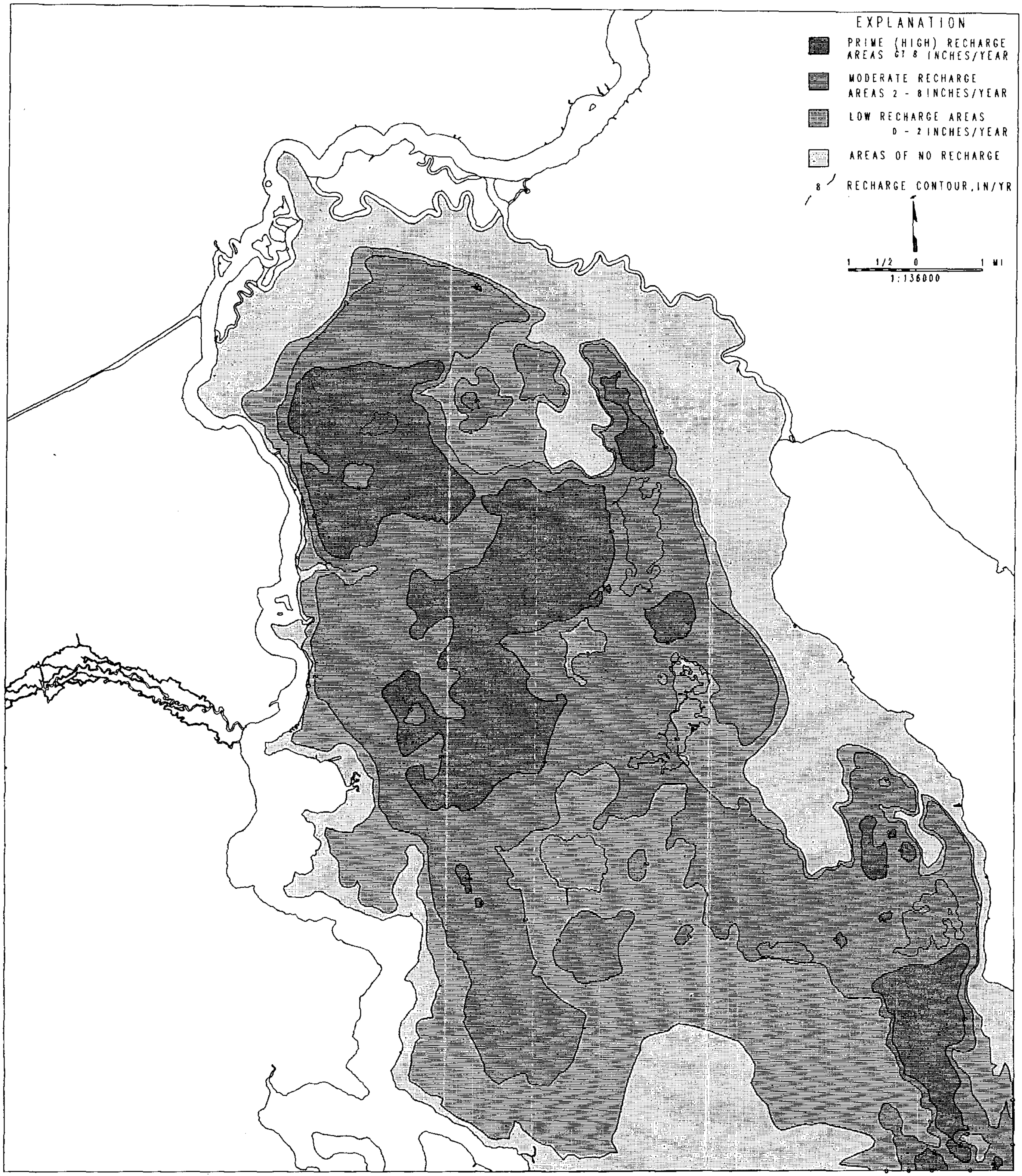

Figure 17. Areas of high, moderate, and low recharge to the Floridan aquifer in the Crescent City Ridge

While the recharge rate per unit area is less in the moderate than the high recharge areas, the total volume or proportion of water contributed in the moderate areas is significant because of the larger area covered. Thus, moderate recharge areas can be just as important as the high recharge areas when the total amount of water that could potentially move into the Floridan aquifer is considered.

