FINAL

Butler and Big Sand Lake Chain of Lakes

Reconnaissance Study

Original Submittal - September 2006

Modified Submittal - December 2008

Performed for

South Florida Water Management District

And

Orange County, Division of Stormwater Management

By

Camp Dresser and McKee, Inc.

Maitland, Florida

Section 1
Introduction

1.1 Background

The South Florida Water Management District (District) and Orange County Stormwater Management Division (County) contracted with Camp Dresser and McKee, Inc. (CDM) to perform a reconnaissance study of an area in West Orange County including the Butler Chain of Lakes and the Sand Chain of Lakes.

The District and the County requested that two assessments be conducted: the potential to develop a statistical relationship that will forecast flooding conditions and the potential contribution from the Surfical Aquifer System (SAS) to the lake's water budget. It was thought that the latter, if it proved significant, would provide justification for the development of an integrated surface water – groundwater model in a later phase.

The study area is shown in **Figure 1-1**. It historically consisted primarily of citrus groves. With increased land values the groves have been converted to residential land uses. In recent years, i.e. 2003 to present, there has been concern with excessively high lake levels among some of the residents of these lake systems. This public concern provided some impetus to study these systems.

1.2 Lake Systems

The Butler Chain of Lakes consists of 10 major lakes: Crescent Lake, Lake Down, Lake Butler, Lake Bessie, Lake Chase, Lake Blanche, Lake Tibet Butler, Lake Sheen, Pocket Lake and Fish Lake. There are also a number of minor lakes (areas < 50 acres). With the exception of Crescent Lake, these lakes appear to be interconnected relatively well i.e. the stages tend to equalize.

The Butler Chain drains to the south, ultimately to Lake Sheen. When the lake level increases to approximately 99 feet National Geodetic Vertical Datum (NGVD) the water will overtop a natural weir and spill out into Cypress Creek Swamp. The water sheet flows through this wetland area, for approximately 2 miles, finally discharging under SR535, through twin 60 inch reinforced concrete pipes (RCP) into the Reedy Creek Improvement District's (RCID) drainage system. Ultimately this system discharges into Reedy Creek thence to the Kissimmee River.

The Sand Chain of Lakes consists of 7 major lakes: Spring Lake, Little Sand Lake, Lake Serene, Big Sand Lake, Boo Boo Lake, Lake Crowell, and Lake Willis. Spring Lake, Little Sand Lake and Big Sand Lake share limited interconnections. There are surface elevation discontinuities between each lake. These discontinuities are associated with the nature of the interconnections e.g. a weir and culvert connection between Spring Lake and Little Sand Lake.

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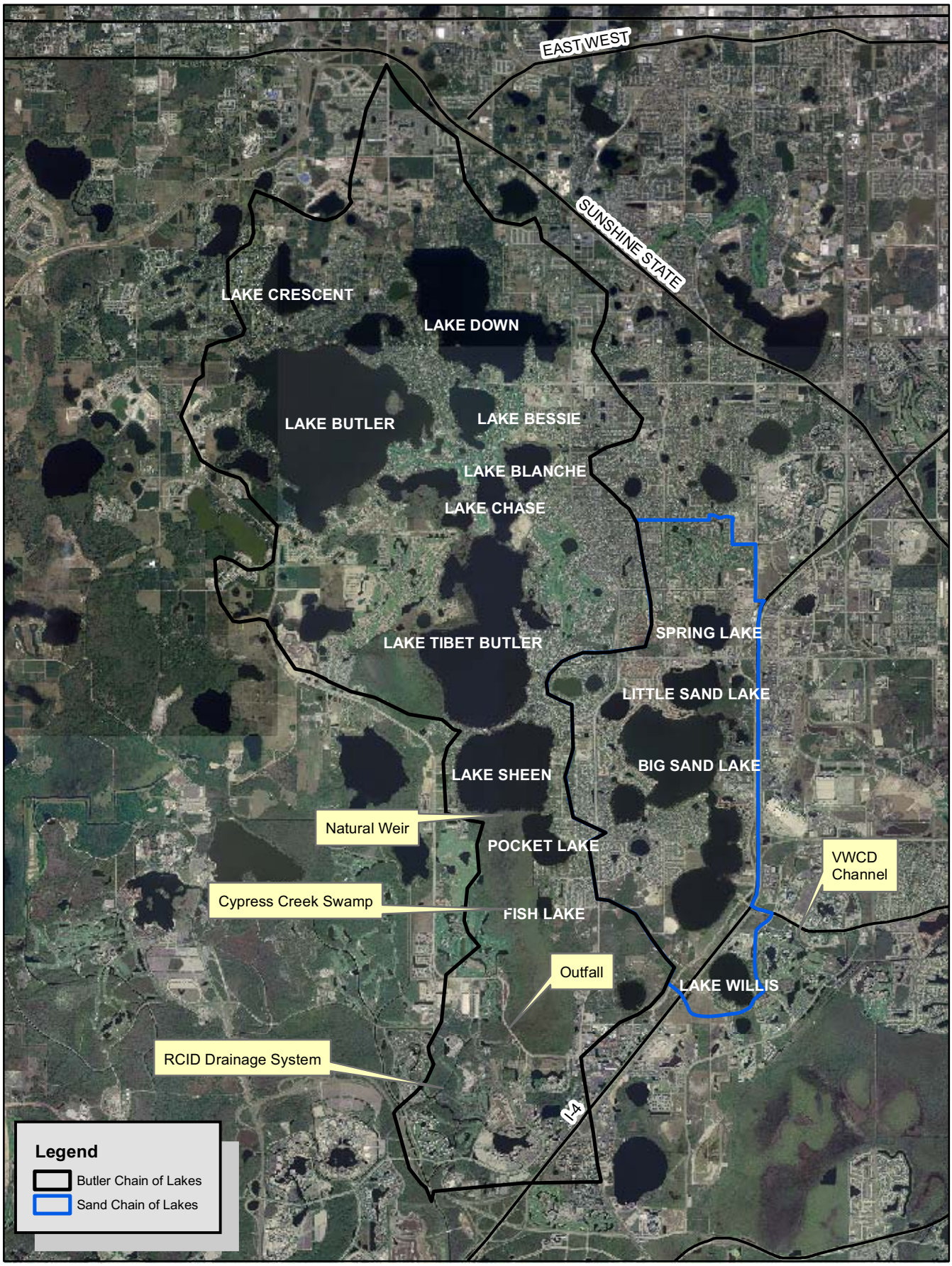

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Figure 1-1
Project Location

The Sand Lake Chain also drains to the south; there is an outfall channel at the southeastern corner of Big Sand Lake. When the lake elevation reaches 96.3 ft NGVD flow will pass through a series of open channels and culverts ultimately ending up in Valencia Water Control District's (VWCD) system. The overflow is connected to the street drainage along Central Florida Parkway and is discharged into a VWCD channel. Ultimately this flow discharges into the Shingle Creek system.

1.3 Report Discussion

During the study period, sections of this report were delivered to the client. This report contains those original submittals; kick off meeting minutes as **Appendix A**, data collection section as Section 2, the water budget analysis as Section 3, the annual water budget bar graphs as **Appendix B**, and comments provided by Orange County Stormwater Department as **Appendix C**.

Subsequent to the submittal of the water budget analysis (September 19, 2006) additional analysis regarding the use of the Palmer Drought Severity Index (PDSI) as a means to forecast the lake level trends was completed. This analysis is included as **Appendix D**.

1.4 Revised Recommendations

The most significant modification to this study was the inclusion of the PDSI analysis. Based upon Orange County comments, more specific recommendations for piezometers locations were also included. Also based upon Orange County comments a tabular comparison of the various integrated modeling options has been included.

As noted in Appendix D, it appears that the PDSI can provide a reasonably accurate means to predict the overall trends of the lake levels. It is recommended that this prediction tool be investigated and tested to see if it could provide a sufficient level of prediction. It is also noted that the PDSI generated and used in this analysis would essentially cover all of Orange County, thus if proved sufficient could be used to predict the overall lake level trends county wide.

The installation of surficial aquifer piezometers could provide a significant amount of data which would prove useful in both the quantification of the surfical contribution as well as providing data with which to calibrate an integrated surface water – groundwater model.

Section 2
Data Collection

2.1 Introduction

Various reports and data were collected according to the objectives and goals of the study. In general the following types of data were collected: time series (e.g. flows, lake stages, rainfall, evapotranspiration (ET), water table and Floridan aquifer stages), GIS information including topographic data, models and model development documentation. These data were collected from a variety of sources including Orange County Stormwater Management Division (OCSMD), South Florida Water Management District (SFWMD), Reedy Creek Improvement District (RCID), United States Geological Survey (USGS), St. Johns River Water Management District (SJRWMD) and references cited in various reports. The following section documents the data collection effort. The data collected, along with a brief summary, is listed below in order to define a basis of evaluation and to point out any data gaps. Note that all figures are located at the end of the section.

In addition to describing the data that was collected, an assessment will be made as to general value of the data and the role it may plan in a subsequent model development phase.

2.2 Topographic Survey

LiDAR was recently developed in a joint effort between OCSMD and SFWMD. These data were obtained from the OCSMD. These data were first converted to a triangulated irregular network (TIN) coverage and then to a grid based or raster coverage. The raster coverage is presented in **Figure 2-1**. The process of generating the TIN requires that the available elevations be interpolated to produce the triangular elements. This conversion took place so that the automated tools available in the ArcGIS tool kit, Archydro, could be used to regenerate the overall basin and subbasins. Revision of the basin boundary may be done prior to development of the water budget. Any analysis in the data collection section will make use of the County supplied basin boundary.

Topographic data for this study area were provided as NAVD. However, the water level data is provided in NGVD, and therefore conversion of the topographic datum was necessary. Changes in values range from 0.87 to 0.9 over the span of the project area.

These data appear to be very good and will be used to define the topography in subsequent phases. Depending upon the model chosen, these data could either define the topography directly (i.e. in a grid based model) or could be used to define subbasins to be used in a lumped parameter model. Additionally these data can be used to generate ("cut") cross sections for either floodplain or overland weir definition.

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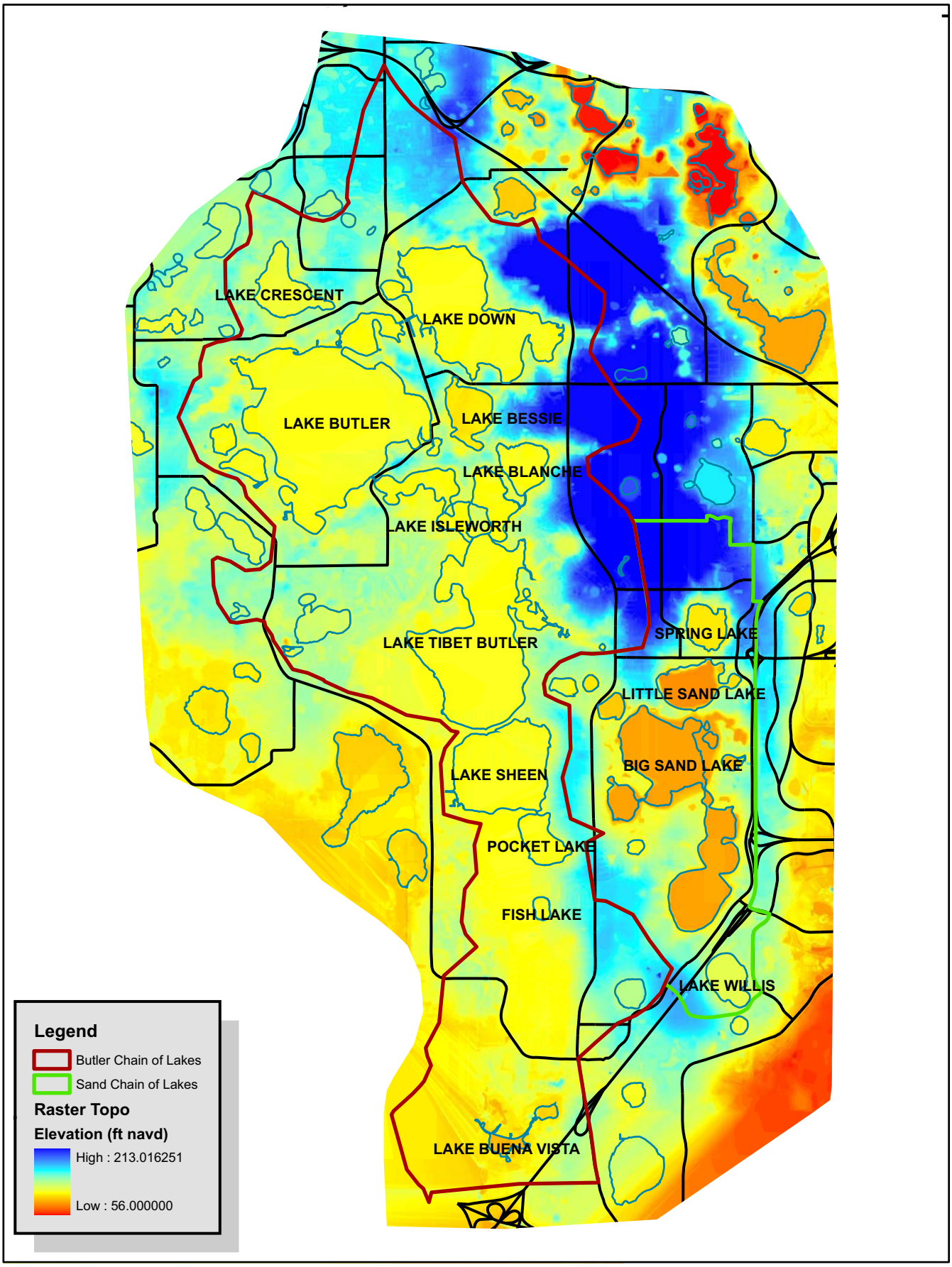

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Figure 2-1
Topographic Raster (NAVD)

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2.3 Rainfall Records

Rainfall records were obtained from both RCID and OCSMD. The rainfall stations are shown on **Figure 2-2**. RCID provided monthly summaries as documented in their "Annual Report of the Chief Engineer". OCSMD provided rainfall records for a number of stations including, but not limited to: Spring Lake, and Lake Sheen. These two are the most appropriate for this study due to its proximity to the project area. The period of record for Spring Lake is from 11/28/1989 to present; the period of record for Lake Sheen is from 06/20/2002 to present.

For the period of 1995 to 2005 the monthly summaries of rainfall provided by RCID and OCSMD (Spring Lake Station) were averaged and the monthly averages are presented in **Figure 2-3**. It is noted that the majority of the year 2000 is not included in the estimate of the OCSMD monthly averages. These data were only sporadically available in 2000. There are some inconsistencies noted in the monthly averages, comparing Spring Lake to RCID the largest being 1.4 inches in August and the smallest being -0.9 inches in December. The average annual rainfalls from both sources are relatively close: 48.43 inches at Spring Lake and 45.79 inches at the RCID gauges.

Other than the data gaps listed above, the rainfall data available from OCSMD is the most complete and therefore it is the most appropriate data to use in any hydrodynamic modeling that may occur in a subsequent phase. This is due to the fact that these data were supplied as an incremental time series (i.e. essentially model ready) that was summarized for this report. In addition to providing direct input to any model that may be chosen in a subsequent phase, these data will also provide an estimate for a component of the water budget.

2.4 Aerial Photography

The latest aerials, dated July 2005, were downloaded from the Florida Department of Environmental Protection, Bureau of Survey and Mapping's web site Land Boundary Information System (LABINS). The aerials for the project area are presented in **Figure 2- 4**.

Aerial photographs could be used to update and verify information obtained from other sources. For example, the aerial photographs can be used when defining the hydraulics of the system and to update land use files.

2.5 GIS Data

A number of GIS layers were collected from SFWMD, OCSMD, RCID and SJRWMD. These data have provided a means to investigate spatially varying information. Additionally there were a number of shape files that were generated during this project including the location of wells.

