Water Budget and Water Quality of Ward Lake, Flow and Water-Quality Characteristics of the Braden River Estuary, and the Effects of Ward Lake on the Hydrologic System, West-Central Florida

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 98-4251

Prepared in cooperation with the
CITY OF BRADENTON PUBLIC WORKS DEPARTMENT,
MANATEE COUNTY ENVIRONMENTAL MANAGEMENT DEPARTMENT,
and the **SOUTHWEST FLORIDA WATER MANAGEMENT DISTRICT**

Cover photo:
Ward Lake outfall and gaging station
Photograph by B.R. Lewelling

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By J.T. Trommer, M.J. DelCharco, *and* B.R. Lewelling

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CONVERSION FACTORS, VERTICAL DATUM, AND ADDITIONAL ABBREVIATIONS

Multiply inch-pound unit	By	To obtain
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per day (ft^3/d)	0.02832	cubic meter per day
foot per mile (ft/mi)	0.1894	meter per kilometer
foot (ft)	0.3048	meter
foot squared (ft^2)	0.0929	square meter
foot per second (ft/s)	0.3048	meter per second
foot per day (ft/d)	0.3048	meter per day
inch (in.)	25.40	millimeter
inch per day (in/d)	25.40	millimeter per day
inch per year (in/yr)	25.40	millimeter per year
mile (mi)	1.609	kilometer
million gallons (Mgal)	3,785	cubic meter
million gallons per day (Mgal/d)	0.43816	cubic meter per second
square mile (mi^2)	2.590	square kilometer
ton, short	0.9072	megagram
ton per year, (ton/yr)	0.9072	megagram per year

Temperature can be converted between degrees Fahrenheit (ºF) and degrees celsius (ºC) as follows:

$$°F = 9/5\ (°C + 32)$$

$$°C = 5/9\ (°F – 32)$$

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

ABBREVIATED WATER-QUALITY UNITS

mg/L = milligram per liter
(mg/L)/yr = milligram per liter per year
ppt = parts per thousand
μS/cm = microsiemens per centimeter at 25 degrees Celsius
(μS/cm)/yr = microsiemens per centimeter per year

ADDITIONAL ABBREVIATIONS

CCI = Conservation Consultants Inc.
FDEP = Florida Department of Environmental Protection
GCREC = Gulf Coast Research and Education Center
IFAS = Institute of Food and Agricultural Sciences
NADP/NTN = National Atmospheric Deposition Program/National Trends Network
NOAA = National Oceanic and Atmospheric Administration
ROMP = Regional Observation Monitoring Well Program
SWFWMD = Southwest Florida Water Management District
USEPA = U.S. Environmental Protection Agency
USGS = U.S. Geological Survey

Water Budget and Water Quality of Ward Lake, Flow and Water-Quality Characteristics of the Braden River Estuary, and the Effects of Ward Lake on the Hydrologic System, West-Central Florida

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Abstract

The Braden River is the largest tributary to the Manatee River. The river was dammed in 1936 to provide the city of Bradenton a source of freshwater supply. The resulting impoundment was called Ward Lake and had a storage capacity of about 585 million gallons. Reconstruction in 1985 increased the size of the reservoir to about 1,400 million gallons. The lake has been renamed the Bill Evers Reservoir and drains about 59 square miles. The Braden River watershed can be subdivided into three hydrologic reaches. The upper reach consists of a naturally incised free-flowing channel. The middle reach consists of a meandering channel affected by backwater as a result of the dam. The lower reach is a tidal estuary.

Water budgets were calculated for the 1993 through 1997 water years. Mean surface-water inflow to Ward Lake for the 5-year period was 1,645 inches per year (equivalent depth over the surface of the lake), or about 81.8 percent of total inflow. Mean ground-water inflow was 311 inches per year, or about 15.5 percent. A mean of 55 inches of rain fell directly on the lake and accounted for only 2.7 percent. Mean surface-water outflow was 1,736 inches, or about 86.4 percent of total water leaving the lake. There was no net ground-water outflow from the lake. Mean surface-water withdrawal for public supply was 229 inches per year, or about 11.4 percent. Mean evaporation was 45 inches and accounted for only 2.2 percent of the mean outflow. Change in lake storage on the budget was negligible.

Most chemical constituents contained in water flowing to Ward Lake meet the standards specified by the Florida Department of Environmental Protection and the U.S. Environmental Protection Agency. Phosphorus is the exception, exceeding the U.S. Environmental Protection Agency limits of 0.10 milligram per liter in most samples. However, the source of the phosphorus is naturally occurring phosphate deposits underlying the watershed. Organic nitrogen and orthophosphate are the dominant species of nutrients in the streams and the lake. A major source of water to the streams is the surficial aquifer system. Mineralized water pumped from the intermediate aquifer system and the Upper Floridan aquifer for irrigation of agricultural areas or golf courses has influenced the chemical composition of the surficial aquifer and surface-water systems.

The Braden River estuary receives freshwater inflow from Ward Lake and from three major streams discharging downstream from the dam. Salinity levels in the estuary are affected by freshwater flow from these sources and by antecedent conditions in the estuary prior to flow events. The lowest salinity levels are often measured at the confluence with Williams and Gap Creeks rather than at the outfall from the lake.

The chemical composition of water flowing from the tributaries to the estuary is similar to the chemical composition of water in the tributaries flowing to Ward Lake and does not appear to be affected by brackish water from high tides. Nitrogen concentrations in water from Glen Creek were greater than in water from all other tributaries in the watershed. Fertilizer from orange groves and stormwater runoff from urban and industrial areas affect the water quality in Glen Creek.

The effects of the reservoir on the hydrology of the watershed were to change the middle reach of the river from a brackish water estuary ecosystem to a freshwater lake ecosystem, raise water levels in the surficial aquifer system adjacent to the river, change water quality, and reduce freshwater flow to the estuary during periods of low flow. The lake acts as a sink for total organic carbon, dissolved solids, calcium, chloride, and sulfate, thereby decreasing loads of these constituents to the estuary.

INTRODUCTION

The Braden River is the largest tributary to the Manatee River (fig. 1). In 1936, the river was dammed, forming Ward Lake. The reservoir provides a source of freshwater supply for the city of Bradenton, a city with a population of more than 46,600 people (University Press of Florida, 1994). Ward Lake drains an area of about 59 square miles (mi^2).

Population growth and increasing land development within the watershed have caused rapid land-use changes. Areas once used primarily for agricultural and low-density residential purposes are rapidly being developed for large medium-to-high density subdivisions with associated golf courses and shopping centers. These changes will affect the hydrology and possibly the water quality of the watershed. Potential environmental stresses related to the effects of modifying freshwater flows from Ward Lake to the downstream estuary are also a concern. The Southwest Florida Water Management District (SWFWMD) is regulating water-supply withdrawals from the lake and is concerned that further withdrawals may affect the

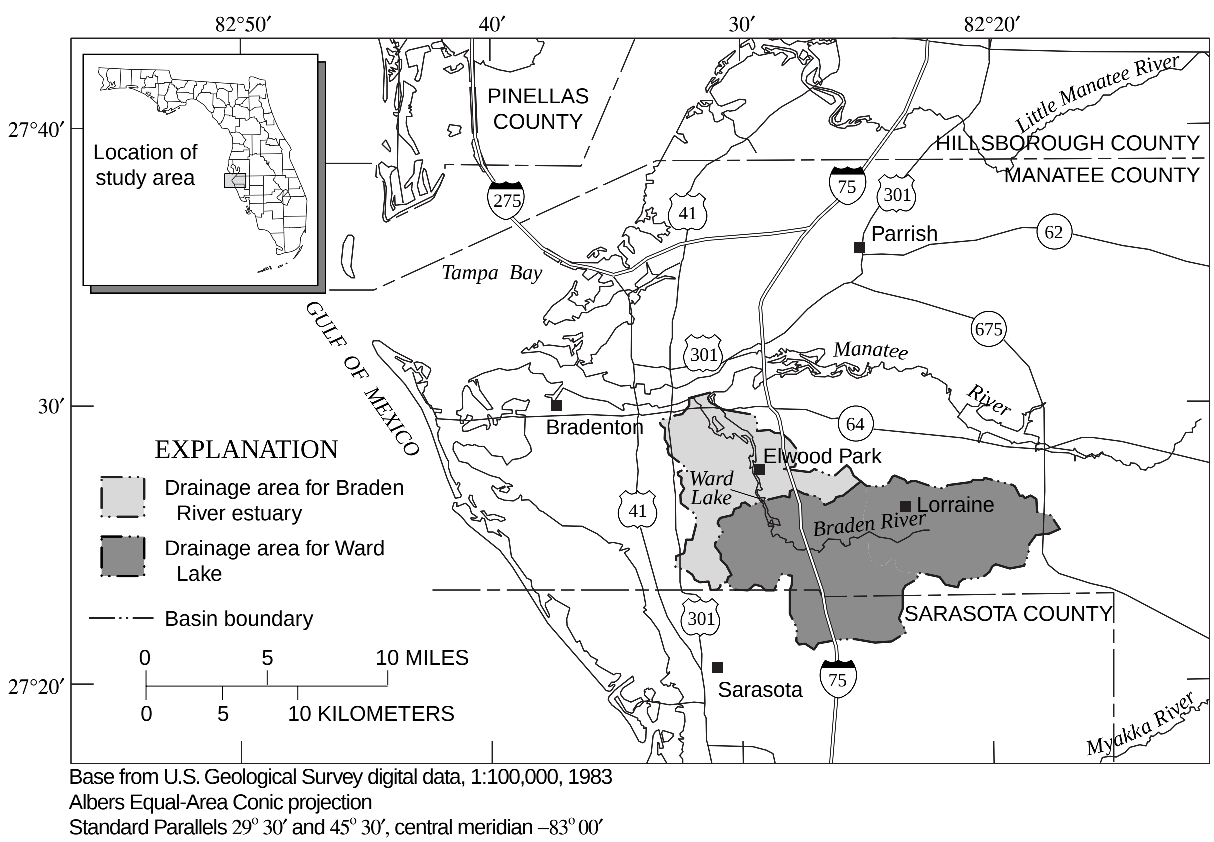

Figure 1. Location of the study area in west-central Florida and the drainage area for the Braden River.

downstream estuary. A detailed water budget and information on the quality of water in the Braden River watershed will be helpful for future resource development and planning.

The U.S. Geological Survey (USGS) began a study of the Braden River watershed in 1992. This study was a cooperative effort with the city of Bradenton Public Works Department, Manatee County Environmental Management Department, and the Southwest Florida Water Management District. Streamflow data were previously collected between 1988 and 1992, at seven gaging stations above Ward Lake, in cooperation with the Manatee County Environmental Action Commission.

Purpose and Scope

The results of the study are presented in two reports. The first report, published in 1997 (DelCharco and Lewelling), provided (1) a hydrologic description of the Braden River watershed and its major subbasins, (2) a description of the data-collection network established to monitor surface drainage, and (3) a description of the method used for measuring discharge at the Ward Lake outfall. This is the second report and presents the 1993-97 water year water budgets for the lake, surface- and ground-water quality, the characteristics of the downstream estuary, and the effects of the reservoir on the hydrologic system. Surface inflows from the upstream tributaries to the lake, rainfall on the lake, surface flows from the immediate area around the lake, ground-water inflow and outflow, evaporation, pumpage to the water plant, and discharge at the outfall are included in the water budget. Water-quality data for Ward Lake, the upstream tributaries, the shallow ground water, and the Braden River estuary are also presented. Water-quality data include specific conductance and concentrations of major ions, nutrients, and total organic carbon. Estimates of chemical loading, tide, and salinity data for the estuary are presented. The effects of the reservoir on the hydrologic system are also discussed.

Acknowledgments

The authors gratefully acknowledge the cooperation and assistance from personnel with the city of Bradenton, Manatee County, and the Southwest Florida Water Management District. Special thanks are given to the late Earl Crawley and to William Taylor, past Directors of the Bradenton Public Works Department; Keith McGurn and Clyde Crews, Bradenton Water Treatment Plant; and to Robert Brown and Greg Blanchard, Manatee County Department of Environmental Management, for their many contributions to the study. Special thanks are given to C.D. Stanley at the Gulf Coast Research and Education Center, Institute of Food and Agricultural Sciences (IFAS), University of Florida, for providing climatological data from the Bradenton 5 ESE weather station.

DESCRIPTION OF THE STUDY AREA

In 1936, the Braden River was dammed about 6 miles (mi) upstream of the mouth to provide a freshwater source for the city of Bradenton's water-supply needs. The dam, an 838-foot (ft) broad-crested weir, created a backwater condition within the banks of the natural channel extending upstream for about 6 mi. The resulting 167-acre reservoir was named Ward Lake (fig. 2). The lake provided storage for about 585 million gallons (Mgal) and is the sole source of freshwater for the city of Bradenton. An average of 5.7 million gallons per day (Mgal/d) was withdrawn from the lake during the study period.

In 1985, a reservoir was constructed by expanding the lake, increasing storage capacity to about 1,400 Mgal. The reservoir was excavated to a depth of about 10 ft below sea level, from the dam to about 1 mi upstream. A thick clay layer underlies the area at this depth. The dam, constructed by driving concrete sheet piles about 10 ft into the clay layer (to a depth of about 20 ft below sea level), was modified at this time to minimize freshwater seepage losses to the estuary or saltwater seepages to the lake that might occur during high tides. Continuous, synthetic, membrane liners were applied to both sides of the dam, extending out along the riverbed and covered with fill material and rip-rap. The crest of the dam ranges from 3.82 to 4.10 ft above sea level. Ward Lake was renamed the Bill Evers Reservoir after it was expanded. This report refers to the reservoir as Ward Lake and refers to the dam as the Ward Lake outfall based on current USGS geographical naming convention.

DelCharco and Lewelling (1997) subdivided the Braden River watershed into three hydrologic reaches based on streamflow characteristics. These were referred to as the upper, middle, and lower reaches. The upper reach of the river consists of a naturally incised channel that is free of any backwater effects

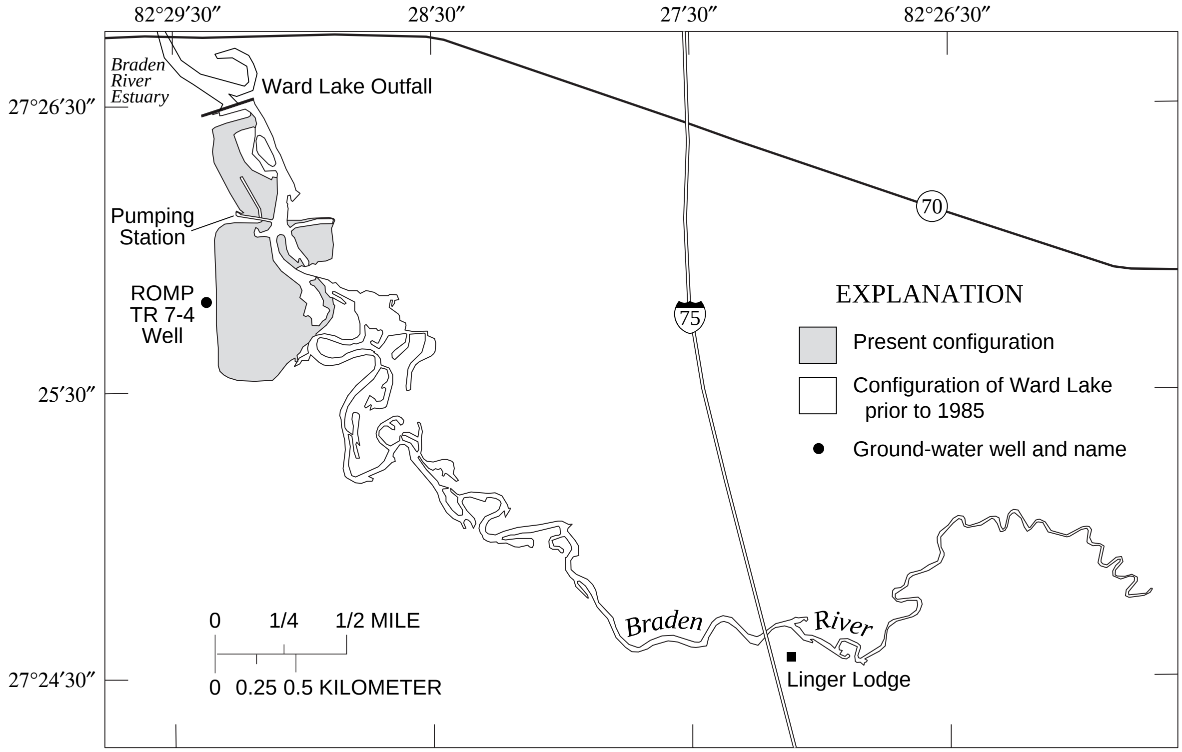

Figure 2. Configuration of Ward Lake prior to 1985 and at present.

from Ward Lake. Land-surface elevations in this part of the watershed range from about 100 ft above sea level along the eastern watershed boundary to about 25 ft above sea level about 0.5 mi east of Interstate Highway 75 (fig. 2). The middle reach of the river consists of meandering channels with many oxbows and is characteristic of streams having variable discharge and easily eroded banks. This is similar to the structure of the river channel below the outfall and is probably a remnant of estuarine conditions that existed prior to construction of the dam. Backwater conditions exist throughout the entire reach. This reach is synonymous with Ward Lake. Land-surface elevations in this part of the watershed average about 25 ft above sea level. The Ward Lake outfall forms the downstream boundary of the middle reach. The lower reach of the river is brackish and tidal, extending from below the outfall to the confluence with the Manatee River. Land-surface elevations are commonly less than 15 ft above sea level in the watershed of the lower reach of the river.