The area-weighted average recharge rate for the Crescent City Ridge area is 4.53 in/yr, for a total of 6,677.7 mgy potentially available as recharge to the Floridan aquifer in the Crescent City Ridge of southeast Putnam County in a year with average rainfall. This seems to be consistent with a recharge rate of 5 in/yr reported by Ross and Munch (1979).

CONCLUSIONS

The mapping of ground water recharge areas is an important part of managing ground water resources to ensure future availability and quality. Amendments to the Florida Water Resources Act (Section 373.0395, Florida Statutes) directed each water management district to designate prime recharge areas as part of the ground water basin resource availability inventory.

Recommended prime ground water recharge areas to the Floridan aquifer are areas that contribute the greatest volume of water per unit area to the Floridan aquifer in a ground water basin. Because of the variability in geology and ground water hydrology in the St. Johns River Water Management District (SJRWMD), recharge rates defining prime recharge areas may vary from basin to basin. For the purpose of this study, prime recharge areas are those areas mapped as high recharge areas.

Rainfall is the source of recharge to the surficial, intermediate, and Floridan aquifer systems in the Crescent City Ridge of southeast Putnam County. The major part of rainfall is lost to evapotranspiration, with some water lost to surface runoff and subsurface seepage. The remainder of the rainfall infiltrates through the soil and unsaturated zone to the water table, from which it may recharge the Floridan aquifer system. A thick layer of permeable surficial sediments allows rainfall to infiltrate quickly, minimizes runoff, and provides temporary storage.

The amount of rainfall that is available to recharge the surficial, intermediate, and Floridan aquifers depends on topography, soil types, the underlying geology, and ground water hydrology. The GIS-driven model used in this study to determine recharge rates to the Floridan aquifer are mapped at a contour interval of 2 in/yr based on:

1. the hydraulic pressure difference resulting from the elevation and configuration of the water table and of the potentiometric surface of the Floridan aquifer, and
2. the thickness and vertical hydraulic conductivity of the semi-confining layers, expressed as the leakage coefficient.

The recharge rates are grouped into high (greater than 8 in/yr), moderate (2-8 in/yr), and low recharge (0-2 in/yr). These recommended recharge groups are delineated based on an assessment of:

1. distribution curves plotting the volume of water recharging the Floridan aquifer within the recharge rate contour intervals,
2. the location of the sandy ridges with the highest topographic elevation, and
3. the location of soils with high infiltration potential.

Areas of high recharge (greater than 8 in/yr) in the Crescent City Ridge generally are in the upland, sandy ridges. These relatively higher land surface elevations are characterized by poorly developed surface drainage patterns with little or no runoff, sinkhole-related features, and by a water table that is relatively deep below the land surface, minimizing evapotranspiration. In addition, the most effective recharge areas have soils with high infiltration potential and surficial sediments which are very permeable, have good internal drainage, and are thick enough to absorb a heavy rainfall and a rise in the water table. High recharge areas are also characterized by sufficient hydraulic pressure (head) difference between the surficial and Floridan aquifers to drive water across the semi-confining layers of varying thickness and hydraulic conductivity. The Floridan aquifer in high recharge areas must also have sufficient gradient and transmissivity to move water away from the area. Significant recharge may also occur through lakes and sinkholes, depending on the degree of hydraulic connection and gradient.