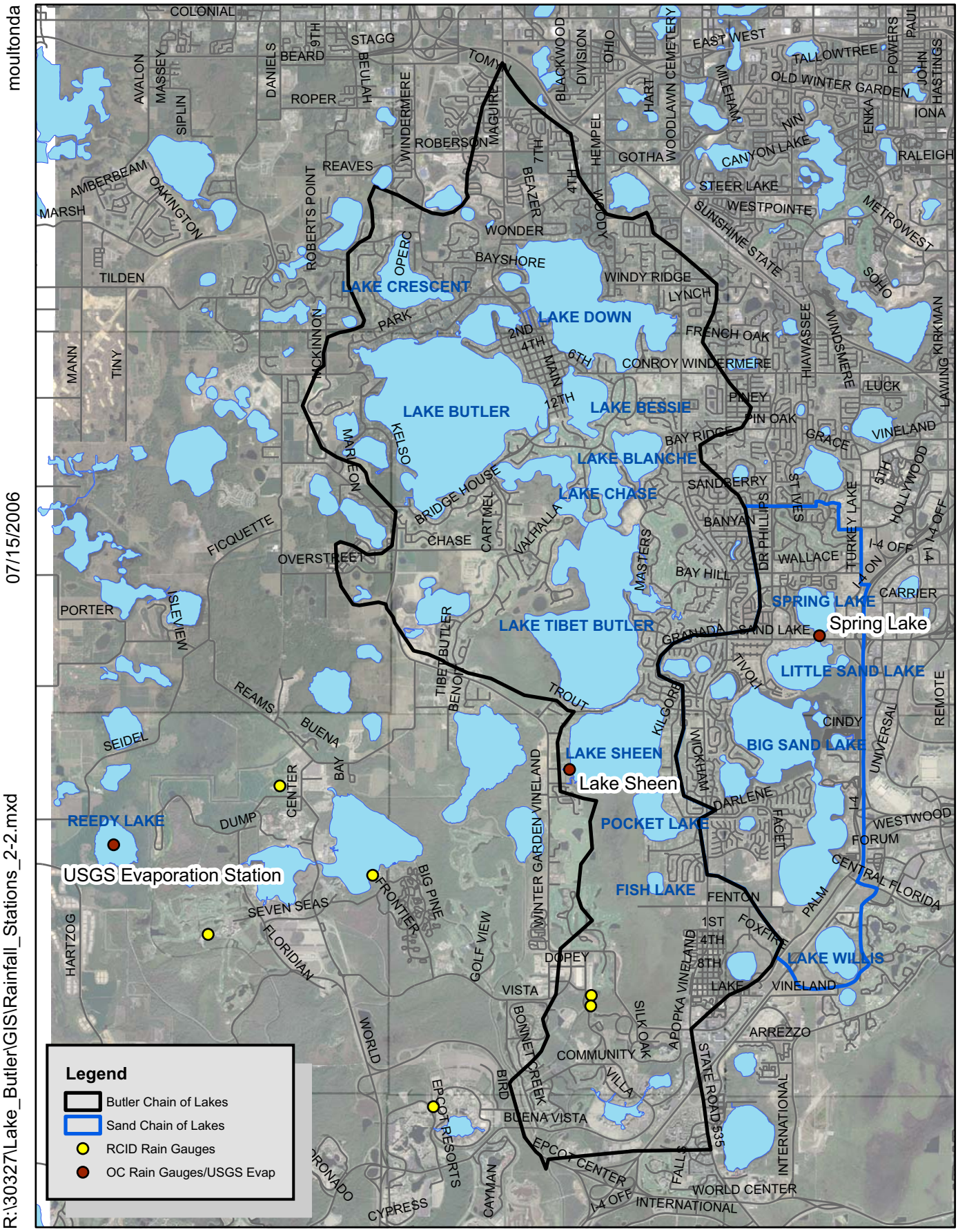

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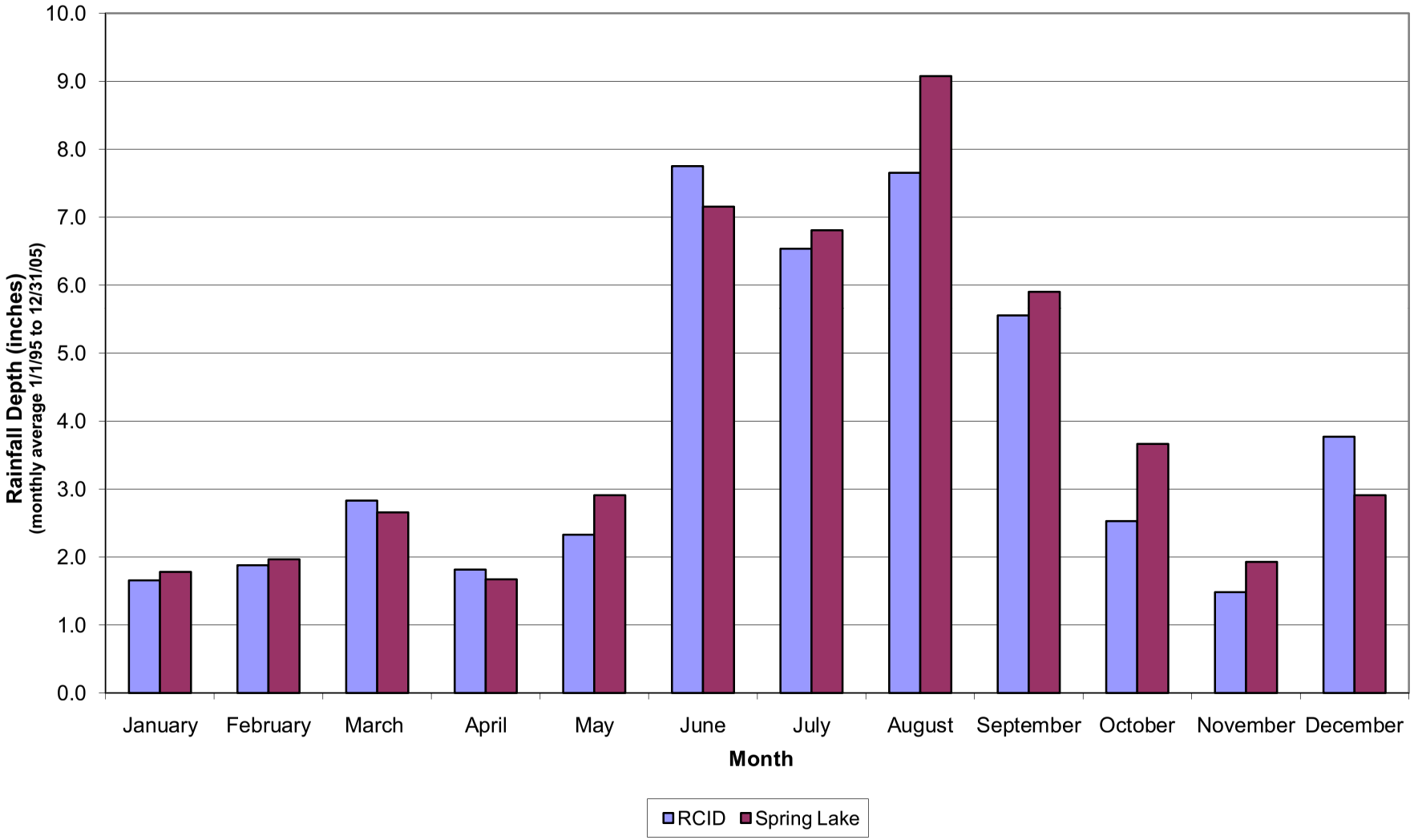
Figure 2-2
Rainfall and Evaporation Stations

Figure 2-3
Comparison of RCID and OC's Spring Lake Rainfall Gauges



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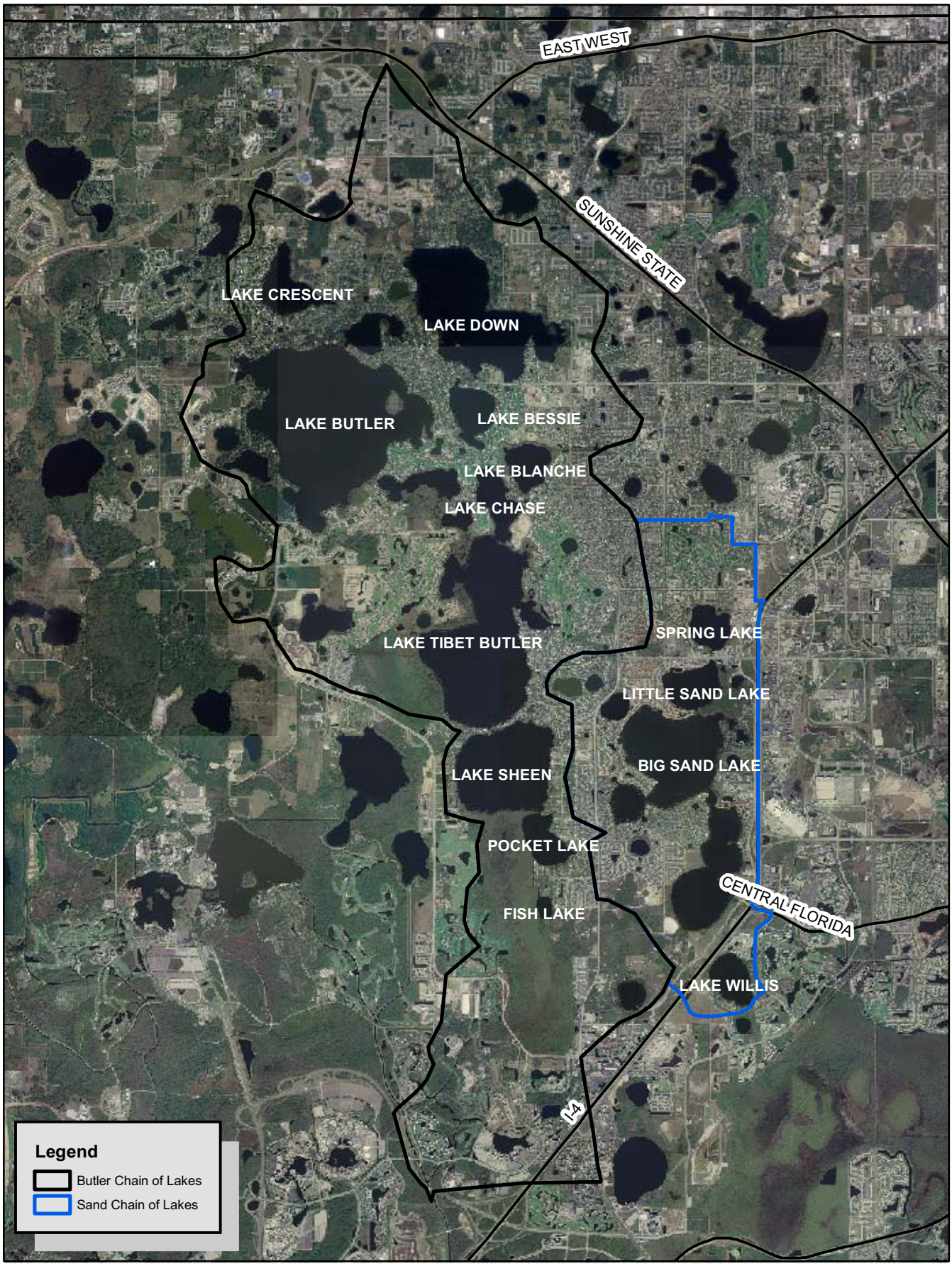

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Figure 2-4
Aerials (2005 - Source LABINS)

2.5.1 Recharge

SFWMD and SJRWMD provided recharge rates to the Floridan Aquifer in this area; this information is presented in **Figure 2-5**. It was noted that there is a slight discrepancy between the coverage supplied by SFWMD and SJRWMD. These discrepancies can be noted at northern end of the Butler Chain of Lakes basin boundary. The project area spans several recharge zones. The western portion of the Butler basin, including Lake Crescent and the western portion of Lake Butler, is in the 8 – 12 inch per year range. The northern most tip of the Butler basin is in the highest range, > 12 inches per year. The central portion of the Butler basin and the northern portion of the Sand Lake Basin are in the 4 – 8 inch per year range. Virtually the rest of both basins are in the 0 – 4 inch per year range.

This information may be used in the development of the water budget. As this area of Orange County is considered a recharge area, the recharge to the Floridan aquifer will be a significant component of the water budget.

2.5.2 Soils

The soils coverage for Orange County was downloaded from the SJRWMD website. The soils for the project area are presented in **Figure 2-6**. The area and percent of each hydrological soil group is provided in **Table 2-1**. The soil groups relate to the runoff potential of each type. "A" soils are sandy and tend to have a very low runoff potential, "B/D" is a dual class soil, they have a moderately low potential for runoff but have some type of hardpan or high water table hindering infiltration (depending upon conditions, may act as "D" soils i.e. high runoff potential), "C" soils tend to contain more clays or silt, the runoff potential increases, "D" soils have the highest runoff potential – typically these soils contain a good percentage of clays or soil types that hinder infiltration. Soil type "W" refers to water and "X" refers to urban or some type of disturbed soil – when the soils were surveyed there was some reason that the soil scientists couldn't define the soil type.

Table 2-1 Percent Soil in Project Basins

Butler Chain of Lakes			Sand Chain of Lakes		
Hydrological Group	**Acres**	**Percentage**	**Hydrological Group**	**Acres**	**Percentage**
A	6370	30.6%	**A**	1901	34.6%
B/D	4384	21.1%	**B/D**	683	12.4%
C	1959	9.4%	**C**	766	14.0%
D	1946	9.4%	**D**	616	11.2%
W	5743	27.6%	**W**	1467	26.7%
X	390	1.9%	**X**	58	1.1%
Total	20791	100.0%	**Total**	5491	100.0%

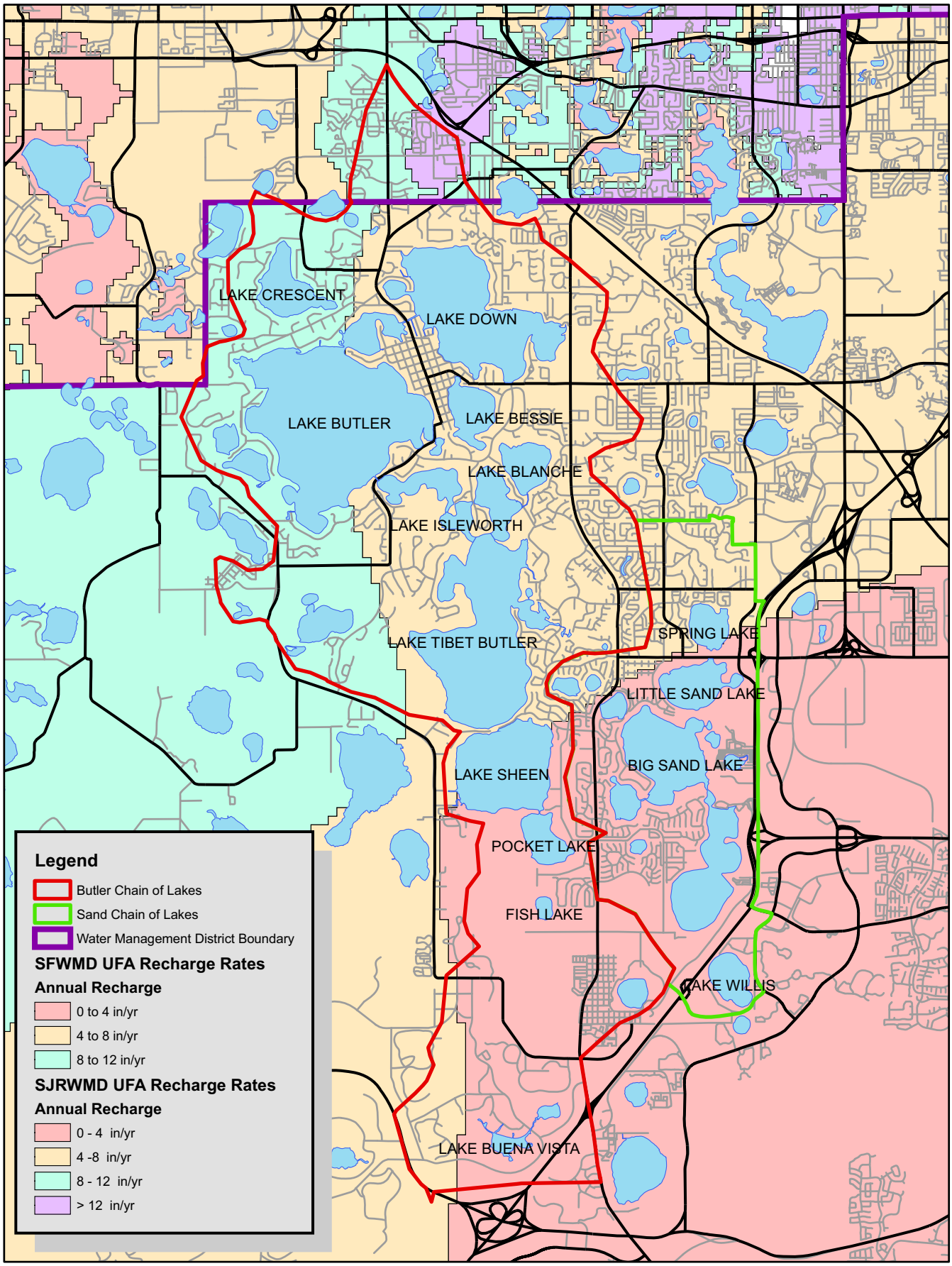

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Figure 2-5
Recharge to Upper Floridan Aquifer (in/yr)

