Regression Analysis of Stage Variability for West-Central Florida Lakes

By Laura A. Sacks, Donald L. Ellison, and Amy Swancar

Prepared in cooperation with the
Southwest Florida Water Management District

Scientific Investigations Report 2008-5147

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
Mark D. Myers, Director

U.S. Geological Survey, Reston, Virginia: 2008

For product and ordering information:
World Wide Web: *http://www.usgs.gov/pubprod*
Telephone: 1-888-ASK-USGS

For more information on the USGS--the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment:

World Wide Web: http://www.usgs.gov
Telephone: 1-888-ASK-USGS

Suggested citation:

Sacks, L.A., Ellison, D.L., and Swancar, A., 2008, Regression Analysis of Stage Variability for West-Central Florida Lakes: U.S. Geological Survey Scientific Investigations Report 2008-5147, 34 p.

Cover photo taken by Dan Duerr, USGS
Dead Lady Lake, December 27, 2005

Contents

Figures

Tables

Conversion Factors and Abbreviations

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
meter (m)	3.281	foot
	Area	
acre (ac)	4,047	square meter
acre (ac)	0.4047	hectare
	Volume	
million gallons (Mgal)	3,785	cubic meter

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).
Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).
Elevation, as used in this report, refers to distance above the vertical datum.

Acronyms

GIS	Geographic Information System
SWFWMD	Southwest Florida Water Management District
USGS	U.S. Geological Survey
VIF	variance inflation factor

Regression Analysis of Stage Variability for West-Central Florida Lakes

By Laura A. Sacks, Donald L. Ellison, and Amy Swancar

Abstract

The variability in a lake's stage depends upon many factors, including surface-water flows, meteorological conditions, and hydrogeologic characteristics near the lake. An understanding of the factors controlling lake-stage variability for a population of lakes may be helpful to water managers who set regulatory levels for lakes. The goal of this study is to determine whether lake-stage variability can be predicted using multiple linear regression and readily available lake and basin characteristics defined for each lake.

Regressions were evaluated for a recent 10-year period (1996-2005) and for a historical 10-year period (1954-63). Ground-water pumping is considered to have affected stage at many of the 98 lakes included in the recent period analysis, and not to have affected stage at the 20 lakes included in the historical period analysis. For the recent period, regression models had coefficients of determination (R^2) values ranging from 0.60 to 0.74, and up to five explanatory variables. Standard errors ranged from 21 to 37 percent of the average stage variability. Net leakage was the most important explanatory variable in regressions describing the full range and low range in stage variability for the recent period. The most important explanatory variable in the model predicting the high range in stage variability was the height over median lake stage at which surface-water outflow would occur. Other explanatory variables in final regression models for the recent period included the range in annual rainfall for the period and several variables related to local and regional hydrogeology: (1) ground-water pumping within 1 mile of each lake, (2) the amount of ground-water inflow (by category), (3) the head gradient between the lake and the Upper Floridan aquifer, and (4) the thickness of the intermediate confining unit. Many of the variables in final regression models are related to hydrogeologic characteristics, underscoring the importance of ground-water exchange in controlling the stage of karst lakes in Florida. Regression equations were used to predict lake-stage variability for the recent period for 12 additional lakes, and the median difference between predicted and observed values ranged from 11 to 23 percent.

Coefficients of determination for the historical period were considerably lower (maximum R^2 of 0.28) than for the recent period. Reasons for these low R^2 values are probably related to the small number of lakes (20) with stage data for an equivalent time period that were unaffected by ground-water pumping, the similarity of many of the lake types (large surface-water drainage lakes), and the greater uncertainty in defining historical basin characteristics. The lack of lake-stage data unaffected by ground-water pumping and the poor regression results obtained for that group of lakes limit the ability to predict natural lake-stage variability using this method in west-central Florida.

Introduction

Lakes have a natural range of stage fluctuation that responds to changes in rainfall, evaporation, and surface- and ground-water flows. Characteristics of each lake influence this stage fluctuation. For example, surface drainage and basin features affect surface-water flows, whereas sub-lake geology and local hydrogeology affect the amount of ground-water exchange between the lake and the surrounding aquifers. Anthropogenic factors also can affect lake-stage fluctuations. For example, structural controls on surface outlets can influence the high range in lake stage. Similarly, withdrawals from the underlying aquifer can increase ground-water outflow (leakage), lowering minimum lake stage. Determining the natural range of stage fluctuation for a lake can be difficult when stage data are limited to periods influenced by human activities.

Concern about how ground-water withdrawals affect lake levels prompted the Florida Legislature to mandate that water management districts establish “minimum levels” for all surface-water bodies (Section 373.042, Florida Statutes). The minimum level for a lake is the level at which “further withdrawals would be significantly harmful to water resources of the area.” To establish a minimum lake level, the processes controlling lake-stage fluctuations in the absence of ground-water pumping need to be understood.

About 1,800 lakes at least 10 ac in size are within the boundaries of the Southwest Florida Water Management District (SWFWMD) (Gant, 1998). Few of these lakes have stage data during periods considered to be unaffected by ground-water pumping. In addition, surface-water outlets for many of the lakes have been structurally modified. Consequently, the lack of lake-stage data uninfluenced by human activities within the SWFWMD jurisdiction makes establishing minimum levels a challenge. Moreover, the length of stage record is not consistent among lakes, and although SWFWMD has stage data for about 730 lakes, more than 1,000 lakes do not have any stage record. When there is no suitable lake stage record, lake characteristics and other available data could potentially be used to estimate lake-stage fluctuations in the absence of ground-water pumping. Beginning in 1998, the U.S. Geological Survey (USGS) in cooperation with SWFWMD initiated a multi-year project to understand the natural range of stage fluctuation for lakes within the SWFWMD jurisdiction using statistical analysis of lake-basin characteristics. The study addressed USGS science goals by quantifying water resources and the effect of human activities on aquatic systems. The study aimed to develop predictive models that could be used to integrate existing hydrologic data into water management strategies.

The purpose of this report is to document whether readily available lake and basin characteristics can be used to predict lake-stage variability for a population of lakes. To fulfill this objective, multiple linear regression analysis was used with numerous explanatory basin and lake characteristics to predict lake-stage variability. Lakes both affected and unaffected by ground-water withdrawals were examined, as were historical and recent periods of stage record. Study lakes were confined to those within the SWFWMD boundaries. Because the goal was to define lake-stage variability using models based on existing data, no new data were collected for this study. Data to define lake and basin characteristics were obtained from numerous sources, including regional maps, site-specific lake information (typically from SWFWMD), and geographic information system (GIS) data.

Description of Study Area

Although lakes are located throughout the SWFWMD jurisdiction, many are concentrated in ridge and upland areas of Polk and Highlands Counties, and in the coastal lowlands north of Tampa Bay (Hillsborough and Pasco Counties) (fig. 1); lakes in these areas were the focus of this study. Most Florida lakes are surface expressions of subsidence features (sinkholes) in the underlying carbonate rock. Dissolution of the carbonate rock forms cavities in the limestone surface, which are then filled in with overlying sands and clays. This infilling can occur slowly or rapidly, forming cover subsidence sinkholes or cover collapse sinkholes, respectively. Thus, beds in the surficial aquifer and intermediate confining unit beneath lakes can be distorted or breached to various degrees (Evans and others, 1994; Tihansky and others, 1996; Swancar and others, 2000).

The study lakes are generally present in areas of recharge to the carbonate Upper Floridan aquifer. In these areas, rainfall that recharges the sandy surficial aquifer may discharge into local surface-water bodies or continue downward through the clay-rich intermediate confining unit, or through breaches in the confining unit, to the carbonate Upper Floridan aquifer (fig. 2). The amount of ground-water outflow (leakage) across the lake bottom is influenced by the downward head difference between the lake and the Upper Floridan aquifer, as well as the nature of the confining unit beneath the lake. Ground-water exchange can vary considerably among Florida lakes as a result of their karstic nature, even when the lakes are near one another (Sacks and others, 1998; Sacks, 2002). Regionally, surficial deposits and the intermediate confining unit beneath study lakes are relatively thin in the coastal lowlands, where they are typically less than 50 ft thick. The deposits are much thicker in the ridge areas, and are up to 400 ft thick beneath lakes in the southern part of the study area (Buono and Rutledge, 1978).

The climate in the study area is humid subtropical. Average annual rainfall is about 50 inches per year (in/yr), with about 60 percent of the rain occurring during the summer wet season (June through September). Rainfall from winter frontal activity generally is not as intense as rainfall from summer thunderstorms. Annual rainfall can range from less than 30 to more than 70 in/yr, with higher rainfall typically associated with years in which hurricanes and tropical storms occur. Average annual lake evaporation is estimated to range from 48 to 63 in/yr (Lee and Swancar, 1997; German, 2000; Swancar and others, 2000; Sumner and Belaineh, 2005; Swancar, 2006).

The Upper Floridan aquifer is the principal source of water for public supply, agriculture, industry, and residential use in the study area (Marella, 2004). In the northern Tampa Bay area, numerous well fields produce water for public supply (fig. 3A). Pumping from these well fields has adversely affected wetlands and has resulted in lowered lake stages (Southwest Florida Water Management District, 1996; Rochow, 1998). Along the central part of the State, ridge areas have historically been used to grow citrus crops, which prefer the well-drained soils characteristic of these areas. As in the northern Tampa Bay area, ground-water pumping has resulted in lowered lake levels in ridge areas (Barcelo and others, 1990; Southwest Florida Water Management District, 2006). Because ground-water use has affected surface-water flows and levels in the region, most of the study area is considered a Water Use Caution Area by the SWFWMD for regulatory purposes. Special management practices are implemented to reduce the stresses on water resources in such areas (Southwest Florida Water Management District, 1993).

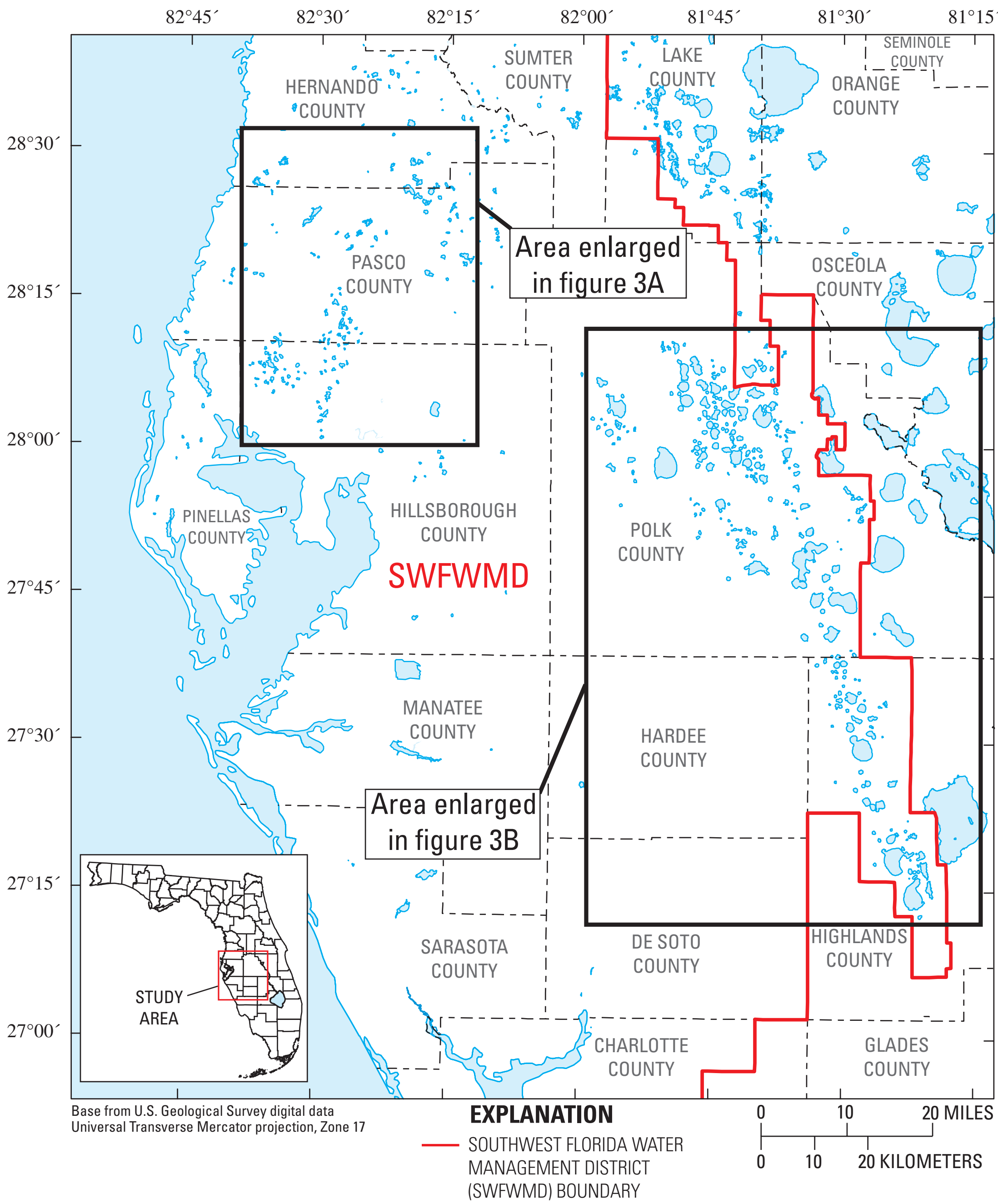

Figure 1. Location of study area in west-central Florida.

Acknowledgments

The authors thank many individuals at Southwest Florida Water Management District for their help in lake-data compilation and discussions about the project. We offer special thanks to Doug Leeper for his promptness and thoroughness providing lake data and for insights into the challenges of the minimum flows and levels program. We also thank Richard Gant, Jill Hood, Mike Kelley, and Melissa Hill for help with data and discussions about study lakes. Kathleen Hammett, Michael DeCharco, and Jie Gao, all formerly with the USGS, worked on earlier phases of the project, giving this report much of its direction. Thanks also to Alejandro Sepulveda (USGS) for help with digital elevation models. The report was improved substantially by reviews by Timothy Diehl, Louis Murray, and Doug Leeper.

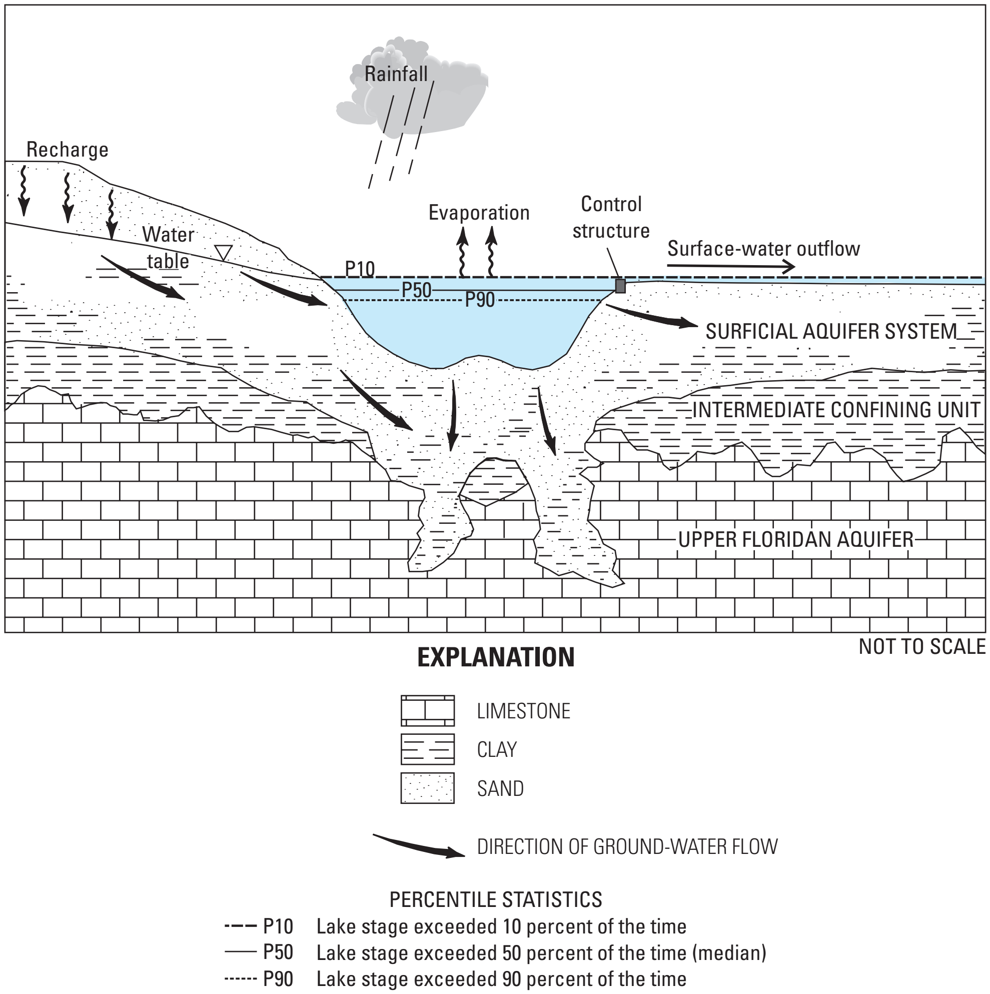

Figure 2. Generalized hydrogeologic section through a west-central Florida lake with surface-water outflow (modified from Tihansky and Sacks, 1997).

Model Development

Several steps were required to develop and test the regression-based models that were the objective of this study. First, appropriate lakes were chosen and stage variability statistics were computed for each lake to use as dependent variables. Next, lake and basin characteristics were defined for each lake to use as potential explanatory variables in the regressions. Lastly, regression models were computed and evaluated for validity.