Daily mean discharge at the outfall, computed for the study period (October 1992 to September 1997) was about 69 cubic feet per second (ft^3/s), or about 45 Mgal/d. Computed mean discharges are strongly affected by high-flow events and are not representative of typical flow patterns (Hammett, 1992). Daily mean discharge was reached or exceeded only 20 percent of the time at the outfall. Median discharge was only 6.5 ft^3/s, or about 4 Mgal/d. Discharges of 0.10 ft^3/s or less occurred about 30 percent of the time. There were many days when no flow occurred over the dam.

Climate in the area is subtropical and humid, with an average annual temperature of 72 ^oF. Mean annual rainfall from 1954 to 1993 was 56.0 in. (National Oceanic and Atmospheric Administration, 1993). About 60 percent of all rainfall occurs during intense, localized thunderstorms from June through September. Winter frontal storms account for most of the rainfall from December through March.

Thick sequences of carbonate rocks and clastic deposits underlie the study area. A multilayered ground-water flow system exists within these deposits and has been divided into three hydrogeologic units: the surficial, intermediate, and Floridan aquifer systems.

The surficial aquifer system is contiguous with land surface and consists of unconsolidated sediments composed mostly of quartz sand with some phosphatic sand, clayey sand, clay, marl (carbonate sediments of low permeability), organic debris, and phosphate that range in age from Holocene to Pliocene. The deposits become increasingly phosphatic and clayey with depth. Discontinuous clay stringers interfinger the unconsolidated materials and can restrict vertical ground-water flow. Some of the wetlands in the watershed may be perched because of underlying clay stringers. The thickness of the surficial aquifer system is variable in the watershed, but is usually less than 40 ft. At a SWFWMD Regional Observation and Monitoring Well Program (ROMP) well site adjacent to Ward Lake (ROMP TR 7-4), the thickness was 21 ft, and at a test site near Linger Lodge the thickness ranged between 16 and 29 ft (fig. 2). The surficial aquifer system is the principal hydrogeologic unit that exchanges water with the surface-water system.

The intermediate aquifer system "includes all rocks that lie between and collectively retard the exchange of water between the overlying surficial aquifer system and the underlying Floridan aquifer system" (Southeastern Geological Society, 1986, p. 5). Sediments in the intermediate aquifer system consist of layers of limestone, dolostone, quartz and phosphatic sand, clayey sand, clay, and chert, ranging in age from Pliocene to Oligocene (Barr, 1996, p. 10). Many of these layers are thin and areally discontinuous. Three small water-bearing zones were identified at the ROMP TR 7-4 site. The intermediate aquifer system is a confined system with a seasonal upward head gradient in the study area; therefore, the potential for upward migration of water to the surficial aquifer system exists. However, the intermediate aquifer system acts as a single confining unit at the ROMP TR 7-4 site (Decker, SWFWMD, written commun.,1989), restricting vertical ground-water flow to the surficial aquifer system. The intermediate aquifer system is about 350 ft thick.

The Floridan aquifer system consists of a vertically continuous sequence of carbonate rock of Tertiary age which is subdivided into the Upper Floridan aquifer, the middle confining unit, and the Lower Floridan aquifer. The middle confining unit and the Lower Floridan aquifer contain saltwater. The Upper Floridan aquifer contains freshwater and is the primary source of irrigation water in the watershed. Head gradient in the Upper Floridan aquifer is also upwards and may provide some recharge to the intermediate aquifer system. However, because of the confining characteristics of the intermediate aquifer system, the Upper Floridan aquifer has little or no direct effect on the surficial aquifer or surface-water systems in the watershed.

DATA COLLECTION

Streamflow, lake-stage, ground-water level, climatological, and pumping data were necessary to construct a detailed water budget for Ward Lake. Water-quality data also were used to complete the evaluation of the Braden River watershed. Data collection methods are summarized below.

Seventeen surface-water stations were established to characterize surface drainage in the Braden River watershed. Thirteen stations were continuous stations and four were partial-record stations (fig. 3, table 1). Peak water-level elevations for high-flow events were collected at the four partial-record stations located on tributaries in the upper reach of the watershed. Discharge was computed at 11 of the continuous stations using a stage/discharge relation developed from a series of streamflow measurements made at each station. Seven of the continuous stations were located upstream of the Ward Lake outfall and were used to measure inflow to Ward Lake. One continuous station located at the outfall was used to measure outflow from the lake. Three continuous stations located below the outfall on tributaries to the Braden River estuary were used to estimate freshwater inflow to the estuary from sources other than Ward Lake. The remaining two continuous stations were used to collect water-level and specific conductance data in the tidal reach of the river. A detailed discussion of the gage network and surface-drainage characteristics for each of the subbasins can be found in the report by DelCharco and Lewelling (1997).

Three well transects were constructed to define the ground-water component of flow to the river (fig. 3, table 2). Each transect consisted of five or six wells arranged in a line perpendicular to the river and completed into the surficial aquifer system. Two sets of paired wells, one at the water table and one near the bottom of the aquifer system, were placed at each end of the transect to monitor head differences. The first transect (T1) was located near Linger Lodge, an area where the river is affected by backwater from the outfall and is representative of the ground-water flow conditions around Ward Lake. The surficial deposits at the Linger Lodge transect are relatively shallow (about 20 ft thick at the river). The river is incised through these deposits to the underlying clay. All flow from the surficial deposits is to the river (fig. 4a). The second transect (T2) was located in the upper reach of the river near Lakewood Ranch. Surficial deposits are about 30 ft thick. The river is incised into, but not through the surficial deposits in this area. Distribution

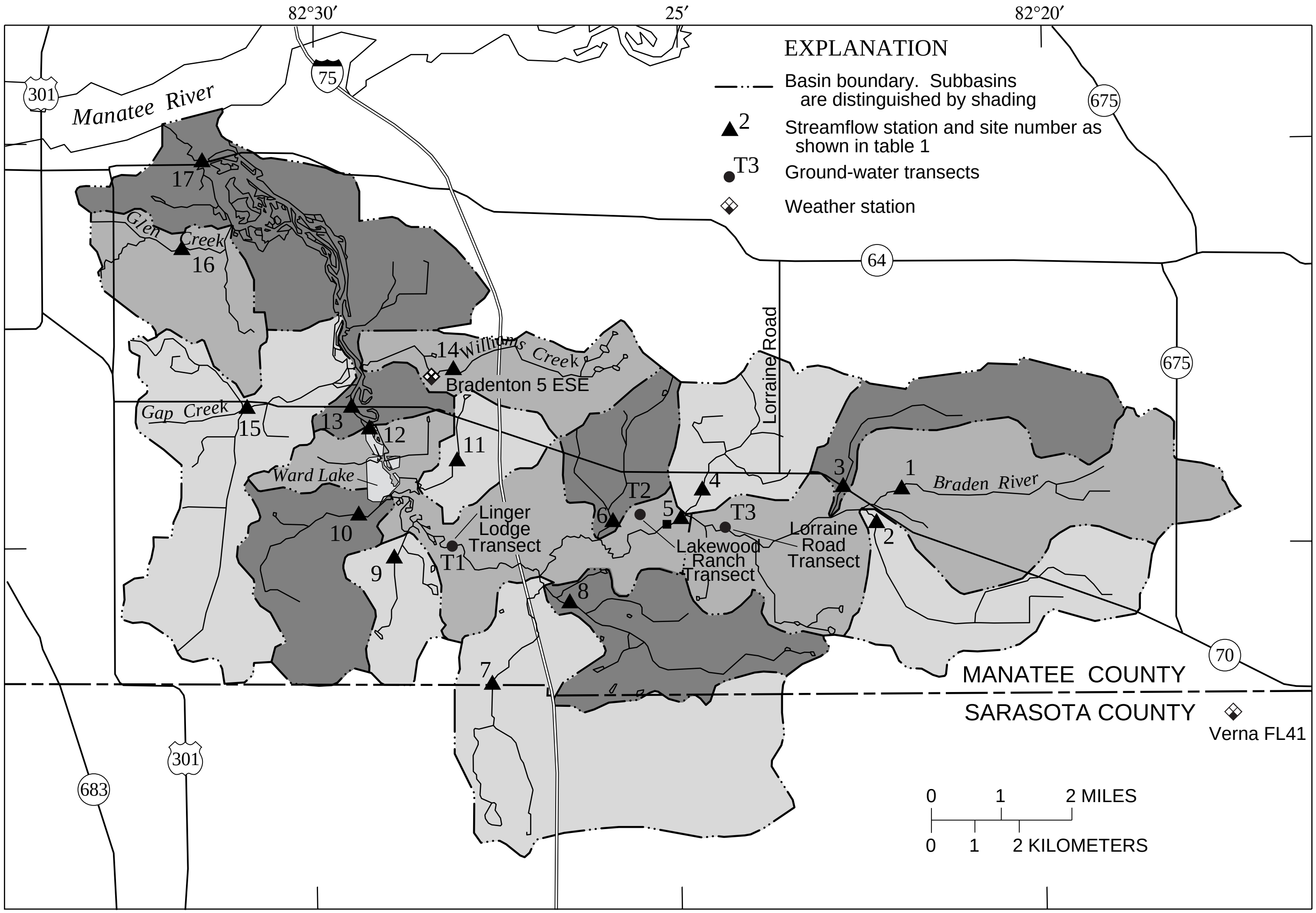

Figure 3. Ward Lake drainage basin and data-collection network.

Table 1. Braden River streamflow station network

Site number[1]	USGS downstream order number	Station	Type of record	Period of record (water years)	Drainage area (square miles)
1	02300024	Braden River near Verna	partial	1993-97	6.8
2	02300025	Tributary No. 1 Braden River near Lorraine	partial	1993-97	5.2
3	02300027	Tributary No. 2 Braden River near Lorraine	partial	1993-97	3.8
4	02300031	Wolf Slough near Lorraine	partial	1993-97	4.0
5	02300032	Braden River near Lorraine	continuous[2]	1988-97	25.6
6	02300034	Hickory Hammock Creek near Lorraine	continuous[2]	1988-97	2.4
7	023000355	Cooper Creek near Sarasota	continuous[2]	1988-97	9.0
8	02300036	Tributary No. 1 to Cooper Creek near Lorraine	continuous[2]	1994-97	4.4
9	02300037	Cedar Creek near Sarasota	continuous[2]	1988-97	1.7
10	02300038	Rattlesnake Slough near Sarasota	continuous[2]	1988-97	3.8
11	02300039	Nonsense Creek near Bradenton	continuous[2]	1988-97	1.4
12	02300042	Ward Lake Outfall near Bradenton	continuous[2]	1976-97[3]	59.2
13	02300044	Braden River near Elwood Park	continuous[4]	1992-97	60.0
14	02300050	Williams Creek near Bradenton	continuous[2]	1994-97	2.7
15	02300056	Gap Creek near Bradenton	continuous[2]	1995-97	7.2
16	02300062	Glen Creek near Bradenton	continuous[2]	1995-97	2.5
17	02300064	Braden River near Bradenton	continuous[4]	1994-97	83.0

[1]Site location shown on figure 3.
[2]Discharge station.
[3]Stage at Ward Lake has been recorded from 1942-47 and from 1976-present, discharge has been computed since 1992.
[4]Stage and conductivity (tidal station).

of hydraulic head indicates that all flow from the surficial aquifer system discharges to the river (fig. 4b). The third transect (T3) was also located in the upper reach of the river at Lorraine Road. Surficial deposits are about 30 ft thick at this site. The river is not deeply incised in this area and flow in the surficial aquifer system is more regional with only partial discharge to the river (fig. 4c).

Climatological data used in the water budget were obtained from the Bradenton 5 ESE station, operated by the Gulf Coast Research and Education Center (GCREC), University of Florida, IFAS, and from the Verna FL41 station, operated by the National Atmospheric Deposition Program/National Trends Network (NADP/NTN). Rainfall data from the Bradenton 5 ESE and Verna FL41 stations (fig. 3) were used as a watershed average in the water budget. Pan-evaporation data used in the budget was collected at the Bradenton 5 ESE station.

The quality of inflow to and outflow from the lake was determined from samples collected at the seven discharge stations upstream of the outfall, at the outfall, and from wells at each of the transects. Samples were collected periodically at the outfall between April 1966 and August 1997, from the upstream discharge sites between June 1993 and August 1997, and from transect wells between September 1995 and August 1997. Water-quality samples also were collected at the three discharge stations downstream from the outfall and at the upper tidal station (fig. 3) to evaluate inflow to the estuary. Samples were collected at the discharge stations between March 1995 and March 1997, and between June 1993 and February 1997 at the tidal site. Samples were analyzed for specific conductance, major ions, nutrients, organic carbon, and dissolved solids.

Table 2. Ground-water transect wells

Well identification	Type of record	Depth of well below land surface (feet)	Length of screen (feet)
Transect No. 1 near Linger Lodge (T1)			
272504082280501	periodic	14.7	2.0
272504082280502	periodic	9.2	2.0
272504082280503	periodic	10.3	9.5
272504082280504	periodic	21.4	2.0
272504082280505	periodic	6.8	2.0
Transect No. 2 at Lakewood Ranch (T2)			
272517082250901	periodic	22.9	2.0
272517082250902	periodic	10.9	2.0
272517082250903	periodic	25.9	2.0
272517082250904	periodic	9.7	2.0
272517082250905	periodic	6.9	2.0
Transect No. 3 near Lorraine Road (T3)			
272507082235901	periodic	21.6	2.0
272507082235902	periodic	6.3	2.0
272507082235903	periodic	19.6	2.0
272507082235904	periodic	7.1	2.0
272507082235905	periodic	11.3	9.5
272507082235906	periodic	1.5	1.5

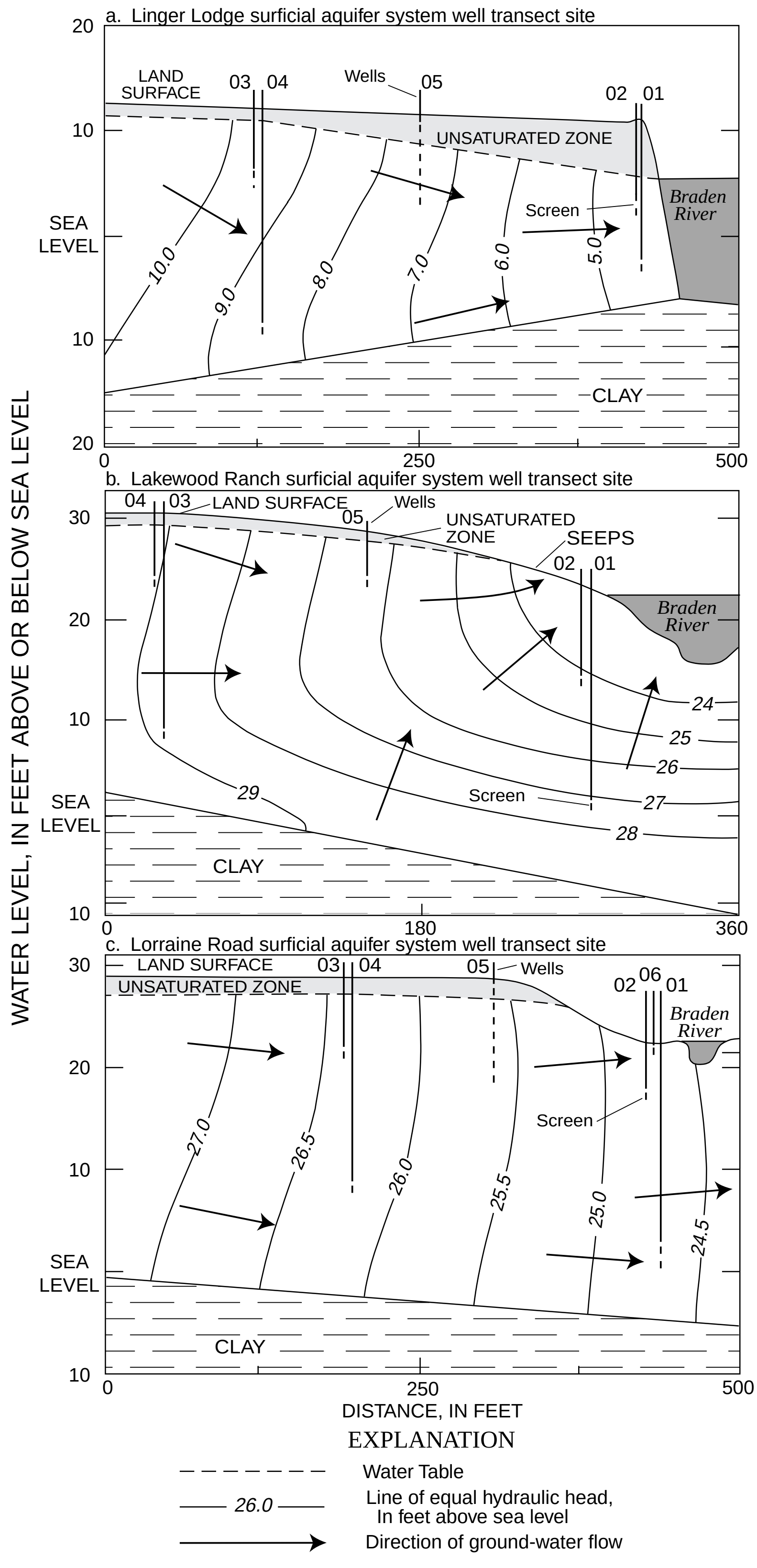

Figure 4. Ground-water flow in the surficial aquifer system at the (a) Linger Lodge, (b) Lakewood Ranch, and (c) Lorraine Road well transects (transect locations shown in fig. 3).