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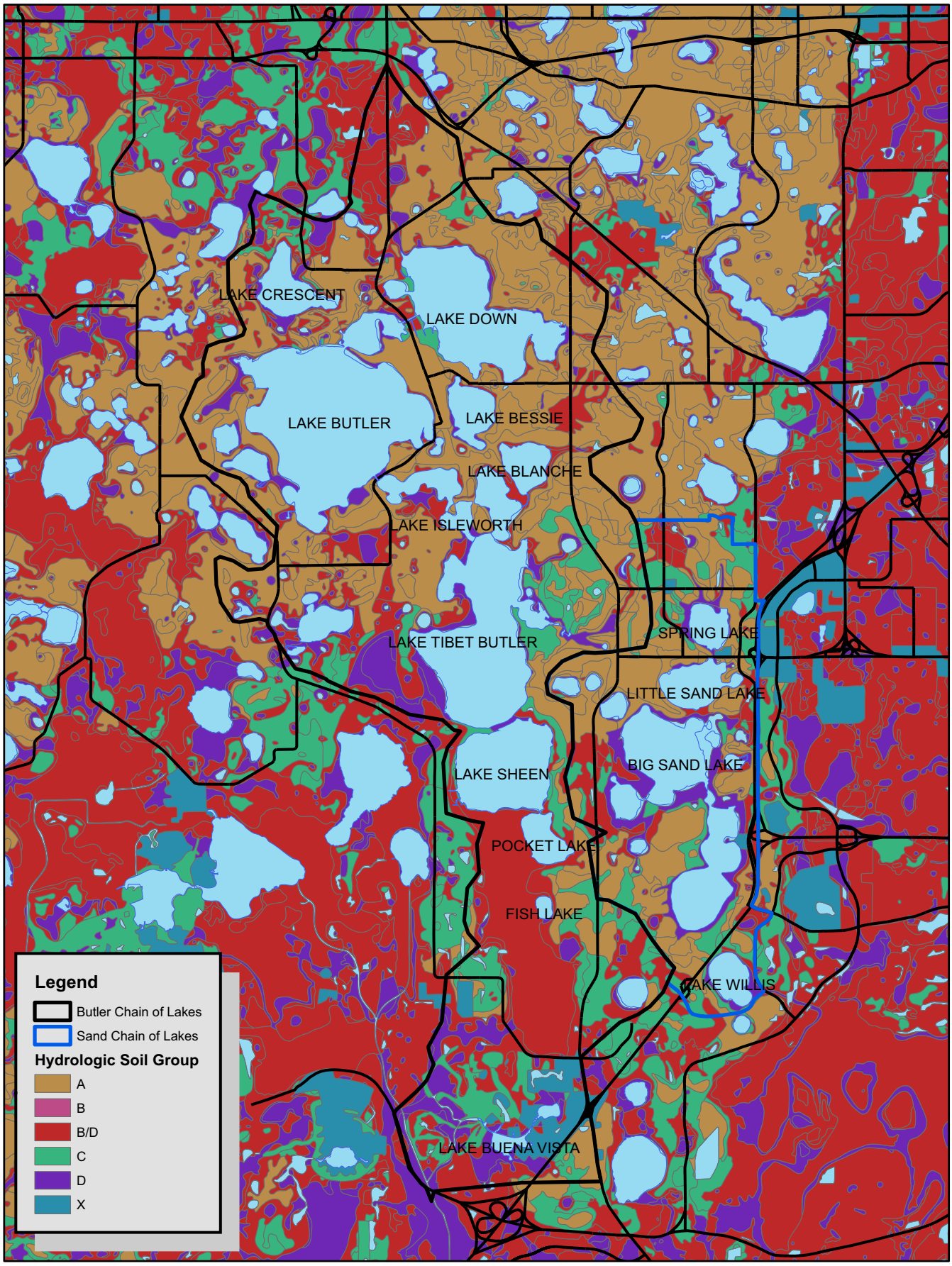

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Figure 2-6
Soils (SSURGO)

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"A" soils make up a large percentage in both basins. In general the "A" soils are located in the northern portion of the basins. These soils are generally consistent with the higher recharge zones. The next largest group, in both basins, is "W", not a soil type, however standing water does make up a large percentage of the basin. Soil type and associated characteristics will be an important input to any modeling effort that may be developed in a subsequent phase. These data will largely define the soil storage available in the unsaturated zone. In addition, this definition of soil storage may be a significant component in the development of the water budget.

2.5.3 Land Use

Orange County also provided the most recent existing land use coverage. These data are presented in **Figure 2-7**. According to the name of the existing land use GIS shape file (LUSE1997_region) it would appear that these data are approximately 10 years old. Development has been robust over the last decade and it is likely that the actual land use is somewhat different at this point in time. The acreages and percentages are presented in **Table 2-2**. It can be seen that in the Butler Chain of Lakes, the majority of the basin is made up of water bodies, low density residential, rural/agriculture and conservation. These land uses make up approximately 90 percent of the basin. The majority land use with the Sand Lake chain is similar, with the exception that conservation makes up a smaller component. Water bodies, low density residential and rural/agriculture make up approximately 80 percent of the basin.

Table 2-2 – Existing Land Use

Butler Chain of Lakes			Sand Chain of Lakes		
Orange County Land Use	**Acres**	**Percentage**	**Orange County Land Use**	**Acres**	**Percentage**
Commercial	827.9	4.0%	Commercial	316.8	5.8%
Conservation	2707	13.0%	Conservation	162.9	3.0%
Industrial	17.75	0.1%	Industrial	24.96	0.5%
Institutional	374.1	1.8%	Institutional	262.3	4.8%
Low Density Residential	5147	24.7%	Low Density Residential	1478	26.9%
Medium Density Residential	249	1.2%	Medium Density Residential	125.1	2.3%
No Designation	0.13	0.0%	No Designation	0.08	0.0%
Parks and Recreation	861.3	4.1%	Parks and Recreation	215.8	3.9%
Rural/Agricultural	4979	23.9%	Rural/Agricultural	1508	27.4%
Waterbody	5641	27.1%	Waterbody	1401	25.5%
Total	**20805**	**100.0%**	**Total**	**5495**	**100.0%**

Land use is an important input to any modeling effort. It will be necessary to review the land use coverages, based upon the most recent aerials to revise these data to be consistent with the existing conditions.

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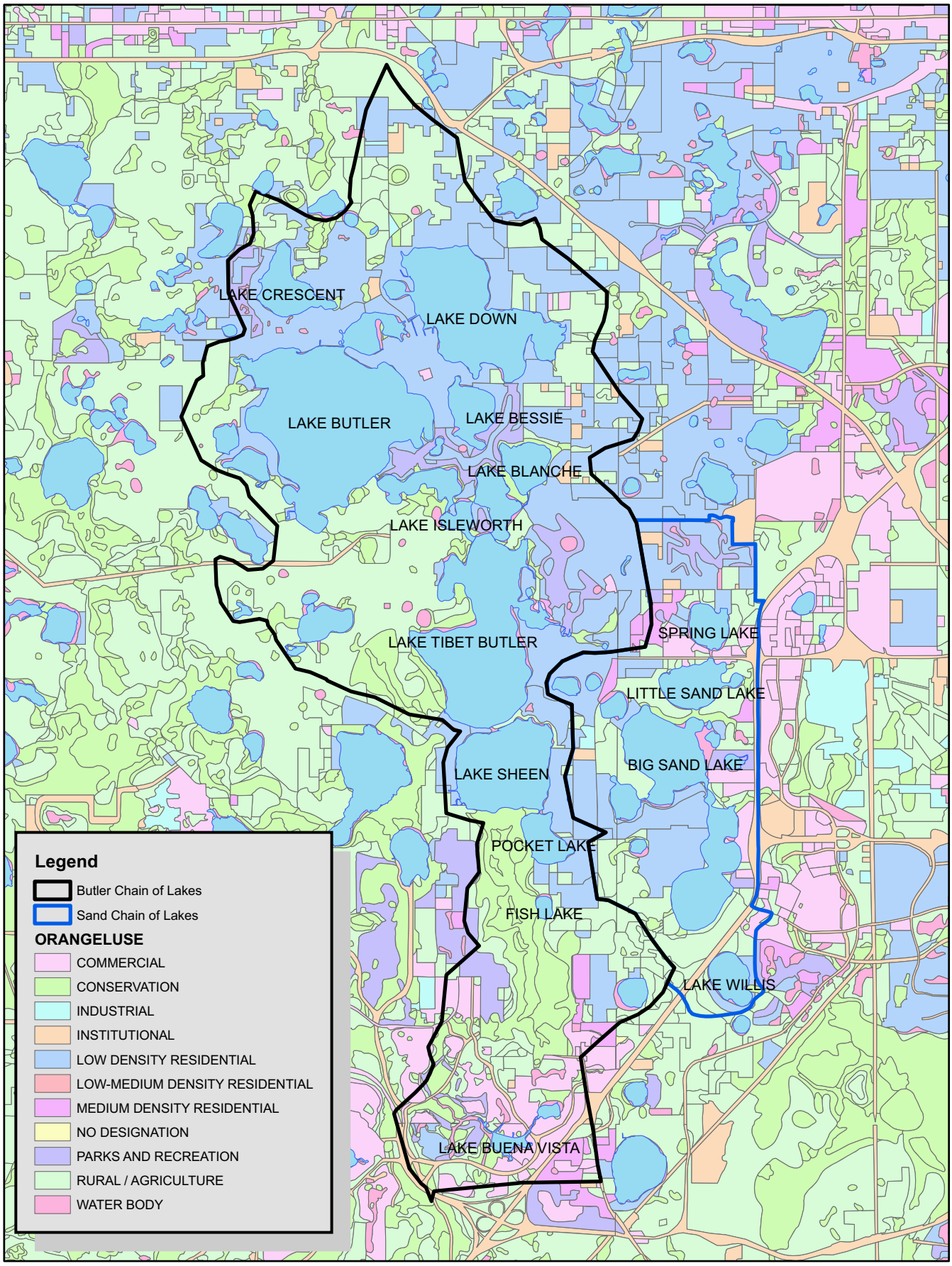

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Figure 2-7
Existing Land Use (1997)

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2.6 Evaporation

During the meeting to define the project goals, held on May 18, 2006, RCID staff indicated that the USGS maintained an evaporation station in Reedy Lake. These data were requested and received from the USGS. The location of the station is shown on Figure 2-2.

A "raft" weather station was maintained on Bay Lake from 11/28/2001 to 10/13/2005. Daily evaporation was measured at this station; in addition various other data (i.e. precipitation, air temperature, relative humidity, wind speed, net radiation, incoming solar radiation, and water temperature) were collected at 30 minute intervals. **Figure 2-8** presents the monthly evaporation measured at this station.

The average measured evaporation for this period was approximately 1500 mm (59 inches). This average value is consistent with other studies conducted on various other lakes in Florida. It is noted that the average annual evaporation is higher than the average rainfall (approximately 12 inches more per year). Thus, on average, standing water will have an overall deficit. This is also validated by Swancar et al (2000).

In addition to these data crop coefficients were also collected for various vegetation /land use types.

These data represent a sizable component of the water budget. They will be used to estimate the evaporation component of the water budget. These data will also be an important input to any continuous simulation model.

2.7 Lake Level and Flow Data

Lake level and flow data collected by OCSMD and USGS were compiled and evaluated. OCSMD provided lake level data for the following lakes: Lake Butler, Lake Sheen, Spring Lake and Big Sand Lake. It is noted that the elevations for Sheen and Big Sand Lakes is a subset of the study period. USGS provided flow data at the outfall of the Butler Chain of Lakes at the south end of Cypress Swamp. **Figure 2-9** presents the stages of the various lakes while **Figure 2-10** presents the outflow from the Butler Chain of Lakes. It is noted that there is not a flow measuring device on the outfall of the Sand Chain of Lakes.

There appear to be erroneous readings of the lake stages presented in Figure 2-9. For example, August through October of 1998 in Spring Lake, the stage drops approximately 10 feet in a day and is maintained at that elevation for several months, then it rises a similar amount in a day.

The USGS maintains a flow gauge at the culverts under SR535, the water elevation is also read. **Figure 2-11** presents the stage for the period of interest (1995 to present). The data shown on this figure seems to "bottom out" at several locations. This is because the gage is set at an elevation of 96.2 feet above sea level. Any elevations