Lake Selection

An initial set of 48 lakes was chosen for study because part of their stage record was deemed unaffected by ground-water withdrawals (Southwest Florida Water Management District, 1999a, 2002). However, the length of these records and their beginning and end points differed for each lake. For example, lakes in Polk and Highlands Counties were considered to be unaffected by ground-water pumping only prior to 1965, whereas lakes in Pasco County, north of Tampa Bay, typically were unaffected by ground-water pumping when their records began in the 1980s. Many of these 48 lakes were relatively large and had substantial surface-water drainage with structural controls on outlets. Regression models using only this set of lakes resulted in poor regression results (Gao, 2005). Results were further weakened by small sample sizes for the various geographic and surface-drainage groupings, as well as incomplete data sets. After adding more detailed basin characteristics and including the entire set of lakes in the regressions, results were still relatively poor (R^2 ranging from 0.17 to 0.57), probably because the length and periods of time for defining stage variability differed among lakes and because smaller seepage lakes (those with no surface-water drainage) were underrepresented.

In an effort to improve regression results, the study was expanded to include a greater number of lakes, with stage record evaluated for consistent time periods. These additional lakes, which were part of a companion study estimating ground-water inflow to lakes (Sacks, 2002), included smaller seepage lakes with a greater geographic distribution than the original 48 lakes. This larger group of lakes, however, did not necessarily contain stage data that were unaffected by ground-water pumping. Two consistent, 10-year time periods of stage record were evaluated for this larger set of lakes: a recent period (1996-2005) and a historical period unaffected by ground-water pumping (1954-63; Southwest Florida Water Management District, 2002). These periods were chosen to maximize the number of lakes with complete stage record, as well as cover both wet and dry periods so that sufficient ranges in lake stage were observed for computing stage variability statistics. Lakes typically had at least one stage observation per month for more than 90 percent of each period. Lakes were excluded from the analysis if more than 20 percent of their record was missing, if gaps in the record corresponded to projected maximum or minimum stage for each period, or if more than 11 consecutive months were missing. Several lakes augmented with ground water or surface water during the recent period also were eliminated from the analysis.

A total of 102 lakes were included in the final statistical analysis, with 98 of the lakes used for the recent period and 20 lakes used for the historical period (table 1). Lakes used for the recent period analysis also were grouped according to similar features, such as surface-water drainage, geographic region, or amount of nearby ground-water pumping, to evaluate if statistical models were improved for these subsets of lakes. Sixty of the lakes were in ridge and upland areas (“highland lakes”), and the remaining 42 lakes were in the Gulf Coastal Lowlands and Western Valley north of Tampa Bay (“lowland lakes”) (fig. 3). Lakes ranged in surface area from 4 to more than 5,500 ac, with a median area of 82 ac (table 1). Highland lakes tended to be larger and deeper, and their basins had greater topographic relief, than lowland lakes. A higher percentage of lowland lakes had surface drainage than highland lakes, but many of these drainage features flowed only during wet periods. Sixty of the lakes had surface-water outflow at “*P10*” stage (exceeded 10 percent of the time), whereas 42 lakes had no surface drainage at *P10* stage. All lakes analyzed for the historical period were highland lakes.

Table 1. Study lakes used in regression analysis.

[P50, stage exceeded 50 percent of time (median); P10, stage exceeded 10 percent of time; max, maximum stage for period 1996-2005]

Map reference number (fig. 3)	Lake	County	Section	Township (south)	Range (east)	Lake surface area (acres)	Used in historical and/or recent analysis	Surface-water outflow? [1]
Lakes in Ridge and Upland Areas (Highland Lakes)								
1	Angelo	Highlands	25	33	28	60	Recent	No
2	Annie	Highlands	6	38	30	86	Recent	P50
3	Chilton	Highlands	7	33	28	23	Recent	No
4	Clay	Highlands	29	36	30	367	Recent	P50
5	Denton	Highlands	2	34	28	66	Recent	No
6	Dinner (Highlands)	Highlands	17	34	29	379	Recent	No
7	Francis	Highlands	22	36	29	539	Historical	P50
8	Huntley	Highlands	5	37	30	680	Historical and recent	P50
9	Jackson	Highlands	30	34	29	3,412	Historical and recent	P50
10	Josephine (Highlands)	Highlands	32	35	29	1,236	Historical and recent	P50
11	June-in-Winter	Highlands	34	36	29	3,504	Historical and recent	P50
12	Letta	Highlands	31	33	29	478	Historical and recent	Max
13	Lotela	Highlands	26	33	28	802	Historical and recent	P10
14	McCoy	Highlands	6	37	30	56	Historical and recent	No
15	Mirror	Highlands	7	37	30	97	Recent	P50
16	Olivia	Highlands	6	33	28	86	Recent	No
17	Pearl	Highlands	6	37	30	66	Recent	P50

Table 1. (Continued) Study lakes used in regression analysis.

[P50, stage exceeded 50 percent of time (median); P10, stage exceeded 10 percent of time; max, maximum stage for period 1996-2005]

Map reference number (fig. 3)	Lake	County	Section	Township (south)	Range (east)	Lake surface area (acres)	Used in historical and/or recent analysis	Surface-water outflow? [1]
18	Pioneer	Highlands	11	33	28	93	Recent	No
19	Placid	Highlands	30	37	30	3,320	Historical	P10
20	Viola	Highlands	14	33	28	73	Recent	No
21	Aurora	Polk	13	30	28	176	Recent	No
22	Blue	Polk	24	30	27	118	Recent	No
23	Clinch	Polk	31	31	28	1,207	Historical and recent	P10
24	Crooked	Polk	1	31	27	5,538	Historical and recent	P10
25	Deer (Polk)	Polk	25	28	25	125	Historical and recent	P50
26	Dinner (Polk)	Polk	15	29	27	24	Recent	No
27	Eagle	Polk	1	29	25	651	Recent	P10
28	Hamilton	Polk	18	28	27	2,162	Historical	P50
29	Hancock	Polk	8	29	25	4,519	Recent	P50
30	Helene	Polk	34	26	25	62	Recent	No
31	Henry	Polk	16	31	26	106	Recent	P10
32	Hickory	Polk	17	32	28	100	Recent	P10
33	Howard	Polk	30	28	26	628	Historical and recent	P10
34	Josephine (Polk)	Polk	13	30	27	14	Recent	No
35	Little Aurora	Polk	13	30	28	18	Recent	No
36	Little Van	Polk	26	27	25	21	Recent	No
37	Mabel	Polk	11	29	27	117	Recent	No
38	Mariana (Sanitary)	Polk	1	28	25	503	Historical and recent	P50
39	McLeod	Polk	7	29	26	512	Recent	P50
40	Medora	Polk	36	27	25	50	Recent	No
41	Menzie	Polk	28	28	27	22	Recent	No
42	Otis	Polk	28	28	26	143	Historical and recent	P50
43	Parker	Polk	8	28	24	2,272	Historical and recent	P10
44	Polecat	Polk	27	30	26	40	Recent	P50
45	Reedy	Polk	35	31	28	3,486	Historical and recent	P50
46	Rochelle	Polk	4	28	26	578	Historical	P10
47	Saddlebag	Polk	6	30	29	287	Recent	No
48	Saint Anne	Polk	14	30	28	15	Recent	No
49	Sara	Polk	17	28	27	41	Recent	P10
50	Scott	Polk	18	29	24	285	Historical	P50
51	Starr	Polk	14	29	27	147	Recent	No
52	Tennessee	Polk	9	27	25	112	Recent	Max
53	Thomas (Polk)	Polk	35	28	25	73	Recent	No
54	Wales	Polk	1	30	27	326	Recent	No
55	Walker	Polk	21	30	26	39	Recent	No
56	Warren	Polk	11	30	27	4	Recent	No
57	Iola	Pasco	15	24	20	107	Recent	No
58	Jessamine	Pasco	11	24	20	77	Recent	No
59	Pasadena	Pasco	16	25	21	373	Recent	No
60	Spring	Hernando	15	23	20	58	Recent	P50

Table 1. (Continued) Study lakes used in regression analysis.

[P50, stage exceeded 50 percent of time (median); P10, stage exceeded 10 percent of time; max, maximum stage for period 1996-2005]

Map reference number (fig. 3)	Lake	County	Section	Township (south)	Range (east)	Lake surface area (acres)	Used in historical and/or recent analysis	Surface-water outflow? [1]
Lakes in Gulf Coastal Lowlands or Western Valley (Lowland Lakes)								
61	Alice	Hillsborough	16	27	17	93	Recent	P10
62	Allen	Hillsborough	10	27	18	28	Recent	P10
63	Bird (Hillsborough)	Hillsborough	26	27	18	26	Recent	P50
64	Boat	Hillsborough	14	28	18	32	Recent	Max
65	Calm	Hillsborough	14	27	17	127	Recent	Max
66	Carroll	Hillsborough	15	28	18	191	Recent	P50
67	Cooper	Hillsborough	11	27	18	82	Recent	P10
68	Deer (Hillsborough)	Hillsborough	1	27	18	35	Recent	P10
69	Egypt	Hillsborough	27	28	18	67	Recent	No
70	Ellen	Hillsborough	10	28	18	53	Recent	P10
71	George	Hillsborough	10	28	18	24	Recent	No
72	Hanna	Hillsborough	18	27	19	30	Recent	P10
73	Hobbs	Hillsborough	1	27	18	67	Recent	P10
74	Hog Island	Hillsborough	6	27	19	47	Recent	P50
75	Juanita	Hillsborough	22	27	17	24	Recent	Max
76	LeClare	Hillsborough	30	27	18	44	Recent	No
77	Merrywater	Hillsborough	22	27	18	25	Recent	P10
78	Mound	Hillsborough	11	27	17	79	Recent	P50
79	Osceola	Hillsborough	3	27	17	64	Recent	P10
80	Platt	Hillsborough	35	27	18	63	Recent	P50
81	Starvation	Hillsborough	21	27	18	52	Recent	P10
82	Stemper	Hillsborough	13	27	18	126	Recent	Max
83	Taylor	Hillsborough	16	27	17	44	Recent	P10
84	Bell	Pasco	13	26	18	80	Recent	P50
85	Big Vienna	Pasco	23	26	18	36	Recent	P10
86	Bird (Pasco)	Pasco	36	26	18	51	Recent	P50
87	Black	Pasco	26	26	17	5	Recent	No
88	Camp	Pasco	34	26	18	19	Recent	Max
89	Cow (East)	Pasco	19	26	19	98	Recent	P50
90	Crews	Pasco	16	24	18	693	Recent	Max
91	Geneva (Mud)	Pasco	26	26	17	13	Recent	Max
92	Gooseneck	Pasco	29	26	19	27	Recent	P10
93	King	Pasco	7	26	19	122	Recent	P50
94	Linda	Pasco	26	26	18	19	Recent	No
95	Moon	Pasco	28	25	17	99	Recent	P10
96	Padgett	Pasco	24	26	18	200	Recent	P50
97	Parker (Ann)	Pasco	35	26	17	93	Recent	P10
98	Pierce	Pasco	9	25	18	39	Recent	Max
99	Saxon	Pasco	30	26	19	81	Recent	P50
100	Tampa	Pasco	32	26	19	28	Recent	P50
101	Thomas (Pasco)	Pasco	11	26	18	164	Recent	P10
102	Wistaria	Pasco	2	26	18	25	Recent	P10

[1] Surface-water outflow occurred at P50 (median), P10, or maximum stage for period 1996-2005.

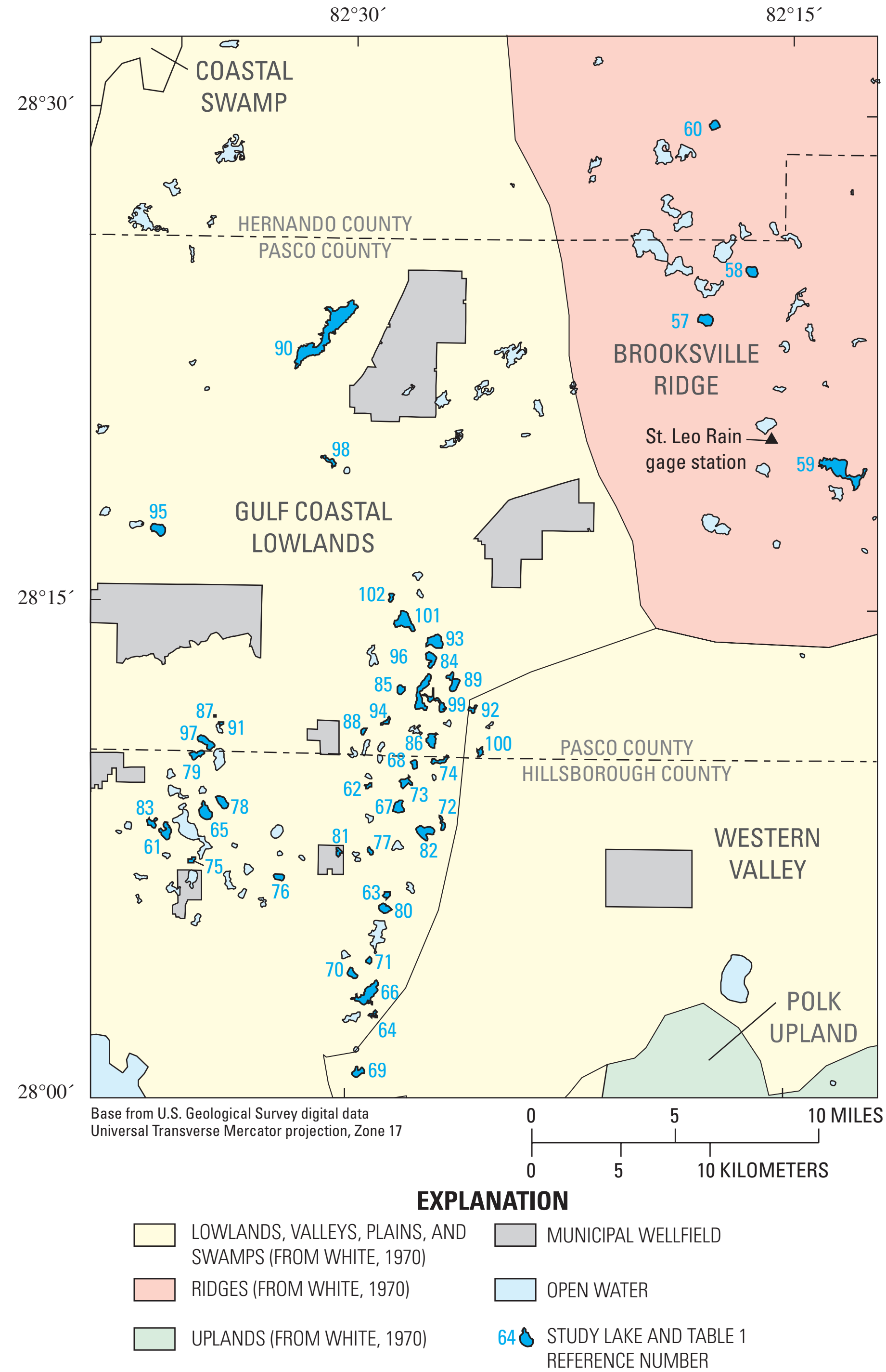

Figure 3A (above) and **3B** (at right). Location of study area lakes and relation to geomorphic regions: (A) lakes north of Tampa Bay; (B) lakes in upland and ridge area of Polk and Highlands Counties.

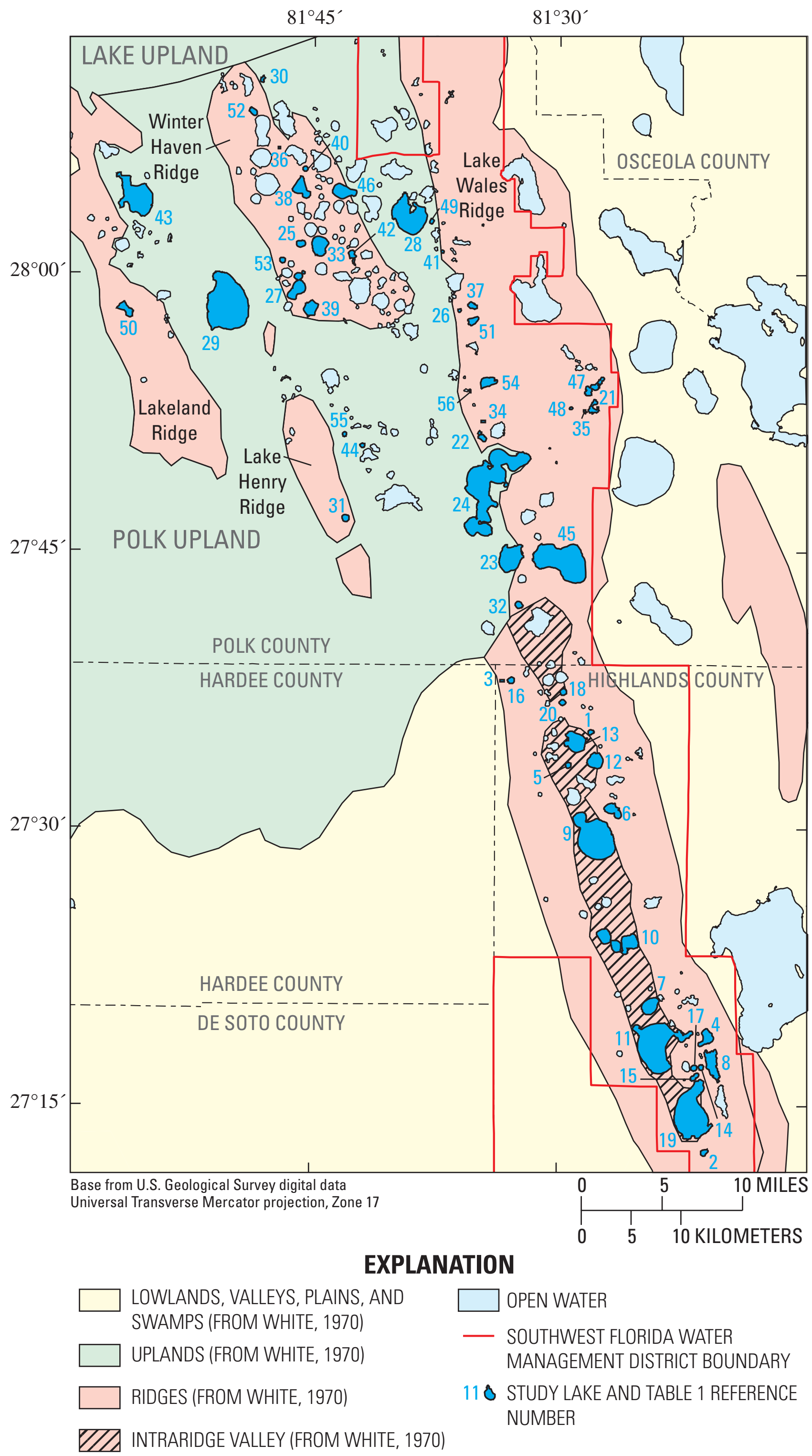

Figure 3A (at left) and **3B** (above). Location of study area lakes and relation to geomorphic regions: (A) lakes north of Tampa Bay; (B) lakes in upland and ridge area of Polk and Highlands Counties.