While the amount of rain falling in moderate recharge areas (2-8 in/yr) is about the same as in high recharge areas, hydrologic and geologic factors reduce the amount of recharge in the moderate areas. These areas exhibit better developed surface drainage patterns and greater runoff than the high recharge areas. The soils and the surficial sediments may be permeable and allow the infiltration of water to the same or a lesser extent, but the hydraulic pressure difference is not as great as in the high recharge areas and/or where the underlying semi-confining layers are thicker, with lower leakage rates.

In low recharge areas (0-2 in/yr), the surface drainage system is better developed, resulting in higher rates of runoff and evapotranspiration. The soils have low soil infiltration potential and the water table is near the land surface. The hydraulic pressure difference is less in the low recharge areas than in the high or moderate recharge areas and/or where the semi-confining layers is thicker, retarding the downward movement of water. In addition, the mineralization of the ground water is higher in the low recharge areas and in discharge areas due to the increase in the dissolved minerals as water moves down gradient from the high recharge areas.

No recharge to the Floridan aquifer occurs in the low-lying areas along the St. Johns River, Dunns Creek, and Crescent Lake. Areas of discharge are areas where leakage is upward from the Floridan to the surficial aquifer and where the Floridan potentiometric surface is above land surface.

The area-weighted average recharge to the Floridan aquifer in the Crescent City Ridge of southeast Putnam County is 4.53 in/yr. Areas with high recharge rates (greater than 8 in/yr) encompass 11,009 acres, or 20 percent of the total recharge area, with 3,206.4 million gallons/year (mgy) of water that could potentially recharge the Floridan aquifer in a year with average rainfall. Moderate recharge areas (2-8 in/yr) cover 25,140 acres, or 46 percent of the area, with 2,979.0 mgy potentially available as recharge. Low recharge areas (0-2 in/yr) encompass 18,091 acres, or 34 percent of the total recharge area, and contribute 491.3 mgy. While the recharge rate per unit area is less in the moderate recharge areas than the high recharge areas, the moderate areas encompass more acreage and contribute a significant volume, or proportion, of the total recharge to the Floridan aquifer.

The GIS ARC/INFO and TIN software produce high quality hydrologic and geologic map coverages and provide the overlay and analysis functions required for the manipulation of the coverages to produce a map of recharge areas. The GIS also provides quality controlled data coverages that maintain the required resolution, increase the speed of data analysis, and ensure the objective handling of the data. The methodology developed in this pilot study of the Crescent City Ridge can be fine-tuned to account for the specific hydrologic and geologic characteristics of recharge areas throughout SJRWMD.

Appendix A

DATA SET FOR GEOLOGIC MAPS

The maps of the elevation of the top of the semi-confining layers (Figure 5) and the elevation of the top of the Ocala limestone (Figure 7) are based on existing well log data from the St. Johns River Water Management District Geophysical Data Base; the Florida Geological Survey Well Log Data System; and Bermes, Leve, and Tarver (1963).

The map of the thickness of the semi-confining layers (Figure 6) is a result of a GIS subtraction of the lattice coverage representing the top of the semi-confining layers minus the coverage representing the top of the Ocala limestone.

ELEVATION OF TOP OF SEMI-CONFINING LAYERS
(TOP OF HAWTHORN GROUP)

LAT	LONG	ELEVATION (feet, msl)	LAT	LONG	ELEVATION (feet, msl)
293626	8143 4	-67	2925 4	8133 5	7
293625	813827	-60	2923 6	813053	-3
293420	8142 2	-75	292335	813238	-5
293239	814335	-56	292349	813352	0
293322	813947	2	292257	813531	-60
293312	8138 7	-15	292314	813648	-60
293134	814250	-50	292439	813723	-15
293216	814120	-12	292338	813825	-69
293225	813921	2	292621	813749	-20
293224	8138 9	5	292535	813836	-62
293142	813940	5	2925 6	813927	-73
293121	813838	2	292529	814359	-79
293055	813945	5	2928 7	813829	20
293012	8138 5	13	2928 9	814028	0
293643	814026	-70	2929 7	814023	-14
2936 9	813547	-44	292839	813945	6
293414	813326	-50	292858	813757	13
293259	813634	-30	292944	8139 1	15
293213	813524	-2	292215	813330	-53
293113	8137 8	-5	293015	814430	-41
293029	813413	-30	291443	813839	-31
2930 5	813612	-10	291823	812808	-44
292811	813635	12	291916	811840	-32
292919	813536	-30	292908	812154	-58
292817	813346	3	293225	813025	-55
292731	813532	15	292648	813726	24
292526	813555	24	292626	813358	18
292619	813222	12	292733	813136	-13
292644	813137	-18	2926 5	813111	-35
2925 9	813029	-51	2925 4	813136	-9