WATER BUDGET FOR WARD LAKE

A water budget for a lake is an expression of the conservation of water mass for the lake, and can be simply stated as the inflow equals the outflow plus the change in storage of the lake for a given period of time (Lee and others, 1991, p. 14). The water budget for Ward Lake is based on water years (October 1 through September 30) for the 5-yr period from October 1, 1992, through September 30, 1997. Data used to construct the water budget were reported as daily values, except for the rainfall data from the Verna FL41 weather station, which was reported as weekly values. Subsequently, all daily value data were summarized to correspond to the weekly Verna rainfall data, and the water budget was calculated using a weekly time step. The unit volume for each term is expressed as an equivalent depth, in inches, over the surface of the lake. A lake surface area of 14,525,500 ft^2 (333 acres) was used to convert all volumes to equivalent depths. The specific components of the water budget used for this study are shown in the following equation.

$$\text{Rainfall + Surface-Water Inflow + Ground-Water Inflow = Evaporation + Surface-Water Outflow + Ground-Water Outflow + Withdrawal for Water Supply + Storage Change} \quad (1)$$

Most components of a water budget are easily measured or estimated. Ground-water flow is the exception, and is an important and largely overlooked component of water budgets because it is the most difficult to quantify as it cannot be measured directly. Cross-sectional flow-net analysis was used to estimate ground-water flow for this study. Flow-net analysis is a graphical technique that can be used to describe steady-state, two dimensional ground-water flow in a homogeneous, isotropic aquifer. A detailed discussion of flow-net analysis can be found in Freeze and Cherry (1979, p. 168-172). A conceptual model of the cross-sectional flow nets used to estimate ground-water flow to Ward Lake are shown on figure 5. For this report, ground-water flow was calculated using the following equation:

$$Q = \frac{mKH}{n} \quad (2)$$

where

Q is the inflow, in cubic feet per day;
m is the number of streamtubes, dimensionless;
K is the horizontal hydraulic conductivity, in feet per day;
H is the head drop across the flow net, in feet; and
n is the divisions of head in the flow net, dimensionless.

Flow nets were constructed using periodic head measurements collected at each of the Linger Lodge transect wells (T1, fig. 3). The Linger Lodge transect was used because it is representative of the area around the lake. Both inflow to the lake from the surficial aquifer system and outflow to the surficial aquifer system from the lake were calculated using flow-net analysis.

Inflow to the lake occurs when ground-water levels are greater than lake stage. Flow nets were constructed for inflow conditions that ranged from a lake stage that was near a record low of 1.7 ft below sea level and ground-water levels ranged from 0.6 ft below sea level to 4.3 ft above sea level at each end of the transect, to about a normal wet-season condition, when the lake was about 4.3 ft above sea level and ground-water levels ranged from 4.6 to 9.0 ft above sea level at each end of the transect.

Outflow to the surficial aquifer system occurs when lake stage is greater than ground-water heads. Five periodic head measurements made during the study reflect these conditions. However, lake stages only averaged about 0.2 ft higher than ground-water levels for these measurements. Continuous ground-water head data are not available for evaluation, but outflow conditions appear to be of limited extent and duration.

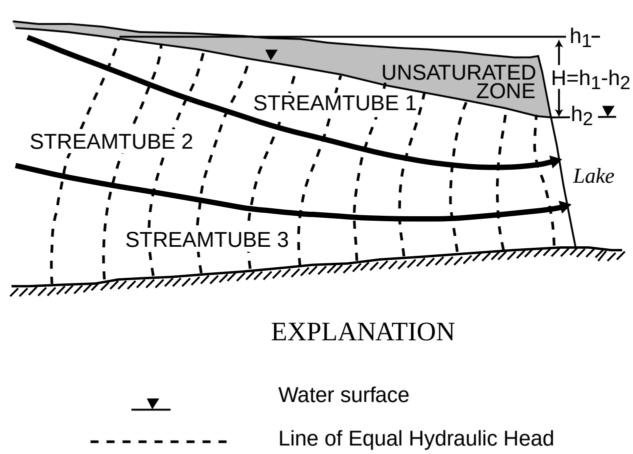

Figure 5. Conceptual model of the cross-sectional flow nets used to calculate ground-water flow to Ward Lake.

The horizontal hydraulic conductivity values of the surficial aquifer system, calculated from slug tests conducted by consultants for an aggregate mine located in the Cooper Creek subbasin, were assumed to be representative of the area around Ward Lake and were used in the flow-net analysis. Estimated values ranged from 0.77 to 3.6 ft/d (Environmental Affairs Consultants, 1995), indicating variable lithology. A value of 2.0 ft/d was used in all flow-net calculations and represents an average hydraulic conductivity.

Results indicate that flow from the surficial aquifer system to the lake could range from 0.87 to 2.7 ft^3/d per square foot of the area of discharge and that flow from the lake to the surficial aquifer system could average about 0.25 ft^3/d per square foot of the area of discharge. In most areas, the lake directly overlies the clay layer; therefore, there is little or no flow through the lake bottom. A range of flow was then calculated by multiplying the discharge rate derived by flow-net analysis by the length of the shoreline and the effective depth of the lake. The length of the shoreline is about 21 mi (110,880 ft). The effective depth is dependent on the lake stage.

Inflow

Ward Lake receives water from precipitation falling directly on the lake, surface-water inflow, and ground-water inflow from ungaged areas around the lake. Rainfall was measured at two nearby weather stations. Surface inflow included direct runoff from ungaged areas. Surface inflow was measured at seven gaging stations and estimated for the ungaged areas based on runoff-per-square-mile calculations from the gaged areas. Ground-water inflow from the surficial aquifer system was calculated using flow-net analysis.

Daily rainfall data from the Bradenton 5 ESE and weekly rainfall data from the Verna FL41 weather stations were used in the water budget. The Bradenton 5 ESE station is located near the northwestern watershed boundary, about 0.5 mi north of the Ward Lake outfall, and the Verna FL41 station is located near the Manatee-Sarasota County line, about 2 mi southeast of the eastern watershed boundary (fig. 3). A weekly sum of the daily rainfall data from the Bradenton 5 ESE station was averaged with the Verna FL41 station data and used as the watershed rainfall component of the water budget. Annual rainfall at the Bradenton 5 ESE and Verna FL41 weather stations and the annual sum of weekly rainfall averages used in the water budget for water years 1993-97 are listed in table 3.

Table 3. Annual rainfall at the Bradenton 5 ESE and Verna FL41 weather stations and annual sum of weekly rainfall averages used in the water budget for water years 1993-97

Water year	Rainfall station (inches)		Annual sum of weekly station averages (inches)
	Bradenton 5 ESE	Verna FL41	
1993	46.13	53.21	49.67
1994	50.89	50.51	50.70
1995	61.23	61.47	61.35
1996	56.94	50.90	53.92
1997	61.17	58.21	59.69
Mean annual	55.27	54.86	55.07

Annual rainfall averages ranged from about 50 to about 61 in., with a mean of 55 in. Rainfall is the smallest part of the inflow component of the water budget.

Surface-water inflow to Ward Lake was measured at seven streamflow stations (fig. 3 and table 1) and includes all ground-water inflow, rain falling directly on the streams, and direct surface runoff to the streams above the stations. Six stations were located on tributaries, and one was located on the main stem of the Braden River above Ward Lake. Eighty-two percent of the drainage area to Ward Lake was monitored by this network. Surface-water inflow from the ungaged area of each subbasin was estimated by calculating runoff-per-square-mile from the gaged area and applying it to the remaining ungaged area. A runoff-per-square-mile average for all the subbasins was used to estimate runoff from the ungaged area adjacent to the lake. Surface-water inflow calculations for the water budgets were made using continuous streamflow data collected during the period from October 1992 through September 1997, except at Tributary No. 1 to Cooper Creek. Continuous streamflow data were collected at this station from October 1994 through September 1997. Data used in the water budget for the 1993 and 1994 water years, for this subbasin, were estimated using average runoff-per-square-mile calculated from adjacent subbasins. Discharge from each subbasin, the ungaged area around Ward Lake, and the total surface-water inflow to Ward Lake for each water year is shown in table 4.

Surface-water flow is the largest inflow component of the water budget. Total surface-water inflow to Ward Lake for each water year ranged from 1,311 to 2,416 in/yr, with a mean value of 1,645 in/yr.

Table 4. Surface-water inflow to Ward Lake, water years 1993-97

Station[1]	Water years				
	1993	1994	1995	1996	1997
Braden River near Lorraine	752	819	1,156	443	724
Hickory Hammock Creek	71	57	97	65	58
Cooper Creek	317	176	395	238	104
Tributary No. 1 to Cooper Creek	137	115	218	107	86
Cedar Creek	70	51	99	100	92
Rattlesnake Slough	108	74	119	154	104
Nonsense Creek	38	32	98	77	77
Ungaged area around Ward Lake	160	142	234	127	134
Total surface-water inflow to Ward Lake	1,653	1,466	2,416	1,311	1,379

[1]Station location shown on figure 3 and described in table 1.

Ground-water inflow to Ward Lake, estimated using flow-net analysis, could range between 988,796 and 1,206,374 ft^3/d or between 0.82 and 1.0 in/d. The greatest inflow to the lake was calculated for the dry period when the lake stage was about 1.7 ft below sea level, indicating that lower lake stages induce ground-water inflow to the lake. Daily inflow corresponding to a recorded lake stage was calculated by developing an equation based on a linear relation between the calculated daily inflow for the highest and lowest lake stages used in the flow nets. The result was multiplied by seven to convert the daily inflow to a total weekly inflow. The following equation was used:

$$Q = (Q_h + ((E_h - E_c) \times 0.032)) \times 7 \qquad (3)$$

where

Q is inflow, in inches per week;
Q_h is the highest inflow to the lake calculated using flow-net analysis, in inches per day;
E_h is the lake stage used in the high inflow analysis, in feet;
E_c is the current lake stage, in feet; and
0.032 is the inflow per 0.01 ft of change in lake stage, in inches per day.

The annual ground-water inflow component to the lake ranged from 303 to 316 in/yr, with a mean of 311 in/yr. Ground-water inflow to the lake is the second most significant part of the inflow component and has largely been overlooked when comparing inflow to and outflow from Ward Lake. Table 5 summarizes the inflow component of the water budget.

Outflow

Water from Ward Lake is lost to evaporation, surface-water outflow, ground-water outflow, and withdrawals for water supply. Evaporation from the lake surface was estimated from pan-evaporation measurements made at the Bradenton 5 ESE weather station. Surface-water outflow was measured at the Ward Lake outfall. Ground-water outflow was estimated as a residual of the water budget. Surface-water withdrawals for public supply were reported by the city of Bradenton.

Table 5. Estimated water-budget for Ward Lake, water years 1993-97

[Unit volume is expressed as an equivalent depth, in inches, over the surface of the lake]

	Water years					Mean
	1993	1994	1995	1996	1997	
Annual Inflow						
Rainfall	50	51	61	54	0	55
Surface water	1,653	1,466	2,416	1,311	1,379	1,645
Ground water	313	316	313	303	311	311
Total	2,016	1,833	2,790	1,668	1,750	2,011
Annual Outflow						
Evaporation	46	44	42	44	47	45
Surface water	1,551	1,310	2,492	1,351	1,977	1,736
Ground water	0	0	0	0	0	0
Withdrawal for water supply	232	231	220	225	237	229
Lake storage change	-2	2	-3	-2	7	<1
Total	1,827	1,587	2,751	1,618	2,268	2,010
Residual	189	246	39	50	-518	1

The rate of evaporation depends on many factors, including temperature, the amount of solar radiation, vapor pressure, and wind speed. Lake evaporation is often estimated from regional pan-evaporation data by applying a pan coefficient, defined as the ratio of the theoretical free-water surface evaporation to pan evaporation (Farnsworth and others, 1982). Lee and Swancar (1997, p. 26) derived a pan-evaporation coefficient of 0.75 by comparing corrected energy-budget evaporation values to observed pan-evaporation values for a lake in central Florida. This coefficient agrees closely with the long-term annual average coefficient of 0.74 used by Farnsworth and others (1982). An annual mean coefficient of 0.75 was applied to pan-evaporation data from the Bradenton 5 ESE weather station to estimate evaporation from Ward Lake. Annual evaporation losses ranged from 42 to 47 in., with a mean of 45 in.

All surface-water outflow from Ward Lake discharges at the outfall. Water-budget calculations were made using continuous streamflow data collected at the outfall during the period from October 1992 through September 1997. Surface-water outflow for each water year ranged between 1,310 and 2,492 in/yr, with a mean value of 1,736 in/yr (table 5).

Flow from the lake to the surficial aquifer system occurs periodically, when ground-water heads are lower than lake stage. Flow-net analysis indicates that flow to the surficial aquifer system could average about 289,017 ft^3/d, or about 0.25 in/d. Weekly outflow was calculated by multiplying the average daily outflow derived from flow-net analysis by seven, and entered into the budget when measurements or storm conditions in the watershed indicated probable flow reversal from the lake to the surficial aquifer system. However, outflow from the lake is small and each annual water budget reflects a net ground-water inflow to the lake; therefore, flow from the lake to the ground-water system was reported as zero for each annual budget.

Ground-water outflow can also occur as seepage around or through the outfall. Two dye studies were conducted to assess the extent of seepage. A network of surficial aquifer system wells was installed around both ends of the dam. Rhodamine dye was used as a fluorescent tracer and traveltime between wells was monitored. The results indicate small lateral seepage losses of 0.0011 ft^3/s to the surficial aquifer around the west-end of the Ward Lake outfall. Rhodamine dye was also placed along the length of the upstream side of the dam at a time when the no flow over the dam was occurring. Water samples were collected along the length of the downstream side of the dam for a period of 36 hours, with no detection of the dye. Thirty-six hours was considered adequate to detect any significant leakage through or under the dam (DelCharco and Lewelling, 1997). Outflow from seepage around the outfall was not included in the water budgets because it was less than 0.03 in/yr.

Ward Lake is the sole source of water supply for the city of Bradenton. Permitted annual average withdrawals from the lake are 6.95 Mgal/d, with a peak monthly withdrawal of 8.19 Mgal/d. The surface-water withdrawal component for each of the annual water budgets was calculated based on pumpage volumes supplied by the city of Bradenton. Withdrawals ranged from 220 to 237 in/yr, with a mean value of 229 in/yr (2,073 Mgal). Table 5 summarizes the outflow component of the water budget.