Defining Lake-Stage Variability

The variability in lake stage, which was used as the dependent variable in regression models, was defined in several different ways. Percentile statistics were used to describe lake-stage variability to be consistent with the SWFWMD minimum flows and levels program (Southwest Florida Water Management District, 1999a). Percentiles of interest include *P10*, *P50* (median), and *P90* (stage exceeded 90 percent of the time; a low stage) (fig. 4). The SWFWMD initially used these percentiles in studies of water levels in wetlands, where the *P10* corresponded to the readily measured plant fringe around the wetland (Southwest Florida Water Management District, 1999b). Differences between percentiles used to describe stage variability for this report are *P10-P50*, *P50-P90*, and *P10-P90*. The *P10-P50* difference corresponds to the range of stage at higher levels, whereas the *P50-P90* difference describes the lower range of lake stage during dry periods. The *P10-P90* difference covers nearly the full range of lake stage during both wet and dry periods. In addition to these percentile differences, the difference between maximum and minimum lake stage (*Max-Min*) for the 10-year period also was used as a dependent variable to describe lake-stage variability. The *Max-Min* variable was included because it represents the full stage range, and because it is derived from the raw stage data, rather than percentile statistics. All stage data were collected by the SWFWMD and USGS, with most of the recent data from the SWFWMD and the historical data from the USGS.

The frequency at which lake stage was measured differed among the study lakes. However, most lakes had at least one observation per month over each of the two 10-year periods. One observation per month was the typical frequency of stage measurement used for the SWFWMD recent lake-stage measurement program. To test the validity of using this measurement frequency to calculate lake-stage statistics, observations based on daily measured stage at Lake Starr and Lake June-in-Winter (fig. 3B; lakes 51 and 11, respectively) were compared for the 10-year recent period. Medians calculated using daily data, monthly average data, and one observation per month were compared using the nonparametric Mann Whitney U-test (Helsel and Hirsh, 2002) because the stage data were not normally distributed. Differences between medians for the groups were not significantly different (p-level 0.05). Thus, the lake record was condensed to one observation per month for all study lakes so that their observation frequencies were identical.

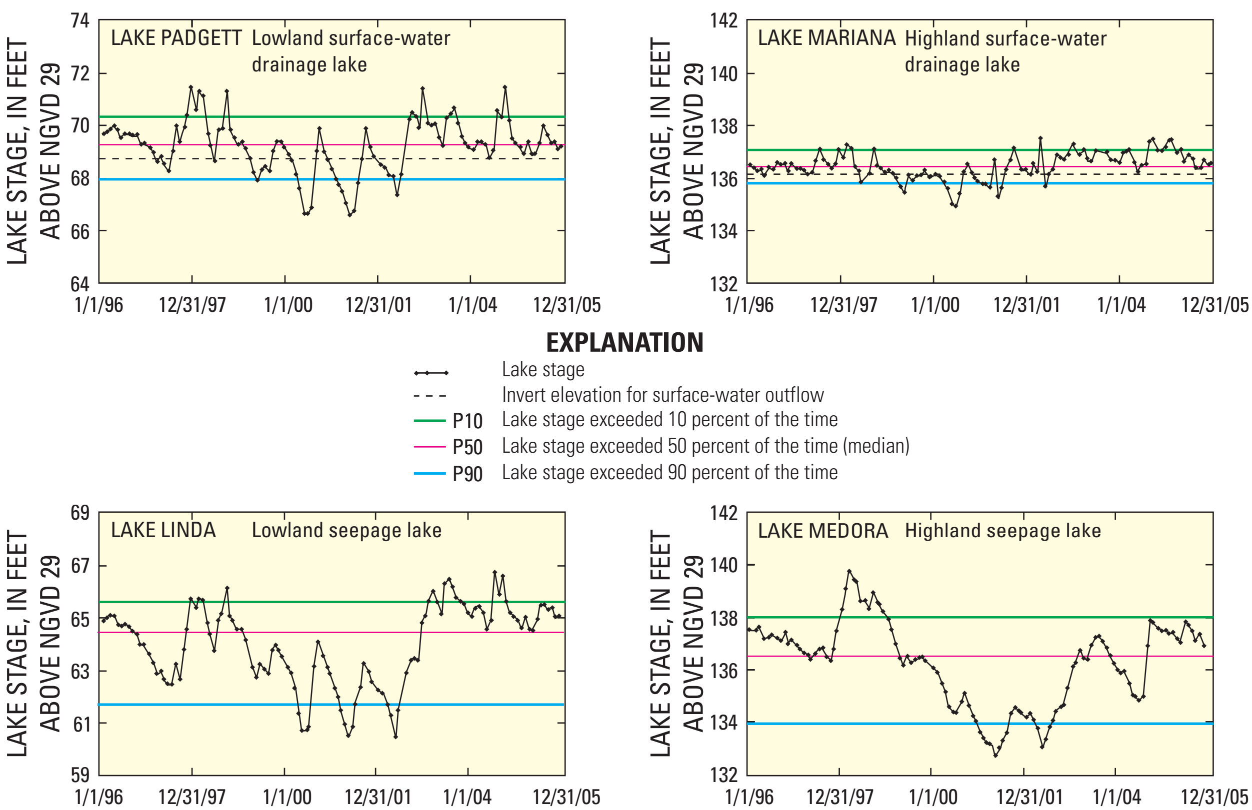

Figure 4. Stage range and percentile statistics for selected surface-water drainage and seepage study lakes within lake clusters in lowland and highland areas, 1996-2005.

Summary statistics for the variables used to define lake-stage variability were calculated for the recent and historical 10-year periods. For the recent period (1996-2005), the median *P10-50* (1.4 ft) was lower than the median *P50-P90* (2.9 ft), but their ranges were similar (0.3 to about 6.4 ft) (table 2). The median *P10-P90* was 4.6 ft, about double the ranges for the *P10-P50* and *P50-P90*. *Max-Min* ranged from 1.9 to 16.1 ft, with a median of 7.4 ft. Lakes with surface-water drainage typically had less stage variability, particularly for the *P10-P50*, than seepage lakes (fig. 5). Highland lakes tended to have a greater range in stage than lowland lakes for the recent period, probably because the highland lakes had a greater range in depth and basins with greater topographic relief than the lowland lakes.

Median stage variability was lower for the historical period, with less range on the high end, than for the recent period (table 2). The reasons for the lower variability for the historical period are likely twofold: (1) the number of lakes included for the historical period was much less than for the recent period (20 compared to 98) and included more large lakes (median surface area 741 ac compared to 80 ac) that had surface-water drainage; and (2) the recent period had more lakes affected by ground-water pumping, resulting in lower *P90* levels than what would be expected without ground-water pumping.

Table 2. Median and range of stage variability statistics for recent and historical periods.

[All units are in feet; P10, stage exceeded 10 percent of the time; P50, stage exceeded 50 percent of the time (median); P90, stage exceeded 90 percent of the time; Max-Min, maximum stage for period minus minimum stage for period; n, number of lakes in group]

Statistic	P10-P50	P50-P90	P10-P90	Max-Min
Recent (1996-2005), n = 98				
Median	1.4	2.9	4.6	7.4
Minimum	.3	.3	.7	1.9
Maximum	6.3	6.5	11.7	16.1
Historical (1954-1963), n = 20				
Median	.9	1.6	2.7	4.5
Minimum	.4	.4	.8	2.1
Maximum	3.1	2.5	4.9	7.2

Discussion of Time Period Used to Compute Lake-Stage Statistics

Although percentiles used to describe lake stage for this study were calculated for 10-year periods, this length of time is not sufficient to describe long-term stage percentiles. Differences between the recent 10-year period and long-term percentile statistics are shown in figure 6A for three lakes with about 60 years of record. This 60-year period includes a period when ground-water pumping increased, likely resulting in declines in lake stage. The long-term percentiles do not, therefore, represent long-term conditions that are consistent. Percentile statistics for the recent 10-year period differed from the 60-year period to varying degrees for the three lakes and for each percentile statistic. *P10* and *P50* statistics were more similar than *P90*, with differences ranging from -0.6 to 0.7 ft. Differences for the *P90* statistic were greater for all lakes, with the greatest difference being for Crooked Lake (5.0 ft) (fig. 3B; lake 24). Long-term percentile statistics included record low stages for Crooked Lake during the 1980s to mid 1990s; because these extreme low levels were not observed during the 10-year recent period, the recent *P90* statistic was considerably greater than the long-term *P90* (fig. 6A).

The 10-year recent period also was compared to a period when stage was unaffected by ground-water pumping (mid 1940s-1965) for the same three lakes (fig. 6A). A comparison of stage values using the Mann-Whitney U-test indicated no significant difference between the medians for the two periods for Lake Clinch (fig. 3B; lake 23), although the difference was statistically significant for Crooked Lake and Lake June-in-Winter ($p < 0.05$). Percentile statistics for these three lakes also were calculated for six different 10-year periods, illustrating how the period over which the statistics were computed results in different percentiles (fig. 6B). Thus, percentile statistics calculated using data from different time periods are not directly comparable, and these 10-year periods are not sufficient lengths of time to represent long-term conditions.

The length of time required to realize long-term homogenous conditions is difficult to assess. If a lake had stage data unaffected by ground-water pumping and with no changes to surface-water drainage for that length of time, then long-term percentile statistics could easily be computed. "Long term" can be defined as the point when the available data are numerous enough to yield a calculated percentile that does not change with the addition of more data. Until this point is reached, the estimation of median lake stage improves as the number of observations increases. The meteorological condition at the beginning of the data period also affects the time required to reach homogenous conditions. A stable median is typically reached more quickly if average rainfall conditions, rather than extremely wet or dry conditions, are present at the beginning of the period considered.

The time necessary to reach a stable median can be illustrated by performing a cumulative median analysis, which simply evaluates the behavior of the median as successive data are added to the calculation. In the following example, monthly average lake-stage data were used to calculate the median as data were added back in time. Cumulative medians were computed for Crooked Lake for both 20- and 15-year periods, from 1965 back to 1945 and from 1960 back to 1945, respectively (fig. 7A). Relatively normal rainfall (47.5 in.) occurred in 1965, whereas greater than normal rainfall (73.0 in.) occurred in 1960. For the 20-year analysis when initial rainfall was close to normal, the cumulative median

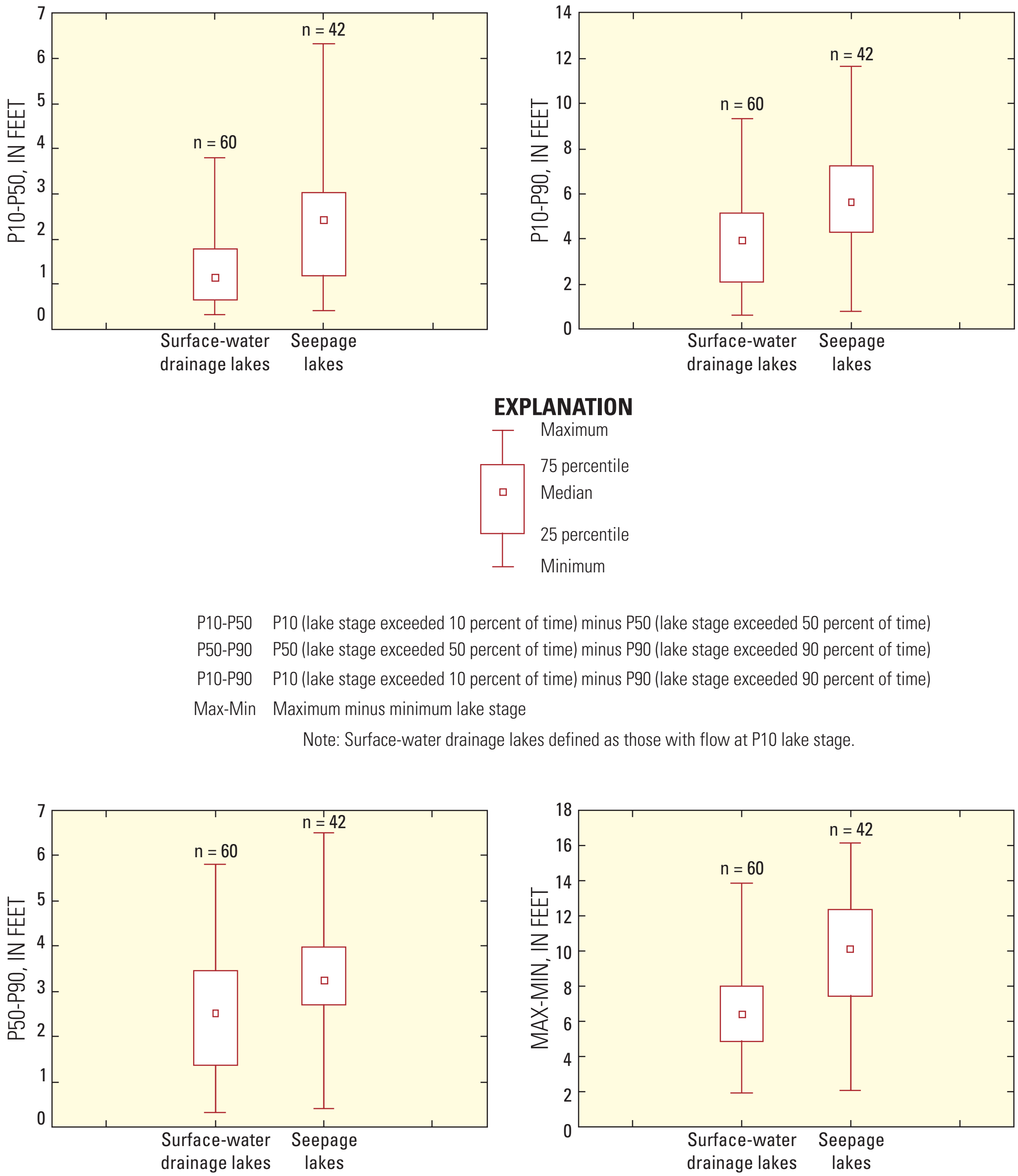

Figure 5. Range of stage variability for surface-water drainage and seepage lakes for the 1996-2005 period.

consistently remained within 1 ft of the 20-year median after only a little more than 1 year. In contrast, the cumulative median for the 15-year analysis varied considerably during the first 3 years and stabilized to within 1 ft of the 20-year median only after 5.5 years (fig. 7A). In this analysis, the cumulative median of Crooked Lake did not completely stabilize after 20 years of data (3 consecutive years with maximum change less than 0.2 ft). Results from this analysis are similar to those for other lakes in the study area, almost all of which have less than 20 years of data unaffected by ground-water pumping. Thus, the time period required to reach a stabilized median likely exceeds the period of record unaffected by ground-water pumping for most lakes in west-central Florida.