ELEVATION OF TOP OF OCALA LIMESTONE

LAT	LONG	ELEVATION (feet, msl)
293626	8143 4	-138
293625	813827	-110
293420	8142 2	-124
293239	814335	-88
293322	813947	-82
293312	8138 7	-65
293134	814250	-90
293216	814120	-52
293225	813921	-38
293224	8138 9	-43
293142	813940	-52
293121	813838	-40
293055	813945	-57
293012	8138 5	-35
293643	814026	-120
2936 9	813547	-109
293414	813326	-110
293259	813634	-72
293213	813524	-35
293113	8137 8	-35
293029	813413	-75
2930 5	813612	-50
292811	813635	-30
292919	813536	-75
292939	813435	-74
292817	813346	-60
292731	813532	-27
292648	813726	-16
292526	813555	-16
292626	813358	-20
293225	813035	-105

LAT	LONG	ELEVATION (feet, msl)
292619	813222	-23
292733	813136	-60
292644	813137	-36
2926 5	813111	-60
2925 9	813029	-76
2925 4	813136	-29
2925 4	8133 5	-18
2923 6	813053	-7
292335	813238	-9
292349	813352	-12
292313	813522	-73
292257	813531	-74
292314	813648	-80
292439	813723	-50
292338	813825	-89
292621	813749	-50
292535	813836	-87
2925 6	813927	-91
2928 7	813829	-25
2928 9	814028	-30
2929 7	814023	-36
292839	813945	-33
292858	813757	-33
292944	8139 1	-35
292215	813330	-55
293015	814430	-97
291443	813839	-35
291823	812808	-58
291916	811840	-37
292908	812154	-144

Appendix B

SOIL INFILTRATION POTENTIAL OF THE SOIL ASSOCIATIONS IN THE CRESCENT CITY RIDGE

Appendix B1. Characteristics of the soil associations in the Crescent City Ridge (from Soil Concervation Service general soils map of Putnam County)

Soil Association	Subsoil Texture	Subsoil Permeability	Subsoil Drainage	Surface Slope	Surface Drainage	Soil Infiltration Potential
Astatula	Sand	Very rapid	Excessively drained	Nearly level to sloping	Slow to moderate	High
Candler-Apopka	Sandy, underlain by loamy sand, sandy loam, or loam	Rapid to very rapid	Well to excessively drained	Nearly level to sloping	Slow to moderate	High
Tavares-Myakka-Bassinger	Sand with some weakly cemented lower layers	Moderate to rapid	Moderately well to poorly drained	Nearly level to gently sloping	Slow to moderate	Moderate
Pomello - Satelite - Immokalee	Sand with some weakly cemented lower layers	Moderate to moderately rapid	Moderately well to poorly drained	Nearly level to gently sloping	Slow to moderate	Moderate
Pomello - Myakka	Sand with some weakly cemented lower layers	Moderate to moderately rapid	Moderately well to poorly drained	Nearly level to gently sloping	Slow to moderate	Moderate
Myakka - Wachula - Placid	Sand with some loamy and weakly cemented lower layers	Moderately slow to moderately rapid	Poorly to very poorly drained	Nearly level	Slow to moderate	Moderate
Fresh Water Swamp	Organic material, clay, silt, and loam subject to flooding	Very slow	Very poorly drained	Level to nearly level	Ponded to very slow	Low

