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

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

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

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
SOUTHWEST FLORIDA WATER MANAGEMENT DISTRICT

Tallahassee, Florida
1999

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

For additional information write to:

District Chief
U.S. Geological Survey
Suite 3015
227 N. Bronough Street
Tallahassee, FL 32301

Copies of this report can be purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286
Denver, CO 80225
800-ASK-USGS

CONTENTS

Figures

Tables

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:

$$^{o}F = 9/5\ (^{o}C + 32)$$

$$^{o}C = 5/9\ (^{o}F - 32)$$

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

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

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.

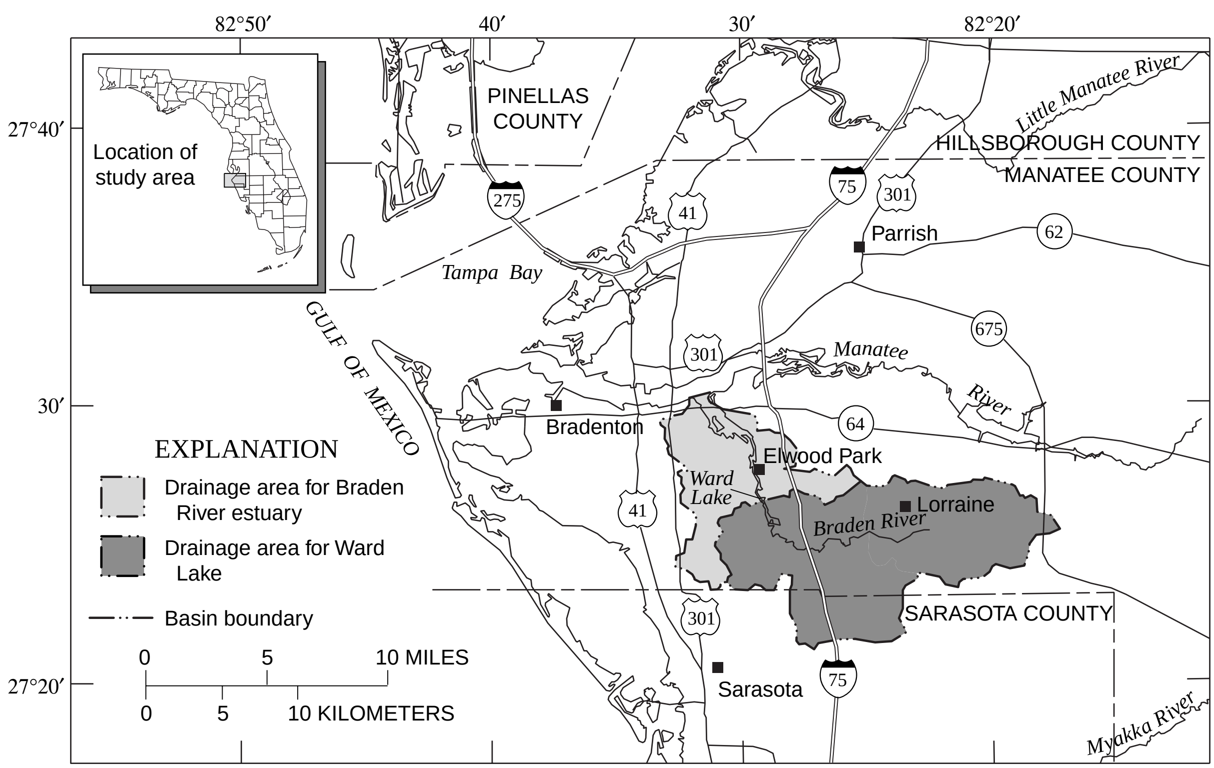
The chemical composition of water flowing from the tributaries to the estuary is similar to the chemical composition of water in the tributaries flowing to Ward Lake and does not appear to be affected by brackish water from high tides. Nitrogen concentrations in water from Glen Creek were greater than 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



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Albers Equal-Area Conic projection
Standard Parallels 29° 30′ and 45° 30′, central meridian –83° 00′