Additional insight can be gained by performing the same cumulative median analysis on rainfall, as several National Weather Service rainfall sites in the study area have more than 100 years of record. Rainfall can be used as a surrogate for lake stage because of its importance in controlling

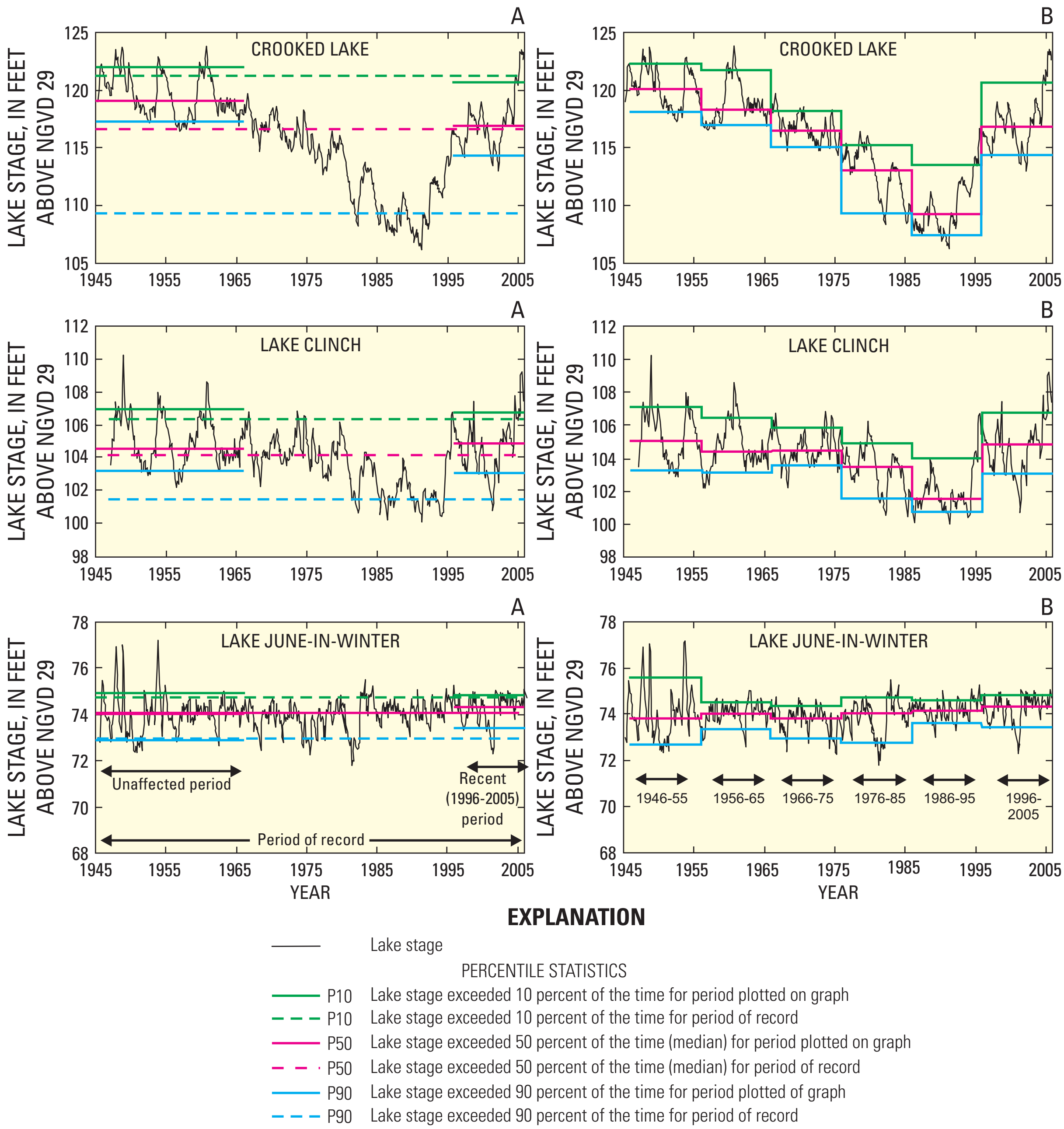

Figure 6. Hydrographs for Crooked Lake, Lake Clinch, and Lake June-in-Winter, (A) with percentile statistics plotted for period of record, for period unaffected by ground-water pumping (mid 1940s to 1965), and for 10-year recent period (1996-2005); and (B) with percentile statistics plotted for sequential 10-year periods between 1946 and 2005.

lake-stage fluctuations; the cyclic and variable nature of rainfall in Florida is typically mirrored by lake-stage fluctuations. Average annual rainfall has not changed substantially over the past 100 years; however, multidecadal periods of above and below average rainfall correspond to the Atlantic Multidecadal Oscillation cycle (Enfield and others, 2001; Basso and Schultz, 2003). A cumulative median analysis was calculated using the St. Leo rain gage in east-central Pasco County for 100 years of record, from 2005 back to 1905 (fig. 7B). The median varied widely for the first 7 years, after which the variability decreased but did not stabilize to the 100-year median (3 consecutive years with maximum change less than 0.5 in.) until about 60 years of data were included. Results from analyses of data from other rain gages indicate similar or even longer periods of time are required to reach a stable median. Long-term changes in climate also would be expected to confound assessments of long-term percentile statistics.

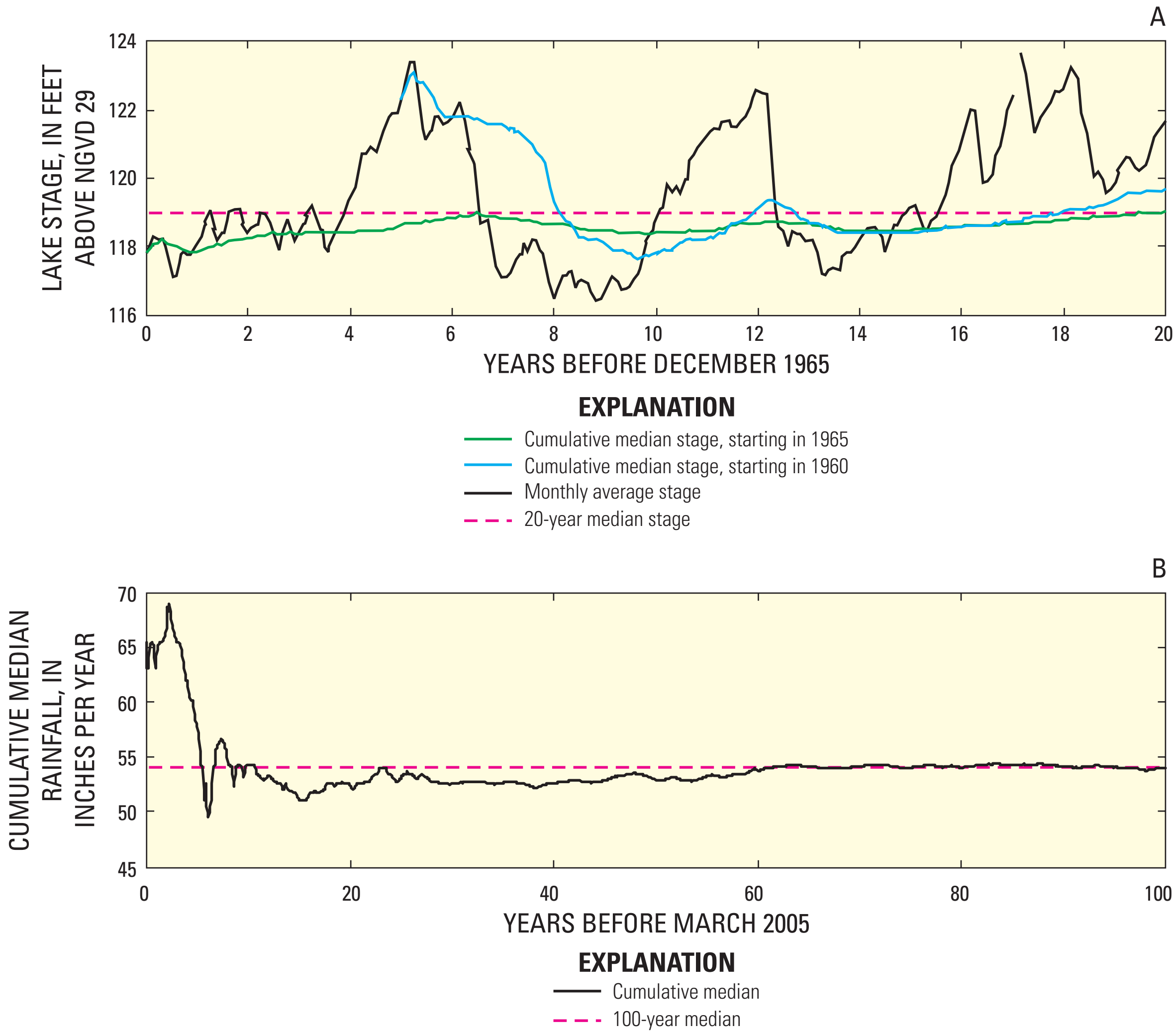

Figure 7. (A) Cumulative median stage for Crooked Lake for 1945-1965 period; and (B) cumulative median rainfall for St. Leo in Pasco County for 1905-2005 period, compared to long-term median data.

If it is assumed that the time period necessary for stabilization of median lake stage under homogeneous conditions is similar to the period required for median rainfall, at least 60 years of homogeneous stage data are needed. This exceeds the period of record for lakes unaffected by ground-water pumping in west-central Florida. As the available data period becomes shorter, meaningful comparisons can only be made with data from the same time periods. This is the approach used for regression analysis herein—stage variability for the lakes is defined using identical 10-year periods. These stage variability statistics, however, do not represent long-term conditions.

Defining Lake and Basin Characteristics

A number of lake and basin characteristics were defined to describe the physical setting of each lake (app. 1). These characteristics were chosen by evaluating variables that could potentially affect lake stage, and were used as potential explanatory variables in the regression models. The data used to define lake and basin characteristics came from numerous sources, including regional maps, site-specific lake information (typically from SWFWMD), and geographic information system (GIS) data. Because no new data were collected for this study, the data describing a given basin characteristic had to be readily available to be used for regression analysis.

Surface-water drainage features can be important controls on lake stage. Outflows diminish the lake-stage peaks, whereas inflows can increase stage during wet periods and moderate stage declines during dry periods by providing a constant source of water to the lake. Surface-water drainage features, such as outflow controls and drainage types, were determined using detailed information from the SWFWMD (app. 1) as well as by examining topographic and aerial maps. The type of surface-water drainage was defined for each lake, based on the following categories from an early Florida Lakes Gazetteer (Florida Board of Conservation, 1969): (1) surface-water outflow only, (2) surface-water inflow only, (3) surface-water inflow and outflow, and (4) no surface-water flow (seepage only). For lakes with surface-water outflow, elevation information was compiled for the control point for the outflow (or invert elevation of a structure). For seepage lakes, the low point in the basin divide from USGS topographic maps was used to calculate an outflow control point elevation. The difference was then computed between this control point elevation and the median lake stage. For lakes with surface-water inflow or with canals connected to other lakes, the surface area of upgradient lakes was computed, as well as the ratio of lake area to upgradient surface area.

Other basin characteristics used to describe potential surface inflows included basin size, engineered stormwater drainage, and land slope. Lake drainage-basin areas were defined by the USGS or SWFWMD; topographic basins were defined by digitizing the topographic highs around each lake from topographic maps. Most study lakes received some degree of stormwater runoff: a categorical basin characteristic was defined to qualitatively describe the degree of stormwater runoff based on data from SWFWMD lake data sheets (Richard Gant, Southwest Florida Water Management District, written commun., 1999-2007). For this characteristic, values ranged from 0 to 4, with 0 representing no stormwater runoff and 4 representing large amounts of stormwater runoff. Land-surface steepness in the topographically defined basin and within 100 m (328 ft) of the shoreline was computed from slope calculations using 1:24,000-scale digital topographic map data. Slopes were defined using a grid-cell size of 10×10 m (32.8×32.8 ft), and digital elevation modeling software.

Rainfall influences lake stage directly through rainfall on the lake, as well as indirectly through surface- and ground-water flows. For the historical period, average annual rainfall for the 10-year period was defined using data from the nearest National Weather Service rainfall station, or the average of the nearest stations if a lake was midway between them. For the recent 10-year period, annual rainfall totals were available in a 2×2-km (1.2×1.2-mi) grid over the study area from NEXRAD, a network of advanced Doppler radars operated by the National Weather Service. When a lake overlapped grids, rainfall for that lake was computed by weighing the rainfall in each grid to the portion of the lake's surface area in that grid. Average annual rainfall, as well as maximum and minimum annual rainfall, was computed from these data for the 10-year period. The difference between maximum and minimum rainfall also was computed, because that difference could influence the stage range over the 10-year period more substantially than the average.

The morphological characteristics of a lake, such as its surface area, perimeter, and depth can affect the amount of ground-water exchange with the surrounding aquifers (Lee, 2002). Surface area was defined from 1:24,000 and 1:100,000-scale topographic maps and, additionally, from 1999 land-use definitions from SWFWMD (app. 1). Maximum depth was computed using the most recent bathymetric mapping data obtained from sources listed in appendix 1. Other variables were computed from these morphological characteristics, including relative lake depth (Wetzel and Likens, 1991) and the ratios of lake surface area to perimeter, lake surface area to maximum lake depth, and basin area to lake surface area.

The hydrogeologic characteristics of a lake can influence the amount of ground-water exchange between it and the surrounding aquifers. Regional maps and corresponding GIS coverages were used to define surface geology (Scott and others, 2001), recharge or discharge rates (Aucott, 1988; Sepulveda, 2002), depth to the Upper Floridan aquifer (Buono and Rutledge, 1978), and thicknesses of the surficial aquifer and intermediate confining unit (Buono and others, 1979) at each lake. Head in the Upper Floridan aquifer beneath each lake was estimated for a low and high head condition by examining semiannual potentiometric surface maps between 1996 and 2005; low conditions were extrapolated from the May 2000 map and high conditions from the September 2004 map (Duerr, 2001; Blanchard and Seidenfeld, 2005, respectively). The head difference and head gradient between the lake stage (at lake bottom) and Upper Floridan aquifer were computed from stage data for these same time periods. There are not enough wells with head data adjacent to the study lakes to compute more accurate head differences between each lake and the underlying Upper Floridan aquifer. For the historical period, the predevelopment potentiometric surface map (Ryder, 1982) was used to define the head in the Upper Floridan aquifer because regional potentiometric surface maps were not available for the 1954-63 period. Geomorphic regions and lake regions, which were used as grouping categories, were defined by White (1970) and Griffith and others (1997), respectively.

The amount of ground water pumped near a lake can lower the Upper Floridan aquifer head near the lake below regional potentiometric surface estimates, affecting the amount of leakage (ground-water outflow) from the lake. For the recent period, ground-water pumping was defined using pumpage estimates from wells with water-use permits (Mike Kelley, Southwest Florida Water Management District, written commun., 2007). Ground-water pumping was defined for each lake in its nearshore area 100 m (328 ft) from the lake, within its topographically defined basin, and within 1 mi of the lake. Average and maximum annual pumping were computed for the 10-year period (1996-2005). Surface-water pumping from the lake was defined using data from the same database. Pumping normalized to lake surface area also was computed. The distance to the nearest well field was used as an explanatory variable for lowland lakes north of Tampa Bay, where well fields with concentrated public supply wells are common.

Another factor influencing ground-water exchange is the continuity of the confining unit near and beneath the lake. Disruptions in the confining unit can focus lake leakage, as well as potential ground-water inflow, downward to the Upper Floridan aquifer. The degree of karstification in each lake basin and in the area within 100 m (328 ft) of the lake was characterized by the number of closed contours on 1:24,000-scale topographic maps. Another indicator of karstification is the number of active sinkholes reported in each lake basin and within 100 m (328 ft) of the lake. Sinkhole databases were obtained from both SWFWMD and Florida Geological Survey files (app. 1), and contained overlapping data from the original files of the (now defunct) Florida Sinkhole Research Institute, as well as reported sinkholes from the past 10 years that were not necessarily in both databases. Reporting of sinkhole formation is probably not consistent throughout the study area, because sinkholes tend to be reported more frequently in populated areas and less frequently in rural areas (Tihansky and others, 1999).

Net leakage, computed as ground-water outflow minus inflow or negative net ground-water flow, was determined for lakes that had stage data during two very dry periods, May 2000 and May 2001. Net leakage was computed as the residual to the monthly water budget for each lake as the difference between rainfall minus evaporation and change in lake stage, with the assumption that surface-water flows were negligible (Deevey, 1988; Sacks and others; 1998). Change in lake stage was computed between the last April and last May observation for both years. Daily rainfall for that period was computed using NEXRAD data, and weighing the amount of rainfall on the lake to the portion of the lake within each grid, as described earlier. Daily evaporation was based on energy-budget evaporation data from Lake Starr, in Polk County (Swancar and others, 2000; Amy Swancar, U.S. Geological Survey, unpub. data, 2007). Most lakes did not have surface-water flow during these very dry periods. However, several lakes were omitted from the analysis because the invert elevations for their outlet were lower than the lake stage for the entire month, indicating surface-water outflow.

The amount of ground-water inflow to the lakes was estimated from data or regression equations from Sacks (2002). A ground-water inflow category also was computed, ranging from 1 to 3, with 3 representing the highest amount of ground-water inflow (Sacks, 2002). As these inflow categories originally were derived from oxygen-18 data, those data also were used directly as an explanatory variable, when available.

Soil types, wetlands, and land use were characterized for each lake. Soil types and their hydrologic characteristics were defined for each lake basin, as well as within 100 m (328 ft) of the shore, from county soil survey maps originally from Natural Resource Conservation Service and digitized by SWFWMD into GIS data bases (app. 1). The fraction of type A (excessively drained) soils was computed for each lake as a surrogate for high surficial aquifer hydraulic conductivity, which could increase the movement of ground water to the lake. Wetlands adjacent to a lake can moderate lake-stage fluctuations by storing excess water during wet periods and by draining into the lake during dry periods. The fraction of wetlands in each lake basin, and within 100 m (328 ft) of the shore, was computed from U.S. Fish and Wildlife Service National Wetland Inventory GIS maps (app. 1). Land use in a lake basin can affect lake stage by changing recharge and drainage patterns in the basin. The fraction of urban and agricultural land use for each basin was defined based on GIS maps from the SWFWMD. For those maps, land-use classifications were photointerpreted based on the Florida Land Use and Cover Classification System from 1:12,000-scale USGS color infrared digital orthophoto quarter quadrangles from 1999.