Figure 2-8
Monthly Evaporation Measured at Bay Lake

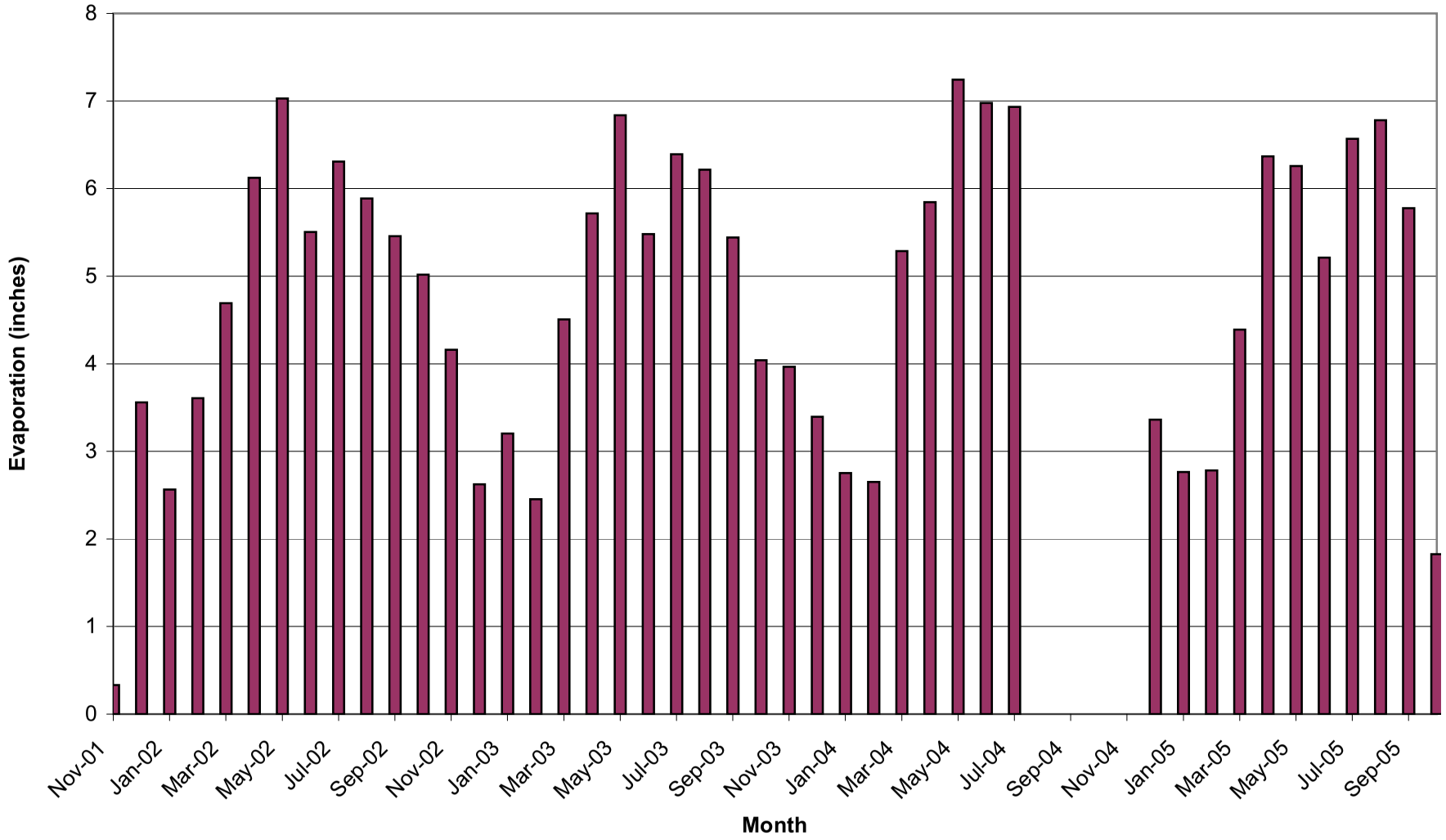


Figure 2-9
Lake Levels in Study Area

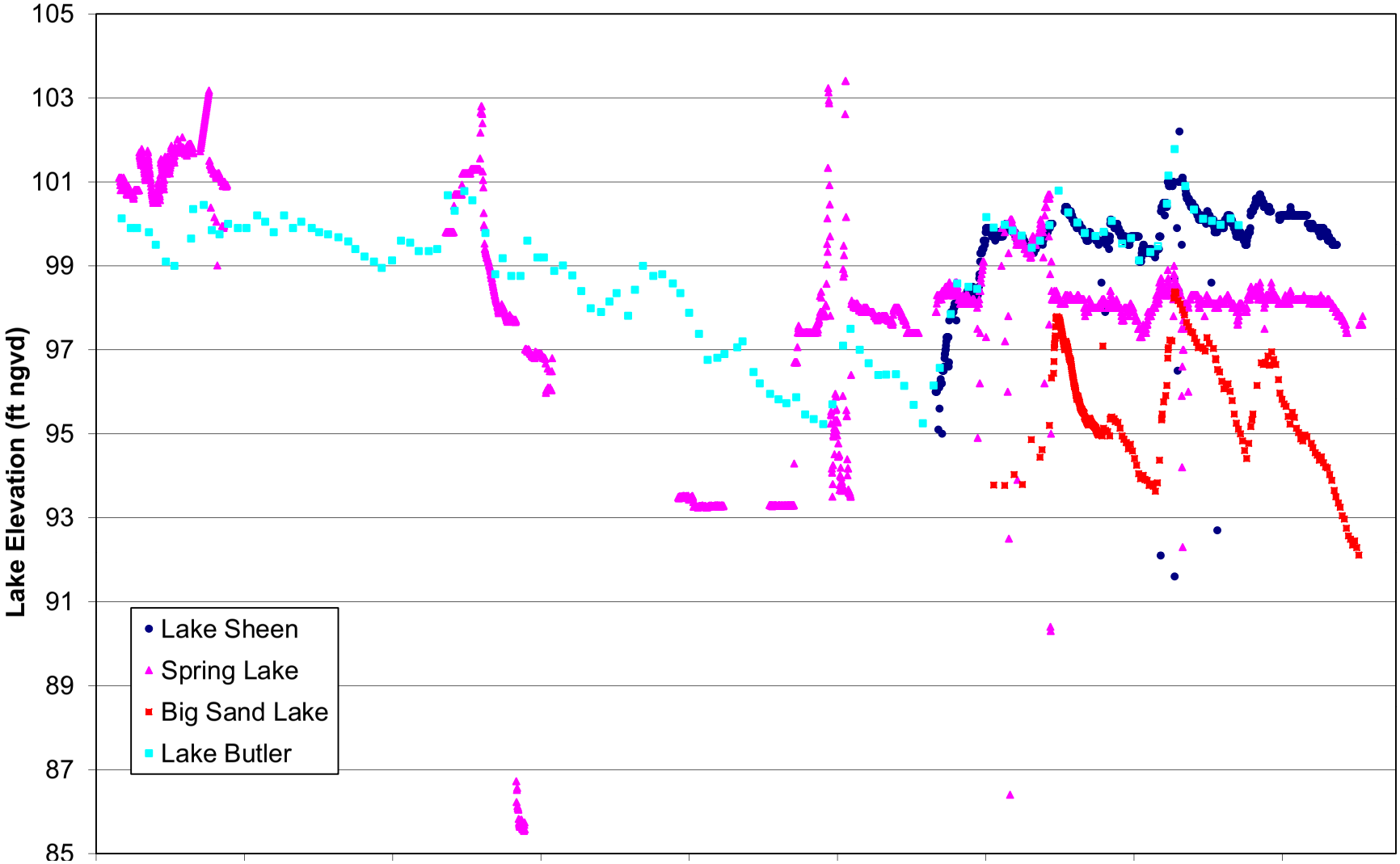


Figure 2-11
Water Level at USGS Gauge - Cypress Creek @ SR535

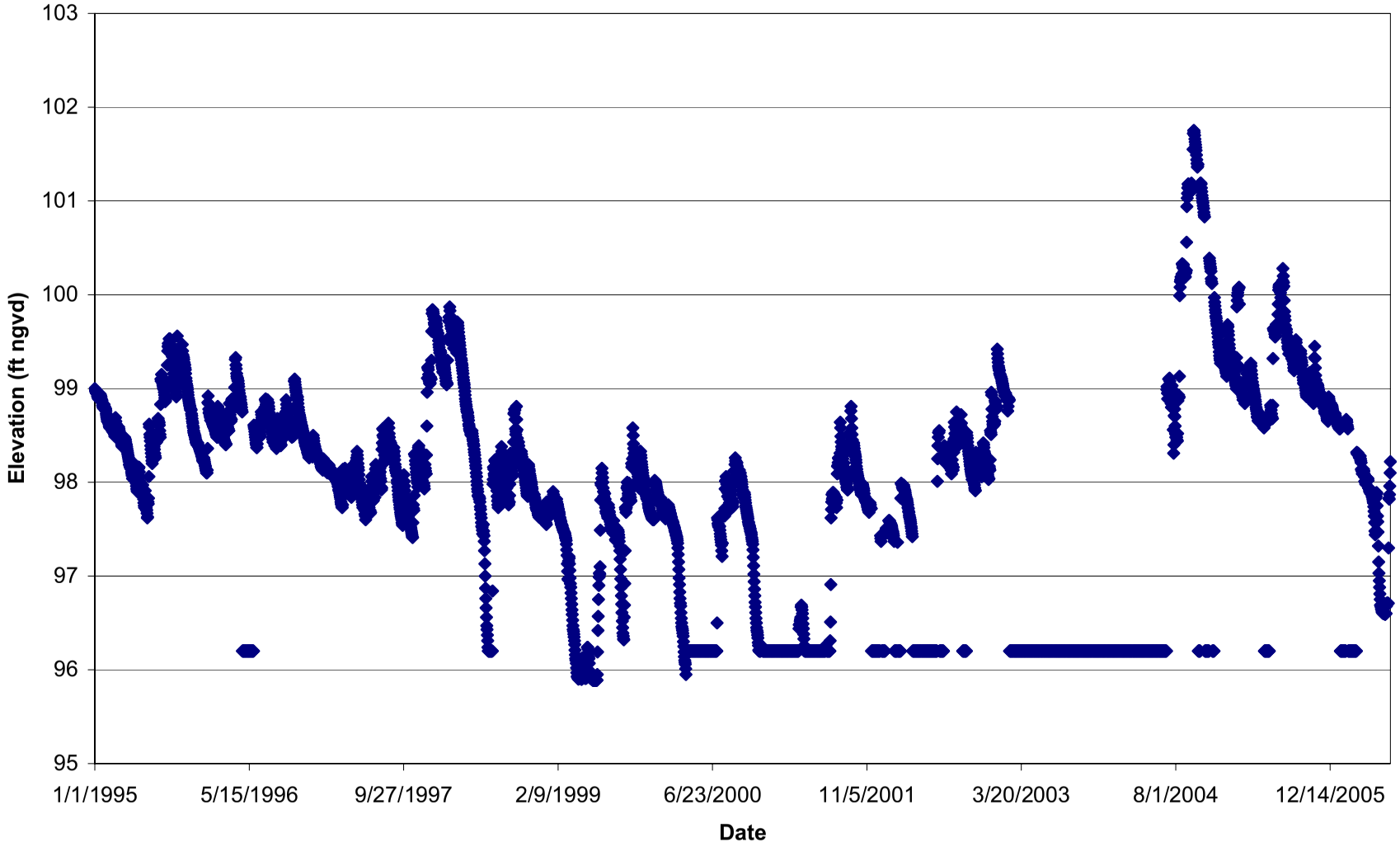
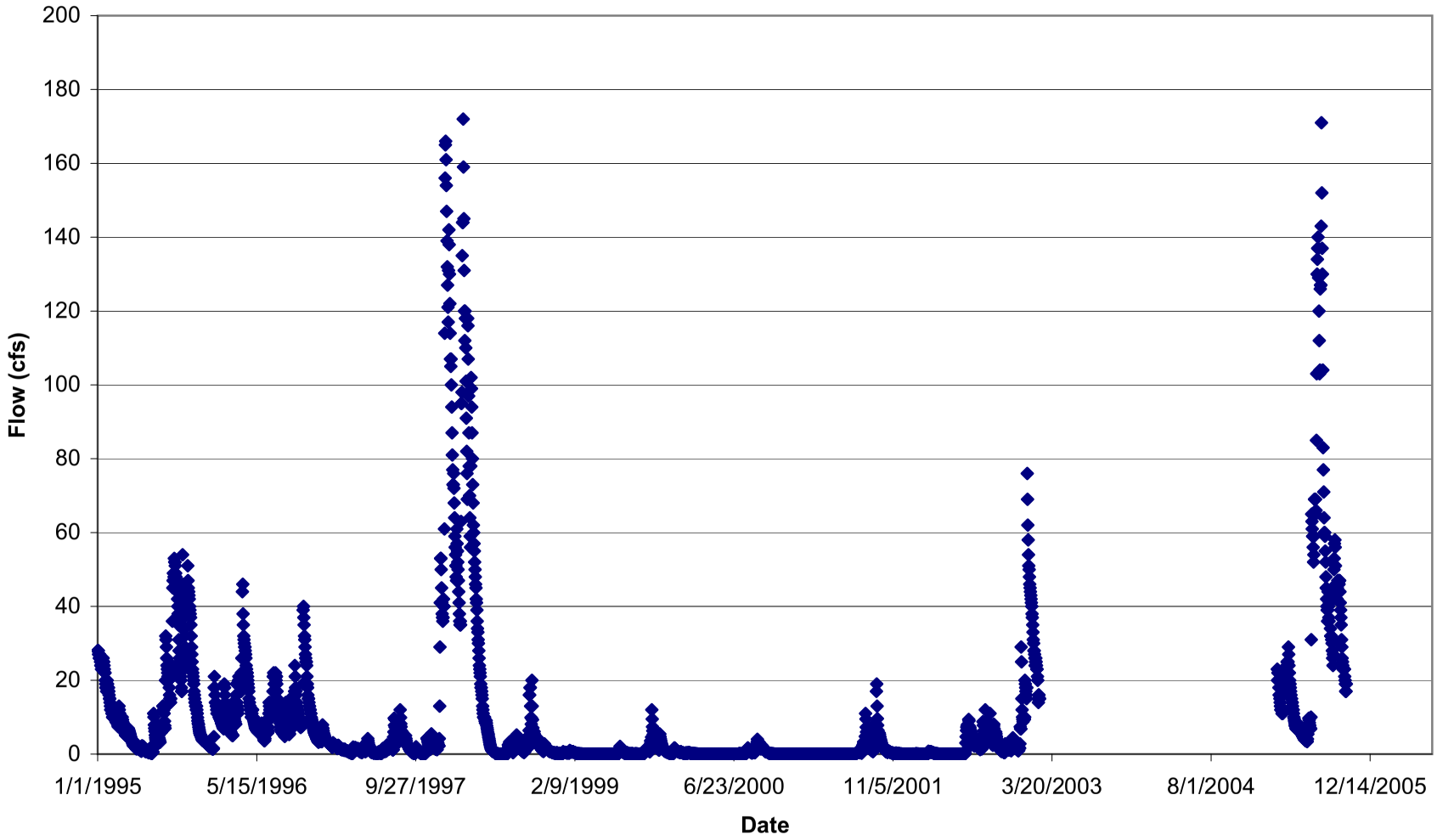


Figure 2-10
USGS Gauge 02264000 - Cypress Creek @ SR535



below this datum are recorded as 96.2 ft and not necessarily the actual water elevation.

Based on available data, it appears that there is a subset of lakes being monitored within the study area. The assumption is made that the chains of lakes equalize, and that it is only necessary to monitor the levels at certain stations.

These data will be useful in subsequent work in a number of ways. They will provide calibration time series for any hydrodynamic model to attempt to match. They will also be important in the generation of the water budget in that they will give an indication of the volume of storage used in a particular lake in a particular point in time.

2.8 Groundwater Elevation Data

Both DISTRICT's DBHYDRO database and the USGS website were searched for applicable wells. There appear to be a significant number of Floridan monitoring wells available; only a limited number of Surfical monitoring wells. Additionally RCID supplied well locations and groundwater stages for a number of wells. **Figure 2-12** shows the locations of all these wells. **Figure 2-13** and **2-14** show data from the period of record of the Surficial and Floridan wells respectively.

While there is sufficient spatial and temporal coverage for understanding the groundwater levels in the Upper Floridan Aquifer (UFA), only a limited number of data points were found for describing the fluctuation of the Surficial Aquifer System (SAS). As noted previously, this area of Orange County is considered to be a significant recharge zone to the UFA. Because of the very limited available SAS water level data, it is recommended that installation and monitoring of SAS water table piezometers be given a high priority, so that the relationship between SAS groundwater levels and lake water levels can be established. This is essential for accurate groundwater-surface water simulation modeling, as well as for confirmation whether drought index based correlations are sufficiently accurate for meeting the District/County objectives.

2.9 Known Flooding Events

The COUNTY complaint logs were obtained in order to determine the areas within the study area that may require immediate attention in terms of flooding probability.

Historical finished floor elevations were also obtained from COUNTY. There are a number of elevations associated with primary residences as well as dock and outbuildings. It appears that these data are not recent; thus they may have limited applicability.

The flooding complaints will provide a means to verify if any modeling exercise is producing appropriate water surface elevations. Also, these data can provide a means to estimate the extent of reported flooding.

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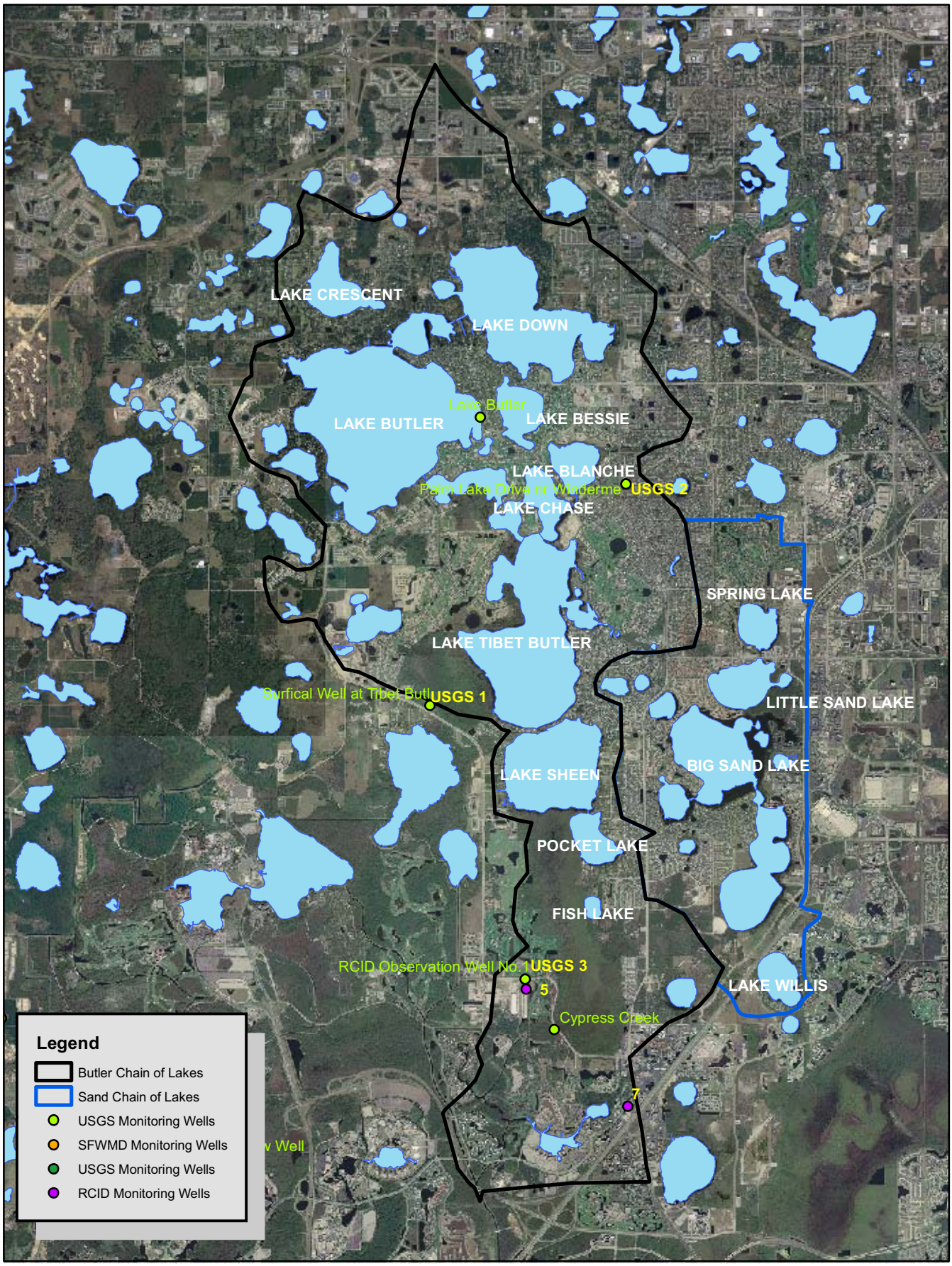

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Figure 2-12
Groundwater Monitoring Sites