Budget Summary

Components of a water budget, whether they are measured or calculated variables, have associated errors based on the degree of uncertainty of the measurements, limitations of methods, and the assumptions made to calculate values. The rainfall, surface inflow and outflow, and withdrawal for supply data used in this study are considered to be reliable. The calculated values of lake evaporation and lake storage can be considered less reliable because of the use of offsite pan-evaporation data and an estimated pan coefficient. Lake stage also can be considered less reliable because of the uncertainty associated with accurately assessing the surface area of the lake. The least reliable component of the budget is ground-water flow. When all the measured or calculated components were entered into each annual water budget, residual values (the imbalance between the inflow and outflow components) ranging from -518 to +246 in/yr remained (table 5). The residual term in a water budget is an accumulation of all the errors in the components of the budget.

Based on the total mean values from water years 1993-97, about 81.8 percent of the inflow to Ward Lake comes from surface water. Ground water accounts for 15.5 percent of the mean total inflow, and rain falling directly on the lake accounts for only 2.7 percent. Surface-water outflow accounts for about 86.4 percent of the total mean outflow from the lake during the study period. Withdrawal for water supply accounts for about 11.4 percent of the mean outflow, and about 2.2 percent was lost by evaporation. On average, the change in lake storage was not significant.

WATER QUALITY

The quality of water in the Ward Lake watershed is important from a water-resource management perspective because the lake provides the water-supply needs of the city of Bradenton. Water managers are concerned that continuing development and land use changes in the watershed could threaten the quality of water in the lake. This section of the report assesses the quality of the surface and ground water flowing to the lake and the quality of water in Ward Lake. The Seasonal Kendall-Tau test (Kendall, 1975, and Smith and others, 1982) was used to identify significant water-quality trends. Significance was based on a two sided significance test (p value) of less than 0.10, or a greater than 90 percent likelihood that the observed trend is real. Concentrations of many water-quality constituents vary with streamflow. To remove the effects of this variation, a simple linear regression analysis was used to adjust constituent concentrations for streamflow. The flow-adjusted constituent concentration is calculated by subtracting the regression predictions from the measured concentrations (residuals). The trend analysis was then conducted on these residuals (Hirsch and others, 1991). Water-quality and flow data also were used to compute constituent loads from the tributaries to the lake, and from the lake to the Braden River estuary.

Surface-water samples were collected from the river at the Braden River near Lorraine station, the six tributaries that drain to Ward Lake, and at the Ward Lake outfall (table 6, 7, and 8; and fig. 3). Samples were collected at the streamflow sites that drain to Ward Lake between June 1993 and August 1997. Samples have been collected at the outfall since 1966. Ground-water samples were collected from wells at the transect sites (table 2 and fig. 3) between September 1995 and August 1997.

Braden River near Lorraine

The water in the river at the Braden River near Lorraine station is a composite of all surface water and ground-water baseflow to the tributaries above the station and is representative of the quality of water in the upper one-third of the Braden River watershed. Some rural, low density development exists along Lorraine Road (fig. 3) and rapid, high density residential development is occurring in the immediate area of the gaging station. However, most of the watershed consists of pastureland, wetlands, forests, and agricultural areas, and is used primarily for the production of cattle, hay, sod, and row crops. Water-quality samples were collected from the river at the gaging station and from surficial aquifer system wells at the nearby Lakewood Ranch transect site and at the upstream Lorraine Road transect site for comparison with the surface-water samples.

Specific conductance values for the surface-water samples measured at the Braden River near Lorraine station ranged from 172 to 917 microsiemens per centimeter (μS/cm), with a mean value of 454 μS/cm (table 6). At the Lakewood Ranch transect site (T2, fig. 3), specific conductance values of water from the surficial aquifer system ranged from 66 to 529 μS/cm, with a mean of 210 μS/cm (table 6). Specific conductance values for the samples from the Lorraine Road transect site (T3, fig. 3) ranged from 403 to 573 μS/cm, with a mean value of 448 μS/cm (table 6). Most conductance values measured at these sites are higher than would be expected for an unconfined ground-water system recharged only by rainfall.

Samples collected at the Verna well field (fig 3.) in 1992, as part of a previous study (Sacks and Tihansky, 1996, p. 57) reported specific conductance values of 1,140 and 1,202 μS/cm for the intermediate aquifer system and the Upper Floridan aquifer, respectively. Mineralized water from these aquifers is the probable source of the high specific conductance values measured in the surficial aquifer system. However, because of the confining characteristics of the intermediate aquifer system, the higher conductance values measured in the surficial aquifer system are probably not the result of upwelling of water from the underlying aquifers, but rather the result of withdrawal from these aquifers for agricultural irrigation.

Ground-water withdrawal for agricultural irrigation has occurred throughout the watershed for many years. Mixing of rain water and irrigation water in the surficial aquifer system is the probable cause of the higher conductance values measured in the watershed. Ground-water samples from the Lakewood Ranch site have lower conductance values than samples from the river or the Lorraine Road site because irrigation has not occurred at the Lakewood Ranch site since 1993. A significant trend in specific conductance was not observed at the Braden River near Lorraine station during the study.

Table 6. Statistical summary of selected water-quality data from the Braden River near the Lorraine station and from the surficial aquifer system at the Lakewood Ranch and Lorraine Road transect sites

[µS/cm, microsiemens per centimeter; mg/L, milligrams per liter, µg/L, micrograms per liter; --, no value; No. number]

Property or constituent	No. of samples	Braden River near Lorraine (02300032)			No. of samples	Lakewood Ranch Transect			No. of samples	Lorraine Road Transect		
		Max	Mean	Min		Max	Mean	Min		Max	Mean	Min
Specific conductance (µS/cm)	18	917	454	172	6	529	210	66	8	573	448	403
Nitrogen, ammonia, total (mg/L as N)	16	0.07	[1] 0.03	<0.01	4	0.03	--	0.01	5	0.98	--	<0.01
Nitrogen, ammonia plus organic, total (mg/L as N)	17	1.1	.65	.40	4	1.2	--	.22	5	2.1	--	.05
Nitrogen, nitrite, total (mg/L as N)	16	.01	[1] .01	<.01	4	.01	--	<.01	5	.04	--	<.01
Nitrogen, NO_2 +NO_3, total (mg/L as N)	16	.14	[1] .04	<.01	4	3.8	--	.28	5	.58	--	<.02
Phosphorus, total (mg/L as P)	17	.51	.25	.09	4	.30	--	<.02	5	.33	--	.02
Orthophosphorus, total (mg/L as P)	16	.48	.22	.08	4	.04	--	.01	5	.16	--	<.01
Organic carbon, total, (mg/L as C)	16	46	21	9.9	5	46	--	3.9	5	70	--	45
Dissolved solids (mg/L)	18	700	328	146	4	320	--	82	4	390	--	264
Calcium, dissolved (mg/L as Ca)	18	120	53	17	4	57	--	5.5	5	98	--	65
Magnesium, dissolved (mg/L as Mg)	18	43	18	5.70	4	25	--	2.1	5	7.0	--	3.6
Sodium, dissolved (mg/L as Na)	18	18	12	6.4	4	6.1	--	2.0	5	12	--	9.8
Potassium, dissolved (mg/L as K)	18	10	4.8	.90	4	11	--	2.9	5	1.4	--	.50
Chloride, dissolved (mg/L as Cl)	20	29	20	10	10	15	7.4	1.8	11	21	15	6.1
Sulfate, dissolved (mg/L as SO_4)	19	360	122	27	4	200	--	7.7	5	130	--	<.20
Strontium, dissolved (µg/L as Sr)	17	12,000	3,250	490	4	1,600	--	470	5	840	--	530
Fluoride, dissolved (mg/L as F)	18	.70	.27	.20	4	.10	--	<.10	5	.20	--	.10

[1]Mean value is estimated using a log-probability regression to predict the values below the detection limit.

Major cation and anion equivalent concentration percentages were plotted on a trilinear diagram to evaluate the chemical composition of surface water, ground water from the surficial aquifer system, and ground water from the intermediate aquifer system and Upper Floridan aquifer (fig. 6). The major ions in all samples collected at the Braden River near Lorraine station and the Lorraine Road and Lakewood Ranch transects are dominated by either calcium sulfate or calcium bicarbonate and are very similar to the major ions in samples previously collected from the deeper aquifers. Ground water from the surficial aquifer system is, at times, the major source of water in the river at the Lorraine station. Ground-water seeps have been noted along many stretches of river bank in the upper reach of the watershed. The high concentrations of major ions in the river-water and shallow ground-water samples (table 6), particularly sulfate and strontium ions, and their distribution on the trilinear diagram (fig. 6), further indicates the surficial aquifer system and the river have been influenced by water from the deeper aquifer systems.

Significant trends in the concentration of the major ions in the river water were not observed during the study. With the exception of some sulfate samples, all parameters were below the limits specified by the FDEP (1994) for Class I waters and are within the range commonly found in Florida streams (Friedmann and Hand, 1989).

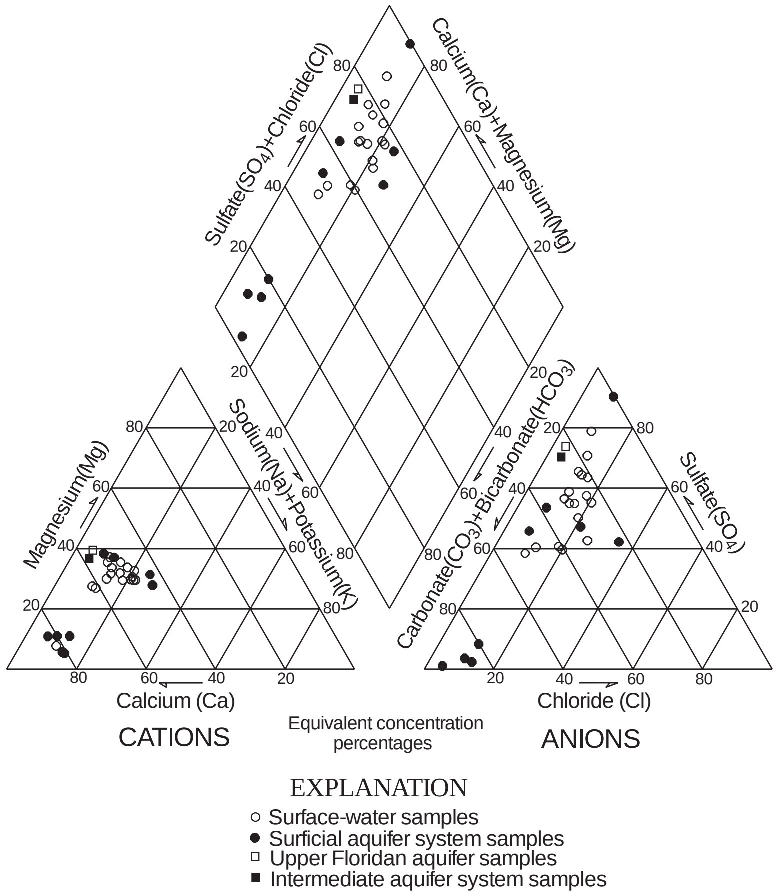

Figure 6. Major cation and anion equivalent concentration percentages of surface water at the Braden River near the Lorraine station and ground water at the Lorraine Road and Lakewood Ranch surficial aquifer system well transects, and from the intermediate aquifer system and the Upper Floridan aquifer.

Organic nitrogen was the dominant nitrogen species in surface-water samples from the Braden River near Lorraine station. Organic nitrogen can be considered to be an indicator of pollution through disposal of sewage or organic waste (Hem, 1985, p. 124); however, sewage is not disposed of in the watershed upstream of the gaging station. Agriculture and cattle grazing are major activities that occur in this area, and are probably the major source of nitrogen in the river. Inorganic nitrogen reaching the river is quickly taken up by algae and aquatic vegetation, leaving mostly organic nitrogen in the river water. Concentrations of ammonia plus organic nitrogen ranged from 0.40 to 1.1 mg/L and concentrations of nitrite plus nitrate nitrogen ranged from below detection limits to 0.14 mg/L (table 6).

Ground water from the surficial aquifer system was sampled at the Lorraine Road site, located in an area used to graze cattle (T3, fig. 3) and at the Lakewood Ranch site, located near the Braden River near Lorraine station (T2, fig. 3). Ammonia was the dominant species of nitrogen in four of the five ground-water samples collected at the Lorraine Road site. These samples were collected between July and November 1996 during wet conditions when the water table was relatively high. Concentrations of ammonia nitrogen in these samples ranged from 0.53 to 0.98 mg/L. During wet conditions, organic nitrogen from manure is converted anerobically to ammonia and percolates to the water table during rainfall. Nitrate nitrogen was the dominant source of nitrogen in the fifth sample collected in January 1997, during an extended dry period. The nitrate concentration was about 0.54 mg/L and the concentration of ammonia was below the detection limit, indicating that nitrification (the process by which the nitrogen in ammonia is aerobically oxidized forming nitrite and then nitrate nitrogen) had occurred. McNeal and others (1994) observed that high nitrate levels occur in ground water underlying vegetable fields during specific times of the year, coinciding with pre- and post-planting activities and that these conditions do not persist. Correlation between the timing of the nitrate spikes observed by McNeal and nitrate levels in samples collected during this study could not be established.

Nitrate nitrogen was the dominant nitrogen species at the Lakewood Ranch transect site. Concentrations of nitrite plus nitrate ranged from 0.28 to 3.8 mg/L and concentrations of ammonia plus organic nitrogen ranged from 0.22 to 1.2 mg/L (table 6). The area was used for row crops and cattle grazing prior to 1994; however, rapid residential development has occurred in this area since. Lawn and landscape fertilization is probably the source of nitrate in the ground water at the Braden River near Lorraine station.

Nitrogen concentrations in all samples from the Braden River near Lorraine station and from the surficial aquifer system are below the limits specified by the FDEP (1994) for Class I waters and the USEPA (1986) for drinking water. A slightly increasing trend of about 0.7 (mg/L)/yr, in the concentration of total nitrogen was observed in samples collected from the river at this station.

Total phosphorus concentrations in samples from the Braden River near Lorraine station ranged from 0.09 to 0.51 mg/L. Total phosphorus concentrations in the ground-water samples collected at from the surficial aquifer system ranged from below the detection limit to 0.30 mg/L at the Lakewood Ranch transect and from 0.02 to 0.33 mg/L at the Lorraine Road transect. Orthophosphate was the dominant species of phosphate in most samples and is the most bioavailable form of phosphorus (table 6). Most total phosphate concentrations were above the recommended upper concentration limit of 0.10 mg/L set by the USEPA (1986) to control eutrophication; however, these concentrations appear to be a natural condition. Research conducted by the University of Florida, Institute of Food and Agricultural Sciences (Stanley and others, 1995) indicates that some orthophosphate may move from vegetable production beds; however, naturally occurring phosphate deposits appear to be introducing considerable amounts of phosphorus into the shallow ground- and surface-water systems in west-central Florida. A significant trend in the concentration of phosphorus was not observed during this study.

Total organic carbon can be a concern for water managers when the concentration becomes great enough to cause harmful disinfection byproducts to form during treatment for water supply. Concentrations ranged from 9.9 to 46 mg/L, in samples from the river at the Braden River near Lorraine station (table 6). An increasing trend of about 5.7 (mg/L)/yr in the concentration of total organic carbon was observed in samples collected at this station.

Slight seasonal variations were observed in specific conductance and in nutrient and major ion concentrations in the river water. Specific conductance and most major ion concentrations were higher in samples collected during the dry season (October through May) than in samples collected during the wet season (June through September). However, concentrations of nutrients were slightly higher during the wet season than during the dry season. Higher major ion concentrations during the dry season are caused by evaporation of river water, ground-water base flow to the river, and less dilution by rainfall or stormwater. Higher nutrient concentrations during the wet season are caused by increased loading due to stormwater runoff and drainage from wetlands, which may be significant sources of nitrogen (Conservation Consultants Inc., 1983).

Tributaries to Ward Lake

The six tributaries that drain to Ward Lake include Hickory Hammock Creek, Cooper Creek, Tributary No. 1 to Cooper Creek, Cedar Creek, Rattlesnake Slough, and Nonsense Creek. Rapid, medium-to-high-density residential development has occurred in the Hickory Hammock Creek, Tributary No. 1 to Cooper Creek, and Cedar Creek subbasins, and residential development has been increasing in the northern and western part of the Cooper Creek subbasin. Rattlesnake Slough drained improved pastureland, a residential area, and a golf course for most of the study. Currently the pastureland is being developed for additional residential use. The Nonsense Creek subbasin, which was largely undeveloped for most of the study, except for a commercial area near the intersection of Interstate Highway 75 and State Highway 70, is also being developed with additional commercial centers and medium-to-high-density residential areas.