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

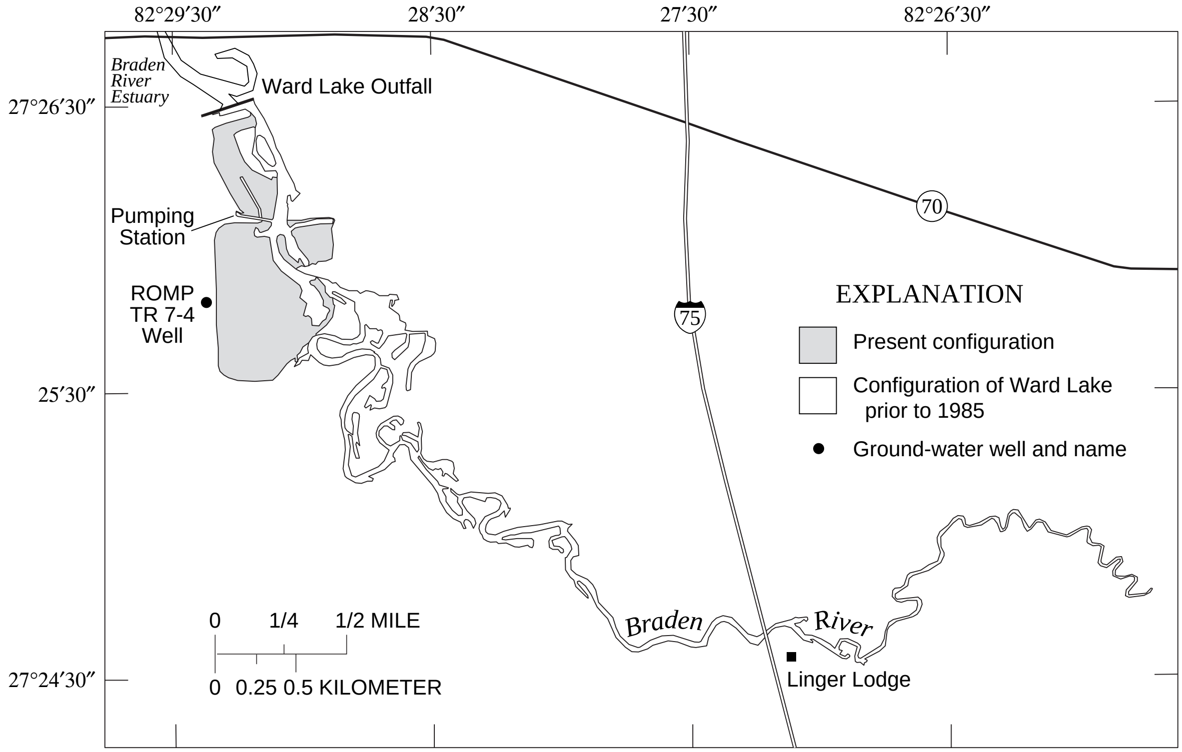


Figure 2. Configuration of Ward Lake prior to 1985 and at present.

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 ^{o}F. 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