Figure 2-13
USGS 1 Surficial Well at Tibet-Butler NR Windermere, Florida

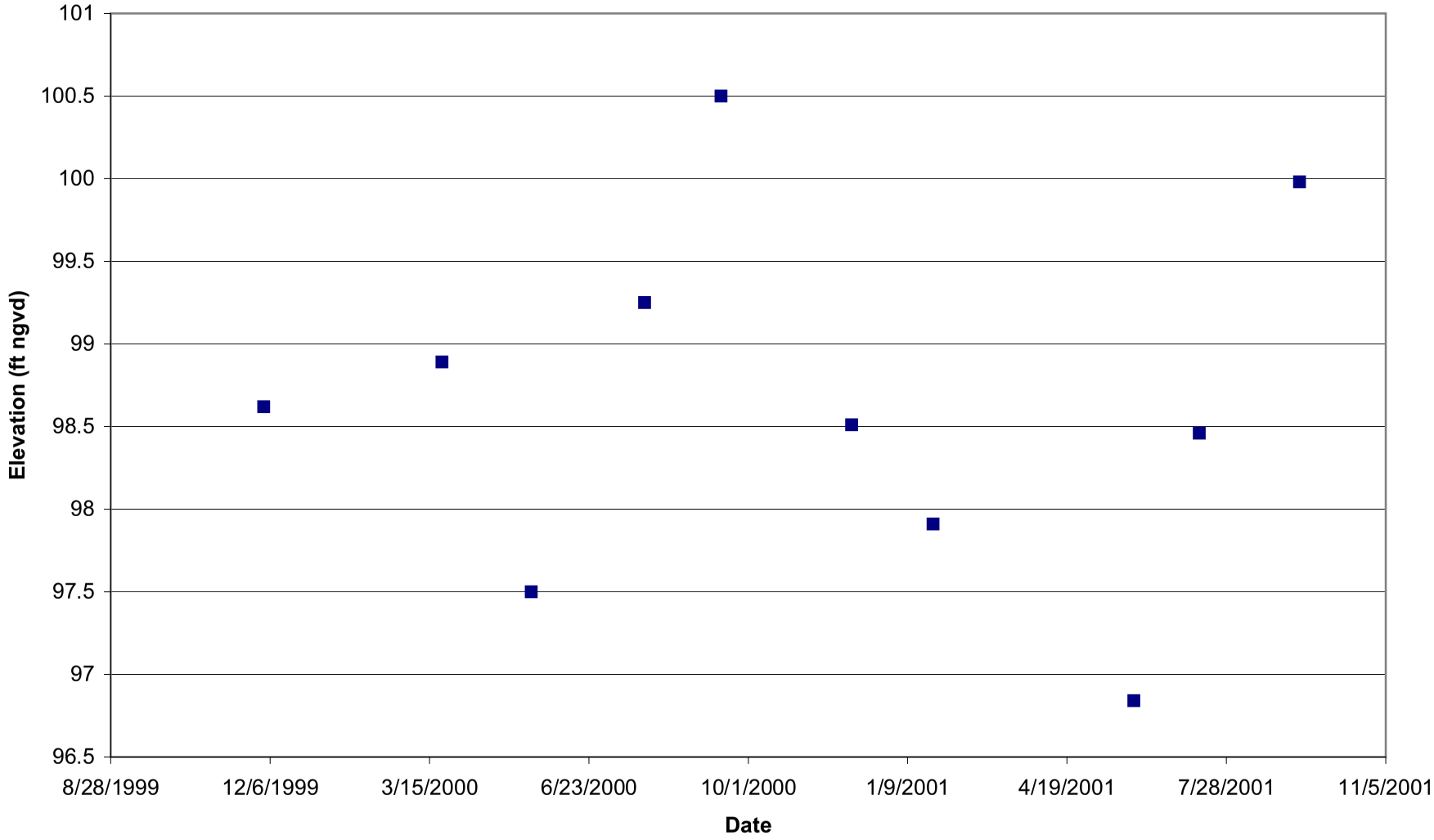
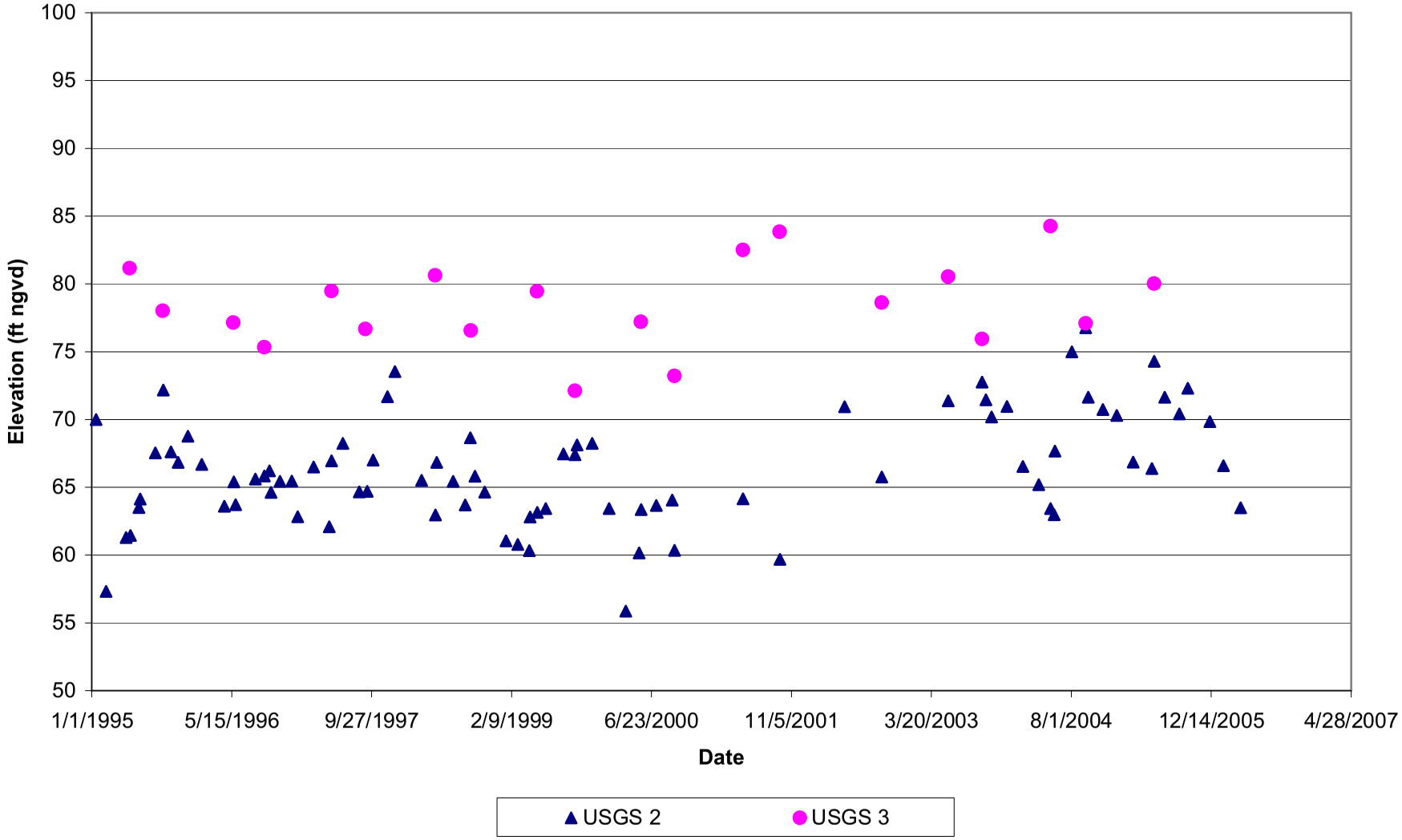


Figure 2-14
Piezeometric Head of the Upper Floridan Aquifer (USGS)



2.10 Reports and Articles

A number of reports and articles were collected which either discussed the areas specifically or treated the area in a more general manner.

- Adamski, J.C. and German E.R., 2004, *Hydrogeology and Quality of Ground Water in Orange County, Florida*, U.S. Geological Survey Water-Resources Investigations Report 03-4257.

- Angas, Robert M., 1946, *Hydrologic Study of Lake Butler Orange County Florida*, A study of the potential effects of placing a public water supply plant drawing from Lake Butler.

- Ardaman & Associates, Inc., 1989, *Final Report Lake Level Study Southwest Orange County – Contract No. 88-480-0875*, Prepared for South Florida Water Management District – Surface Water Management Division.

- Deevy, Edward S., *Estimation of Downward Leakage from Florida Lakes*, Journal of Limnology and Oceanography, 33(6, part1), 1988 page 1308 – 1320.

- EarthTech, May 2005, *Kissimmee Basin Hydrologic Assessment, Modeling and Operations Planning Project – Executive Summary and Task 1.3 – Problem Identification Report*: Prepared for South Florida Water Management District

- German, E. R. and Adamski, J.C.,2005, *Hydrology and Water Quality of Lakes and Streams in Orange County, Florida*, U.S. Geological Survey Scientific Investigations Report 2005-5052.

- McGurk, B. and Presley, P.F., 2002, *Simulation of the Effects of Groundwater Withdrawals on the Floridan Aquifer System in East Central Florida: Model Expansion and Revision*: St. Johns River Water Management District, Palatka, Florida Technical Publication SJ2002-3.

- Milly, P. C. D., 1994 *Climate, Soil Water Storage, and the Average Annual Water Balance*, American Geophysical Union Water Resources Research, Vol. 30, No.7, Pages 2143 – 2156, July 1994.

- O'Reilly Andrew M., *Hydrogeology and Simulation of the Effects of Reclaimed-Water Application in West Orange and Southeastern Lake Counties, Florida*, U.S. Geological Survey Water Resources Investigations Report 97-4199.

- Parsons Engineering Science, January 1998, *Draft Final Report Water Quality Model for the Butler Chain of Lakes*: Prepared for Orange County, Florida - Environmental Protection Division

- Smith, Patricia L., *Ecological Assessment Cypress Creek Swamp and the Butler Chain of Lakes Natural Water Level Fluctuations*, Prepared for Orange County Stormwater Management Division, May 27, 2006.

- Sumner, David M., *Evaporation at Reedy Lake, Reedy Creek Improvement District, Orange County, Florida*., Document dated October 24, 2005. U.S. Geological Survey.

- Swancar, A., Lee, T.M., 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.

- Smith, P.L., 2006, *Ecological Assessment Cypress Creek Swamp & The Butler Chain of Lakes Natural Water Level Fluctuations*: Prepared for Orange County Florida – Stormwater Management Division.

- Tibbals, C.H., 1990, *Hydrology of the Floridan Aquifer System in East-Central Florida*: U.S. Geological Survey Professional Paper1403-E.

- Various Authors, Historical Documents, primarily lake stage, rainfall and evaporation from 1936-1945, newspaper articles and copies of letters. All referring to the Lake Butler Area.

- Wolock, D. M. and Gregory J. McCabe, 1999, *Explaining Spatial Variability in Mean Annual Runoff in the Conterminous United States*, Journal of Climate Research Vol. 11 149-159, 1999.

These reports/articles all provide significant background or directly applicable discussion/documentation of various components of the hydrological system. These data provided a means to gain a more complete understanding of the system to be analyzed.

2.11 Groundwater / Surface Water Models

There are a number of modeling efforts completed for both chains of lakes as well as regional groundwater models.

2.11.1 Surface Water Models

Stormwater master plans have been developed for both Cypress Creek and Shingle Creek Basins. Cypress Creek Stormwater Master Plan was completed in 1996 by Singhofen and Associates (SAI). This effort included the development of an Advanced Interconnected Pond Routing (ICPR) model. The portion of Cypress Creek that was studied was essentially the entire Butler Chain of Lakes. It was modeled in relatively high resolution. Similarly, Dyer, Riddle, Mills and Precourt (DRMP) completed a Stormwater Master Plan, for Shingle Creek. The Sand Chain of Lakes is tributary to Shingle Creek. This master plan also included generation of an ICPR model. In the case of Shingle Creek, the Sand Chain of Lakes was a small component of the system

and was modeled relatively simply. CDM is currently in possession of both models and the reports. It is noted that both models have been upgraded to ICPR for Windows (version 3.0).

The Environmental Protection Agency's Stormwater Management Model (SWMM) was subsequently applied to both areas. In 1998, Parsons Engineering Science, Inc. converted the Cypress Creek ICPR model to SWMM version 4.31. This conversion was part of an effort to develop an overall finite element water quality model of the entire chain of lakes. CDM is currently in possession of both the SWMM model as well as the water quality model. In 2003, CDM conducted a lake level study of the Sand Chain of Lakes. This effort made some use of the existing ICPR model of Shingle Creek, but primarily relied on additional survey. This model has recently been updated to SWMM 5 (i.e. a Windows based version).

These surface water models will be useful in a number of ways. One could directly make use of the storage and connectivity described in these models to define the surface water system in another modeling exercise. In addition to this, one could make use of the storage defined for each of the lakes in the development of the water budget.

2.11.2 Groundwater Models

Similarly there has been a significant effort in characterizing and modeling the groundwater system. Tibbals (1990) modeled and documented a USGS MODFLOW model of the entire area of East Central Florida. The modeled area stretches from Flagler County in the northeast, to St. Lucie County in the southeast, to Glades County in the southwest, to Putnam County in the northwest. Only the report was obtained in this effort. The report discusses a generalized hydrogeology of the region. Additionally, this was a modeling effort to attempt to estimate the impacts on the Floridan Aquifer of the population increase in this region of Florida. This report is generally considered to have laid the groundwork for many subsequent modeling exercises.

The Central Florida area (i.e. the Greater Orlando area) is largely regulated by two water management districts (WMD): the South Florida Water Management District and the St. Johns River Water Management District. SJRWMD has developed a steady state MODFLOW model of this region. McGurk and Presley (2002) discuss the development of the SJRWMD's steady state model. Both the report and the model have been obtained.

Currently the SFWMD and the SJRWMD are engaged in a cooperative effort to develop a transient MODFLOW model of the Greater Orlando area. Discussions with SFWMD staff, who are currently calibrating this model, have indicated that the calibration is proceeding well. However, it was noted that there continues to be some work to be done on this model. Subsequent to finalizing the model, it will be necessary for SFWMD to document their work to produce the report.

There currently is a groundwater representation available for Central Florida. It is a steady state MODFLOW model. Although it is not a transient model, the information available in the model should be sufficient for use in this study.

The data available in these models will provide a published representation of the geometry and aquifer properties in the study area. Additionally, various abstractions will be defined in these model and be available for use.

2.11.3 Modeling Discussion

It would appear that there are sufficient data available to characterize the surface water system with possibly minimal verification/updating from survey or review of construction or as-built plans. It is noted that subsequent to the meeting to define the project goals both DISTRICT and COUNTY staff provided additional information regarding outfalls from the Lake Butler Chain of Lakes to the RCID. The main connection is the set of culverts located at the south end of Cypress Creek Swamp, the location of the USGS gauging station. There was empirical information supplied that indicated a culvert connection between Lake Tibet and Lake Mabel. This connection will need to be verified in the field or from "as-built" plans.

During the meeting to define the project goals it was noted that there is a natural weir, or scarp, located at the northern end of the Cypress Creek Swamp. Initially during the meeting, the elevation of the scarp was discussed. It thought that the elevation of the top of this scarp was approximately 99 feet National Geodetic Vertical Datum (NGVD). Naturally, it would be necessary for the stage of the water in the lakes to reach this elevation prior to any overland flow taking place. It was suggested that the Orange County Surveyor be dispatched to measure, specifically, the elevation. Subsequent to the meeting, COUNTY staff reviewed a number of sources including the available LiDAR topography, the Stormwater Master Plan for Cypress Creek and the 1989 Lake Level Study. These three sources are somewhat consistent in their reporting of the elevation of the scarp to be approximately 99.0 feet NGVD. For any hydrodynamic model that may be developed in a subsequent phase the LiDAR data will be used to generate a cross section to define this scarp.

2.12 Summary and Discussion

The data that has been collected has provided a good general understanding of the project area; especially with regards to the surface water stages and flows. However, it is noted that there is a significant deficit in Surficial Aquifer levels, which would improve the understanding of this system more fully. Much of the data collected is directly applicable to the development of the water budget.

Section 3
Annual Water Budget and Statistical Analysis

3.1 Introduction

One of the more significant reasons for this study is to attempt to quantify the contribution of the Surfical Aquifer System (SAS) to each of the lake systems. Additionally, if available data would support it, a statistical relationship that could be used to forecast lake levels would be developed. The study period was defined to be from 1995 to 2005.

Various means were used to achieve these ends, including application of an existing MODFLOW model, review and discussion of the Palmer Drought Severity Index, review of SAS monitoring data as obtained during the data collection stage, review of a recently obtained seepage study of the Butler Chain of Lakes, an investigation of the cross correlation between rainfall and lake level and the development of a water budget.

This introduction will provide a brief overview as to what was investigated. The subsequent subsections will elaborate on each of the components. The section will culminate with a conclusion and a recommendation section.

During the data collection period the St Johns River Water Management District (SJRWMD) MODFLOW model of East Central Florida was obtained. This is a steady state model of the average 1995 conditions which includes the study area. The lakes in the study area were modeled as constant head cells. The calibration period was simulated and the model derived estimates of the contribution of the SAS to these constant head cells and the recharge from these cells to the Upper Floridan Aquifer (UFA) are reported. These estimates of the UFA recharge to assist in the development of the water budget.

As the study area receives a significant amount of rainfall each year, > 50 inches, an appreciation of the drought condition for the study period was considered essential. There are a number of means to quantify the drought conditions; in many cases an index is developed. This report considers the Palmer Drought Severity Index and includes both a discussion of the index as well as a graphical representation of the regions drought condition over the study period.

In order to quantify the contribution of the SAS to the lake systems, it would be ideal if a large number of SAS monitoring wells were available covering much of the basin. During the data collection phase, only one SAS well was located. This well was located west of Lake Tibet-Butler, adjacent to SR535. The period of record for this well was during a moderate to severe drought period. It is interesting that during this period, the SAS level never dropped below the lake level.

South Florida Water Management District (SFWMD) and Orange County Environmental Protection Division (EPD) are currently funding a study to quantify the hydrological and nutrient balance for the Lake Butler Chain. A component of this study was a year long monitoring of the seepage into each of several lakes in the Butler Chain. These seepage values are reported and contrasted with various other estimates.

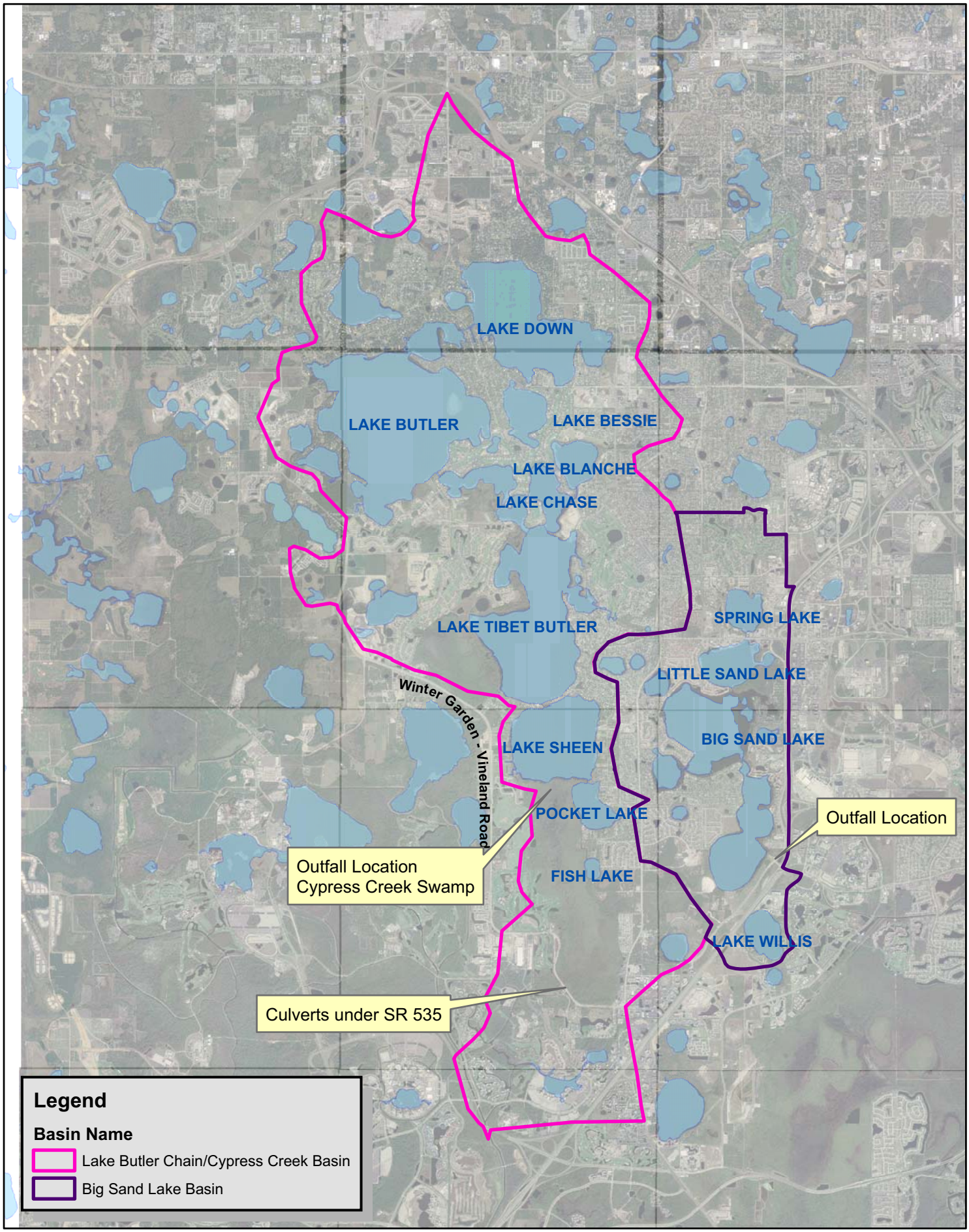
Previously, CDM developed a spreadsheet which compares time series and determine if there is a correlation between the data sets. It is possible to introduce temporal lag factors to either time series. For the period of 1970 to 2005 the time series of rainfall and Lake Butler level were compared. Regardless of the time lag, a very weak correlation was found between these two data sets.