Specific conductance values at the six stations ranged from 181 to 894 µS/cm (table 7). The highest specific conductance value was measured at the Cedar

Table 7. Statistical summary of selected water-quality data from the tributaries draining into Ward Lake

[µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; No., number]

Property or constituent	No. of samples	Hickory Hammock Creek (02300034)			No. of samples	Cooper Creek (023000355)			No. of samples	Tributary 1 to Cooper Creek (02300036)		
		Max	Mean	Min		Max	Mean	Min		Max	Mean	Min
Specific conductance (µS/cm)	14	507	420	326	11	784	561	379	10	795	506	292
Nitrogen, ammonia, total (mg/L as N)	18	0.08	[1]0.04	<0.01	14	0.35	0.13	0.03	13	0.14	0.04	0.02
Nitrogen, ammonia plus organic, total (mg/L as N)	18	1.1	.53	.26	14	1.7	.95	.53	13	1.50	.83	.51
Nitrogen, nitrite, total (mg/L as N)	17	.02	[1] .01	<.01	14	.04	[1] .01	<.01	13	.03	[1] .01	<.01
Nitrogen, NO_2 + NO_3, total (mg/L as N)	17	.24	.10	.05	14	.24	[1] .05	<.01	13	.33	[1] .06	<.01
Phosphorus, total (mg/L as P)	18	.36	.11	.04	14	.88	.27	.07	13	.73	[1] .18	<.20
Orthophosphorus, total (mg/L as P)	17	.15	.08	.05	14	.77	.23	.04	13	.57	.17	.02
Organic carbon, total (mg/L as C)	18	49	21	7.9	14	57	22	7.9	13	80	33	14
Dissolved solids (mg/L)	18	378	283	214	14	558	373	234	13	616	365	8
Calcium, dissolved (mg/L as Ca)	18	78	57	36	14	120	78	52	13	120	74	41
Magnesium, dissolved (mg/L as Mg)	18	21	10	7.0	14	21	10	6.0	13	27	13	4.7
Sodium, dissolved (mg/L as Na)	18	19	14	11.0	14	21	15	11.0	13	29	18	11
Potassium, dissolved (mg/L as K)	18	5.5	3.4	1.4	14	9.8	4.5	1.1	13	14	4.7	1.3
Chloride, dissolved (mg/L as Cl)	18	31	23	18	14	29	21	13	13	36	26	14
Sulfate, dissolved (mg/L as SO_4)	18	140	66	39	14	230	105	39	13	260	102	31
Strontium, dissolved (µg/L as Sr)	18	3,500	1,027	520	14	2,200	1,004	570	13	3,330	1,344	340
Fluoride, dissolved (mg/L as F)	18	.30	.22	.20	14	.40	.253	.20	13	.50	.31	.20
		Cedar Creek (02300037)				**Rattlesnake Slough (02300038)**				**Nonsense Creek (02300039)**		
		Max	**Mean**	**Min**		**Max**	**Mean**	**Min**		**Max**	**Mean**	**Min**
Specific conductance (µS/cm)	15	894	556	397	13	540	415	290	12	654	444	181
Nitrogen, ammonia, total (mg/L as N)	16	4.7	.36	0.02	17	0.18	0.06	0.02	14	0.25	0.06	0.02
Nitrogen, ammonia plus organic, total (mg/L as N)	16	5.4	1.0	.50	17	2.10	1.0	.39	14	1.5	.78	.41
Nitrogen, nitrite, total (mg/L as N)	16	<.01	<.01	<.01	17	.07	[1] .02	<.01	14	.01	.010	<.01
Nitrogen, NO_2 + NO_3, total (mg/L as N)	16	6.1	.58	.08	17	.73	[1] .18	<.01	14	<.01	<.01	<.01
Phosphorus, total (mg/L as P)	16	.32	.15	.04	17	.62	.36	.12	14	.14	[1] .06	<.20
Orthophosphorus, total (mg/L as P)	16	.21	.11	.06	17	.56	.32	.12	14	.04	.03	.01
Organic carbon, total (mg/L as C)	16	68	26	6.1	17	49	23	12	14	84	32	6.9
Dissolved solids (mg/L)	16	594	379	272	17	1,060	312	206	14	412	285	152
Calcium, dissolved (mg/L as Ca)	16	110	73	52	17	140	48	29	14	130	72	25
Magnesium, dissolved (mg/L as Mg)	16	24	13	8.4	17	68	14	6.8	14	12	5.5	2.6
Dissolved solids (mg/L)	16	594	379	272	17	1,060	312	206	14	412	285	152
Calcium, dissolved (mg/L as Ca)	16	110	73	52	17	140	48	29	14	130	72	25
Magnesium, dissolved (mg/L as Mg)	16	24	13	8.4	17	68	14	6.8	14	12	5.5	2.6
Sulfate, dissolved (mg/L as SO_4)	15	180	81	49	17	480	74	28	14	39	16	6.7
Strontium, dissolved (µg/L as Sr)	15	3,300	1,358	690	17	19,000	1,669	360	14	700	375	140
Fluoride, dissolved (mg/L as F)	16	.50	.39	.30	17	1.2	.56	.40	14	.40	.24	.10

[1]Mean value is estimated using a log-probability regression to predict the values below the detection limit.

Creek station and probably reflects the influence of lawn and golf course irrigation water from the deeper aquifers. The lowest conductance value was measured at the Nonsense Creek station, on August 18, 1997, during a period of heavy summer rainfall. The Nonsense Creek subbasin is the smallest of the six subbasins and is highly influenced by stormwater runoff from the commercial areas and the major roads during the summer wet season. Specific conductance values at the Nonsense Creek station averaged about 298 μS/cm during the wet season. The mean specific conductance values measured at each of the six stations ranged from 415 to 561 μS/cm (table 7). During the dry season a large part of the water in the tributaries is base flow from the surficial aquifer system. The high specific conductance indicates that irrigation water from the deeper aquifers has influenced the shallow ground- and surface-water systems. An increasing trend of about 18 (μS/cm)/yr, in specific conductance was observed in samples from Hickory Hammock Creek. Significant trends in specific conductance values were not observed in samples from the remaining tributaries during the study.

Major cation and anion equivalent concentration percentages from samples collected at the six stations and from the intermediate aquifer system and the Upper Floridan aquifer collected at the Verna well field, were plotted on a trilinear diagram. The major ions in all samples are dominated by either calcium sulfate or calcium bicarbonate (fig. 7). Ground water from the surficial aquifer system, at times, is the major source of water in the tributaries. The high concentrations of major ions in the surface-water samples (table 7), particularly sulfate and strontium ions, and the distribution of the plotted equivalent concentration percentages on the trilinear diagram (fig. 7), indicates the surficial aquifer system and the tributaries have been influenced by water from the deeper aquifer systems, probably as a result of lawn, landscape, and golf course irrigation. Increasing trends in the concentration of chloride and dissolved solids were observed in samples from Hickory Hammock Creek. The increases were about 1.7 and 8.4 (mg/L)/yr, respectively. Increasing trends in the concentration of chloride and dissolved solids also were observed in samples from Cedar Creek. The increases were about 1.0 and 12 (mg/L)/yr, respectively. A decreasing trend in chloride concentration was observed in samples from Rattlesnake Slough. The decrease was about 1.9 (mg/L)/yr. Significant trends were not observed in the concentration of major ions in samples from the remaining tributaries. With the exception of the concentration of sulfate in a sample collected at the Tributary No. 1 to Cooper Creek station and a sample collected at the Rattlesnake Slough station, all constituent concentrations were below the limits specified by the FDEP (1994) for Class I waters and are within the range commonly found in Florida streams (Friedmann and Hand, 1989).

Organic nitrogen was the dominant nitrogen species in surface-water samples collected at all six stations. Cattle grazing has occurred in the Cooper Creek, Tributary No. 1 to Cooper Creek, Rattlesnake Slough, and Nonsense Creek subbasins at times during the study and is a source of the nitrogen in these subbasins. Concentrations of ammonia plus organic nitrogen as nitrogen ranged from 0.26 to 5.4 mg/L (table 7). Fertilizers applied to lawns, landscaping, or golf courses is also a source of nitrogen in these subbasins, as well as in the Hickory Hammock Creek and Cedar Creek subbasins. Inorganic nitrogen reaching retention ponds and the tributaries is quickly taken up by algae and aquatic vegetation, leaving mostly organic nitrogen in water. Nitrogen concentrations were the highest in the Cedar Creek subbasin and the lowest in the Hickory Hammock Creek subbasin. A slightly increasing trend of about 0.4 (mg/L)/yr, in the concentration of total nitrogen was observed in samples collected at the Cooper Creek station. Significant trends in nitrogen concentrations were not observed in samples from the remaining tributaries to Ward Lake. Nitrogen concentrations in all samples from the tributaries are below the limits specified by the FDEP (1994) for Class I waters and the USEPA (1986) for drinking water.

Total phosphorus concentrations in samples from the six tributaries ranged from below the detection limit at the Tributary No. 1 to Cooper Creek and Nonsense Creek stations to 0.88 mg/L at the Cooper Creek station. Orthophosphate was the dominant species of phosphate in most samples. Most sample concentrations were above the recommended upper concentration limit of 0.1 mg/L set by the USEPA (1986) to control eutrophication; however, the source is from naturally occurring phosphate deposits. Decreasing trends of about 0.02 and 0.06 (mg/L)/yr in the concentration of total phosphorus were observed in samples from Hickory Hammock and Cedar Creeks, respectively. An increasing trend of about 0.05 (mg/L)/yr was observed in samples from Cooper

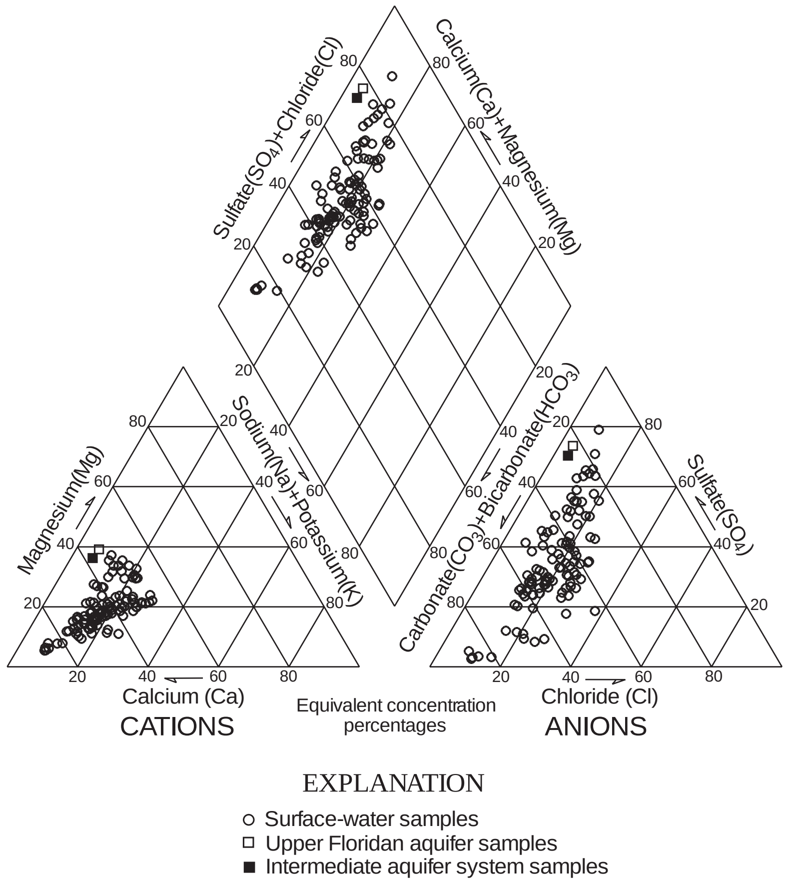

Figure 7. Major cation and anion equivalent concentration percentages of surface water from the tributaries to Ward Lake, and of ground water from the intermediate aquifer system and the Upper Floridan aquifer.

Creek, and may be related to the mining of sand and shell in the subbasin. Trends were not observed in samples from the remaining tributaries.

Total organic carbon concentrations ranged from 6.1 to 84 mg/L in samples from the six tributaries. An increasing trend of about 3.1 (mg/L)/yr was observed in the concentration of organic carbon in samples collected from Hickory Hammock Creek during the study. Significant trends were not observed in the remaining tributaries.

The same seasonal variations observed in specific conductance, and in nutrient and major ion concentrations in the river water at the Braden River near Lorraine station were observed in water from each tributary. Specific conductance values and most major ion concentrations were higher in samples collected during the dry season than in samples collected during the wet season, and concentrations of nutrients were slightly higher during the wet season than during the dry season.

Ward Lake Outfall

The water in Ward Lake is a composite of water flowing from the upper reach of the Braden River, all the tributaries to the lake, and from the surficial aquifer system near the lake. Continuing residential and commercial development is also occurring in areas surrounding Ward Lake.

Specific conductance values measured at the outfall ranged from 150 to 1,000 µS/cm, with a mean of 451 µS/cm (table 8). Ground-water samples from the surficial aquifer system at the Linger Lodge well transect site (fig. 3) are representative of the water in the surficial aquifer system adjacent to Ward Lake. Specific conductance values were less than those measured in the surficial aquifer system in the upper reach of the watershed, in the river, or in Ward Lake, and ranged from 49 to 70 µS/cm, with a mean value of 56 µS/cm (table 8). The surficial aquifer system in the area around Ward Lake is not influenced by irrigation from the deeper aquifers; it is recharged primarily by

Table 8. Statistical summary of selected water-quality data from Ward Lake and from the surficial aquifer system transect site near Linger Lodge

[µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; No., number]

Property or constituent	No. of samples	Ward Lake near Bradenton (02300042)			No. of samples	Linger Lodge Transect		
		Max	Mean	Min		Max	Mean	Min
Specific conductance (µS/cm)	93	1,000	451	150	9	70	56	49
Nitrogen, ammonia, total (mg/L as N)	63	0.15	[1]0.04	<0.01	6	0.02	--	<0.01
Nitrogen, ammonia plus organic, total (mg/L as N)	62	1.5	.90	.55	6	<.20	--	<.20
Nitrogen, nitrite, total (mg/L as N)	62	.04	[1].01	<.01	6	<.01	--	<.01
Nitrogen, NO_2 + NO_3, total (mg/L as N)	62	.30	[1].03	<.01	6	.37	.21	.07
Phosphorus, total (mg/L as P)	62	.49	.29	.08	6	.03	--	<.02
Orthophosphorus, total (mg/L as P)	63	.45	.23	.05	6	.01	--	<.01
Organic Carbon, total, (mg/L as C)	58	41	15	<.10	6	2.5	2.0	1.8
Dissolved solids (mg/L)	10	542	296	142	6	48	36	24
Calcium, dissolved (mg/L as Ca)	11	75	47	20	6	73	15	1.9
Magnesium, dissolved (mg/L as Mg)	11	35	14	4.7	6	5.3	2.4	.60
Sodium, dissolved (mg/L as Na)	11	29	16	6.6	6	11	4.4	1.8
Potassium, dissolved (mg/L as K)	11	7.9	4.8	2.0	6	1.2	.65	.20
Chloride, dissolved (mg/L as Cl)	11	44	26	11	6	8.3	3.4	.80
Sulfate, dissolved (mg/L as SO_4)	11	220	90	22	6	17	13	8.7
Strontium, dissolved (µg/L as Sr)	10	12,000	2,664	520	13	300	111	20
Fluoride, dissolved (mg/L as F)	11	.80	.34	.20	6	<.10	--	<.10

[1]Mean value is estimated using a log-probability regression to predict the values below the detection limit.

rainfall, and periodically by lake water. A significant trend in specific conductance values was not observed in samples from Ward Lake collected near the outfall during the study.

Major cation and anion equivalent concentration percentages from samples collected at the Ward Lake outfall, from the surficial aquifer system at the Linger Lodge well transect site (T1, fig. 3), and from the intermediate aquifer system and the Upper Floridan aquifer at the Verna wellfield were plotted on a trilinear diagram. The major ions in most samples are dominated by either calcium sulfate or calcium bicarbonate (fig. 8). Two of the six surficial aquifer ground-water samples have a higher percentage of sodium and chloride ions, indicating a greater influence from rainfall. The remaining four surficial aquifer ground-water samples plot in an area of the diagram that is similar to lake water samples and probably reflect recharge conditions from the lake to the aquifer system.

Comparison of water from the deeper aquifers with water in the surficial aquifer system and in the lake indicates that the shallow ground- and surface-water systems are not as influenced by pumpage from the deeper aquifers as the water in the upper reaches of the river or in the tributaries draining to the lake. Significant trends in the concentration of major ions were not observed for samples from Ward Lake. Table 8 presents a summary of selected water-quality data for samples from Ward Lake and from the surficial aquifer system at the Linger Lodge transect site.