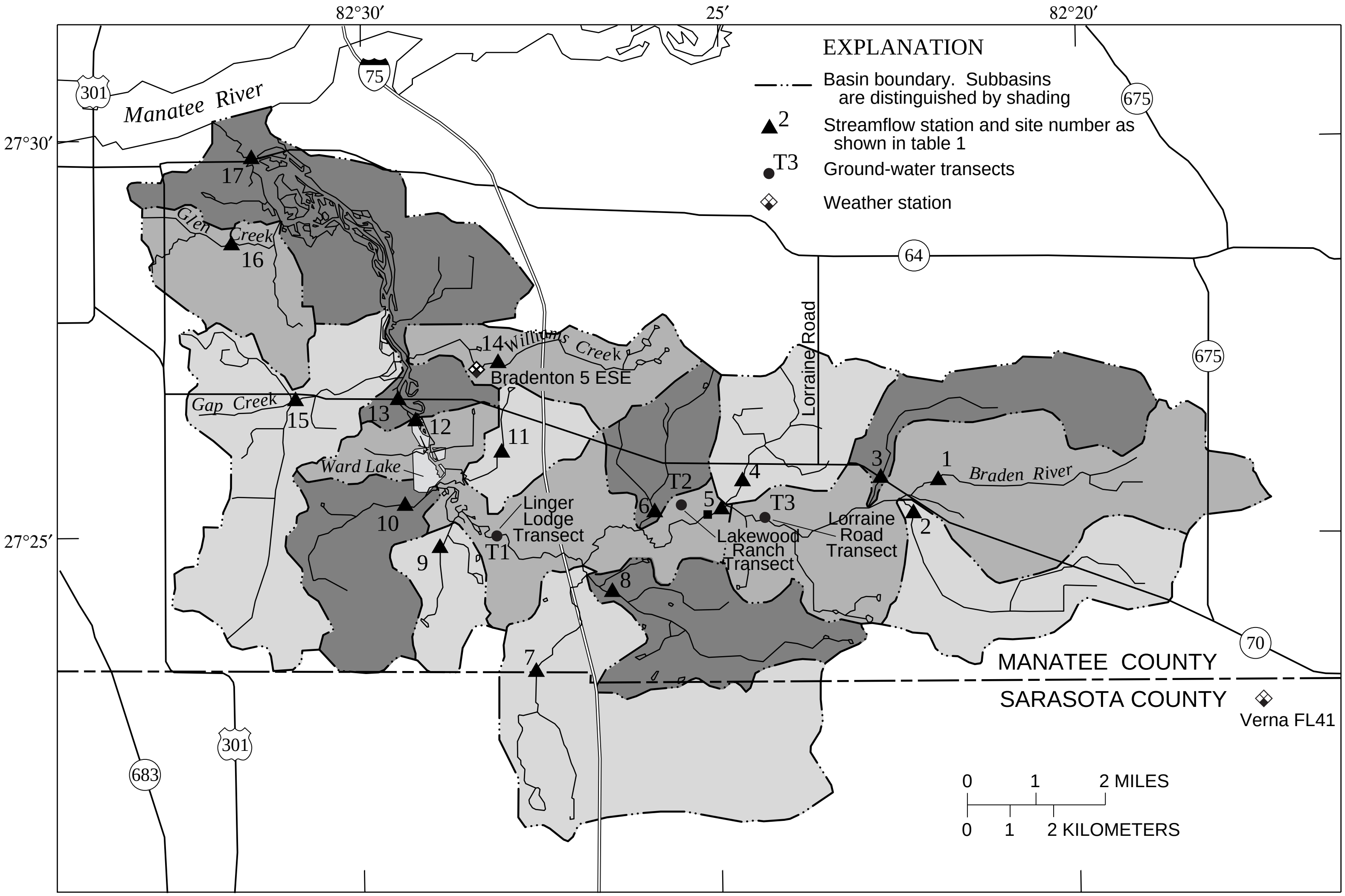


Figure 3. Ward Lake drainage basin and data-collection network.