The last major item included in this section was the development of a water budget for the Butler Chain, as a whole. A water budget was not developed for the Sand Lake Chain due to a lack of two specific data sets i.e. SAS water levels and a long term period of record which represents the majority of the lake levels. The water budget included estimates of rainfall, surface water inflow, SAS inflow, evaporation, surface water outflow and recharge to the UFA. As there were little measured data to quantify either SAS inflow or UFA recharge a balancing term was introduced. This balancing term includes net groundwater movement as well as potential sources of error in the development of the water budget.

3.2 Background

In general terms, these two lake systems are outfall limited. Both systems are presented in **Figure 3-1**. The outfall for the Sand Lake Chain is a series of culverts and open channels that drain from the southeast corner of Big Sand Lake into the Valencia Water Control District and hence to Shingle Creek. It is noted that the control elevation in the outfall system is 96.3 feet NGVD, contrast this with the normal high water level (NHWL) of 90.0. The Butler Chain of Lakes is somewhat less controlled. At the southern end of Lake Sheen, the outfall location from the system, it was noted that there is a "scarp" or natural weir running parallel to the southern shore line which is at a slightly higher elevation (i.e. approximately 99.0 feet NGVD). The water discharged from the lake must stage up to this elevation. Subsequently the water must traverse approximately 2 miles of wetland (Cypress Creek Swamp). There is a significant amount of storage and head loss through this system. The outfall for this system is ultimately a set of twin culverts (60 inch diameter) under SR535 which discharges into Reedy Creek Improvement District's (RCID) system, ultimately discharging into Reedy Creek.

It has been suggested that there is a significant flow from the groundwater component to the lake systems. As both these basins are located in a defined groundwater recharge zone for the Upper Floridan Aquifer (UFA), it seems unlikely that the UFA is the source of these waters. Thus the Surfical Aquifer System (SAS) may be the potential source. It is intuitive that the water table elevation would have to



CDM

N

1.5 0.75 0 1.5 Miles

Figure 3-1 - Study Area
Butler and Sand Chains of Lakes Reconnaissance Study
South Florida Water Management District

be higher than the lake level in order for SAS flow to the lake systems (i.e. Darcy's Law). Quantifying the periods of time when this occurs will likely prove to be the most difficult. As noted in the Data Collection Section, only very limited (both temporally and spatially) data were found defining the water levels in the SAS.

Both of these lake systems have been the source of recent general public complaints of nuisance flooding. It has been noted that the flooding has been associated with docks, landscaping and outbuildings.

The Big Sand Lake Advisory Board (BSLAB) has initiated the placement and operation of portable pumps to reduce the level of the Sand Lake system. BSLAB has operated pumps three times in the recent past: August 2003, February 2005 and August 2005. Additionally there has been some discussion with Orange County and the BSLAB regarding the construction of a permanent pump station.

3.3 Methodology

Various methodologies are used in Section 3.4 to review the collected data, these methods are described in detail in their appropriate subsection.

A monthly water budget was developed for the Lake Butler Chain for the period of 1995 to 2005. Lake water levels were used to estimate the change in lake storage for a specific period. This change in lake storage was compared to the difference between inputs (i.e. rainfall and surface runoff) and outputs (i.e. evaporation and surface outflow). A residual (balancing term) was introduced into the water budget to balance the equation. This is an inclusive error term. This term includes error and uncertainty in any of the estimates. In addition, this term also includes a net groundwater term (i.e. the difference between SAS inflow and UFA recharge).

The statistical analysis made use of a lagged cross correlation analysis of the rainfall and lakes stage data.

3.4 Data Summary

This section will discuss the data used in general and address several gaps in the data collected and documented in the previous deliverable. In general, this section will provide a number of estimates used subsequently in a comparison with values generated by the water budget analysis.

The SJRWMD's MODFLOW model was obtained and the 1995 average steady state condition period was simulated. The model results were queried and the model estimated SAS contribution and UFA recharge were reported.

The Palmer Drought Severity Index was reviewed. This index is a convenient way to estimate how the existing net rainfall (i.e. precipitation – evaporation) is related to a long term net rainfall average.

The single SAS monitoring well is reviewed and with comparisons to Lake Butler water levels. The monitoring period is during a severe drought in Central Florida, regardless, it can be seen that the SAS level typically greater than the lake level.

The study done for Orange County EPD is reviewed and the average seepage measured for the year 2005 is reported. This seepage is ultimately compared with the values generated by the MODFLOW model as well as the balance term in the water budget.

3.4.1 Groundwater Model

As noted in the data collection section, the steady state MODFLOW model, developed by the SJRWMD, was obtained. This model covers the entire project area.

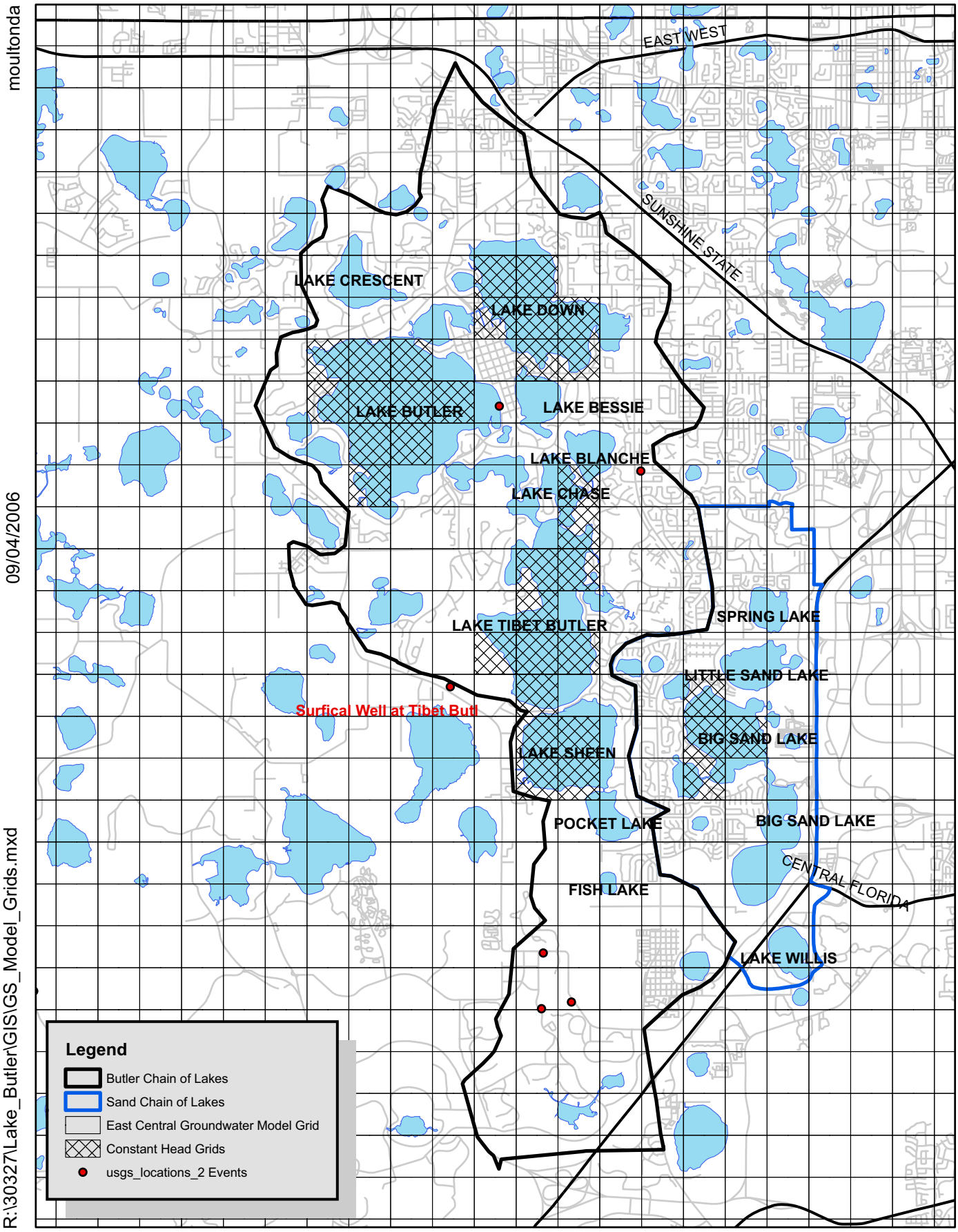
The model was provided both as input files for 88/96 MODFLOW version as well as a Groundwater Vistas input file. The model input files were imported into proprietary software called Groundwater Modeling System (GMS).

The model covers central Florida, from Polk County in the southwest to Volusia County in the northeast. The model is a steady state model calibrated to the average 1995 condition. The uniform grid spacing is 2500 feet. There are 4 layers in the model: the Surfical Aquifer System (Layer 1 - SAS), the upper portion of the Upper Floridan Aquifer (Layer 2 - UFA – all of the Ocala Formation and the uppermost part of the Avon Park Formation), the lower portion of the UFA (Layer 3 – dolostone zone within the Avon Park Formation) and the Lower Floridan Aquifer (Layer 4 - LFA). There are two confining layers represented as reduced leakance in Layer 1 (representing the Intermediate Confining Unit ICU) and reduced leakance in Layer 3 (representing the Middle Semi-Confining Unit).

In the project area, a subset of the lakes is represented as constant head boundary conditions; these cells are shown in **Figure 3-2**. There are a total of 35 cells that make up the majority of the project area lakes. It is noted that a portion of Lakes Butler, Down, Chase, Tibet-Butler, Sheen and Big Sand are represented. The defined constant heads range from 98.5 to 99.9 NGVD. Compared to typical water levels in the lakes, the model is low for the Butler Lakes (weight average normal water level = 100.1 feet NGVD) and high for the Sand Lakes (weighted average normal water level = 93.8 feet NGVD).

Using the GMS interface, a flow budget was developed for the constant head grid cells that make up the lakes representation. From this flow budget, the model estimated that the lateral inflow to these cells (representative of SAS flow into the lakes) was approximately 10.5 inches/year. The vertical recharge to the UFA was approximately 13.5 inches/year. It is noted that this value tends to be at the high end of the estimates provided in the District's GIS recharge coverages.

The simulated horizontal hydraulic conductivity of the SAS in the vicinity of the lakes is 20 feet/day. The Intermediate Confining Unit (ICU) is defined as having a leakage



Butler and Big Sand Chain of Lakes
Reconnaissance Study
South Florida Water Management District

CDM

1 inch equals 1.5 miles

N

Figure 3-2
Constant Head Cells Representing Project Lakes

of ranging from 1.3E-4 to 6.9E-5 feet/day/foot. These values were used, as described in Section 3.6.3 below, to estimate components of the water budget.

3.4.2 Palmer Drought Index

Drought, in varying degree, is a regular natural occurrence. It is the deficiency of net precipitation, relative to a long term average, over the course of a time period. (Net precipitation is the difference between precipitation and evapotranspiration (ET).) The effects of this departure from the long term average can be considered in the light of difference perspectives.

One method used to quantify the severity of a drought is an index. In this study the Palmer Drought Severity Index (PDSI) was considered. The PDSI is a hydrological drought index and is based upon the supply and demand concept of the water budget. It is calculated based upon precipitation and temperature data as well as the local water content of the soil. When developing this index, Palmer took into account the duration of the drought. This was to reduce the effect an abnormally wet month, in the midst of a long term drought, would have on the index. The range of values and description for the PDSI are presented in **Table 3-1**.

Table 3-1 Palmer Drought Severity Index

Palmer Classification	
Index Value	**Description**
>4.0	extremely wet
3.00 to 3.99	very wet
2.00 to 2.99	moderately wet
1.00 to 1.99	slightly wet
0.50 to 0.99	incipient wet spell
0.49 to -0.49	near normal
-0.50 to -0.99	incipient dry spell
-1.00 to -1.99	mild drought
-2.00 to -2.99	moderate drought
-3.00 to -3.99	severe drought
< -4.00	extreme drought

The PDSI, as calculated by the National Oceanic and Atmospheric Administration (NOAA) for Central Florida is presented in **Figure 3-3**. It is noted that during the period of 1995 to 2005 Central Florida has been in a number of droughts, the most severe being the period of April 1998 to July 2001. During this period the average PDSI was -3.58 which is defined as a severe drought. It was during this drought that the water levels were collected at the SAS monitoring well whose water levels are shown on **Figure 3-4**. The trend of water levels and the PDSI seem to be consistent.

Figure 3-3
Palmer Drought Index vs. Lake Butler Stage

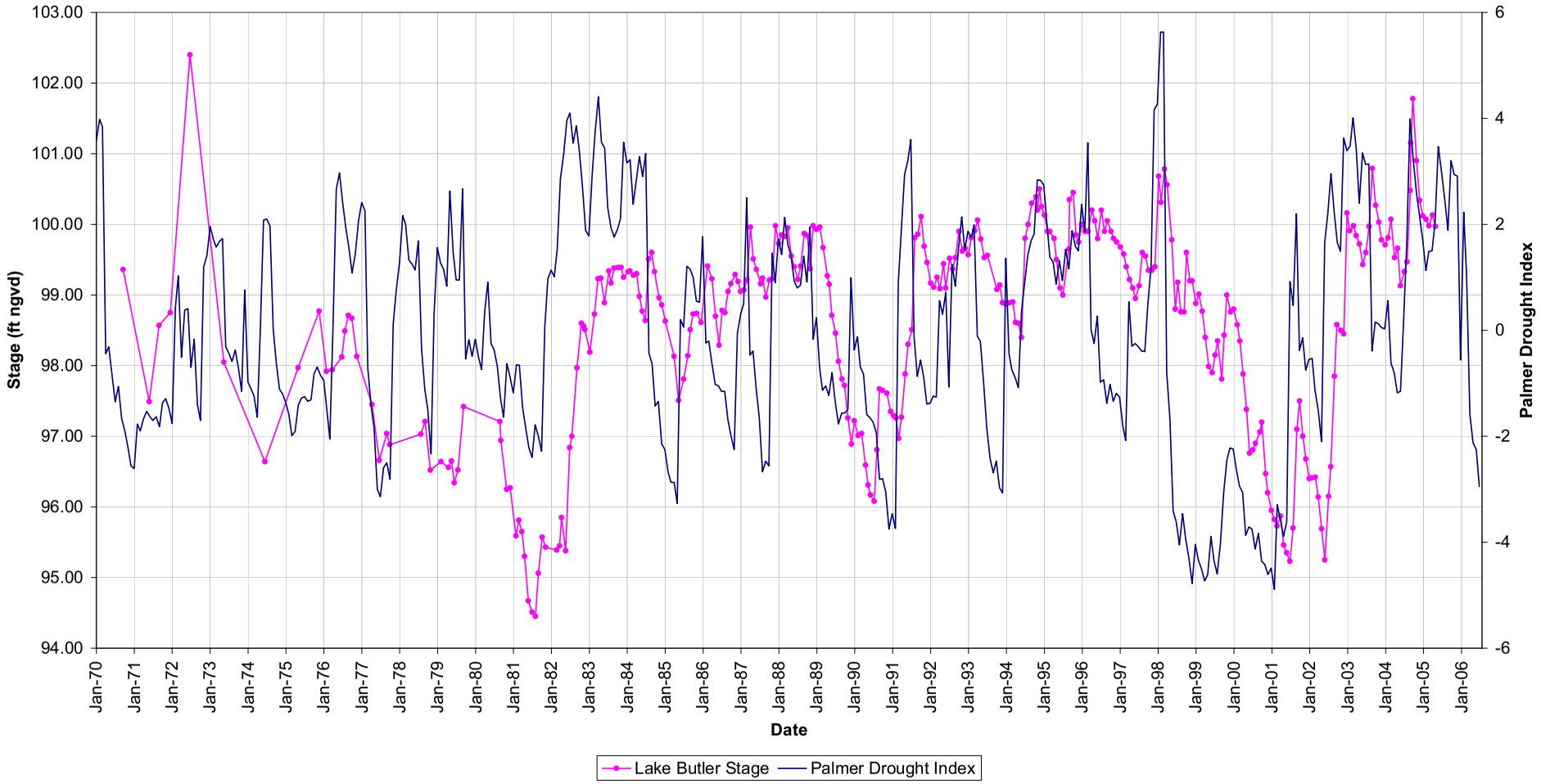


Figure 3-4
SAS Levels Compared with Lake Butler
West of Lake Tibet-Butler

3.4.3 SAS Water level Data

During the data collection phase, only a single SAS well was identified within the study area. Its location, shown on Figure 3-2, is immediately to the west of Lake Tibet-Butler in a conservation/wetland area. The time series groundwater level data from this well is shown on Figure 3-4. The time series runs from December 1999 to September 2001. The time series of Lake Butler water levels is also plotted on Figure 3-4.