Statistical Techniques

Multiple linear (least squares) regression was used to predict lake-stage variability from basin and lake characteristics. Multiple linear regression models predict the relation between a response (or dependent) variable and several explanatory (or independent) variables:

$$Y = \beta_0 + \beta_1 \; \xi_1 + \ldots \; \beta_k \, \xi_k \; + \varepsilon \, , \tag{1}$$

where Y is the dependent (or response) variable, β_0 is the intercept, β_1 is the slope coefficient for the first explanatory variable (x_1), β_k is the slope coefficient for the k^{th} explanatory variable (x_k), and ε is the error, or unexplained “noise” in the data. Basin characteristics were first plotted graphically against lake-stage variability predictors to examine their general relations. A correlation matrix also was used to determine which basin characteristics had statistically significant correlations ($p < 0.05$) with stage variability.

Model selection criteria generally followed those presented in Helsel and Hirsch (2002). Final regression models were chosen as those with the lowest Mallow’s Cp values, provided that slope coefficients for all explanatory variables were statistically significant (α level = 0.05). Regression residuals were evaluated for normality by examining probability plots, and residuals were plotted against predicted values to assess uniform scatter (heteroscedasticity). Explanatory variables were transformed based on an assessment of linearity and scatter in partial residual plots, and whether the transformation resulted in a lower Mallow’s Cp value for the model. The influence of possible outliers on regression results was evaluated by examining the Cook’s Distance variable and by comparing residuals to the residuals computed if individual data points were omitted.

Multi-collinearity (cross-correlation between explanatory variables) was assessed by examining the variance inflation factor (VIF) and the relation (or R^2) between each explanatory variable and all other explanatory variables in the model. All final regression models presented in this report had VIF values less than 1.5, which were close to the ideal value of 1; VIF values greater than 10 can cause serious instability in regression models (Helsel and Hirsch, 2002). Another factor considered was the ratio of the number of observations (cases) to the number of explanatory variables. To avoid undue bias toward individual observations, this ratio was always greater than 10, and was typically greater than 20. For example, if there were 50 observations, the maximum number of explanatory variables considered was four.

Regressions were computed for the entire group of lakes, as well as subsets based on surface-water drainage, geographic distribution, and the amount of ground-water pumping. Regressions were run for stage variability statistics computed for both the recent (1996-2005) and historical (1954-63) periods for the four dependent variables defining lake-stage variability: *P10-P50, P50-P90, P10-P90*, and *Max-Min*.

Regression Analysis of Stage Variability

Final regression models to predict lake-stage variability for the recent period (1996-2005) for the entire group of lakes had R^2 values ranging from 0.60 to 0.74 (table 3, app. 2). The model predicting the difference between maximum and minimum stage (*Max-Min*) had the highest R^2 value, whereas the *P50-P90* model had the lowest R^2 value. Standard errors for the recent period models ranged from 21 to 37 percent of the average stage variability. R^2 values for models based on the subset of highland lakes were greater than those for the entire group of lakes, ranging from 0.68 to 0.82; standard errors ranged from 19 to 35 percent (table 3). R^2 values for other groupings (geographic and surface-water drainage types) were lower or similar to those for the entire group of lakes. Lakes minimally affected by ground-water pumping also were evaluated by examining groups of lakes with the lowest average annual ground-water pumping within 1 mi of the lake (for example, less than 150 Mgal/yr for 32 lakes). These regressions also yielded lower R^2 values than those for the entire group of lakes. The reason for better regression outcomes for the entire group of lakes probably is due to the greater spread of dependent and explanatory variables compared to those for the subsets.

Regression results for the historical period were poor (maximum $R^2 = 0.28$). Lakes available with historical data were mostly large surface-water drainage lakes, with a relatively small range in stage, thereby reducing the range of the dependent variables (table 2). The low number of lakes (20) available for regression analysis for this period also greatly constrained the number of valid regression models. In addition, data available for the historical period had considerably more uncertainty than data for the recent period. For example, Upper Floridan head was assumed to be from a map of predevelopment head conditions, rainfall was from regional rainfall sites, and changes in outlet structures may not have been thoroughly documented. Because the regression results for the historical period were so poor, these models would not provide reasonable estimates of lake-stage variability, and they are not presented in this report.

Of the more than 60 variables (app. 1) that were considered in the regression modeling, 7 were included in the final models to predict lake-stage variability (table 3). Many of the other variables were significant in different versions of regression equations, but were not in final models because they resulted in a model that had a higher Mallow's Cp than the final model. In addition, some variables were not considered in the same models because they were cross-correlated (for example, intermediate confining unit thickness and depth to Upper Floridan aquifer).

Explanatory Variables Used to Predict Stage Variability

Several explanatory variables were common to all of the final regression models for the recent period for the entire group of lakes: (1) invert elevation difference, specifically, the difference between the invert or control point elevation for outflow and median lake stage (*INV DIFF*), (2) net leakage for May 2000 (*NET LEAKAGE*), and (3) maximum annual ground-water pumping within 1 mi of the lake (*MAX GW 1 MI*) (table 3). Head gradient for May 2000 (*HD GR 5-00*) was in two of the models, and thickness of the intermediate confining unit (*ICU THCK*) and the difference between the highest and lowest annual rainfall for 1996-2005 (*MX-MN PREC*) were each in one of the models. These variables are related to different aspects of lake water budgets: *INV DIFF* is directly related to surface-water outflow, *MX-MN PREC* is related to rainfall, and the remaining variables are related to ground-water exchange.

The final regression models for the highland lakes subset for the recent period included many of these same explanatory variables. *INV DIFF* and *NET LEAKAGE* were in all of the models, and *ICU THCK, HD GR 5-00*, and *MX-MN PREC* were each in one model. One additional variable, *GW IN CAT*, which is related to the amount of ground-water inflow, was in two models (table 3).

Invert elevation difference (*INV DIFF*) was in all of the final regression models and had the highest standardized slope (beta coefficient) in the *P10-P50* model for all lakes (0.51) and for the highland lakes subset (0.61) (table 3). Invert elevation is used synonymously with control point elevation for cases in which a structure does not control the outflow. The positive slope of the regressions indicates that the higher this elevation above the lake-stage median, the greater the stage variability. For lakes with lower invert elevation differences, the stage

Table 3. Summary of final regressions for entire group of lakes and for highland lakes subset for recent (1996-2005) period.

[P10, stage exceeded 10 percent of the time; P50, stage exceeded 50 percent of the time (median); P90, stage exceeded 90 percent of the time; Max-Min, maximum minus minimum stage for period; R^2, coefficient of determination; VIF, variance inflation factor; INV DIFF (feet), difference between invert or control point elevation and median lake stage; NET LEAKAGE (inches per month), leakage minus ground-water minus inflow for May 2000; MAX GW 1MI (million gallons per year), maximum annual ground-water pumping within 1 mile of the lake; ICU THCK (feet), thickness of intermediate confining unit; HD GR 5-00 (unitless), head gradient between the lake bottom and the Upper Floridan aquifer in May 2000; MX-MN PREC, maximum minus minimum annual rainfall for 1996-2005; GW IN CAT, ground-water inflow category, where 1 is lowest and 3 is highest; percentile statistics and maximum and minimum stage for 1996-2005 period]

Dependent variable	P10-P50	P50-P90	P10-P90	Max-Min
All Lakes				
R^2	0.66	0.60	0.69	0.74
Adjusted R^2	.64	.58	.68	.73
Standard error, feet	.70	.85	1.28	1.71
Average dependent variable	1.91	2.99	4.91	8.32
Standard error, percent	37	28	26	21
Number of lakes in model	89	89	89	89
Maximum VIF	1.2	1.2	1.2	1.3
Intercept	-.376	1.14	.720	-1.62
Explanatory variable 1	INV DIFF [1]	NET LEAKAGE	NET LEAKAGE	NET LEAKAGE
Slope for variable 1	.747	.290	.443	.676
Standardized slope [2], variable 1	.51	.56	.49	.51
Explanatory variable 2	GW MAX 1 MI [3]	ICU THCK	INV DIFF [1]	INV DIFF [1]
Slope for variable 2	.0338	-.00358	1.16	1.64
Standardized slope, variable 2	.33	-.29	.42	.40
Explanatory variable 3	NET LEAKAGE	INV DIFF [1]	GW MAX 1 MI [3]	MX-MN PREC
Slope for variable 3	.149	.417	.0501	.0918
Standardized slope, variable 3	.32	.26	.25	.22
Explanatory variable 4	HD GR 5-00 [4]	GW MAX 1 MI [3]	HD GR 5-00 [4]	GW MAX 1 MI [3]
Slope for variable 4	.212	.0186	.451	.0168
Standardized slope, variable 4	.22	.16	.25	.15
Highland Lakes Only				
R^2	0.68	0.77	0.82	0.80
Adjusted R^2	.66	.75	0.80	0.79
Standard error, feet	.77	.67	1.11	1.71
Average dependent variable	2.19	2.92	5.10	8. 95
Standard error, percent	35	23	22	19
Number of lakes in model	52	52	52	52
Maximum VIF	1.2	1.4	1.2	1.3
Intercept	.998	3.80	2.60	-1.25
Explanatory variable 1	INV DIFF [1]	NET LEAKAGE	NET LEAKAGE	INV DIFF [1]
Slope for variable 1	.931	.320	.500	2.02
Standardized slope, variable 1	.61	.65	.55	.47
Explanatory variable 2	NET LEAKAGE	ICU THCK [4]	INV DIFF [1]	NET LEAKAGE
Slope for variable 2	.186	-.598	1.41	.628
Standardized slope, variable 2	.38	-.28	.49	.46
Explanatory variable 3	GW IN CAT	INV DIFF [1]	HD GR 5-00 [4]	MX-MN PREC
Slope for variable 3	-.563	.438	.347	.0952
Standardized slope, variable 3	-.26	.28	.19	.24
Explanatory variable 4			GW IN CAT	
Slope for variable 4			-.638	
Standardized slope, variable 4			-.16	

[1] Natural log of variable used in model, after adding 3 to make all values positive.
[2] Also called beta coefficient.
[3] Square root of variable used in model.
[4] Natural log of variable used in model.

range is reduced, particularly at high stages when water flowing out of the lake limits the rise in stage. Although this variable is more important in controlling the variability of high lake stage (*P10-P50*) than the full range of stage, it was still a significant variable in the model for predicting the variability in the low range (*P50-P90*), probably because the invert elevation influences median (*P50*) stage as well as higher stages.

Net leakage for May 2000 (*NET LEAKAGE*) was another explanatory variable in all of the final models, and had the highest standardized slope in many of these models (table 3). Net leakage had a positive slope in the regressions, indicating that lakes with higher net leakage have a greater range in stage. Although net leakage is not necessarily equivalent to gross leakage, ground-water inflow should have been low during the May 2000 dry period over which this variable was calculated. Net leakage includes both lateral ground-water outflow, which is influenced by head gradients in the surficial aquifer, as well as vertical ground-water outflow, which is influenced by head gradients between the lake and the Upper Floridan aquifer. Because this variable is based on conditions during an extended regional drought (Verdi and others, 2006), it reflects a maximum loss to ground water for each lake. This variable requires two observations of lake stage between April and May 2000. Final regression models for the entire group of lakes include 89 lakes instead of the initial 98 lakes (app. 2) because 5 lakes did not have sufficient observations during this time, and an additional 4 lakes experienced surface-water outflow during this period.

Maximum annual ground-water pumping within 1 mi of the lake (*GW MAX 1MI*) was another explanatory variable in all of the final regression models for the entire group of lakes, and had a positive slope in each model (table 3). Thus, lakes with more nearby pumping are expected to have a greater range in stage than those with less pumping. Use of the variable describing *maximum* annual pumping for the 10-year period resulted in a lower Mallow's Cp and higher R^2 value than use of the variable describing *average* annual pumping, although the latter variable also was significant in some regression models. Maximum annual pumping may be a better predictor of lake-stage variability than average annual pumping because it considers the most extreme pumping condition. Agricultural and residential ground-water pumping increases during dry periods. The year with the greatest ground-water pumping probably would have resulted in the greatest drawdown in head in the Upper Floridan aquifer near the lake, inducing additional ground-water leakage and lowering the lake stage. Ground-water pumping was not in final regression models for the highland lakes subset.

The head gradient between the lake and the Upper Floridan aquifer for May 2000 (*HD GR 5-00*) was included in both the *P10-P50* and *P10-P90* regression models for the entire group of lakes, and for the *P10-P90* model for the highland lakes subset (table 3). The positive slope of this variable in the regressions indicates that as the head gradient increases, the stage range also increases. A larger head gradient implies greater potential leakage between aquifers. Head gradients are larger for lakes in the Brooksville Ridge and are smaller for lakes in the southern Lake Wales Ridge because of the greater depth to the Upper Floridan aquifer farther south. This greater depth probably isolates the lakes to some degree from drawdowns in the aquifer. Areas with larger gradients, however, do not necessarily indicate greater leakage, because confining unit properties are also an important factor controlling the amount of leakage between aquifers.

Thickness of the intermediate confining unit (*ICU THCK*) was included in the *P50-P90* regression models for the entire group of lakes and for the highland lakes subset (table 3). The slope for this variable was negative, implying that as the thickness of the confining unit increases, stage variability decreases. Greater confinement between the surficial and Upper Floridan aquifers indicates less water leakage between these aquifers; therefore, water within the surficial aquifer would be more likely to flow laterally toward the lake than downward. Less confinement would result in less ground-water inflow and more leakage, resulting in greater stage variability, particularly at low stage. The thickness of the confining unit increases from north to south in the study area, and is greatest in the southern ridge area. Although the regional trend in confining unit thickness is reflected in this variable, confining beds beneath Florida lakes are disrupted to varying degrees because of their karst origin (Evans and others, 1994; Tihansky and others, 1996).

A variable defining the range in annual rainfall for the 10-year recent period (*MX-MN PREC*) was included in the *Max-Min* models for the entire group of lakes and for the highland lakes subset (table 3). This variable characterizes precipitation extremes for the study period, rather than typical rainfall conditions. Average annual rainfall was not in any of the models because it was fairly similar between lakes, and thus was not useful for predicting lake-stage variability. Extremes in precipitation directly influence extreme highs and lows in lake stage for that same period. Although the *Max-Min* variable captures this full range in lake stage, the other dependent variables, which are based on differences in *P10*, *P50*, and *P90* statistics, do not characterize those extremes.

Lastly, an indicator of the amount of ground-water inflow (*GW IN CAT*) was included in the final *P10-P50* and *P10-P90* regression models for the highland lakes subset (table 3). This variable had a negative slope in the regressions, indicating that a lake with more ground-water inflow is expected to have less stage variability than one with less inflow. Although the ground-water inflow category can generally indicate how much inflow a lakes receives under steady-state conditions (Sacks, 2002), ground-water inflow is a transient phenomenon (Lee, 2000; Swancar and others, 2000). Lakes can receive substantial ground-water inflow following high recharge events, resulting in short-term high inflow rates, even if relatively little ground-water inflow occurs during most of the year (Sacks and others, 1998; Lee, 2000; Metz and Sacks, 2002).

Five of the seven variables in the final regression models were related to ground-water exchange: *NET LEAKAGE, GW MAX 1 MI, HD GR 5-00, ICU THCK*, and *GW IN CAT* (table 3). The VIFs were low for all models (table 3), and R^2 values were low between variables included in the same model (greatest 0.08), indicating little, if any, cross-correlation. It is likely that these variables would be cross-correlated if enough site-specific data were available to define them accurately. For example, leakage is dependent on the thickness of the confining unit and head gradients, which in turn, are influenced by ground-water pumping. The variable *NET LEAKAGE* is not expected to represent leakage for the entire 10-year period over which stage variability was computed. Rather, it is an estimate of net outflow for an extremely dry period, when heads in the Upper Floridan aquifer were probably locally drawn down due to ground-water pumping. The ground-water pumping variable (*GW MAX 1MI*) characterizes maximum annual pumping for the 10-year period, and therefore should influence leakage for a longer period than the month over which *NET LEAKAGE* was computed. The karstic nature of Florida lakes results in much variability in their sub-lake geology and the degree of connection between the lakes and Upper Floridan aquifer. Site specific conditions, such as breaches in the confining unit beneath a lake, interact with regional hydrogeologic characteristics, such as the intact thickness of the confining unit *(ICU THCK*) and regional head gradients (*HD GR 5-00*), to affect ground-water exchange. In addition to influencing direct lake leakage, these regionally defined hydrogeologic characteristics also affect ground-water flow patterns around the lakes, which in turn, influence potential contributing areas for ground-water inflow to the lake (Lee, 2002). The inclusion of these regionally defined variables appears to supplement more “lake-specific” variables in predicting stage variability.

Comparison between Predicted and Observed Lake-Stage Variability

The final regression equations for the recent period (table 3) were used to predict stage variability for 12 lakes not used to develop the regression models. Three of these lakes had complete stage data for the 1996-2005 period, but were not part of the original analysis. The other nine lakes were part of the original data set, but were omitted from the final analysis because of periods of missing stage data or periods when the lake was augmented with ground water or surface water. Lake and basin characteristics used as explanatory variables in the regressions were defined for the lakes, and regression equations were solved to compute stage variability (percentile differences and *Max-Min* stage; table 4). The predicted values from the regressions were then compared to observed stage

Table 4. Observed lake-stage variability and basin characteristics for lakes not used to develop regression models.