Organic nitrogen was the dominant nitrogen species in samples from Ward Lake. Cattle grazing and inflow from the upper reach of the river and from the tributaries are the major sources of nitrogen in the lake. Concentrations of ammonia plus organic nitrogen as nitrogen in samples from the lake ranged from about 0.55 to about 1.5 mg/L. Nitrate nitrogen was the dominant species of nitrogen in the ground-water

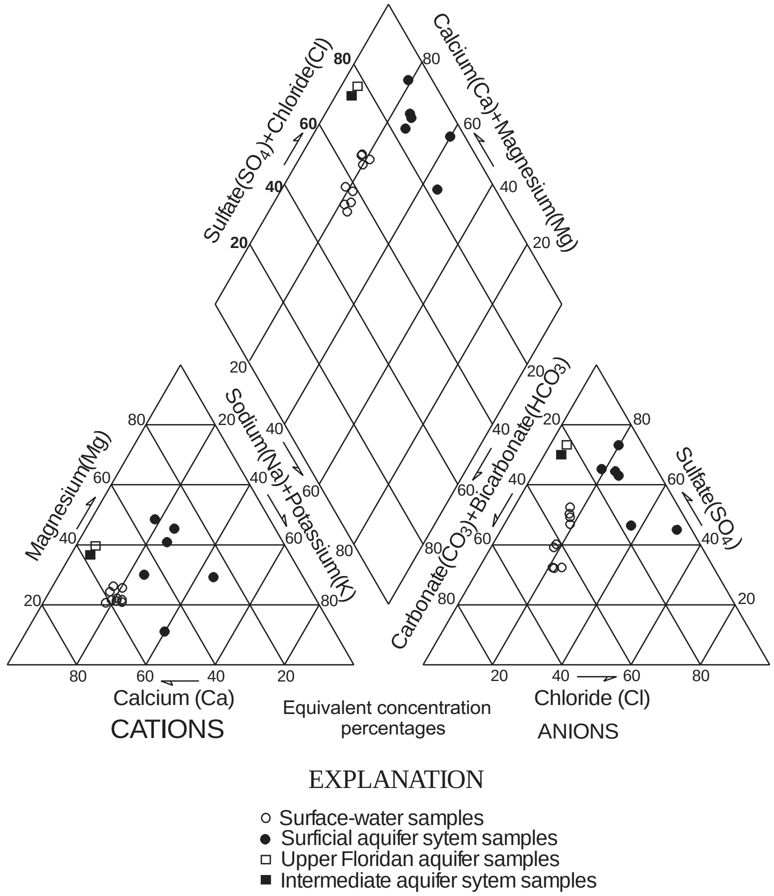

Figure 8. Major cation and anion equivalent concentration percentages of water from Ward Lake, from the surficial aquifer system at the Linger Lodge well transect, and from the intermediate aquifer system and the Upper Floridan aquifer.

samples from the surficial aquifer system collected at the Linger Lodge transect site. Fertilizer applied to lawns and inflow from the surficial aquifer system may also provide inorganic forms of nitrogen to the lake. Concentrations of nitrite plus nitrate nitrogen in ground-water samples ranged from 0.07 to 0.37 mg/L. A significant trend in nitrogen concentration was not observed during the study. Nitrogen concentrations in all samples from the tributaries were below the limits specified by the FDEP (1994) for Class I water and the USEPA (1986) for drinking water.

Total phosphorus concentrations from Ward Lake ranged from 0.08 to 0.49 mg/L. Orthophosphate was the dominant species of phosphate in most samples. Most sample concentrations were above the recommended upper concentration limit of 0.10 mg/L set by the USEPA (1986) to control eutrophication; however, the source is from naturally occurring phosphate deposits. A significant trend in the concentration of phosphorus was not observed during the study.

Total organic carbon concentrations ranged from below the detection limit to 41 mg/L in samples from the lake. The concentration of total organic carbon in samples from the surficial aquifer system at the Linger Lodge site ranged from 1.8 to 2.5 mg/L. Inflow from the tributaries and the upper reach of the Braden River is the primary source of organic carbon in the lake. Significant water-quality trends were not observed in water from Ward Lake.

The same seasonal variations observed in specific conductance, nutrient, and major ion concentrations in the river water in the upper reach of the river and at the tributaries were observed in water from the lake. Specific conductance values and most major ion concentrations were higher in samples collected during the dry season than in samples collected during the wet season, and concentrations of nutrients were slightly higher during the wet season than during the dry season.

Constituent Load

Constituent load is the amount of a constituent transported by water during a specific time period. In this report, the load is presented as tons per year (tons/yr). Loads were calculated using the inflow volume from the Braden River above Ward Lake, the tributaries to the lake, runoff from ungaged areas surrounding the lake, ground water, and rainfall. Discharge at the Ward Lake outfall was used to calculate loads to the Braden River estuary. Flow volumes were multiplied by the mean concentration of selected constituents for each flow source, and a conversion factor of 0.037795 to convert inches per year and milligrams per liter to tons per year. Annual loads from each source were then summed and reported as the load of selected constituents to Ward Lake or to the estuary in table 9. The following equation was used:

$$L = V \times C \times 0.037795 \qquad (4)$$

where

L is the calculated load, in short tons per year;

V is inflow volume, in inches per year, over the surface of Ward Lake (from the water budget);

C is the average annual constituent concentration, in milligrams per liter.

The greatest inflow to Ward Lake occurred during the 1995 water year. The greatest loading of nitrogen, phosphorus, chloride, and dissolved solids also occurred in 1995. Calcium and sulfate loading to the lake was greater in 1993, even though inflow to the lake was less, and may be related to pumpage for agricultural irrigation in the upper reaches of the watershed. Loading of most constituents was the least during the 1994 and 1996 water years. Both years were dry, with rainfall and subsequent inflow to the lake being less than during the 1993, 1995, and 1997 water years. Total organic carbon loads were higher in the 1995, 1996, and 1997 water years.

Inflows from the Braden River above Ward Lake were similar to the combined inflows from the six tributaries for most of the study period. Constituent loading patterns also were similar. However, during the 1996 water year, loading of selected constituents from the tributaries was between 1.3 and 2.7 times greater than loading from the Braden River above the lake. Inflow from the tributaries was also greater than inflow from the river and may be related to increased landscape and golf course irrigation in the subbasins. Constituent loading generally increased as inflow increased; however, total organic carbon was the exception. During the 1995, 1996, and 1997 water years, total organic carbon loads increased unrelated to inflow (table 9).

Table 9. Estimated loads of selected chemical constituents to Ward Lake and to the Braden River estuary, water years 1993-97

[in/yr, inches per year; loads are in tons per year]

Water year	Inflow[1] to Ward Lake (in/yr)	Total nitrogen	Total phosphorus	Total organic carbon	Dissolved solids	Calcium	Chloride	Sulfate
1993	1,827	51	11	931	25,559	4,411	1,516	9,468
1994	1,587	44	12	749	17,944	3,415	1,313	5,843
1995	2,751	99	29	1,481	28,008	4,290	1,957	8,544
1996	1,618	47	11	1,609	15,219	2,847	1,222	3,743
1997	2,268	54	11	1,636	17,957	3,114	1,420	5,279
Mean	2,010	59	15	1,281	20,937	3,615	1,486	6,575

Water year	Outflow[1] to the Braden River estuary (in/yr)	Total nitrogen	Total phosphorus	Total organic carbon	Dissolved solids	Calcium	Chloride	Sulfate
1993	1,551	47	18	522	15,476	2,872	1,348	3,928
1994	1,310	52	13	629	15,745	2,674	1,337	4,803
1995	2,492	98	36	1,412	22,604	3,391	1,695	6,216
1996	1,351	41	13	919	13,429	2,196	1,225	3,166
1997	1,977	73	19	1,270	14,645	2,167	1,420	2,615
Mean	1,736	62	23	1,175	16,380	2,660	1,405	4,146

[1]Flow volumes are based on the water budget.

The greatest outflow from Ward Lake and the greatest constituent loading to the Braden River estuary occurred during the 1995 water year. Loading of constituents to the estuary also generally increased as flow increased. The load of total organic carbon, dissolved solids, calcium, chloride, and sulfate being discharged to the estuary were less than those entering the lake. Only a small amount of the difference can be attributed to pumpage from the lake for water supply. The lake appears to be a sink for these constituents. Nitrogen loading to the estuary exceeded nitrogen loading to the lake during the 1994 and 1997 water years. Nitrogen loading to the estuary was less than nitrogen loading to the lake during the remainder of the study. The variability may be related to evaporation of lake water and to growth cycles of phytoplankton and aquatic vegetation in the lake and along shallow shorelines. Phosphorus loading to the estuary exceeded phosphorus loading to the lake during the entire study. Naturally occurring phosphatic clay deposits underlie west-central Florida, including the Braden River watershed, and introduce considerable amounts of phosphorus into the surface-water system (Stanley and others, 1995). Dissolution of phosphorus from clay deposits underlying the lake probably account for the difference.

CHARACTERISTICS OF THE BRADEN RIVER ESTUARY

The Braden River below the Ward Lake outfall is brackish and is tidally influenced. The estuary receives freshwater from four major sources: Ward Lake, Williams Creek, Gap Creek, and Glen Creek (fig. 3, and table 1). Freshwater flow to the estuary is important for the ecological health of the system. The SWFWMD has been charged by the State of Florida to establish minimum levels of flow for rivers in west-central Florida. Minimum flows will be based on various rates of freshwater flow that will provide a specific range of fresh and saline waters in the estuary, and on how these flow rates will affect existing water supplies (SWFWMD, 1997, p. 1). Streamflow, specific conductance, and water-quality data have been collected by the USGS to improve the understanding of the characteristics of the Braden River estuary.

Streamflow and water-quality data have been collected at the Ward Lake outfall, Williams Creek, Gap Creek, and Glen Creek. Continuous specific conductance data have been collected at the Braden River near Elwood Park and Braden River near Bradenton sites, and quarterly specific conductance measurements have been made at ten locations in the river. A regression analysis was performed to derive an equation that could be used to predict salinity in the river. The quarterly measurements were used to construct salinity profiles.

Inflows

Flow from Ward Lake is the main source of freshwater to the estuary. Annual mean flow from Ward Lake, for water years 1993 through 1997, was 69.2 ft^3/s; however, the median flow from the lake was only 6.5 ft^3/s. Median flows are about an order of magnitude smaller than mean flows. Flow events greater than 200 ft^3/s only occur about 10 percent of the time and there are many days when there is no flow from the lake. Williams Creek drains a small subbasin and discharges to the upper part of the estuary, about 1 mi downstream of the outfall. Annual mean flow at the station is 2.5 ft^3/s, but Williams Creek has a median flow of only 0.5 ft^3/s and periods of no flow. Gap Creek is the second largest subbasin in the watershed and is also the second largest source of freshwater to the estuary. Annual mean flow is 11.2 ft^3/s, and median flow is about 3.5 ft^3/s. Gap Creek had no zero flow days during the study; it discharges to the river near Williams Creek. Glen Creek is the third major freshwater creek discharging to the river; it drains to the lower part of the estuary and has an annual mean flow of 3.2 ft^3/s and a median flow of about 1.2 ft^3/s.

Tidal Fluctuations

Analysis of elevation data from the two continuous tidal stations indicated there is about a 1-hour lag between stations and that the tides occur as a progressive wave in the river. Spectral analysis (Sheng, 1994, p. 59) of tidal data for both stations showed the strongest signal at 12.4 hours and two weaker, but broader signals at 23.9 and 25.8 hours. These signals define the tide as a mixed (semidiurnal and diurnal) tide. Tidal elevations are also affected by an overlying seasonal fluctuation due to increased freshwater flows. The mean tidal elevation was 0.9 ft higher in the wet season than in the dry season during the 1995 water year, and 0.5 ft higher during the 1997 water year.

This effect precludes the use of tidal data collected from estuaries or bays affected by freshwater flows for the purpose of estimating “sea level rise.”

Elevation of the high tide in the river is normally several feet below the crest of the outfall; however, storm events on March 13, 1993, and October 7, 1996 caused tidal elevations to overtop the outfall, impacting the city of Bradenton’s water supply with brackish water. The high chloride concentrations were quickly flushed out of the system by freshwater flows from upstream. Peak tidal elevations during these storms were 4.91 and 4.37 ft above sea level, respectively. Zero flow occurs at the outfall at an elevation of 3.82 ft above sea level.

Salinity

Salinity is difficult to measure in the field, but specific conductance can easily be measured and salinity can be approximated from these measurements. Therefore, specific conductance was used in this study to approximate salinity. Conductance values of 1,000, 18,500, and 20,000 μS/cm are about 0.5, 6.0, and 12.0 parts per thousand (ppt) salinity, respectively.

Continuous specific conductance was recorded at the Braden River near Elwood Park station between 1994 and 1997 and at the Braden River near Bradenton station between 1995 and 1997. The daily mean conductance at the Elwood Park station exceeded 1,000 μS/cm, or about 0.5 ppt, more than 70 percent of the time. This value was exceeded more than 99 percent of the time at the Bradenton station (fig. 9). Median daily mean conductance at the Elwood Park and the Bradenton stations was about 9,000 and 30,000 μS/cm (5.5 and 18.5 ppt salinity), respectively.

Simple linear regression analysis was performed using the daily mean discharge from Ward Lake and the daily mean specific conductance values from the Elwood Park station. A strong relation between low freshwater flow and high specific conductance exists; however, the data show a great variability for flow rates less than 100 ft^3/s and did not result in a strong regression equation. Monthly mean values of specific conductance and flow at the outfall also were compared and showed similar results.

The freshwater/saltwater interface was considered to be 0.5 ppt salinity, for this report. The interface can be estimated by observing the position of lines of equal salinity, commonly referred to as isohaline lines. Salinity profiles were constructed from 14 sets of specific conductance measurements made between the outfall and the mouth of the river. Measurements were made between September 1993 and August 1997, and were made at or near high tides to minimize tidal effects on the data. Simple linear regression analysis of the position of the measured isohaline lines and the 7-day flow over the outfall was used to derive equations that could be used to predict the position of the isohaline lines. Similar to the results of the regression analysis of the continuous data, the resulting equations could not reliably predict the position when flows were less than 100 ft^3/s. Multiple linear regression analysis of the position of the measured isohaline lines and flows at the outfall, at Gap Creek and at Williams Creeks was also used with similar results. Conservation Consultants, Inc. (CCI), a consulting company for the city of Bradenton, developed regression equations based on 48 sets of measurements and also concluded that, because of scatter in the data at low flows, the equations could not reliably predict the position of isohaline lines (CCI, 1997). Antecedent salinity conditions in the river probably have a greater effect on the position of isohaline lines than low-to-moderate flow rates at the outfall. Another factor influencing the regression analysis is the assumption that the lowest salinity is at the outfall and the highest salinity is at the mouth of the river. Often, the lowest salinities were measured at the confluence of Williams and Gap Creeks, about 1-mi downstream of the outfall. Four salinity profiles of the Braden River estuary representing several different freshwater-flow conditions are shown in figure 10.

On October 4, 1994, following a long wet season and a recent storm event, salinity was the lowest measured during the study. Salinity was below 3.0 ppt from the outfall to near the mouth (fig. 10a). Flow at the time of measurement was 432 ft^3/s. Continuous specific conductance data indicate salinity was below 0.5 ppt for most of July, 1994 and from August 9 through October 18, 1994. The low salinity antecedent condition and a moderate-flow event caused the 0.5-ppt isohaline line to be located about 3 mi downstream of the outfall.