Appendix B2. General description of soil properties

Subsoil Texture - particle size distribution of the subsoil

Loam - composed of clay, silt, sand, and organic matter
Clay - less than 0.002 mm diameter
Silt - 0.002 - 0.05 mm diameter
Sand - 0.05 - 2.0 mm diameter
Gravel - 2.0 - 70.0 mm diameter

Subsoil permeability - reflects a soil's ability to transmit water or air through its pore spaces; depends on structure and texture

Very slow - less than 0.06 inches per hour
Slow - 0.06 to 0.2 inches per hour
Moderately slow - 0.2 to 0.6 inches per hour
Moderate - 0.6 to 2.0 inches per hour
Moderately rapid - 2.0 to 6.0 inches per hour
Rapid - 6.0 to 20.0 inches per hour
Very rapid - greater than 20.0 inches per hour

Subsoil drainage - reflects the soil's natural drainage tendencies

Very poorly drained - wet nearly all of the time with a dark grey or black surface layer with a grey or light grey subsoil, with or without mottling in the deeper parts.
Poorly drained - wet for long periods of time, light grey, and may be mottled from the surface downward.
Somewhat poorly drained - wet for significant periods, but not all of the time, and commonly mottled.
Moderately well drained - commonly have a slowly permeable layer in or beneath the solum, with uniform color in the upper part and mottling in the lower part of the profile.
Well drained - commonly of intermediate texture and nearly free of mottling.
Somewhat excessively drained - very permeable and no mottling.
Excessively drained - commonly very porous and permeable with a low water holding capacity.

Surface slope - describes the percent grade of the soil body.

Depressions
Levels
Nearly level
Gently sloping
Sloping, moderately steep
Steeply sloping
Severely sloping - greater than 45 degree slope

Surface runoff - reflects the amount and rate with which rainfall is removed from the surface without infiltrating.

Ponded - in depressions
Very slow - on level or nearly level slopes
Slow - nearly level or gently sloping
Moderate - on moderate slopes
Rapid - on steep slopes
Very rapid - on steep or very steep slopes

Appendix C

WATER TABLE ELEVATION DATA AND STATISTICAL ANALYSIS

Water Table Elevation Data

SITE = Auger hole site identifier
LSE = Land surface elevation at site (feet, msl)
WTE = Water table elevation at site (feet, msl)
LAT LONG = Latitude and longitude of site

SITE	LSE	WTE	LAT	LONG
1	12	9.9	293418	813812
2	59	42.3	293357	813906
3	50	47.6	293348	813926
4	75	62.4	293323	813924
5	75	42.0	293335	813802
6	91	70.7	293252	813949
7	80	57.8	293229	813939
8	87	67.0	293159	814003
9	20	17.1	293155	814103
10	93	69.4	293106	814016
11	32	29.5	293006	814014
12	81	73.3	293108	813917
13	73	67.3	293109	813820
14	66	55.0	293114	813738
15	70	45.0	293227	813818
16	66	55.0	293331	813723
17	70	45.0	293317	813555
18	40	36.2	293244	813534
19	40	15.6	293249	813443
20	45	40.5	293200	813515
21	48	38.9	293128	813518
22	58	48.4	293119	813602
23	71	60.9	293110	813646
24	66	55.2	293043	813601
25	27	22.1	293022	813415
26	52	44.6	293021	813448
27	66	57.8	293004	813601
28	67	53.8	292947	813600
29	63	48.0	292927	813429
30	53	40.0	292908	813558
31	52	41.8	292828	813557
32	52	40.4	292837	813514
33	64	41.0	292835	813422
34	48	41.0	292808	813429
35	57	45.6	292724	813411
36	37	32.7	292811	813256
37	62	50.8	292743	813212