[Units in feet unless otherwise noted; P10, stage exceeded 10 percent of the time; P50, stage exceeded 50 percent of the time (median); P90, stage exceeded 90 percent of the time; Max-Min, maximum stage for period minus minimum stage for period; INV DIFF, difference between invert or control point elevation and median lake stage; HD GR 5-00, head gradient between the lake bottom and the Upper Floridan aquifer in May 2000; ICU THCK, thickness of intermediate confining unit; NET LEAKAGE, leakage minus ground-water minus inflow for May 2000; in/mo, inches per month; GW IN CAT, ground-water inflow category, where 1 is lowest and 3 is highest; MAX GW 1MI, maximum annual ground-water pumping within 1 mile of the lake; Mgal/yr, million gallons per year; MX-MN PREC, maximum minus minimum annual rainfall for 1996-2005; percentile statistics and maximum and minimum stage for 1996-2005 period]

Lake	County	Section	Township	Range	Observed stage variability				Basin characteristics						
					P10-P50	P50-P90	P10-P90	Max-Min	INV DIFF	HD GR 5-00 (unitless)	ICU THCK	NET LEAKAGE (in/mo)	GW IN CAT (unitless)	MAX GW 1MI (Mgal/yr)	MX-MN PREC (inches)
Annie	Polk	3	29	27	1.9	3.0	4.9	8.1	6.8	0.227	70	2.8	2	578	40.56
Big Fish[1]	Pasco	28	24	19	5.4	2.1	7.6	12.0	6.0	.564	35	2.2	1	180	36.39
Curve[2]	Pasco	1	26	18	1.8	3.0	4.8	7.0	2.8	.392	20	2.3	1	115	41.88
Placid[2]	Highlands	30	37	30	1.1	1.8	2.9	5.3	.7	.083	375	1.5	3	2,098	33.51
Raleigh[3]	Hillsborough	27	27	17	6.1	5.7	11.8	15.4	8.0	1.019	20	9.4	1	3,905	31.50
Rogers[3]	Hillsborough	27	27	17	6.1	4.1	10.2	13.3	11.2	.964	20	6.9	1	3,932	31.50
Seminole[2]	Pasco	35	26	17	1.0	1.6	2.5	4.8	-.3	.458	20	3.0	2	40	31.00
Sirena[2]	Highlands	1	37	29	2.2	3.2	5.4	9.0	.4	.076	370	2.3	3	870	29.87
Tulane[2]	Highlands	27	33	28	2.8	3.6	6.4	10.7	16.2	.122	230	11.8	3	87	43.36
Venus	Polk	9	29	27	2.0	3.4	5.5	9.8	15.1	.223	70	2.9	2	325	45.25
Verona[2]	Highlands	23	33	28	3.4	3.7	7.0	12.5	33.2	.119	240	7.6	3	256	44.21
Virginia	Hillsborough	3	27	18	1.4	4.7	6.1	10.6	5.5	.594	20	4.2	1	39	33.36

[1]Intermittently augmented with ground water during low stage beginning in 2000.
[2]Missing more than 11 consecutive months of data.
[3]Surface water pumped into lake during wet periods in 1998 and 2002.

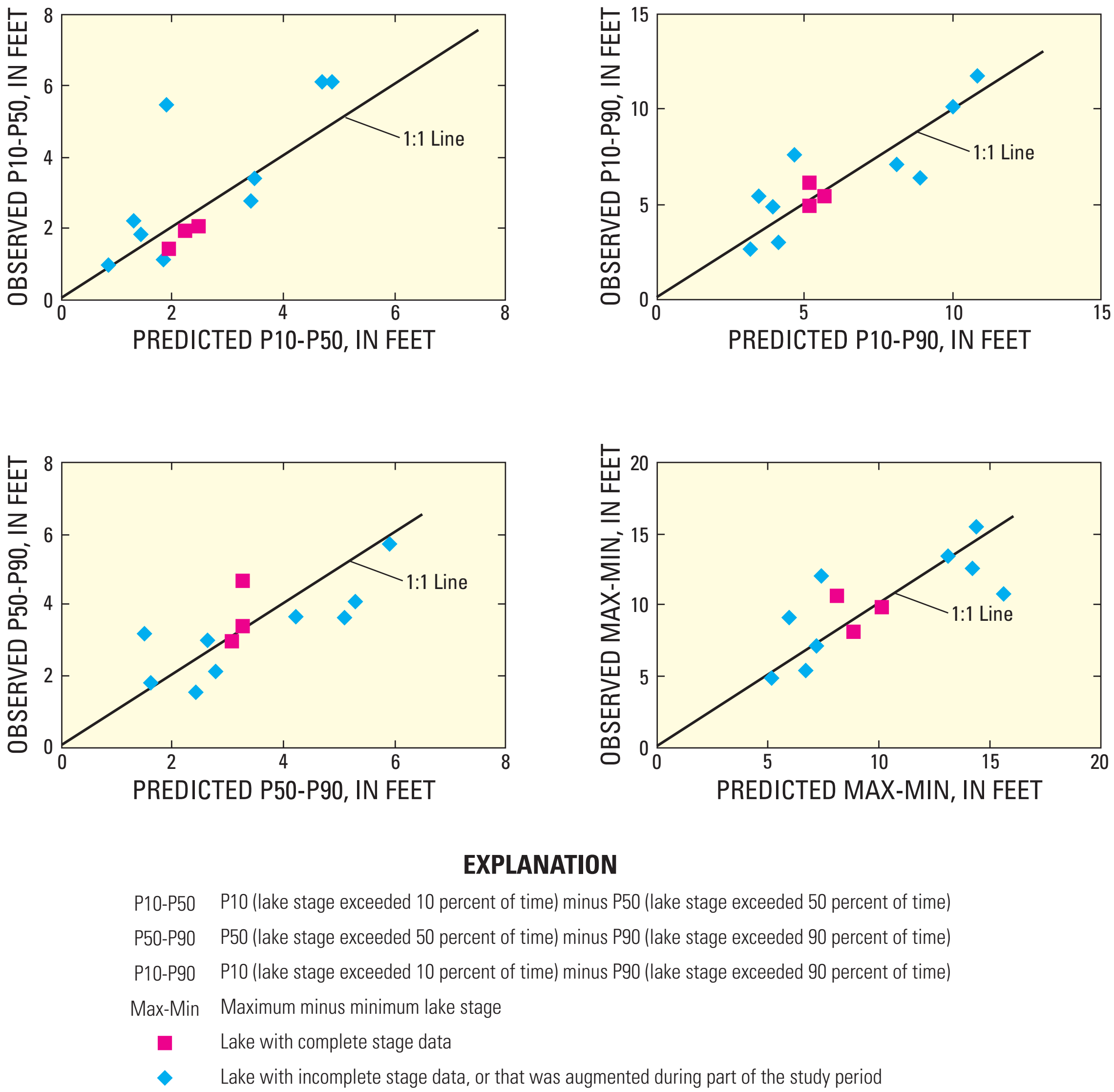

Figure 8. Comparison between observed and predicted stage variability for 1996-2005 period, using regression equations for the entire group of lakes.

variability. Because lake-stage statistics for nine of the lakes were derived from incomplete stage data, values of observed stage variability are not expected to be equivalent to values that would have been derived if the data were complete. Comparing the modeled to observed stage data for lakes with incomplete data indicates the rigor of the modeling method and provides an example of a realistic application, as many lakes have similar problems with their stage records.

Predicted and observed stage variability for the 12 lakes plot close to a 1:1 line for most lakes (fig. 8). Median differences (using the absolute value) ranged from 11 to 23 percent for the different models that predict stage variability (table 4 and 5). The smallest median difference was for the *Max-Min* model and the largest median difference was for both the *P10-P50* and *P50-P90* models.

Predicted values for Big Fish Lake had the biggest discrepancy from observed for the *P10-P50* range. This lake has a wide range in surface area. During extended droughts, the lake has dried up completely, and at high stage the lake connects with a vast network of adjacent wetlands and can more than double in surface area (Doug Leeper, Southwest Florida Water Management District, written commun., 2003). This type of lake was probably not represented sufficiently in the regression derivations. In addition, Big Fish Lake was augmented with ground water during recent low stages, when it likely would have dried out. Thus, the observed low stage is not representative of its stage if it were not augmented.

Differences between predicted and observed values of stage variability were generally greater for the six highland lakes using the highland lake regression models, compared

Table 5. Predicted lake-stage variability for recent period (1996-2005) for lakes not used to develop regression models.

[P10, stage exceeded 10 percent of the time; P50, stage exceeded 50 percent of the time (median); P90, stage exceeded 90 percent of the time; *Max-Min*, maximum stage for period minus minimum stage for period]

Lake	Predicted stage variability (feet)				Difference between predicted and observed variability (percent)			
	P10-P50	P50-P90	P10-P90	Max-Min	P10-P50	P50-P90	P10-P90	Max-Min
Data Based on Regression for Entire Group of Lakes								
Annie (Polk)	2.2	3.1	5.1	8.8	17	3	5	8
Big Fish	1.9	2.8	4.7	7.4	-65	32	-38	-38
Curve	1.4	2.7	3.9	7.2	-20	-11	-19	2
Placid	1.9	1.6	4.1	6.7	68	-9	42	26
Raleigh	4.9	5.9	10.8	14.3	-19	4	-9	-7
Rogers	4.7	5.3	10.0	13.1	-22	30	-2	-2
Seminole	.9	2.5	3.2	5.2	-10	58	26	8
Sirena	1.3	1.5	3.5	6.0	-39	-52	-35	-33
Tulane	3.5	5.1	8.9	15.6	25	42	40	46
Venus	2.5	3.3	5.6	10.1	25	-5	3	3
Verona	3.5	4.3	8.1	14.1	4	17	15	14
Virginia	1.9	3.3	5.1	8.0	38	-31	-16	-24
Median of absolute values					**23**	**23**	**18**	**11**
Data Based on Regression for Highland Lakes Subset								
Annie (Polk)	2.5	3.1	5.4	9.0	32	5	10	11
Placid	.8	1.3	2.4	5.6	-25	-26	-16	5
Sirena	.9	1.5	2.7	5.5	-60	-52	-51	-39
Tulane	4.2	5.6	10.0	16.2	55	55	57	52
Venus	3.1	3.5	6.3	10.7	54	1	16	10
Verona	4.1	4.5	8.8	15.0	20	24	25	20
Median of absolute values					**43**	**25**	**21**	**15**

to using regression models derived for the entire set of lakes (table 5). The reason for this is not clear, but this result does not support using these subregional models to predict lake stage variability. Most of the highland lakes used in this analysis are in the southern Lake Wales Ridge, and only two lakes (near each other) are in Polk County. Results might have been better if the lakes had been more equally distributed in the ridge and upland parts of the study area.

Limitations

The regression models presented in this report predict lake-stage variability for a period when ground-water pumping potentially affected lake stage. Although the models can be used to predict stage variability for periods of ground-water pumping, the SWFWMD objective for the minimum flows and levels program is to understand natural variability in lake stage for periods unaffected by pumping. Regression results based on the historical period data, which were unaffected by ground-water pumping, were considerably poorer than results based on recent period data. Reasons for these poor outcomes are probably related to greater uncertainty in basin characteristic data for the historical period compared to the recent period, as well as a much smaller number of lakes with available stage data. One of the challenges of including only lakes unaffected by ground-water pumping is the lack of data available for consistent time periods. Earlier regression analyses using varying time periods also resulted in poor regressions (Gao, 2005), with questionable validity due to the inconsistent lengths of record and inconsistent time periods used to define lake-stage variability.

One of the most important variables in the regressions (*INV DIFF*) was partly derived from the elevation of the invert or control point for surface-water outflow. Estimates of the control point elevation are difficult because of limitations in the quality of the data. For example, outlet elevation data were not always current and, in a few cases, were contradictory, indicating the need for additional field measurements. Control point elevations in outlet channels also can change with sediment and vegetation accumulation and subsequent clearing. Another source of uncertainty in this analysis was outlet structures with adjustable crests or lift gates. Regression results would be expected to improve with more accurate data for elevations of structures or control points, which regulate surface-water outflow.

Most of the other variables in the final regression models were related to ground-water exchange with the lakes. Site-specific information was not available for Upper Floridan aquifer head and confining unit properties near most lakes. This site-specific information would help better define head gradients and the thickness of the confining unit. Regional maps used for this study inherently introduce errors because of the heterogeneity in confining unit properties beneath and adjacent to Florida karst lakes. However, the significance of these regionally defined basin characteristics in the final regressions indicates the relevancy of these characteristics in describing lake-stage variability, particularly when larger populations of lakes are considered. Hydrogeologic data used for this study were taken from maps nearly 30 years old. Although considerably more data are currently available to improve these maps, updated maps of geologic and hydrogeologic units by the Florida Geological Survey were still in draft form as of this writing (Jonathan Arthur, Florida Geological Survey, written commun., 2007). Regression models potentially could be improved once these updated maps become available.

Many of the final regression models presented in this report include a variable defining the amount of ground-water pumping within 1 mi of the lake. Regression models could be used with that variable set to zero to get an estimate of stage variability without pumping. However, other variables in the model such as net leakage and head gradient between the lake and Upper Floridan aquifer were derived from measurements during the period affected by ground-water pumping. Therefore, there is no simple method for removing the effects of pumping from the recent period models.

Several of the variables in the final regression models were computed using stage data. Net leakage required two stage observations between April and May 2000, and could not be calculated if those data were not available. Fortunately, many lakes in the SWFWMD do have stage data for this period because of interest in monitoring low lake levels for the extreme drought that occurred. Invert elevation difference also is calculated as the difference between the invert (or control point) elevation and median lake stage. If sufficient stage data are not available to compute a median stage, it may be possible to estimate the median as a “typical” lake stage based on observations from local residents, from lakeshore and vegetative characteristics, and from aerial photographs such as USGS digital orthophoto quadrangles. To use the regression equations presented in this report, however, at least some lake-stage data must be available for analysis.

Summary and Conclusions

The range of variability in the stage of Florida lakes can differ depending upon many factors. Surface-water flows, hydrogeologic characteristics of the lake, and meteorological conditions can all influence lake stage. In addition, anthropogenic factors such as the amount of ground-water pumping near the lake, structural controls on outlets, and land use also can influence the range of lake stage. The goal of this report was to document whether lake-stage variability could be predicted for a population of lakes using multiple linear regression and readily available lake and basin characteristics of each lake.

Lake-stage variability was defined in terms of differences in percentile statistics (*P10-P50*, *P50-P90*, *P10-P90*), as well as the *Max-Min* stage for a recent 10-year period (1996-2005) and for a historical 10-year period (1954-63). Although lakes chosen for the historical period were deemed to be unaffected by ground-water pumping, many of the lakes for the recent period probably were affected. Stage variability was computed and basin characteristics were compiled for 102 lakes, with 98 lakes considered for the recent period and 20 considered for the historical period. Stage variability tended to be greater for seepage lakes than for lakes with surface-water flows, and also for the recent period compared to the historical period.

For the recent period, the final regression models incorporated up to four explanatory variables to predict lake-stage variability. Associated R^2 values ranged from 0.60 to 0.74, and standard errors ranged from 21 to 37 percent of the average stage variability. Regression results for the subset of lakes in highland (ridge and upland) regions were slightly better than results for the entire group of lakes, with R^2 values ranging from 0.68 to 0.82. These models included most of the same explanatory variables present in models for the entire group of lakes. Other groupings of lakes had regression results that were poorer or similar to regressions for the entire group of lakes.

The most important explanatory variables in the regressions were those describing net leakage and the height over median lake stage at which surface-water outflow occurs. Net leakage was included in all of the final models and was the most important explanatory variable in regressions describing the full range (*P10-P90* and *Max-Min*) and low range in stage variability (*P50-P90*). This variable was computed for an extremely dry period (May 2000) as the residual to a monthly water budget for each lake. The positive slope in the regressions indicates that lake-stage variability increases as net leakage increases. The variable describing the elevation at which surface-water outflow occurs was the most important explanatory variable in the model predicting the high range in stage variability (*P10-P50*), and was also in all of the final models. The positive slope in the regressions indicates that stage variability increases as the invert (or control point) elevation above the median lake stage increases.

Other explanatory variables in final regression models included the range in annual rainfall for the period, and several variables related to local and regional hydrogeology. The range in annual rainfall had a positive slope in the model describing *Max-Min* stage, thereby characterizing climatic extremes for the period. A variable describing ground-water pumping within 1 mi of each lake had a positive slope in all of the final regression models, illustrating how ground-water pumping can increase lake-stage variability. A variable describing the head gradient between the lake and the Upper Floridan aquifer was included in several of the models, and had a positive slope in each. A variable describing the thickness of the intermediate confining unit also was included in one of the final models. The negative slope suggests that stage variability is greater where the confining unit is thinner. An explanatory variable in several of the final models for the highland lake subset is related to the amount of ground-water inflow the lake receives. The negative slope implies that lakes with more ground-water inflow tend to have less stage variability. Many of these explanatory variables characterize various aspects of ground-water exchange. Although none of these ground-water variables were cross-correlated in regression models, cross correlation might be expected if they could be defined more precisely from site specific information.

The regression equations were used to predict lake-stage variability for the recent period for 12 additional lakes. Using the models based on the entire group of lakes, median differences between predicted and observed values ranged from 11 to 23 percent. Median differences were greater for the highland lakes subset, ranging from 15 to 43 percent. The lake with the poorest match between predicted and observed values had a large increase in surface area at high lake stage, indicating that this type of lake might not have been represented sufficiently in the regression derivations.

Regression outcomes for the historical period were considerably poorer (maximum $R^2 = 0.28$) than for the recent period. The poor regression results are likely related to the lower number of lakes with data unaffected by ground-water pumping for equivalent time periods, the similarity of many of the lake types (large surface-water drainage lakes), and the greater uncertainty in defining historical basin characteristics.