Figure 10b shows the salinity distribution in the estuary on March 29, 1996, the first day of a moderate freshwater-flow event that occurred after a period of no flow at the outfall. Flow at the time of measurement was 186 ft^3/s. The 0.5-ppt isohaline line was located near the outfall and a stratified condition existed for about 2 mi downstream. The extent of the lens of

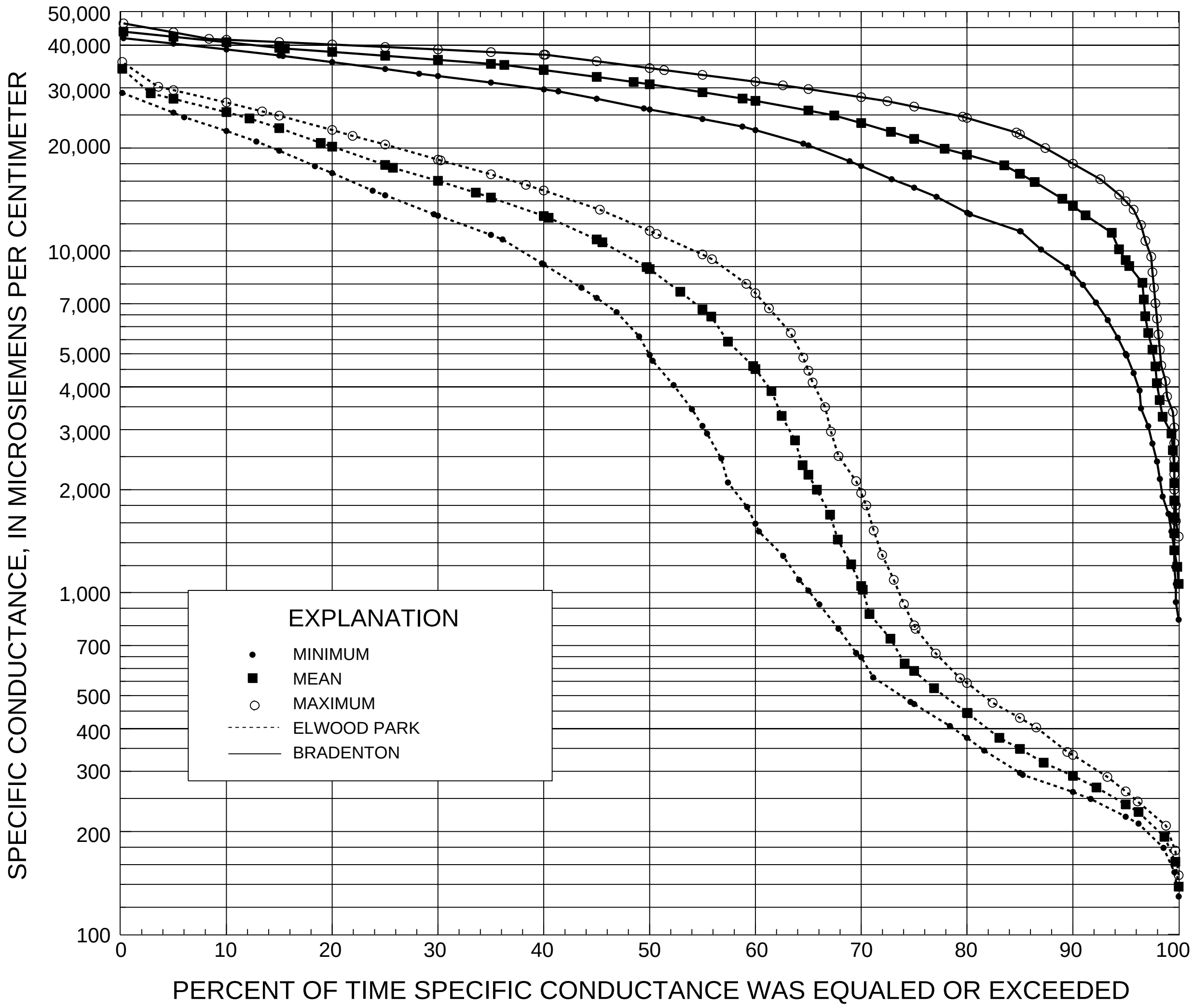

Figure 9. Duration curves of specific conductance at the Braden River near Elwood Park and the Braden River near Bradenton stations.

fresher water was enhanced by flows from Williams and Gap Creeks. The 6-, 9-, 12-, and 15-ppt isohaline lines are closely spaced about 3 mi downstream of the outfall. High salinity antecedent conditions existing in the river prior to the moderate-flow event resulted in stratification in the upper part of the river and confinement of the 0.5-ppt isohaline line to a small area near the outfall.

Salinity data collected on March 8, 1994, at the end of a week-long moderate, freshwater-flow event, showed stratification occurs for about 2 mi downstream of the outfall (fig. 10c). Flow at the time of measurement was 1.7 ft^3/s. High antecedent salinity conditions existed prior to the flow event. The lowest salinity was not measured near the outfall, but in the vicinity of Williams and Gap Creeks. This profile is common in about 35 percent of the profiles constructed from USGS data and illustrates the influence of Williams and Gap Creeks on the salinity distribution in the upper estuary.

On April 25, 1997, after an extended dry period with no flow at the outfall, the lowest salinity measurements were again in the vicinity of Williams and Gap Creeks (fig. 10d). High antecedent salinity conditions existed in the estuary and there was no flow at the outfall. However, mean daily outflow from the creeks to the estuary for the week prior to the measurement was about 11 ft^3/s.

The salinity profiles show the influence of freshwater flows from Williams and Gap Creeks on the distribution of salinity in the river. They also illustrate the difficulty in fitting the measured data to linear regression models that assume that freshwater flow from the outfall is the only input to the system.

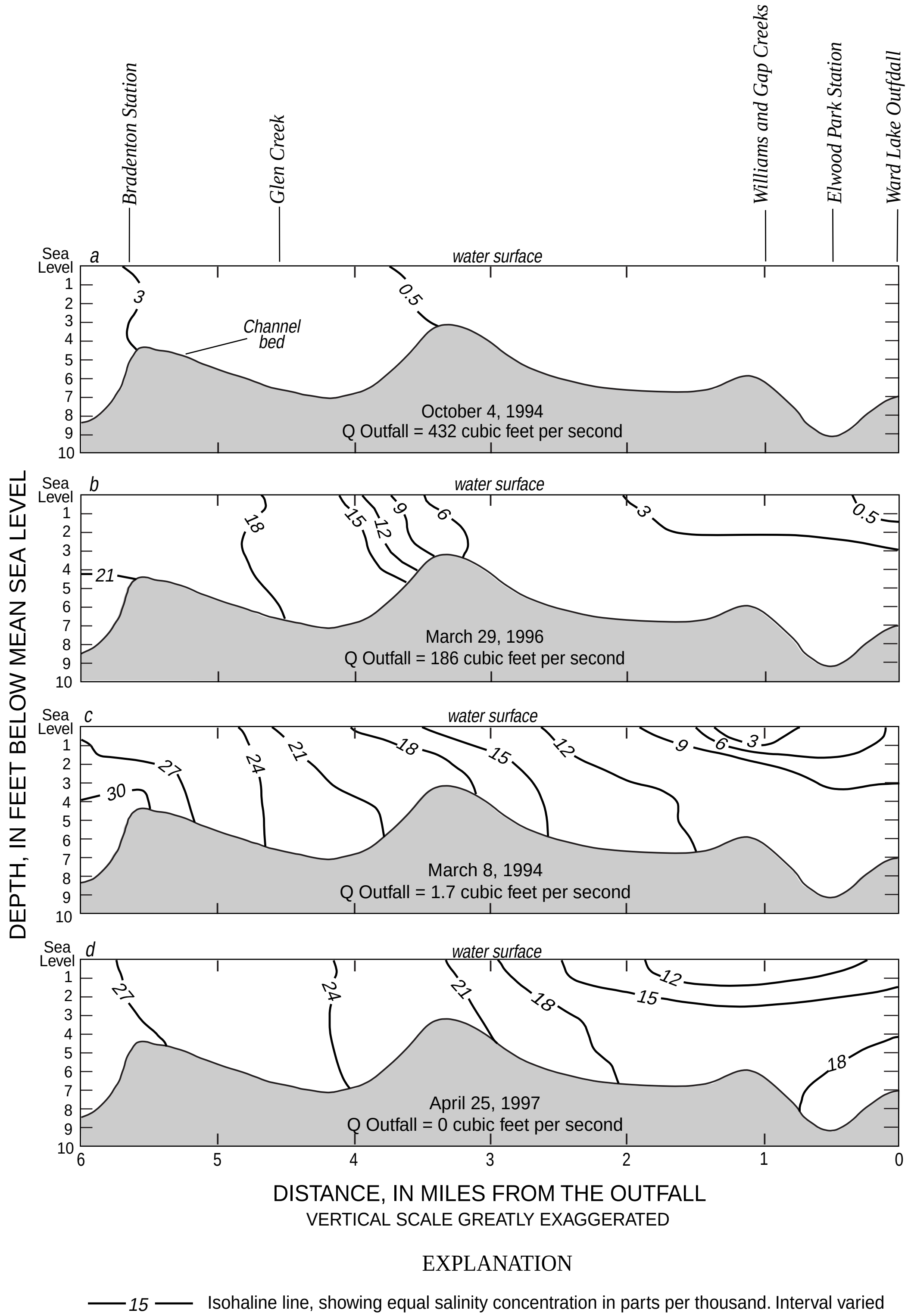

Figure 10. Salinity profiles of the Braden River estuary.

The effects of a large flow event at the outfall on the entire estuary are shown in figure 11. A storm event at the end of October 1995 caused a peak flow of 1,250 ft^3/s at the outfall on November 1. Flow in Williams and Gap Creeks also peaked on November 1, with a combined peak flow of 317 ft^3/s. Specific conductance at the Elwood Park station decreased immediately. Conductance at the Bradenton station decreased over a 12-hr period to below 5,000 μS/cm, and remained at that level for about 4 days. Conductance at the Elwood Park station remained below 1,000 μS/cm for about 18 days, even though flow at the outfall had fallen to below 100 ft^3/s after 5 days. Conductance began to rise at the Elwood Park station after 18 days, but after only 3 days at the Bradenton station. A large freshwater-flow event affects the specific conductance near the Bradenton station for a much shorter time period because of its proximity to the Manatee River and the Gulf of Mexico. Fluctuations in the conductance data shown in figure 10 are the result of tidal pumping as the salinity wedge is moved further upstream with each successive tide cycle.

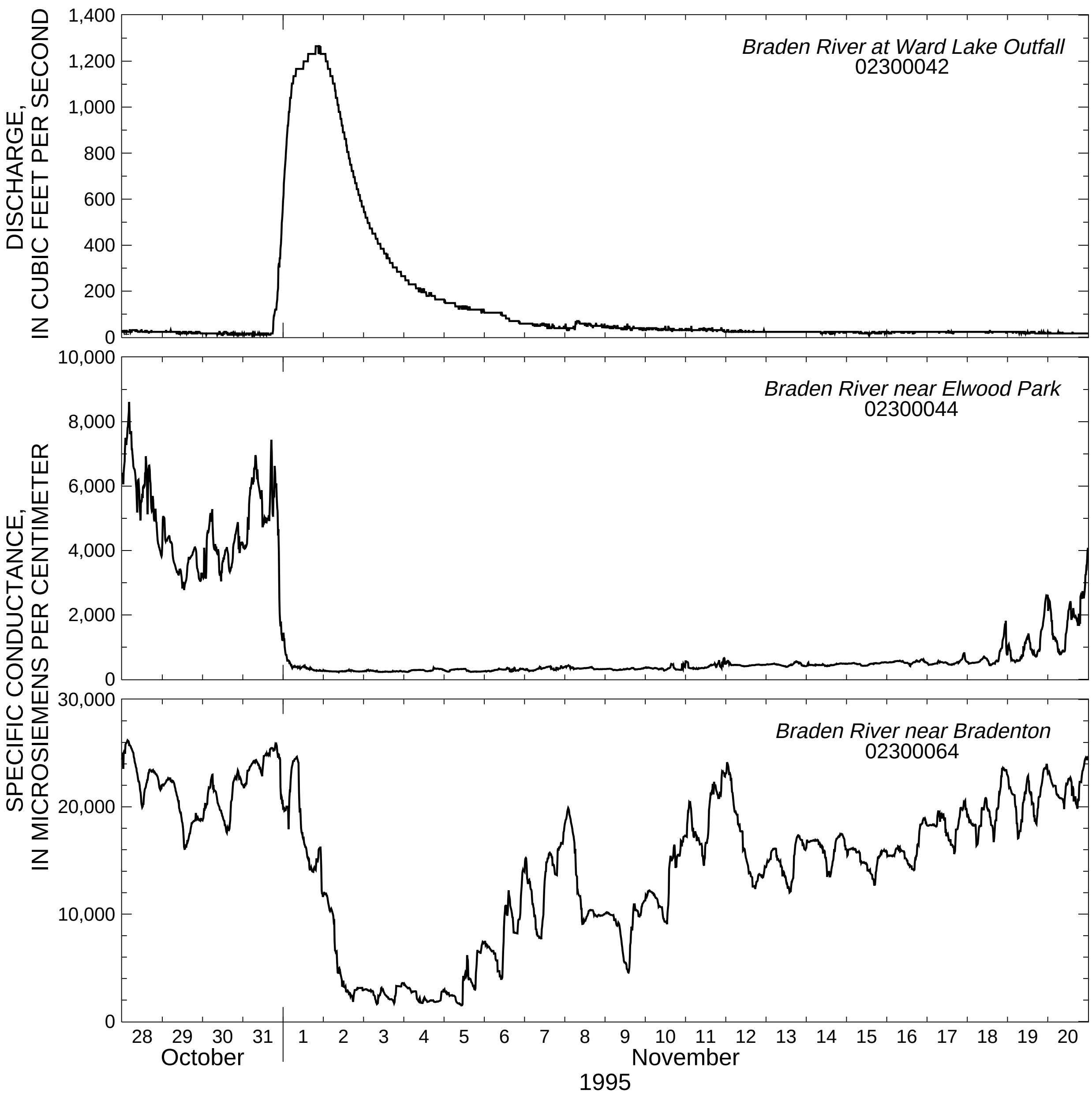

Figure 11. Comparison of instantaneous discharge at the Ward Lake outfall with specific conductance at the Braden River near Elwood Park and the Braden River near Bradenton stations, October 28 to November 20, 1995.

Table 10. Statistical summary of selected water-quality data from the tributaries draining to the Braden River estuary, water years 1995-97

[µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; No., number]

Property or constituent	No. of samples	Williams Creek (02300050)			No. of samples	Gap Creek (023000356)			No. of samples	Glen Creek (02300062)		
		Max	Mean	Min		Max	Mean	Min		Max	Mean	Min
Specific conductance (µS/cm)	17	748	352	144	18	1,060	733	586	18	1,270	1,010	342
Nitrogen, ammonia, total (mg/L as N)	17	0.10	0.05	0.01	21	0.22	0.10	0.03	18	0.29	0.11	0.01
Nitrogen, ammonia plus organic, total (mg/L as N)	17	1.5	.96	.48	21	2.1	.99	.68	18	1.4	.91	.57
Nitrogen, nitrite, total (mg/L as N)	17	.03	[1] .01	<.01	21	.07	.03	<.01	18	.26	[1] .09	<.01
Nitrogen, $NO_2 + NO_3$, total (mg/L as N)	17	.54	[1] .06	<.02	21	.32	.20	.04	18	7.3	3.9	.19
Phosphorus, total (mg/L as P)	17	.49	.21	.04	21	1.2	.54	.28	18	.44	.28	.08
Orthophosphorus, total (mg/L as P)	17	.43	.18	.03	21	.93	.46	.26	18	.34	.22	.04
Organic carbon, total, (mg/L as C)	4	65	--	27	6	70	50	16	4	74	--	8.5
Dissolved solids (mg/L)	17	524	253	134	21	782	492	292	17	936	726	210
Calcium, dissolved (mg/L as Ca)	4	63	--	16	6	120	82	52	4	110	--	41
Magnesium, dissolved (mg/L as Mg)	4	13	--	4.8	6	43	22	11	4	60	--	9.2
Sodium, dissolved (mg/L as Na)	4	14	--	10	6	38	28	16	4	40	--	14
Potassium, dissolved (mg/L as K)	4	5.1	--	3.0	6	5.5	5.4	4.4	4	7.70	--	3.6
Chloride, dissolved (mg/L as Cl)	4	26	--	17	6	74	47	25	4	70	--	15
Sulfate, dissolved (mg/L as SO_4)	4	73	--	12	6	280	139	65	4	290	--	36
Strontium, dissolved (µg/L as Sr)	4	610	--	320	6	8,800	3,420	1,300	4	1,200	--	320
Fluoride, dissolved (mg/L as F)	4	.30	--	.10	6	.80	.55	.40	4	.80	--	.30

[1]Mean value is estimated using a log-probability regression to predict the values below the detection limit.

Water Quality in the Tributaries that Drain to the Braden River Estuary

The Williams Creek subbasin was largely an agricultural area with some residential areas for most of the study; however, rapid residential and commercial development has occurred recently in the western part of the subbasin. The Gap Creek subbasin is the largest of the subbasins draining to the estuary and contains heavily developed residential, commercial, and industrial areas, as well as citrus groves and some cattle grazing areas. The Glen Creek subbasin is the smallest of the three subbasins and drains urban and highly industrialized areas and a large orange grove.

Specific conductance values at the three tributaries ranged from 144 to 1,270 µS/cm (table 10). The highest conductance value was measured at the Glen Creek station. The lowest conductance value was measured at the Williams Creek station. Mean specific conductance values for the Williams, Gap, and Glen Creek subbasins were 352, 733, and 1,010 µS/cm, respectively (table 10). Significant trends in specific conductance were not observed in the tributaries during the study.