SITE	LSE	WTE	LAT	LONG
38	38	34.1	292655	813134
39	73	60.8	292625	813212
40	58	43.2	292625	813311
41	53	36.4	292531	813307
42	56	46.0	292520	813209
43	64	43.8	292515	813046
44	69	57.9	292429	813059
45	74	66.0	292405	813131
46	60	55.6	292316	813054
47	40	27.7	292245	813034
48	40	34.5	292356	813227
49	42	32.2	292359	813306
50	42	35.6	292429	813323
51	30	27.0	292407	813414
52	23	19.4	292246	813400
53	24	19.9	292258	813531
54	30	25.9	292407	813557
55	38	35.7	292441	813713
56	58	50.9	292518	813607
57	42	38.1	292557	813609
58	45	37.7	292535	813448
59	50	36.4	292736	813534
60	70	44.5	292741	813700
61	57	41.5	292900	813711
62	84	69.7	292939	813740
63	58	37.3	292937	813828
64	94	68.7	292858	813802
65	55	40.9	292856	813855
66	30	23.9	292923	813929
67	26	11.5	292921	814011
68	20	16.7	292823	814026
69	30	28.1	292804	813931
70	22	18.6	292805	813841
71	24	15.7	292713	813926
72	45	35.3	292649	813756
73	26	22.8	292555	813755
74	38	34.7	294537	813837
75	37	33.9	292614	813523
76	30	26.5	292400	813756

Minitab Statistical Analysis

Plot of land surface elevation vs. water table elevation

LSE = Land surface elevation (feet, msl)
WTE = Water table elevation (feet, msl)

```
 WTE (feet, msl)
     -
     -                                               *
*
     -                                          *      * *
**
     -                                          **
   60+                                        * *
     -                                 *   3 *      *
     -                                * *   *
     -                          *     *  *
     -                            * **2   *   2
   40+                     * * 2* 3 **    *      *
     -                  3 3* 2  * *   *
     -                  2  *
     -             3*     *
     -          ** 2
   20+        2*
     -      3  *
     -          *
     - *
     -
      --+---------+---------+---------+---------+---------+-
        15        30        45        60        75        90

                          LSE (feet, msl)
```

```
  The regression equation is:

WTE (feet) = 2.92 feet + 0.745 LSE (feet)

  Predictor          Coef           Stdev       t-ratio
  Constant          2.925           1.575          1.86
  LSE             0.74523         0.02871         25.96

  s = 4.899         R-sq = 90.1%     R-sq(adj) = 90.0%
```

Appendix D

FLORIDAN AQUIFER POTENTIOMETRIC SURFACE DATA

Data for the map of the elevation of the potentiometric surface of the upper Floridan aquifer in the Crescent City Ridge (Figure 10) are from the USGS and St. Johns River Water Management District Floridan water level network. The data were collected in September 1988.

LAT	LONG	WATER LEVEL (feet, msl)	SJRWMD WELL NO.
282245	804716	27.3200	BR0202
29 451	813444	16.8800	L-0066
291344	811557	27.0100	V-0090
2922 4	82 228	50.8500	M-0052
292657	813752	22.1200	P-0416
292737	8122 2	12.3500	F-0182
292859	813757	18.5200	P-0408
293313	811324	14.0100	F-0158
293729	812212	16.1500	SJ0115
294128	812913	16.6600	SJ0263
2943 8	82 022	85.2800	P-0001
2947 1	812633	89.3500	SJ0317
2948 7	82 2 9	82.8400	C-0120
2938 2	815919	81.8500	P-0008
292622	813744	23.4100	P-0373
291343	812546	31.7800	V-0089
2926 6	813125	30.0600	P-0242
292138	82 616	50.5900	M-0012
291216	812156	25.1400	V-0062
292557	8133 4	31.2800	P-0690
293933	813428	18.9100	P-0172
291448	812749	27.1700	V-0225
292736	813134	23.0000	P-0517

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