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

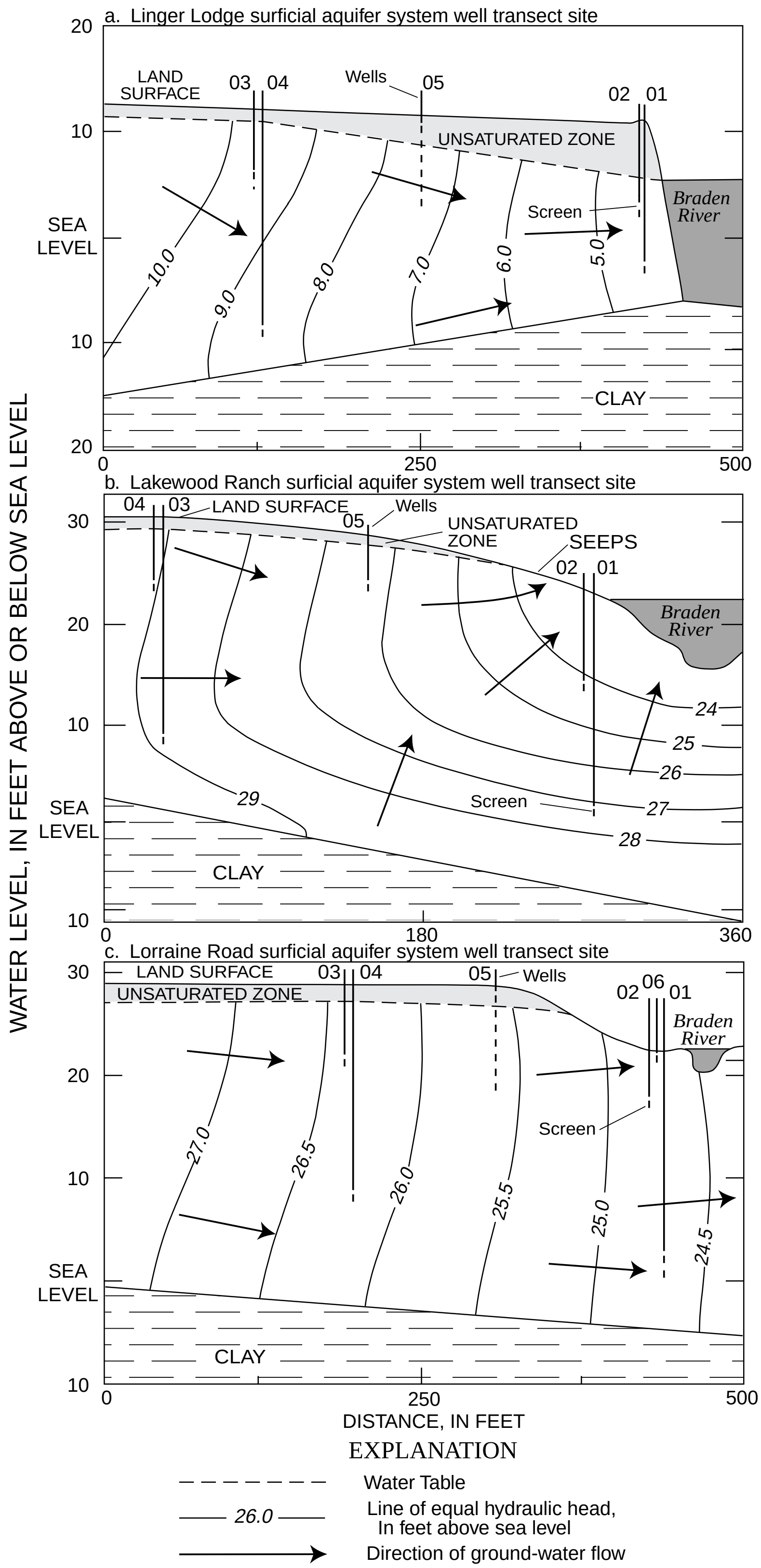


Figure 4. Ground-water flow in the surficial aquifer system at the (a) Linger Lodge, (b) Lakewood Ranch, and (c) Lorraine Road well transects (transect locations shown in fig. 3).

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.

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

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:

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

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.

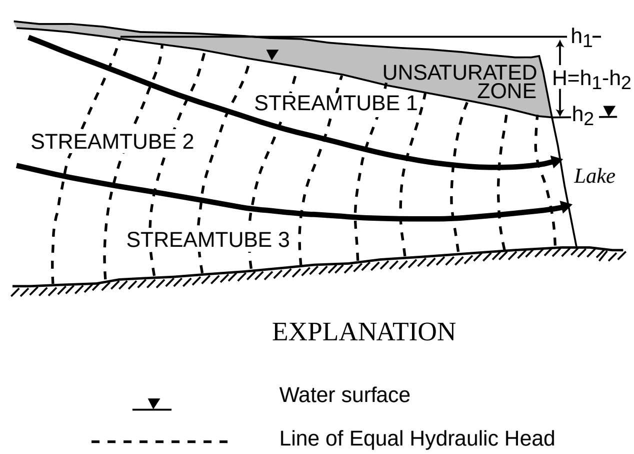


Figure 5. Conceptual model of the cross-sectional flow nets used to calculate ground-water flow to Ward Lake.

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).

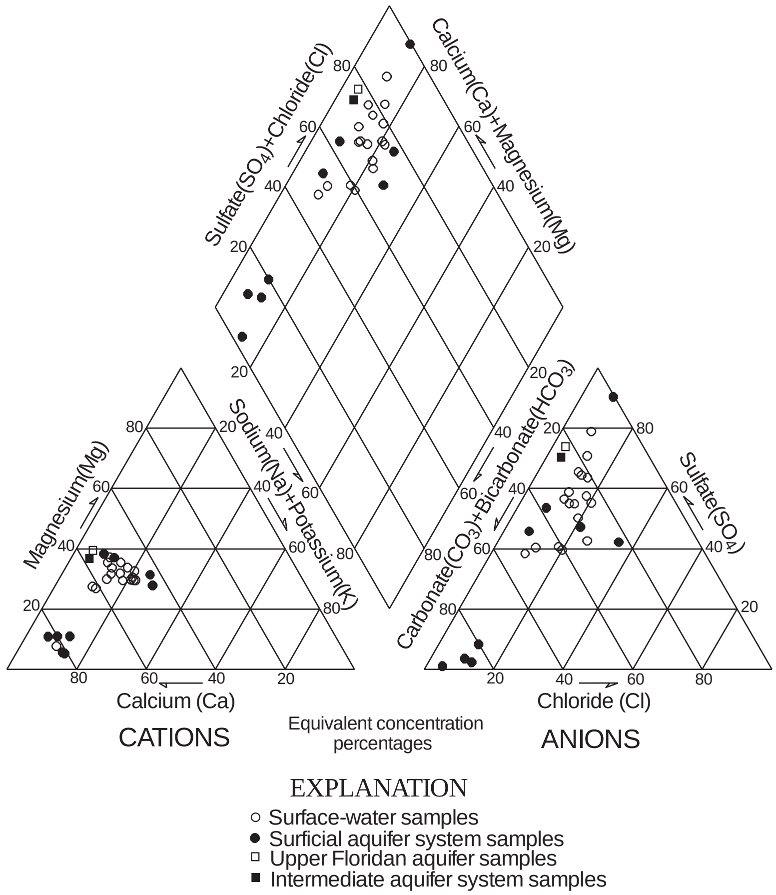


Figure 6. Major cation and anion equivalent concentration percentages of surface water at the Braden River near the Lorraine station and ground water at the Lorraine Road and Lakewood Ranch surficial aquifer system well transects, and from the intermediate aquifer system and the Upper Floridan aquifer.

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 groundwater 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