The major ions in samples from these tributaries are dominated by calcium bicarbonate and calcium sulfate, similar to samples from tributaries that drain to Ward Lake. Ground water from the surficial aquifer system is, at times, a major source of water in the tributaries. The major ion concentrations, particularly sulfate and strontium (table 10), in samples from these creeks indicate that the shallow ground-water and the surface-water systems have been influenced by water from the deeper aquifers, probably as a result of irrigation in the subbasins. The range in ion concentrations in samples collected at the Williams, Gap, and Glen Creek stations is similar to concentrations in samples from the tributaries that drain to Ward Lake. Comparison of ion ratios for samples collected at Williams, Gap, and Glen Creeks with samples collected from the estuary at the Elwood Park station indicates the creeks have not recently been affected by brackish water from high tides. An insufficient number of samples were available to determine if any trends existed for the major ion concentrations. All constituent concentrations were below the limits specified by the FDEP (1994) for Class I waters and are within the range commonly found in Florida streams (Friedmann and Hand, 1989).

Organic nitrogen was the dominant nitrogen species in samples collected at the Williams and Gap Creek stations. Nitrate nitrogen was the dominant species in samples collected at the Glen Creek station and is probably related to fertilizer used in the orange groves and to stormwater runoff from the urban and industrial areas in the western part of the subbasin. Significant trends in the concentration of nitrogen were not observed in these tributaries. Nitrogen concentrations in all samples from the tributaries are below the limits specified by the FDEP (1994) for Class I waters and the USEPA (1986) for drinking water. However, nitrogen concentration in samples from Glen Creek are greater than in all samples collected from the remaining watershed. Mean total nitrogen concentration for the samples collected was 4.0 mg/L, and more than half of the samples collected from this creek had a nitrate concentration greater than 4.0 mg/L. High nitrate concentrations can cause excessive aquatic growth in the creek or in downstream receiving waters.

Total phosphorus concentrations ranged from 0.04 to 1.2 mg/L. Orthophosphate was the dominant species of phosphorus in most samples. Similar to the tributaries above the outfall, most phosphorus concentrations were above the recommended upper concentration limit of 0.10 mg/L set by the USEPA (1986) for eutrophication. The source is also from naturally occurring phosphate deposits underlying the watershed. A significant trend was not observed in phosphorus concentrations during the study.

Total organic carbon concentrations in samples from the three tributaries ranged from 8.5 to 74 mg/L, and also were similar to concentration ranges observed in the tributaries above the outfall. A significant trend was not observed in any of these tributaries.

With the exception of samples collected at Glen Creek, specific conductance and the concentration of dissolved solids were slightly higher for samples collected during the dry season. Nutrient concentrations were higher in samples collected during the wet season. Seasonal variation could not be determined for the Glen Creek subbasin.

EFFECTS OF THE RESERVOIR ON THE HYDROLOGIC SYSTEM

The dam, when originally built in 1936, created a permanent backwater condition in the Braden River for about 6 mi upstream. The immediate effects on the hydrology of the watershed were to flood the middle reach of the river and the lower reaches of the tributaries discharging to the river, raise water levels in the surficial aquifer system adjacent to the river, change water quality, and reduce freshwater flow to the estuary during periods of low flow.

The channel structure of the middle reach of the river is similar to the river channel below the outfall and appears to be a remnant of the estuarine environment that existed prior to construction of the dam. The braided, meandering nature of the river channel can be observed from the outfall upstream to a point about 0.5 mi below the confluence with Hickory Hammock Creek (fig. 3, table 1). Upstream of this point, the river exhibits a single channel structure with no evidence of braiding or oxbows. The average channel slope of the river changes from about 8 ft/mi to almost flat near Hickory Hammock Creek. The nature of the river channel and measurements of the elevation of the river bottom indicate the extent of the tidal reach was near Hickory Hammock Creek prior to construction of the dam. Impoundment of the river raised water levels and changed this reach from a brackish water estuarine ecosystem to a freshwater lake ecosystem. Raised water levels also drowned out the lower reaches of the tributaries discharging to the river. The resulting backwater condition slows the conveyance of stormwater from the subbasins and may have an effect on flooding.

Water levels in Ward Lake, which are usually 2 to 3 ft higher than tidal water levels, have raised head levels in the surficial aquifer system adjacent to the lake. There is a two-way exchange of water between the lake and the surficial aquifer system. When lake levels are higher than head levels in the surficial aquifer, the lake is a source of recharge water to the surficial aquifer system. When lake levels are lower than head levels in the surficial aquifer system, flow reverses and the lake receives water discharging from the surficial aquifer system. Most flow is from the surficial aquifer system to the lake because rainfall usually maintains ground-water levels above lake levels, except during storm events. The ground-water component of the total flow at the outfall averaged 15.5 percent during the study. The shallow ground-water system is, at times, a major source of water to the river and would still be a significant component of the Braden River hydrologic system if the dam had not been built. Ground water from the surficial aquifer system discharges to the river throughout the entire watershed and has often been an overlooked or underestimated component of this hydrologic system.

The outfall forms a saltwater barrier between the freshwater in Ward Lake and the brackish water in the downstream estuary (except occasionally, when a major storm causes a surge to overflow the dam). This limits the upstream migration of the saline wedge and effectively reduces the size of the brackish water ecosystem available for spawning and for juvenile saltwater fish populations. However, the outfall has caused the evolution of a large freshwater ecosystem with related plant, fish, and wildlife communities.

Ward Lake appears to have some positive effects on water quality, acting as a sink for total organic carbon, dissolved solids, calcium, chloride, and sulfate. During the study, loads of these constituents discharging to the estuary were less than loads entering the lake. Only a small amount of the difference can be attributed to removal by pumpage from the lake for water supply. Constituent loading would not be expected to decrease if the river were not dammed. While the lake may be reducing the loading of some constituents to the estuary, expansion of the reservoir in 1985, appears to have increased phosphorus loading to the estuary. Phosphatic-clay deposits were exposed during excavation and increased dissolution of phosphorus from these deposits may be occurring.

Evaporation losses from the lake are greater than if the river was in a natural state because of increased surface area. However, evaporation is a very small part of the water budget and accounts for an average of only 2.2 percent of all the outflow during the study. Losses due to pumpage for public supply are larger and account for an average of 11.4 percent. Constituent enrichment caused by evaporation or constituent removal by pumpage have minimal effects on the water quality of both the lake and the estuary. Freshwater outflow to the estuary was reduced by an average of 13.6 percent by evaporation and pumpage during the study. Discharge to the estuary was less than inflow to the lake during dry periods of the study when flow rates were low. An average difference of about 12 ft^3/s (8 Mgal/d) was calculated for the dry periods for water years 1993-97 and would have been discharged to the estuary if the dam had not been built. Reduction in the amount of freshwater flowing to the estuary can affect the salinity concentration and distribution in the estuary.

SUMMARY AND CONCLUSIONS

The Braden River was dammed in 1936 to provide the city of Bradenton a source of freshwater supply. The resulting impoundment was called Ward Lake and had a storage capacity of about 585 Mgal of water. Reconstruction in 1985 increased the size of the reservoir to about 1,400 Mgal, at an elevation of about 3.82 ft above sea level. The lake has been renamed the Bill Evers Reservoir and drains about 59 mi^2.

The Braden River watershed can be subdivided into three hydrologic reaches which have been referred to in a previous report as the upper, middle, and lower reaches of the river. The upper reach consists of a naturally incised, free flowing channel. The middle reach consists of a meandering channel where the flow is affected by backwater as a result of the dam. The lower reach is a tidal estuary, extending from the outfall to the confluence with the Manatee River. Six principal tributaries flow into Ward Lake and three flow into the estuary.

Three major hydrogeologic units underlie the watershed. They are the surficial, intermediate, and Floridan aquifer systems. The surficial aquifer system is primarily an unconfined sand aquifer that is contiguous with land surface and less than 40 ft thick. The intermediate aquifer system is about 350 ft thick; however, the aquifer system acts as a confining unit in the study area. The Floridan aquifer system is a confined system, and only the upper part contains freshwater. The Floridan aquifer system has little effect on the surficial aquifer or surface-water systems because of the confining characteristics of the overlying intermediate aquifer system.

Ward Lake receives water from precipitation falling directly on the lake, surface-water inflows, direct runoff from adjacent land, and from ground-water seepage. Rainfall measured at two stations was averaged and used as the rainfall input to the water budget. Surface-water inflows to the lake were measured at seven streamflow stations and estimated for the ungaged area by calculating runoff-per-square-mile from the gaged areas. Ground-water seepage, which ranged between 0.82 and 1.0 in/d, was estimated using flow-net analysis.

Water leaves the lake by evaporation, surface-water outflow, ground-water outflow, and as withdrawals for public water supply. Evaporation was estimated from pan evaporation measured at the Bradenton 5ESE weather station. Surface outflow was measured at the Ward Lake outfall. Outflow from the lake to the surficial aquifer system appear to be of limited extent and duration. Withdrawals for water supply were obtained from the city of Bradenton.

Water budgets were calculated for the 1993 through 1997 water years. Mean surface-water inflow to Ward Lake for the 5-year period was 1,645 in/yr, or about 81.8 percent of the mean inflow. Ground-water inflow to the lake is the second most significant part of the inflow component of the budget. Mean ground-water inflow was 311 in/yr, which represents about 15.5 percent of the mean inflow. Rain falling directly on the lake accounts for about 2.7 percent of the inflow. Mean surface-water outflow was 1,736 in., or about 86.4 percent of the mean total outflow. There was no net ground-water outflow from the lake. Mean surface-water withdrawals for water supply were 229 in., or about 11.4 percent of the mean total outflow. Evaporation accounted for only 2.2 percent of the mean total outflow. Change in lake storage on the water budget was negligible.

Surface water and ground water from the surficial aquifer system in the upper reach of the watershed has been influenced by more mineralized water from the intermediate aquifer system and the Upper Floridan aquifer. Ground-water pumpage for agricultural activities has occurred in this reach of the watershed for many years. Oganic nitrogen is the dominant species of nitrogen in the surface water at the Braden River near Lorraine station. Agricultural activities are the sources of nitrogen in this part of the watershed. Phosphorus concentrations in most samples exceeded the USEPA limit of 0.10 mg/L; however, the source of the phosphorus is naturally occurring phosphate deposits that underlie most of west-central Florida. Significant trends in specific conductance or the concentrations of major ions and nutrients were not observed in samples collected at the Braden River near Lorraine station. The concentration of total organic carbon in samples from this station showed an increasing trend of about 5.7 (mg/L)/yr during the study.

The six tributaries that drain to Ward Lake have been influenced by water from the intermediate aquifer system and the Upper Floridan aquifer. Water is pumped from these aquifers to irrigate golf courses, lawns, and landscaping in these rapidly developing subbasins. Increasing trends in the concentration of chloride and dissolved solids were observed in samples from Hickory Hammock and Cedar Creeks. A decreasing trend in the concentration of chloride was observed in samples from Rattlesnake Slough. Oganic nitrogen was the dominant species of nitrogen in water from all six tributaries. Cattle grazing and fertilizer are the sources of nitrogen in these subbasins. Phosphorus concentrations in most samples exceeded the USEPA limit of 0.10 mg/L. Decreasing trends in the concentration of phosphorus were observed in samples from Hickory Hammock and Cedar Creeks, and an increasing trend was observed in samples from Cooper Creek. The concentration of total organic carbon in samples from the six tributaries ranged from 6.1 to 84 mg/L. An increasing trend of about 3.1 (mg/L)/yr was observed in samples from Hickory Hammock Creek. Significant trends were not observed in samples from the remaining tributaries.

Water in Ward Lake is a composite of all water flowing from the upper reach of the Braden River, the tributaries to the lake, and from the surficial aquifer system near the lake. The surficial aquifer system near the lake has not been influenced by more mineralized water from the intermediate aquifer system and the Upper Floridan aquifer. Oganic nitrogen is the dominant species of nitrogen in the lake water and nitrate nitrogen was the dominant species in surficial aquifer system samples. Phosphorus concentrations in most samples exceeded the USEPA limit of 0.10 mg/L. The concentration of total organic carbon in samples from the lake ranged from below the detection limit to 41 mg/L and from 1.8 to 2.5 mg/L in samples from the surficial aquifer system. Significant trends in any water-quality constituent were not observed during the study.

Constituent loads for total nitrogen, phosphorus, organic carbon, dissolved solids, calcium, chloride, and sulfate were calculated for each water year. The greatest loading of nitrogen, phosphorus, chloride, and dissolved solids occurred in 1995. Calcium and sulfate loading to the lake was greater in 1993. Loading of most constituents was the least during the

1994 and 1996 water years. Both years were dry, with rainfall and subsequent inflow to the lake being less than during the remaining water years of the study. Total organic carbon loads were higher in the 1995, 1996, and 1997 water years. Loading of most constituents to Ward Lake generally increases as inflow increases. However, during the 1995, 1996, and 1997 water years, total organic carbon increased unrelated to flow. The greatest outflow from Ward Lake also occurred during the 1995 water year. Volumes of total organic carbon, dissolved solids, calcium, chloride, and sulfate being discharged to the estuary were less than those entering the lake. Only a small amount of the difference can be attributed to pumpage from the lake for water supply. The lake appears to be a sink for these constituents. The difference in nitrogen loading to the lake and to the estuary was variable and may be attributed to growth cycles of aquatic vegetation in and around the lake. Phosphorus loading to the estuary exceeded loading to the lake during the entire study and may be related to dissolution of phosphate from clayey deposits underlying the lake.

The Braden River estuary receives freshwater from four major sources: Ward Lake, Williams Creek, Gap Creek, and Glen Creek. Ward lake is the main source of freshwater to the estuary, with an annual mean flow of 69.2 ft^3/s and a median flow of 6.5 ft^3/s. Gap Creek is the second largest source of freshwater to the estuary and has an annual mean flow of 11.2 ft^3/s and a median flow rate of 3.5 ft^3/s. Williams and Glen Creeks have annual mean flows of 2.5 and 3.2 ft^3/s and median flows of 0.5 and 1.2 ft^3/s, respectively.

There is about a 1-hour lag in tides between the mouth of the river and at the Ward Lake outfall. Mean tidal elevation is higher in the wet season than in the dry season. Elevation of the high tide in the river is normally several feet below the crest of the outfall; however, storm events have caused tidal elevations to overtop the outfall, impacting the city of Bradenton’s water supply.

Antecedent salinity conditions in the river probably have a greater effect on salinity profiles than low-to-moderate flow rates at the outfall. Freshwater flows from Williams and Gap creeks affect the salinity in the upper part of the estuary, and often, the lowest salinities in the river were measured at the confluence with Williams and Gap Creeks.

The water draining to the Braden River estuary from Williams, Gap, and Glen Creeks appears to be influenced by water from the intermediate aquifer system and the Upper Floridan aquifer. Comparison of ion ratios for samples from these tributaries with samples from the estuary at the Elwood Park station also indicates that saltwater from high tides has not recently affected the water quality in the creeks. Organic nitrogen is the dominant species of nitrogen in water from Williams and Gap Creeks. Nitrate nitrogen was the dominant species in water from Glen Creek and is probably related to fertilizer use in the orange groves and to stormwater runoff from the urban and industrialized areas of the subbasin. Nitrogen concentration in samples from Glen Creek are greater than in all samples collected from the remaining watersheds. Phosphorus concentrations in most samples exceeded the USEPA limit of 0.10 mg/L. Total organic carbon concentrations ranged from 8.5 to 74 mg/L and also were similar to concentration ranges observed in the tributaries above the outfall. Significant trends in any water-quality constituents were not observed in samples from these tributaries.

Prior to the construction of the dam, the tidal reach of the river probably extended to an area near Hickory Hammock Creek. Impoundment of the river raised water levels 2 to 3 feet above tidal water levels, flooding the middle reach of the river and the lower reaches of the tributaries that drain to the river. Head levels also were raised in the surficial aquifer system adjacent to the lake. Ground water from the surficial aquifer system discharges to the river throughout the watershed. During the study, ground water accounted for an average of 15.5 percent of the total annual flow at the outfall. Ground water has been an overlooked or underestimated component of the Braden River hydrologic system.

The dam forms a barrier between the freshwater in the lake and the brackish water in the estuary, limiting the upstream migration of the saltwater wedge, except occasionally when a storm surge causes brackish water to overflow the dam. The lake also acts as a sink for total organic carbon, dissolved solids, calcium, chloride, and sulfate, decreasing the loads of these constituents to the estuary.

Discharge to the estuary was decreased by an average of 13.6 percent by evaporation from the lake and by pumpage for water supply during the study period. Reduction in the amount of freshwater flowing to the estuary can affect the salinity concentration and distribution in the estuary.

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