Regression models based on existing stage data have limited usefulness for setting regulatory levels for west-central Florida lakes as part of the State-mandated minimum flows and levels program. Insufficient historical data are available to accurately predict lake-stage variability in the absence of ground-water pumping. Regression analysis for the recent period, however, did emphasize the influence of ground-water pumping on lake stage by demonstrating the statistical significance of variables describing ground-water pumping, head gradients, and lake leakage. Regardless of the limitations, results from this study are useful in defining those basin characteristics that are important in controlling stage variability. In particular, surface-water outflow and leakage were determined to be important factors influencing stage fluctuations. The number of variables in final regression models related to hydrogeologic characteristics also underscores the importance of ground-water exchange in controlling the stage of karst lakes in Florida.

References Cited

Aucott, W.R., 1988, Areal variation in recharge to and discharge from the Floridan aquifer system in Florida: U.S. Geological Survey Water-Resources Investigations Report 88-4057, 1 sheet.

Barcelo, M.D., Slonena, D.L., Camp, S.C., and Watson, J.D., 1990, Ridge II: A hydrogeologic investigation of the Lake Wales Ridge: Brooksville, Southwest Florida Water Management District, 130 p.

Basso, R., and Schultz, R., 2003, Long-term variation in rainfall and its effect on Peace River flow in west-central Florida: Brooksville, Southwest Florida Water Management District, 39 p.

Blanchard, R.A., and Seidenfeld, A.V., 2005, Potentiometric surface of the Upper Floridan aquifer, west-central Florida, September 2004: U.S. Geological Survey Open-File Report 2005-1222, 1 sheet.

Buono, Anthony, and Rutledge, A.T., 1978, Configuration of the top of the Floridan aquifer, Southwest Florida Water Management District and adjacent areas: U.S. Geological Survey Water-Resources Investigations Open-File Report 78-34, 1 sheet.

Buono, Anthony, Spechler, R.M., Barr, G.L., and Wolansky, R.M., 1979, Generalized thickness of the confining bed overlying the Floridan aquifer, Southwest Florida Water Management District: U.S. Geological Survey Open-File Report 79-1171, 1 sheet.

Deevey, E.S., Jr., 1988, Estimation of downward leakage from Florida lakes: Limnology and Oceanography, v. 33, no. 6, pt. 1, p. 1308-1322.

Duerr, A.D., 2001, Potentiometric surface of the Upper Floridan aquifer, west-central Florida, May 2000: U.S. Geological Survey Open-File Report 01-20, 1 sheet.

Enfield, D.B., Mestas-Nunez, A.M., Trimble, P.J., 2001, The Atlantic Multidecadal Oscillation and its relation to rainfall and river flows in the continental U.S.: Geophysical Research Letters, v. 28, no. 10, p. 2077–2080.

Evans, M.W., Snyder, S.W., and Hine, A.C., 1994, High-resolution seismic expression of karst evolution within the Upper Floridan aquifer system, Crooked Lake, Polk County, Florida: Journal of Sedimentary Research, v. B64, p. 232-244.

Florida Board of Conservation, 1969, Florida lakes: Part III Gazetteer: Tallahassee, Fla., 145 p.

Gant, R.D., 1998, Directory of lakes within the Southwest Florida Water Management District: Brooksville, Southwest Florida Water Management District, 58 p.

Gao, Jie, 2005, Lake stage fluctuation study in west-central Florida using multiple regression models: Tampa, University of South Florida, M.S. thesis, 81 p.

German, E.R., 2000, Regional evaluation of evapotranspiration in the Everglades: U.S. Geological Survey Water-Resources Investigations Report 00-4217, 48 p.

Griffith, G.E., Canfield, D.E., Horsburgh, C.A., and Omernik, J.M., 1997, Lake regions of Florida: U.S. Environmental Protection Agency report EPA/R-97/127, Corvallis, Oreg., National Health and Environmental Effects Research Laboratory, 89 p.

Helsel, D.R., and Hirsch, R.M., 2002, Statistical methods in water resources: U.S. Geological Survey, Techniques of Water-Resources Investigations, book 4, chap. A3, 510 p.

Lee, T.M., 2000, Effects of nearshore recharge on groundwater interactions with a lake in mantled karst terrain: Water Resources Research, v. 36, p. 2167-2182.

Lee, T.M., 2002, Factors affecting ground-water exchange and catchment size for Florida lakes in mantled karst terrain: U.S. Geological Survey Water-Resources Investigations Report 02-4033, 53 p.

Lee, T.M., and Swancar, Amy, 1997, The influence of evaporation, ground water, and uncertainty in the hydrologic budget of Lake Lucerne, a seepage lake in Polk County, Florida: U.S. Geological Survey Water-Supply Paper 2439, 61 p.

Marella, R.L., 2004, Water withdrawals, use, discharge, and trends in Florida, 2000: U.S. Geological Survey Scientific Investigations Report 2004-5151, 136 p.

Metz, P.A., and Sacks, L.A., 2002, Comparison of the hydrogeology and water quality of a ground-water augmented lake with two non-augmented lakes in northwest Hillsborough County, Florida: U.S. Geological Survey Water-Resources Investigations Report 02-4032, 74 p.

Rochow, T.F., 1998, The effects of water table level changes on freshwater marsh and cypress wetlands in the Northern Tampa Bay region: Brooksville, Southwest Florida Water Management District Environmental Section Technical Report 1998-1, 64 p.

Ryder, P.D., 1982, Digital model of predevelopment flow in the Tertiary limestone (Floridan) aquifer system in west-central Florida: U.S. Geological Survey Water-Resources Investigations Report 81-54, 61 p.

Sacks, L.A., 2002, Estimating ground-water inflow to lakes in central Florida using the isotope mass-balance approach: U.S. Geological Survey Water-Resources Investigations Report 02-4192, 47 p.

Sacks, L.A., Swancar, Amy, and Lee, T.M., 1998, Estimating groundwater exchange with lakes using water-budget and chemical mass-balance approaches for ten lakes in ridge areas of Polk and Highlands Counties, Florida: U.S. Geological Survey Water-Resources Investigations Report 98-4133, 51 p.

Scott, T.M., Campbell, K.M, Rupert, F.R., Arthur, J.D., Missimer, T.M., Lloyd, J.M., Yon, J.W., and Duncan, J.G., 2001, Geologic map of the state of Florida: Florida Geological Survey Map Series 145, 1 sheet.

Sepulveda, Nicasio, 2002, Simulation of ground-water flow in the intermediate and Floridan Aquifer systems in peninsular Florida: U.S. Geological Survey Water-Resources Investigations Report 02-4009, 130 p.

Southwest Florida Water Management District, 1991, Public facilities report: Water control structures and facilities: Brooksville, 98 p.

Southwest Florida Water Management District, 1993, Southern Water Use Caution Area Management Plan: Brooksville, 98 p.

Southwest Florida Water Management District, 1996, Northern Tampa Bay Water Resources Assessment Project: Volume 1. Surface water/groundwater interrelationships: Brooksville, 468 p.

Southwest Florida Water Management District, 1999a, Establishment of minimum levels for category 1 and category 2 lakes: Brooksville, 159 p.

Southwest Florida Water Management District, 1999b, Establishment of minimum levels in palustrine cypress wetlands: Brooksville, 127 p.

Southwest Florida Water Management District, 2002, Establishment of reference lake water regime for the Highlands Ridge area of Polk and Highlands Counties: Brooksville, 30 p.

Southwest Florida Water Management District, 2006, Southern water use caution area recovery strategy, Final report: Brooksville, 305 p.

Sumner, D.M., and Belaineh, G., 2005, Evaporation, precipitation, and associated salinity changes at a humid, subtropical estuary: Estuaries, v. 28, no. 6, p. 844-855

Swancar, Amy, 2006, Magnitude and variability of all components of a central Florida lake water budget during recent climate extremes, 1996-2004, in Proceedings of the 22nd Annual Water Resources Seminar, April 7, 2006, Orlando, Florida: American Society of Civil Engineers.

Swancar, Amy, Lee, T.M., and O'Hare, T.M., 2000, Hydrogeologic setting, water budget, and preliminary analysis of ground-water exchange at Lake Starr, a seepage lake in Polk County, Florida: U.S. Geological Survey Water-Resources Investigations Report 00-4030, 65 p.

Tihansky, A.B., 1999, Sinkholes, west-central Florida, in Galloway, Devin, Jones, D.R., and Ingebritsen, S.E., eds., Land subsidence in the United States: U.S. Geological Survey Circular 1182, p. 121-140.

Tihansky, A.B., Arthur, J.D., and DeWitt, D.W., 1996, Sublake geologic structure from high-resolution seismic-reflection data from four sinkhole lakes in the Lake Wales Ridge, central Florida: U.S. Geological Survey Open-File Report 96-224, 72 p.

Tihansky, A.B., and Sacks, L.A., 1997, Evaluation of nitrate sources using nitrogen-isotope techniques in shallow ground water within selected lake basins in the Central Lake District, Polk and Highlands Counties, Florida: U.S. Geological Survey Water-Resources Investigations Report 97-4207, 27 p.

Verdi, R.J., Tomlinson, S.A., and Marella, R.L., 2006, The drought of 1998-2002: Impacts on Florida's hydrology and landscape: U.S. Geological Survey Circular 1295, 34 p.

Wetzel, R.G., and Likens, G.E. 1991. Limnological analyses (2d ed.): New York, Springer-Verlag, 391 p.

White, W.A., 1970, The geomorphology of the Florida peninsula: Tallahassee, Florida Geological Survey Bulletin 51, 164 p.

Appendix 1. Lake and basin characteristics evaluated as explanatory variables in regression analysis.

[Variables abbreviated in bold used in final regressions (table 3). GIS, geographic information system; SWFWMD, Southwest Florida Water Management District; UFA, Upper Floridan aquifer; USGS, U.S. Geological Survey; m, meters]

Variable	Source of data
Invert or control point elevation minus median lake stage (1996-2005 for recent period and 1954-63 for historical period); **INV DIFF**	Minimum flows and levels reports for individual lakes[1], lake data sheets for each lake[2], reports on water control structures (SWFWMD, 1991), and unpublished surveys (Doug Leeper, SWFWMD, written commun., 2006-07).
Surface-water drainage type	Categories defined in Florida Board of Conservation (1969), supplemented by sources listed above.
Geomorphic province	White (1970)
Geographic group (lowlands or highlands)	Same as above
Lake district	Griffith and others (1997)
Surface geology	Scott and others (2001)
UFA recharge/discharge rate	Aucott (1988) and Sepulveda (2002)
Sum of surface area of upgradient or adjoined lakes	Lake data sheets for each lake[2], minimum flows and levels reports for individual lakes[1], 1:24,000 and 1:100,000 scale USGS topographic maps.
Lake drainage basin area	Lake data sheets for each lake[2], minimum flows and levels reports for individual lakes[1], USGS data reports.
Topographic basin area	1:24,000 scale USGS topographic maps
Topographic basin perimeter	Same as above
Stormwater drainage; categorical	Lake data sheets for each lake[2]
Maximum lake depth, from 1996-2005 median stage	Minimum flows and levels reports for individual lakes[1]; unpublished data from Doug Leeper (SWFWMD, written commun., 2006); lake data sheets for each lake[3]; Hillsborough County Watersheds Atlas (accessed 7/2/2008 at *http://www.hillsborough.wateratlas.usf.edu*); Florida Lake Watch (accessed 7/2/2008 at *http://lakewatch.ifas.ufl.edu*); Sacks and others (1998).
Relative lake depth (z_r)	50* z_{max}*sqrt($\boldsymbol{p}$)/sqrt(A); where z_{max} is maximum depth and A is surface area; z_r expressed as percentage of the mean diameter of the lake (Wetzel and Likens; 1991).
Lake surface area	1:24,000 and 1:100,000 scale USGS topographic maps, and 1999 land-use definitions photointerpreted by SWFWMD from 1:12,000 USGS color infrared digital orthophoto quarter quadrangles (accessed 7/2/2008 at *http://www.swfwmd.state.fl.us/data/gis*).
Lake perimeter	See lake surface area, above
Ratio of lake surface area to perimeter	See lake surface area, above
Ratio of lake surface area to maximum depth	See lake surface area and maximum lake depth, above
Ratio of lake drainage basin area to lake surface area	See lake drainage basin area and lake surface area, above
Ratio of topographic basin area to lake surface area	See topographic basin area and lake surface area, above
Ratio of lake surface area to upgradient lakes surface area	See lake surface area and sum of surface area of upgradient or adjoined lakes, above
Head difference between lake and UFA head, May 2000	Duerr (2001)
Head difference between lake and UFA head, September 2004	Blanchard and Seidenfeld (2005)
Head gradient between lake stage (at lake bottom) and UFA, may 2000; **HD GR 5-00**	Duerr (2001) and maximum lake depth, above
Head gradient between lake stage (at lake bottom) and UFA, September 2004	Blanchard and Seidenfeld (2005) and maximum lake depth, above
Head difference between median lake stage (1954-63) and predevelopment UFA head	Ryder (1982)
Head gradient between median lake stage (1954-63) and predevelopment UFA head	Ryder (1982) and maximum lake depth, above
Depth to UFA from 1996-2005 median lake stage	Buono and Rutledge (1978)
Depth to UFA from lake bottom	Buono and Rutledge (1978) and maximum lake depth, above
Thickness of intermediate confining unit; **ICU THCK**	Buono and others (1979)

Appendix 1. (Continued) Lake and basin characteristics evaluated as explanatory variables in regression analysis.

[Variables abbreviated in bold used in final regressions (table 3). GIS, geographic information system; SWFWMD, Southwest Florida Water Management District; UFA, Upper Floridan aquifer; USGS, U.S. Geological Survey; m, meters]

Variable	Source of data
Thickness of surficial aquifer from 1996-2005 median lake stage	Buono and Rutledge (1978) and Buono and others (1979)
Reported sinkholes within 100 m of lake	Florida Geological Survey (accessed 7/2/2008 at *http://www.dep.state.fl.us/geology/gisdatamaps/sinkhole_database.htm*) and SWFWMD (accessed 7/2/2008 at *http://www.swfwmd.state.fl.us/data/gis*)
Reported sinkholes in topographic basin	Same as above
Closed depressions within 100 m of lake	Digitized 1:24,000 scale USGS topographic maps (accessed 7/2/2008 at *http://www.swfwmd.state.fl.us/data/gis/*); Alejandro Sepulveda, U.S. Geological Survey, written commun., (2006).
Closed depressions in topographic basin	Same as above
Fraction of type A (excessively drained) hydric soils within 100 m of lake	County soil survey maps originally from Natural Resource Conservation Service and digitized by SWFWMD into GIS data bases (accessed 7/2/2008 at *http://www.swfwmd.state.fl.us/data/gis*).
Fraction of type A (excessively drained) hydric soils in topographic basin	Same as above
Fraction of wetlands within 100 m of lake	U.S. Fish and Wildlife Service National Wetland Inventory GIS maps (accessed 7/2/2008 at *http://www.swfwmd.state.fl.us/data/gis/*).
Fraction of wetlands in topographic basin	Same as above
Average land slope within 100 m of lake	Digitized 1:24,000 scale USGS topographic maps (accessed 7/2/2008 at *http://www.swfwmd.state.fl.us/data/gis/*) and digital elevation modeling (Alejandro Sepulveda, U.S. Geological Survey, written commun., 2006).
Average land slope in topographic basin	Same as above
Fraction of urban land use in topographic basin	Florida Land Use and Cover Classification System photointerpreted by SWFWMD from 1:12,000 USGS color infrared digital orthophoto quarter quadrangles from 1999 (accessed 7/2/2008 at *http://www.swfwmd.state.fl.us/data/gis*).
Fraction of agricultural land use in topographic basin	Same as above
Average annual rainfall, 1996-2005	NEXRAD rainfall data, originally from National Weather Service, obtained from SWFWMD's internal database (Melissa Hill, SWFWMD, written commun., 2006).
Maximum annual rainfall, 1996-2005	Same as above
Minimum annual rainfall, 1996-2005	Same as above
Difference between maximum and minimum annual rainfall; **MX-MN PREC**	Same as above
Annual average rainfall, 1954-63	National Weather Service data
Net leakage, May 2000; **NET LEAKAGE**	NEXRAD rainfall data, originally from National Weather Service, obtained from SWFWMD's internal database (Melissa Hill, SWFWMD, written commun., 2006); evaporation data from Swancar and others (2000) and USGS unpublished data.
Net leakage, May 2001	Same as above
Distance to nearest wellfield	GIS coverage of well fields from SWFWMD (accessed 7/2/2008 at *http://www.swfwmd.state.fl.us/data/gis/*)
Ground-water inflow	Data or regressions from Sacks (2002)
Ground-water inflow as fraction of inflows	Same as above
Ground-water inflow category; **GW IN CAT**	Same as above
$\delta^{18}O$ of lake water	Sacks (2002), and Sacks and others (1998)
Average annual ground-water pumping within 1 mi of lake (1996-2005)	Mike Kelley, SWFWMD, written commun. (2007)
Maximum annual ground-water pumping within 1 mi of lake (1996-2005); **GW MAX 1MI**	Same as above

Appendix 1. (Continued) Lake and basin characteristics evaluated as explanatory variables in regression analysis.

[Variables abbreviated in bold used in final regressions (table 3). GIS, geographic information system; SWFWMD, Southwest Florida Water Management District; UFA, Upper Floridan aquifer; USGS, U.S. Geological Survey; m, meters]

Variable	Source of data
Average annual ground-water pumping (1996-2005) in topographic basin	Same as above
Maximum annual ground-water pumping (1996-2005) in topographic basin	Same as above
Average annual ground-water pumping (1996-2005) within 100 m of lake	Same as above
Maximum annual ground-water pumping (1996-2005) within 100 m of lake	Same as above
Average annual pumping from lake (1996-2005)	Same as above
Ratio of average annual ground-water pumping in basin to lake surface area	Same as above
Ratio of average annual ground-water pumping within 100 m of lake to lake surface area	Same as above
Ratio of average annual pumping from lake to lake surface area	Same as above

[1]Doug Leeper, SWFWMD, written commun. (2006); accessed 7/2/2008 at *http://www.swfwmd.state.fl.us/documents*).
[2]Richard Gant, SWFWMD, written commun. (1999-2007).