The period of record for the SAS well spans the most severe drought in the period 1995 to 2005. Referring to Figure 3-4, one can see that the most extreme drought in this period occured in February of 2001 (PDSI = -4.89), this was after approximately one year of drought. Figure 3-4 indicates that at that point in time, the SAS level was approximately 2 feet higher than the stage in Lake Butler. This would suggest that even during a severe drought the SAS may not drop below the lake level. This indicates that the SAS groundwater system is probably closely controlled by the lake levels, and there is sufficient net recharge even during severe drought to keep the water table at or above the lake level.

3.4.6 Additional Studies

Subsequent to the data collection phase of this project, it was determined that Orange County's Environmental Protection Department (EPD) had contracted with Environmental Research and Design, Inc (ERD) to develop a hydrologic and nutrient budget for the lakes. A draft copy of *Butler Chain of Lakes Hydrologic/Nutrient Budgets and Management Plan* (July 2006) was obtained from EPD and reviewed.

As a component of this study, ERD installed 64 seepage meters within the Butler Chain of Lakes during February of 2004. These meters were monitored monthly for a year (December 2004 to December 2005) and have provided a number of seepage readings from several locations within the lakes, including the shoreline and mid-lake spots. The monitored period had an average PDSI of 2.3 or "moderately wet" conditions, as seen on Table 3-1.

The measured seepage rates indicate that in general the flow is varied both by lake as well as by location on a specific lake. Lake Butler, for example, varies from a low average rate of 1.04 to a high average rate of 9.43 liters/m^2 – day. In contrast, Wauseon Bay varies from a low average rate of 0.29 to a high average rate of 1.02 liters/m^2 – day.

One can see that the seepage inflows in several lakes: Fish, Louise and Pocket are quite significant i.e. approximately 40 percent of the annual rainfall depth. The seepage in the remaining lakes is also significant, although not quite as high.

Table 3-2 documents the estimated annual seepage within the Butler Chain. The values are reported as annual volumes per year per lake. The sum of these average annual volumes will give an estimate of the seepage for the year. This sum is 6,252.5

acre-feet/year. Based upon a lake area of 5,775 acres, this equates to a seepage inflow of approximately 13 inches per year.

It is noted that this study indicates that there is seepage flow into the lakes continually throughout the year. These data are included as **Attachment 1**.

Table 3-2 – Measured Seepage into Lakes of the Butler Chain

Lake	Surface Area (ac)	Annual Seepage Inflow (ac-ft/yr)	Annual Depth Increase (inches)
Blanche	129.6	116.2	11
Butler	1614	2220.5	17
Chase	145.8	130.8	11
Down	930	1066.7	14
Fish	25.8	46.4	22
Isleworth	48.6	43.6	11
Louise	124.5	213.7	21
Pocket	126.4	215.4	20
Sheen	582	765.6	16
Tibet	1190	1322.8	13
Wauseon Bay	123.5	110.8	11
Weighted Average	**458.2**	**1329.4**	**15**

3.5 Statistical Relationship

A component of this study was to determine if it would be possible to develop an "alert model" i.e. a relatively simple statistical relationship between one or more hydrological inputs that could be used to forecast lake levels. During the meeting to define project goals and success factors, an item that was considered significant to all was the groundwater inflow seepage component of the water budget. It was also postulated that it would be necessary to include some representation of the SAS water levels in this type of relationship.

During the data collection, it became apparent that there were very few data associated with SAS water levels in the project area. There was only one SAS monitoring well found: USGS 282631081323301, was in the Butler Chain, immediately west of Lake Tibet-Butler. This well has a relatively short period of record, December 1999 to September 2001. It is noted that this period has an average PDSI of -3.0, which falls into the "severe drought" category.

In order to attempt to define a statistical relationship describing this system, a cross correlation between rainfall and lake stage was developed. This was an attempt to determine how strongly correlated the lake stage was with rainfall. A cross correlation spreadsheet was developed by CDM and it included a means for the introduction of a

time lag factors. It was thought that if there was a strong correlation between rainfall and the lake stage, it would subsequently be possible to define a best fit line to estimate the lake stage based upon precipitation inputs. While not including a SAS component would at least provide a somewhat reasonable means to forecast the lake water levels.

The two parameters correlated were the lake levels of Lake Butler (measured at various intervals – ranging from daily to monthly) and the Orlando International Airport (OIA) daily rainfall records. The OIA rainfall record was used as there was a long period of record. The analysis attempted to find a correlation between these two data sets from 01/01/1970 to the present.

It was determined that regardless of the time lag introduced there was very poor correlation between rainfall and lake levels. There could be a number of reasons that, essentially, no relationship was found between these two measured values. For example, due to the spatial variability of rainfall, the OIA dataset may not be sufficiently local, the level of the lake might be such that a significant volume is being discharged during the period reviewed thus altering the lake water level, and/or the contribution of the SAS may be more significant.

Thus, at this point in time, it appears that the development of a statistical relationship to forecast lake levels based upon the available data and rainfall input is not possible.

3.6 Annual Water Budget

In order to gain an improved understanding of the hydrologic factors controlling lake levels an annual water budget scheme was developed and used to perform numerical quantitative evaluation of the lake system. The control volume was the Butler Chain of Lakes including the following lakes: Fish, Fish, Lost Cove , Bessie, Blanche, Brenda, Buena Vista, Burden, Butler, Chase, Crescent, Down, Estes, Isleworth, Louise, Mitzi, Rhea, Ruby, Sheen, Story, Tibet-Butler, Valerian, and William Davis.

The control volume is the lake system, to the edge of land. As this surface area varies as water level changes, a simplification used was to keep a constant surface area. It is also assumed that all of the lakes surface areas, within the basin were lumped together. It is also noted that there are some components of the water budget, the surface runoff for example, that is a function of the tributary area. The tributary area is defined as the overall basin as defined by County.

In its simplest form, a water budget has three components and can be described as $\Delta S = Q_{in} - Q_{out}$ or as $Q_{in} - Q_{out} - \Delta S = 0$. Where ΔS represents the change in storage, Q_{in} represents the water entering the control volume and Q_{out} represents the water leaving the control volume. In addition to those three terms, there is another, RES or residual that can be defined for unknown components. Thus the equation can be written: $Q_{in} - Q_{out} - \Delta S = RES$ where RES (the residual or a balance term) are any of those unknown components which cannot be accurately quantified.

In the case of this water budget, the RES term represents all unknown/uncertainty. It was hoped that this term would essentially be a "net groundwater" term. However, in considering the overall system, it is felt there are other components that are not fully understood /quantified. For example, the assumption was made that the flow measured at SR 535 would represent the surface water outflow from the lake control volume. However, once flow is being measured at SR535, it implies certain storage in the Cypress Creek Swamp has been satisfied. It is conceivable, for example, that there are periods in which water is leaving the lake system, into the Cypress Creek Swamp but has not yet begun to discharge.

It is possible to rewrite the equation with more specific terms and provide a discussion of these points.

$$\Delta S_L = \left(P + GW_{in} + SW_{ro}\right) - \left(ET + GW_{out} + SW_{out}\right) \text{ - RES}$$

Where: ΔS_L = the change in lake storage in inches
P = the precipitation input in inches
GW_{in} = the contribution of the SAS input in inches
SW_{ro} = the basin surface water runoff input in inches
ET = the evaporation/evapotranspiration output in inches
GW_{out} = the recharge to the UFA output in inches
SW_{out} = the surface water discharge to the receiving water output in inches
RES = an error term in inches

Each of these components will be considered in turn.

There are some components of the water budget that occur outside of the control volume, for example the surface water outflow (strictly a flow rate) or the stormwater runoff from the tributary basin (a volume or depth over the land area). In these cases, the calculated volume will be normalized over the lake area, converting the calculated volume to a depth over the lake area.

3.6.1 Lake Storage

This parameter can be quantified by the water level time series for each lake system and the stage/area definition defined in the surface water models collected. The lake storage is assumed to be equal to the change in depth of the lakes water surface elevation over the period of interest i.e. monthly. The surface area of the lake system is also evaluated as constant, i.e. 5775 acres.

Due to the lack of lake level readings available for each individual lake, it is necessary to make assumptions regarding the tendency for the lake levels to equalize out over the system. There are two lakes monitored in each system, one typically long term the other has recently been established.

In the Butler Chain of Lakes, Lake Butler has been monitored for a significant period of time (at least from the early 1970s). In July 2002 Orange County Stormwater Management Division (OCSMD) installed a gauge in Lake Sheen.

Figure 3-5 presents a plot of the elevations reported in both lakes for the common period. A review of these data indicates that the assumption of water levels equalizing appears to hold true. There is a period in October of 2004 in which the levels in Lake Sheen are significantly below the levels reported in Lake Butler however this is very close to the period in which Hurricane Jeanne passed through and there may have been some impacts to this gauge. Overall, one could make the assumption that the levels tend to equalize over the system. It is noted that there are several smaller lakes, Rhea for example, that are isolated from the main chain, these lakes will not have a similar stage, however it is assumed that the response will be similar to the main chain.

In the Sand Lake Chain both Spring Lake and Big Sand Lake are being monitored. Spring Lake has been monitored for a significant period of time (this gauge was established in 1989) and recently OCSMD has also been monitoring the levels in Big Sand Lake. This latter monitoring of Big Sand Lake has been due to public complaint regarding the lake level. The water level in Big Sand Lake has been monitored since 01/28/2003.

Figure 3-6 presents a comparison of the stages in Spring Lake and Big Sand Lake for the common period. Unlike the Butler Chain Lakes, it appears that the assumption of equalization doesn't hold true. Spring Lake is separated from Big Sand Lake by the following: an outfall weir upstream of culvert crossings under Sand Lake Road, the aforementioned culvert crossings and at the downstream side of Little Sand Lake, there was for a significant period of time, a wall/weir. Thus, both Spring and Little Sand Lake are held up at higher elevations that Big Sand Lake. There are periods when pumping has proceeded in Big Sand Lake, and one can see the effects in the time series, however this action is not sufficient to produce the major differences between the two lake systems. Due to the lack of a period of record of lake levels for the entire study period, a water budget was not developed for the Sand Lake Chain.

Figure 3-5
Lake Levels in Study Area

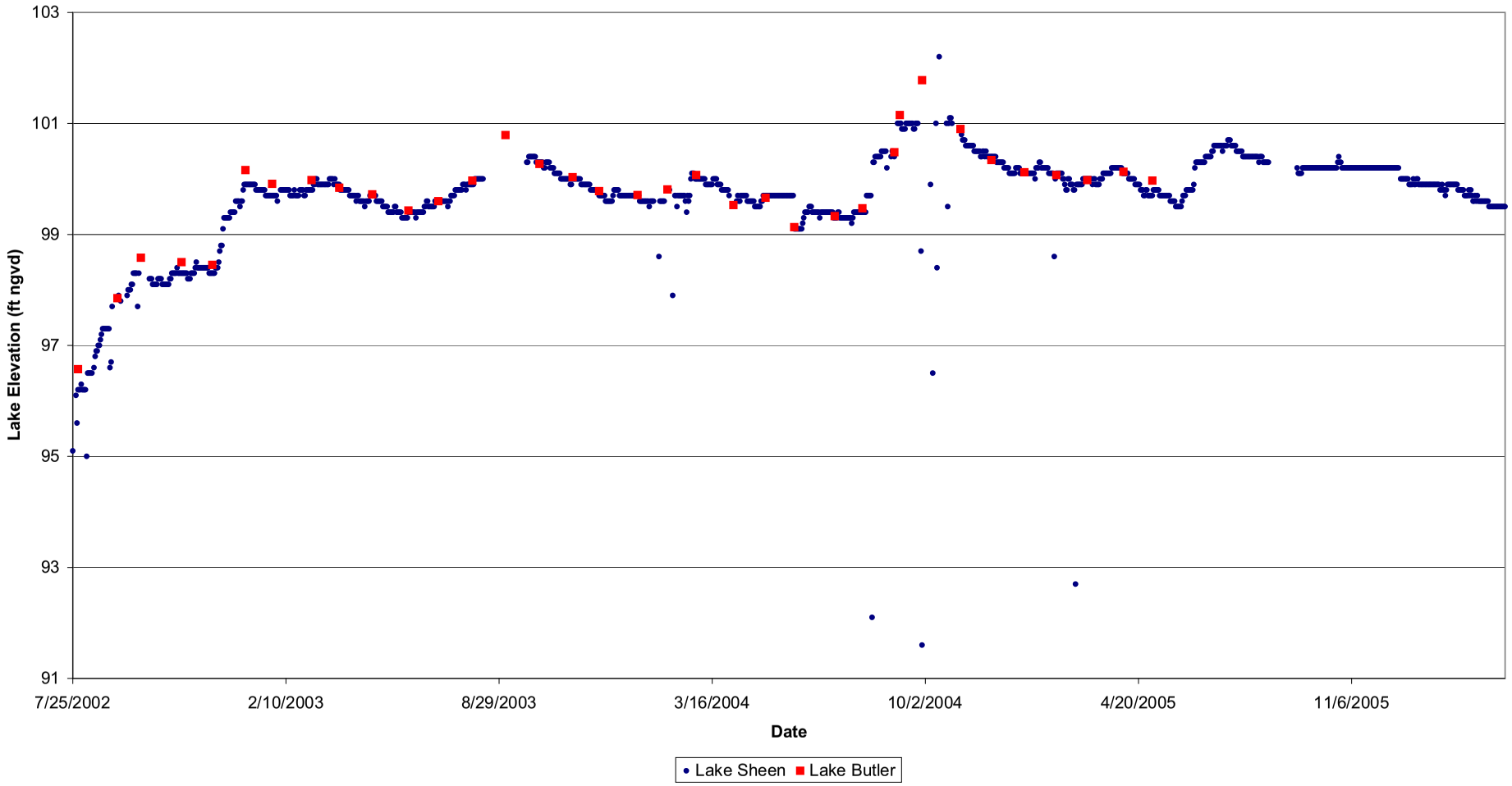
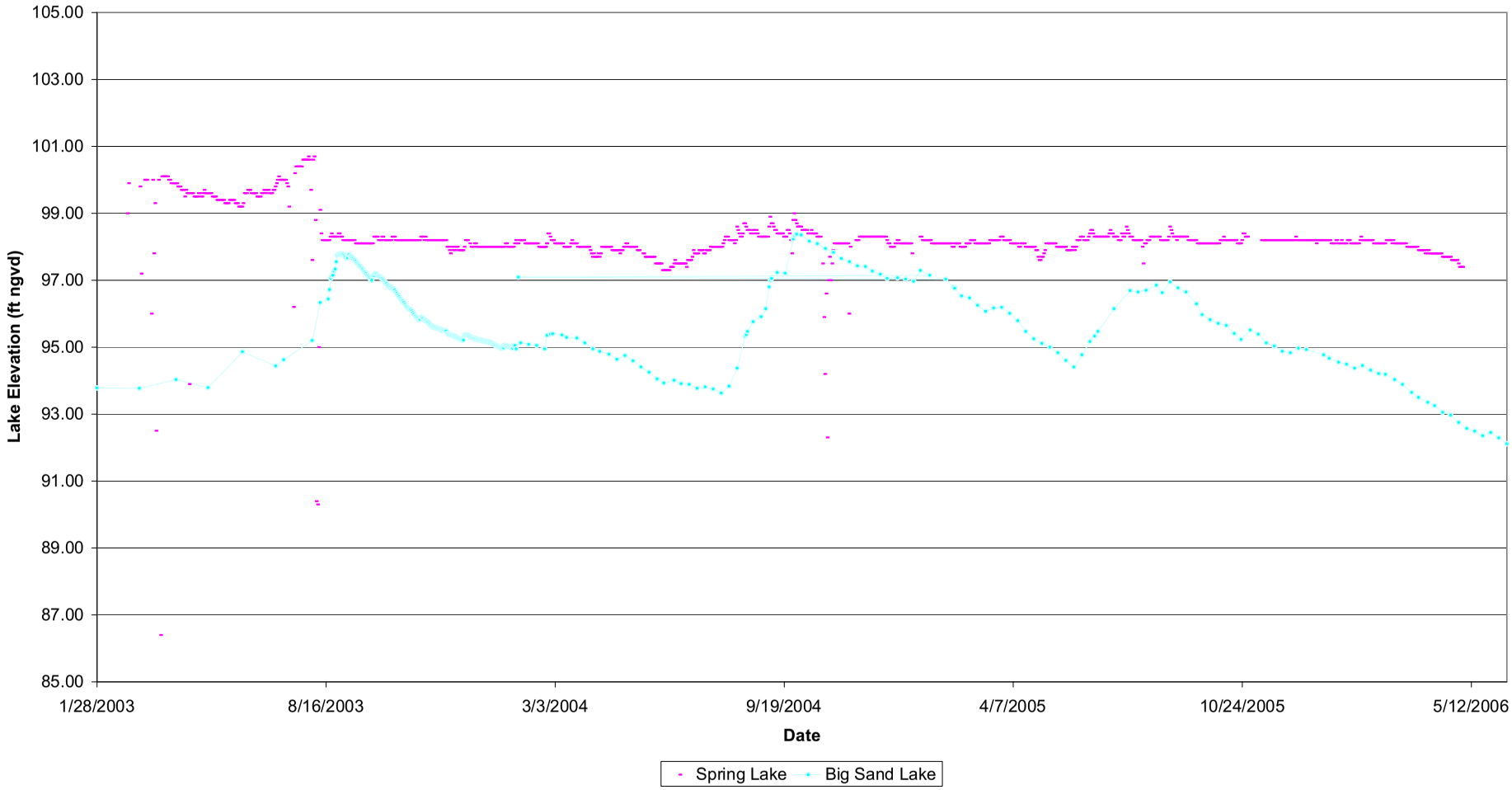


Figure 3-6
Lake Levels Comparison of Spring Lake and Big Sand Lake



3.6.2 Precipitation

This is the largest component of flow into the system. OCSMD has monitored the rainfall in both these basins for a significant length of time. Rainfall data was obtained from OCSMD for many rainfall gauges including, but not limited to, Spring Lake and Lake Sheen. Due to the period of record for Spring Lake and its central location, these data was used to define the contribution from rainfall. For those periods of time in which the Spring Lake gauge was out of service, rainfall from Orlando International Airport was used to gap fill.