Appendix 2. Lakes and associated dependent and explanatory variables used to derive final regressions in table 3.

[Units are in feet unless otherwise noted. Percentile statistics and maximum and minimum stage are shown for the recent (1996-2005) period. P10, stage exceeded 10 percent of the time; P50, stage exceeded 50 percent of the time (median); P90, stage exceeded 90 percent of the time; Max-Min, maximum stage for period minus minimum stage for period; INV DIFF, difference between invert or control point elevation and median lake stage; HD GR 5-00, head gradient between the lake bottom and the Upper Floridan aquifer in May 2000; ICU THCK, thickness of intermediate confining unit; NET LEAKAGE, leakage minus ground-water minus inflow for May 2000; in/mo, inches per month; MX-MIN PREC, difference between maximum and minimum annual rainfall; MAX GW 1MI, maximum annual ground-water pumping within 1 mile of the lake; GW IN CAT, ground-water inflow category, where 1 is lowest and 3 is highest; Mgal/yr, million gallons per year; MX-MN PREC, maximum minus minimum annual rainfall for 1996-2005; n/a, not available]

Lake	County	P10-P50	P50-P90	P10-P90	Max-Min	INV DIFF	HD GR 5-00 (unitless)	ICU THCK	NET LEAKAGE (in/mo)	MX-MN PREC (inches)	MAX GW 1MI (Mgal/yr)	GW IN CAT (unitless)
Lakes in Ridge and Upland Areas (Highland Lakes)												
Angelo	Highlands	3.5	2.8	6.3	10.9	10.63	0.053	240	6.3	41.6	926	2
Annie	Highlands	.6	.3	.9	3.8	-.43	.118	380	-2.3	33.0	732	3
Chilton	Highlands	2.3	3.5	5.9	10.9	4.01	.136	230	6.9	44.6	0	3
Clay	Highlands	.6	1.3	1.9	4.0	-.46	.026	355	2.1	34.4	438	2
Denton	Highlands	3.3	2.6	6.0	11.7	7.02	.096	250	4.2	42.8	749	3
Dinner (Highlands)	Highlands	2.7	1.8	4.5	6.6	17.83	.059	250	5.1	32.2	1,264	2
Huntley	Highlands	.3	.6	1.0	3.1	-.13	.037	360	-.3	31.9	469	2
Jackson	Highlands	1.3	1.5	2.8	4.5	1.14	.063	300	1.5	34.4	1,886	2
Josephine (Highlands)	Highlands	.3	.3	.7	1.9	-.11	.032	360	.0	36.3	769	3
June-in-Winter	Highlands	.5	.9	1.4	2.8	-1.26	.050	375	n/a [1]	36.0	1,840	3
Letta	Highlands	2.9	2.7	5.6	8.8	3.62	.048	245	5.2	38.7	1,472	2
Lotela	Highlands	3.2	4.6	7.9	11.5	2.94	.076	240	5.3	42.3	1,162	2
McCoy	Highlands	1.2	2.1	3.3	7.4	2.68	.045	360	2.0	31.3	413	3
Mirror	Highlands	1.8	5.0	6.8	11.3	-1.18	.063	370	14.2	31.5	592	3
Olivia	Highlands	2.1	2.9	5.0	9.2	4.67	.149	230	5.0	41.6	282	3
Pearl	Highlands	1.3	2.6	3.9	7.9	-.09	.049	365	2.9	29.9	598	3
Pioneer	Highlands	2.8	2.9	5.7	10.1	7.81	.077	230	7.0	45.9	738	2
Viola	Highlands	2.8	3.5	6.4	11.9	4.44	.091	240	6.8	47.2	556	3
Aurora	Polk	2.1	3.2	5.3	11.5	11.86	.074	100	3.9	53.8	1,018	3
Blue	Polk	3.2	4.0	7.2	13.4	11.74	.196	100	4.8	58.6	667	3
Clinch	Polk	1.9	1.8	3.7	8.4	.40	.136	190	2.3	49.0	1,150	2
Crooked	Polk	3.8	2.5	6.3	10.4	3.08	.275	130	1.7	54.1	2,294	1
Deer (Polk)	Polk	.5	.7	1.2	5.5	-.23	.228	110	n/a [2]	29.6	175	2
Dinner (Polk)	Polk	2.8	5.3	8.1	14.1	14.76	.146	80	7.5	49.2	386	3
Eagle	Polk	2.0	2.9	4.9	7.4	.70	.248	130	1.9	30.8	512	2
Hancock	Polk	.5	1.5	2.0	6.0	-1.35	.199	130	1.3	32.3	710	2
Helene	Polk	1.5	4.1	5.6	8.6	3.67	.290	50	3.2	38.2	147	1
Henry	Polk	2.5	2.7	5.2	7.0	1.80	.439	210	3.4	48.1	789	2

Appendix 2. (Continued) Lakes and associated dependent and explanatory variables used to derive final regressions in table 3.

[Units are in feet unless otherwise noted. Percentile statistics and maximum and minimum stage are shown for the recent (1996-2005) period. P10, stage exceeded 10 percent of the time; P50, stage exceeded 50 percent of the time (median); P90, stage exceeded 90 percent of the time; Max-Min, maximum stage for period minus minimum stage for period; INV DIFF, difference between invert or control point elevation and median lake stage; HD GR 5-00, head gradient between the lake bottom and the Upper Floridan aquifer in May 2000; ICU THCK, thickness of intermediate confining unit; NET LEAKAGE, leakage minus ground-water minus inflow for May 2000; in/mo, inches per month; MX-MIN PREC, difference between maximum and minimum annual rainfall; MAX GW 1MI, maximum annual ground-water pumping within 1 mile of the lake; GW IN CAT, ground-water inflow category, where 1 is lowest and 3 is highest; Mgal/yr, million gallons per year; MX-MN PREC, maximum minus minimum annual rainfall for 1996-2005; n/a, not available]

Lake	County	P10-P50	P50-P90	P10-P90	Max-Min	INV DIFF	HD GR 5-00 (unitless)	ICU THCK	NET LEAKAGE (in/mo)	MX-MN PREC (inches)	MAX GW 1MI (Mgal/yr)	GW IN CAT (unitless)
Hickory	Polk	1.3	3.6	4.8	7.4	.40	.082	210	4.6	45.3	470	3
Howard	Polk	.7	2.2	2.9	5.4	.23	.164	105	3.6	33.9	598	2
Josephine (Polk)	Polk	4.0	4.0	8.0	16.1	14.61	.131	90	5.6	59.5	609	3
Little Aurora	Polk	2.1	3.2	5.3	13.1	12.34	.065	100	4.4	57.0	746	3
Little Van	Polk	.4	.4	.8	2.1	2.02	.177	90	-2.3	35.0	530	3
Mabel	Polk	3.3	3.9	7.2	12.2	33.10	.126	80	4.9	50.4	1,215	3
Mariana	Polk	.7	.6	1.3	2.6	-.21	.206	100	.5	28.6	693	2
McLeod	Polk	2.1	3.6	5.6	7.4	-.20	.248	130	3.6	34.9	628	2
Medora	Polk	1.5	2.5	4.1	7.1	3.77	.151	80	1.5	33.3	565	1
Menzie	Polk	2.9	3.1	6.0	9.9	17.46	.231	80	4.3	35.3	569	2
Otis	Polk	2.1	2.6	4.7	7.9	-.69	.150	90	5.0	30.2	892	2
Parker	Polk	.4	1.8	2.2	5.5	.38	.580	100	2.2	38.8	357	2
Polecat	Polk	.4	1.1	1.5	3.7	-.80	.409	190	1.4	50.8	814	3
Reedy	Polk	.9	.6	1.6	2.8	-1.34	.020	210	n/a [1]	47.4	2,076	2
Saddlebag	Polk	1.9	3.7	5.6	10.8	5.68	.130	100	3.3	56.7	1,346	3
Saint Anne	Polk	1.9	2.4	4.3	10.4	5.32	.048	100	3.5	59.1	515	3
Sara	Polk	2.5	3.5	5.9	9.8	1.11	.212	70	4.0	39.5	498	2
Scott	Polk	.6	1.4	2.0	4.1	-2.01	.652	130	n/a [1]	39.2	87	2
Starr	Polk	3.0	4.6	7.7	13.5	44.72	.113	80	5.1	50.0	900	2
Tennessee	Polk	.8	2.0	2.8	4.8	1.57	.100	100	1.2	36.7	283	2
Thomas (Polk)	Polk	2.4	3.9	6.3	9.6	8.14	.222	130	3.0	32.3	193	2
Wales	Polk	3.1	4.4	7.4	13.6	18.67	.073	90	4.4	49.5	1,444	2
Walker	Polk	2.8	4.1	6.9	12.3	13.32	.424	200	4.0	47.2	637	3
Warren	Polk	4.7	4.8	9.5	15.6	8.42	.138	90	7.5	48.9	175	2
Iola	Pasco	3.1	3.5	6.6	9.3	13.34	33.692	55	2.6	31.1	168	2
Jessamine	Pasco	5.3	6.4	11.7	15.2	60.50	22.703	55	8.1	33.5	498	3
Pasadena	Pasco	6.3	4.0	10.3	13.3	9.65	3.667	55	4.3	30.1	371	1
Spring	Hernando	.5	2.4	3.0	4.3	-.15	2.012	30	1.6	31.9	65	2

Appendix 2. (Continued) Lakes and associated dependent and explanatory variables used to derive final regressions in table 3.

[Units are in feet unless otherwise noted. Percentile statistics and maximum and minimum stage are shown for the recent (1996-2005) period. P10, stage exceeded 10 percent of the time; P50, stage exceeded 50 percent of the time (median); P90, stage exceeded 90 percent of the time; Max-Min, maximum stage for period minus minimum stage for period; INV DIFF, difference between invert or control point elevation and median lake stage; HD GR 5-00, head gradient between the lake bottom and the Upper Floridan aquifer in May 2000; ICU THCK, thickness of intermediate confining unit; NET LEAKAGE, leakage minus ground-water minus inflow for May 2000; in/mo, inches per month; MX-MIN PREC, difference between maximum and minimum annual rainfall; MAX GW 1MI, maximum annual ground-water pumping within 1 mile of the lake; GW IN CAT, ground-water inflow category, where 1 is lowest and 3 is highest; Mgal/yr, million gallons per year; MX-MN PREC, maximum minus minimum annual rainfall for 1996-2005; n/a, not available]

Lake	County	P10-P50	P50-P90	P10-P90	Max-Min	INV DIFF	HD GR 5-00 (unitless)	ICU THCK	NET LEAKAGE (in/mo)	MX-MN PREC (inches)	MAX GW 1MI (Mgal/yr)	GW IN CAT (unitless)
Lakes in Gulf Coastal Lowlands or Western Valley (Lowland Lakes)												
Alice	Hillsborough	2.9	3.4	6.3	9.2	2.88	.728	20	4.7	33.7	298	1
Allen	Hillsborough	1.3	4.6	5.9	8.2	.11	.761	20	3.9	33.4	30	1
Bird (Hillsborough)	Hillsborough	2.0	3.9	5.9	9.9	-1.08	1.123	20	6.9	37.8	279	1
Boat	Hillsborough	1.1	2.8	4.0	5.9	1.76	.560	25	3.7	33.0	332	2
Calm	Hillsborough	2.5	3.2	5.7	8.6	3.49	.763	20	4.1	33.5	1,287	1
Carroll	Hillsborough	1.3	3.2	4.5	7.0	-.29	.434	25	3.7	34.2	340	1
Cooper	Hillsborough	1.0	2.4	3.3	6.2	.02	.266	25	6.9	37.5	138	1
Deer (Hillsborough)	Hillsborough	1.6	2.7	4.4	6.4	.62	.798	30	3.0	37.8	96	1
Egypt	Hillsborough	.7	1.3	1.9	4.2	6.16	1.429	20	3.1	35.8	31	2
Ellen	Hillsborough	.6	1.5	2.1	4.9	.43	.339	20	n/a [2]	34.1	188	2
George	Hillsborough	1.0	2.7	3.8	5.6	6.94	.536	20	4.9	31.1	10	2
Hanna	Hillsborough	1.0	4.0	5.0	7.3	.74	.262	50	3.6	39.6	397	1
Hobbs	Hillsborough	2.6	3.5	6.2	8.9	2.56	.436	30	4.2	35.6	114	1
Hog Island	Hillsborough	1.1	2.5	3.6	6.4	-2.00	.463	40	4.3	38.6	203	2
Juanita	Hillsborough	2.9	4.5	7.4	10.3	3.86	1.043	20	6.5	31.5	2,849	1
LeClare	Hillsborough	1.2	3.2	4.3	7.4	2.94	.734	20	3.8	37.3	124	1
Merrywater	Hillsborough	3.8	5.2	9.0	11.7	2.60	.277	20	6.4	35.3	1,223	1
Mound	Hillsborough	.6	1.3	1.9	4.4	-.23	.722	20	n/a [2]	34.1	1,026	2
Osceola	Hillsborough	1.2	3.2	4.4	6.7	.88	.499	20	3.2	28.9	77	1
Platt	Hillsborough	1.4	3.8	5.2	8.8	-.14	.489	20	4.3	38.4	286	1
Starvation	Hillsborough	3.6	5.8	9.4	13.9	.26	.555	20	7.2	33.0	4,059	2
Stemper	Hillsborough	1.1	3.6	4.8	8.3	1.21	.248	40	3.8	35.6	421	1
Taylor	Hillsborough	1.7	3.6	5.3	8.8	.84	.648	20	3.2	33.4	286	1
Bell	Pasco	1.1	1.9	3.0	5.9	-.12	.562	20	2.4	41.7	140	1
Big Vienna	Pasco	.8	2.4	3.1	6.9	.35	.392	20	3.4	37.2	204	1
Bird (Pasco)	Pasco	1.0	1.4	2.4	4.9	-.58	.683	35	3.1	39.5	236	1
Black	Pasco	1.2	1.8	2.9	5.5	4.26	.471	20	4.5	31.0	35	1
Camp	Pasco	2.5	6.5	9.0	12.9	3.45	.451	20	7.0	32.4	1,041	1

Appendix 2. (Continued) Lakes and associated dependent and explanatory variables used to derive final regressions in table 3.

[Units are in feet unless otherwise noted. Percentile statistics and maximum and minimum stage are shown for the recent (1996-2005) period. P10, stage exceeded 10 percent of the time; P50, stage exceeded 50 percent of the time (median); P90, stage exceeded 90 percent of the time; Max-Min, maximum stage for period minus minimum stage for period; INV DIFF, difference between invert or control point elevation and median lake stage; HD GR 5-00, head gradient between the lake bottom and the Upper Floridan aquifer in May 2000; ICU THCK, thickness of intermediate confining unit; NET LEAKAGE, leakage minus ground-water minus inflow for May 2000; in/mo, inches per month; MX-MIN PREC, difference between maximum and minimum annual rainfall; MAX GW 1MI, maximum annual ground-water pumping within 1 mile of the lake; GW IN CAT, ground-water inflow category, where 1 is lowest and 3 is highest; Mgal/yr, million gallons per year; MX-MN PREC, maximum minus minimum annual rainfall for 1996-2005; n/a, not available]

Lake	County	P10-P50	P50-P90	P10-P90	Max-Min	INV DIFF	HD GR 5-00 (unitless)	ICU THCK	NET LEAKAGE (in/mo)	MX-MN PREC (inches)	MAX GW 1MI (Mgal/yr)	GW IN CAT (unitless)
Cow or East	Pasco	.5	.8	1.3	2.7	-.09	.654	20	1.4	37.9	98	1
Crews	Pasco	2.3	3.9	6.2	11.9	4.06	-.026	20	13.2	29.2	138	1
Geneva	Pasco	.8	1.5	2.3	4.6	1.13	.655	20	n/a [2]	31.0	28	1
Gooseneck	Pasco	1.2	3.0	4.2	6.8	.50	.640	20	3.4	35.9	106	2
King	Pasco	1.1	2.9	4.0	7.0	-.64	.283	20	1.8	41.8	208	1
Linda	Pasco	1.1	2.8	3.9	6.3	3.52	.709	20	2.2	39.4	141	1
Moon	Pasco	1.4	3.6	5.1	7.4	1.22	.338	20	2.7	33.1	0	1
Padgett	Pasco	1.0	1.3	2.4	4.8	-.57	.671	20	3.6	40.8	195	1
Parker or Ann	Pasco	1.0	2.2	3.2	5.0	.32	.561	20	3.2	30.1	63	1
Pierce	Pasco	1.3	3.7	5.1	8.1	2.22	.101	20	n/a [2]	32.4	0	1
Saxon	Pasco	1.2	1.3	2.5	5.5	-2.03	1.109	20	2.8	39.2	160	2
Tampa	Pasco	1.3	3.2	4.5	8.0	-2.62	.536	35	n/a [1]	35.8	222	2
Thomas (Pasco)	Pasco	1.1	3.0	4.1	6.0	.33	.308	20	.9	40.2	203	1
Wistaria	Pasco	1.2	3.0	4.2	6.3	.57	.255	20	3.2	38.8	73	1

[1] Net leakage not computed because surface-water outflow occurred during computation period.

[2] Net leakage not computed because insufficient stage data between April and June 2000.