3.6.3 Groundwater Contribution from the SAS

During the project goals meeting, OCSMD staff indicated that this was the component of water budget that County is most interested in defining. It was noted in the Data Collection Section that the groundwater model was obtained. This model does not provide a dynamic estimation of the contribution of the SAS to the water budget of the lakes i.e. flow varying as a function of temporally varying lake water levels. The groundwater model gives a steady state estimate of the SAS flow for 1995 conditions. This estimate is based upon a constant lake level defining the effects of the lake.

The volume of water that enters the lakes will be a function of the horizontal hydraulic conductivity, the thickness of the SAS, the driving head in the SAS, the length from the basin divide to the lake and the perimeter of the lake or lakes the flow is entering. One may estimate the contribution of the SAS to the lakes water budget by an application of Darcy's Law:

$$Qi = -Kb\frac{dh}{dl}W$$

Where: Qi = discharge in cubic feet per day

Kb = the transmissivity of the SAS (negative sign indicates flow is in the direction of decreasing head) in square feet per day

dh/dl = the hydraulic gradient in foot per foot

W = the perimeter of the lake system in feet

As noted in the SAS/Palmer Drought Index sections, February of 2001 is a period of extreme drought. During this period, the SAS was approximately 2.0 feet above the lake level. It is expected that this would represent the low flow condition. Thus if one was to estimate the distance from the basin divide to the lakes edge is approximately 1 mile; this would results in hydraulic gradient of 3.8E-4. Using the hydraulic conductivity from the East Central Florida MODFLOW model of 20 feet/day, an average value of the SAS of 50 feet and the perimeter of the lake system (361,253 ft – measured in Arcmap GIS) this would result in a discharge of 3.1 ac-ft per day or 2.4 inches per year. This is the potential volume that could discharge into the lake.

However, there are no temporal variations to either the lake or SAS levels associated with this annual volume.

3.6.4 Surface Water Runoff

Another significant component will be the runoff from the lake system's contributing basin. Infiltration will take up a component of the rainfall reducing the overall flow. The component of the rainfall that does not runoff will fill the available soil storage. This storage will satisfy ET requirements, interflow to surface water features or percolate through the Intermediate Confining Unit (ICU) to the UFA.

A weighted runoff coefficient was calculated for the tributary area based upon published percent impervious values for land use and a pervious runoff coefficient of 0.05 and 0.70 for pervious and impervious respectively. This results in a runoff coefficient of 0.15 for the Butler Chain of Lakes.

3.6.5 Evaporation and Transpiration

The United States Geological Society (USGS) has monitored evaporation at a nearby lake (Reedy Lake) for a several years. These data were collected previously. A comparison of the measured evaporation is made with the calculation of potential evapotranspiration (PET) presented in Smajstrla et al. This comparison is shown in **Figure 3-7**.

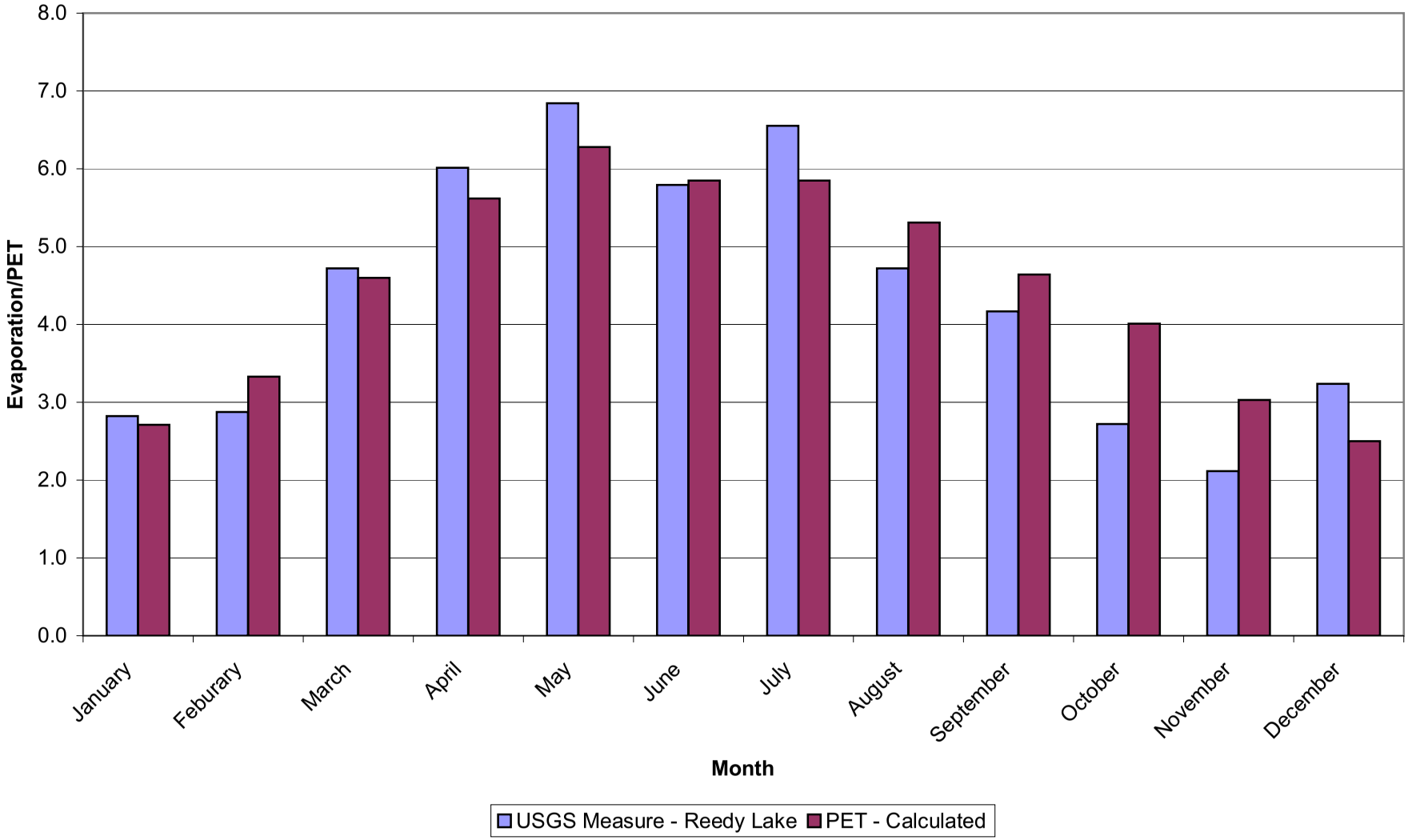
In general, one can see that the measured evaporation compares favorably with the calculated PET. There is some monthly variation, the largest being in October. It must be born in mind that the measured data was collected for approximately 4 years (11/28/2001 to 10/13/2005); contrast with the calculated PET which made use of 25 years of hourly weather data (1952 – 1976). If one compares the annual totals they are within 2 percent of each other; measured evaporation 52.6 inches, calculated PET 53.7 inches.

For the period in which it is available, the measured evaporation will be used. For non monitored times, the calculated PET will be used to estimate the evaporation from the system.

3.6.6 Recharge to the Upper Floridan Aquifer

This area is regarded as one of the more significant recharge areas to the Upper Floridan Aquifer (UFA). As noted in the Data Collection Section, the annual recharge rate varies spatially across study area from 0 to >12 inches per year. It is noted that these values encompass the full range that the Water Management Districts (WMD) have defined for recharge. This full range of potential values indicates that there is likely a significant amount of variation in either the vertical hydraulic conductivity of the Intermediate Confining Unit (ICU) or a significant variation in the driving head i.e. the difference between the water table elevation and the UFA potentiometric surface.

Figure 3-7
Comparision of Measured Evaporation and Calculated PET



Typically one would expect recharge from the lake system to the UFA to be through the bottom of the lake system or into a karst feature, such as sinkholes.

This value can be calculated with the information contained in the SJRWMD's East-Central MODFLOW model. As mentioned in Section 3.2.3, a water budget was estimated based upon the 1995 existing conditions steady state model. This flow budget estimated the recharge, to be approximately 0.44 ac-ft per day per cell. This is equivalent to a recharge value of approximately 0.04 inches per day or approximately 14.6 inches/year. It is reiterated that the model is calibrated to average 1995 conditions, based upon figure 4-3, the average PDSI for Central Florida was approximately 1.5 or "slightly wet". One would expect the recharge to be slightly greater than normal.

3.6.7 Surface Water Discharge

In the Butler Chain of Lakes the ultimate outfall of the lake system is out of the southern edge of Lake Sheen, through the Cypress Creek Swamp, ultimately discharging through twin 60 inch reinforced concrete pipes (RCPs), under SR 535, into Reedy Creek Improvement District (RCID). The United States Geological Survey (USGS) maintains a stage/flow recorder at this location. It is convenient to assume that this represents the outflow from the lake system, it is noted that there is significant amount of storage contained in the Cypress Creek Swamp, thus there is the potential for a significant amount of uncertainty with this term.

During the period of approximately February 2003 to February 2005, SR 535 was widened. The recording of stages and flows was suspended until the widening was complete. Thus there are no flow data during this period. As the flow data is used to calculate the surface water outflow volume, this lack of data results in a significant deficit in these data. It was during this period that Hurricanes Charley, Jeanne and Francis hit and these storms resulted in a significant amount of public notice due to the resultant lake levels. Thus the lack of flow records during this time significantly impacted the calculation of the water budget.

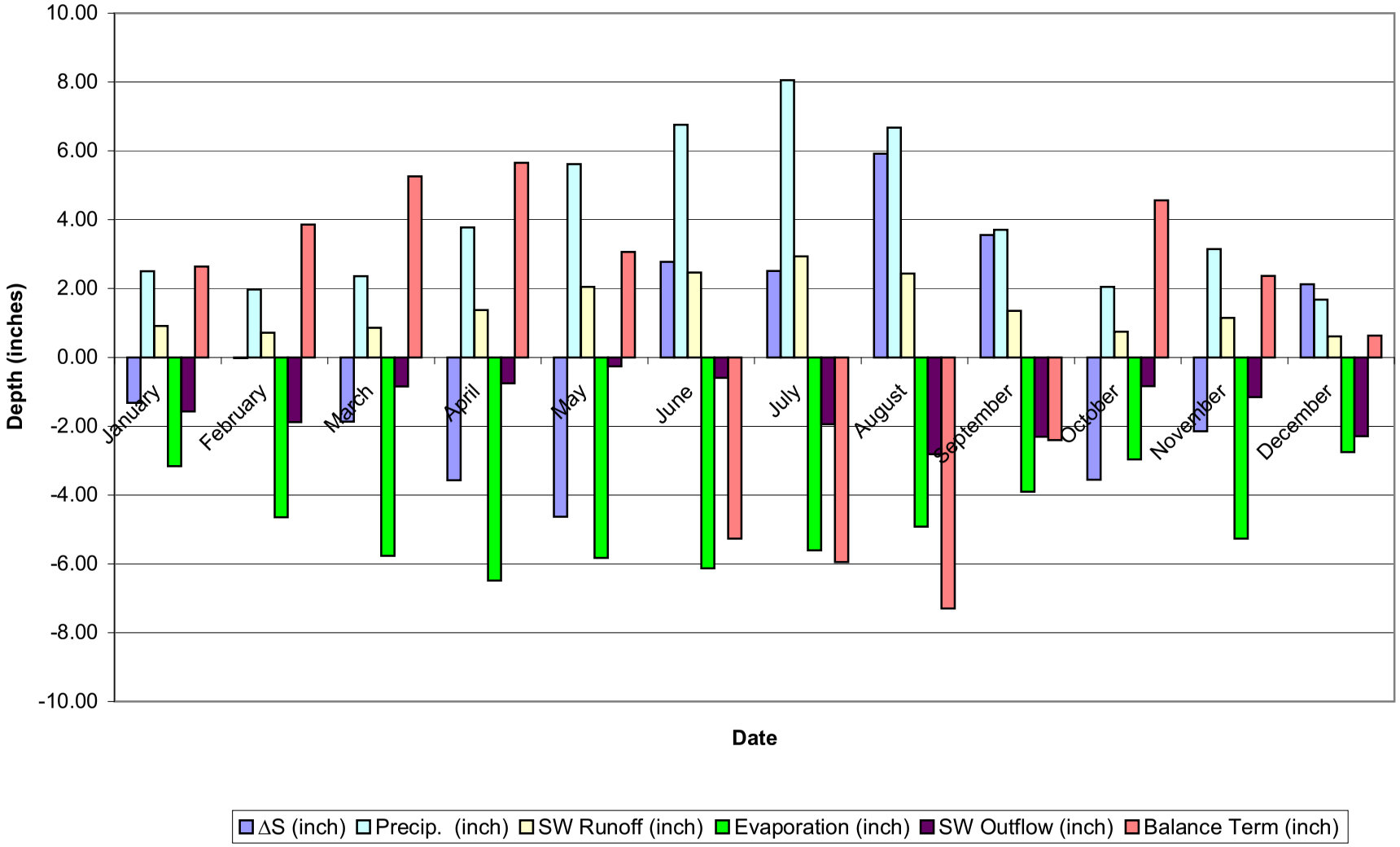
It was noted that USGS also maintains a flow recorder immediately downstream of SR 535, at RCID's structure S-103A. These data were downloaded, there was a period of overlap of several months at the beginning of the flow record (between SR 535 and S-103A recorders) and the average difference between each record was approximately 0.4 cfs. The flow records at S-103A were used to gap fill the SR 535 period of record.

The flow data is converted to an equivalent volume and is normalized over the lake area as a depth in inches.

3.6.8 Residual Term

The residual term is a "balance term" for all those parameters that one doesn't have measured data to support. In this application this would include SAS inflow into the

Figure 3-8
Lake Butler - Water Budget Components
Average Conditions



lake system, recharge from the lakes to the UFA and other less well defined sources of error. These other sources of error need to be considered and are discussed below.

The control volume is the lake area of the Butler Chain of Lakes. It was expected that surface water outflow could be quantified by the flow readings at SR 535. Largely this is correct, however it is noted that there may be times when there is discharge being measured at the meter when Lake Sheen is below the control elevation (i.e. 99.0 NGVD). This flow could be attributed to local runoff from the Cypress Creek Swamp; obviously then, not the flow out of the lake system. If one considers the results of the water budget, it can be seen that there are a number of periods in which the stage of the representative lake is less than the overflow elevation. In general, it appears that the expectation of flow at SR 535 when the lake is discharging is essentially correct.

Another potential source of error concerns the resolution of the rainfall. The rainfall is used with the land area and the runoff coefficient to calculate the surface water runoff. If an actual time series was used, rather than the monthly total, it is possible that there would be significantly less runoff generated. It is possible that the incremental rainfall intensity might be less than the infiltration rate.

The evaporation is also applied as a constant monthly term, based either on the measured evaporation or the calculated evapotranspiration. Similar to the temporal effects of rainfall intensity on the generation of runoff, one could make the same argument for evaporation; this term may be reduced if one considers the daily or hourly rainfall. Specifically, evaporation will be reduced if it is raining.

3.7 Results

The average values of the water budget components for the 10 year period (1995 to 2005 are presented as **Figure 3-8**.The water budget bar charts for each year are provided in **Appendix B**.

As noted previously, a good portion of the study period was defined by the PDSI as a drought, varying from Severe to Extreme. This is evidenced by the lower than normal rainfall totals. The total balance term sums to approximately 7 inches.

In general, one can see that the balance term tends to vary seasonally, with the shifting from a net positive term during the dryer winter months to a net loss of water from the lakes during the wetter summer months.

Table 3-3 – Average Annual Water Budget Component Terms

Month	ΔS (inches)	Precipitation (inches)	SW Runoff (inches)	Evaporation (inches)	SW Outflow (inches)	Balance Term (inches)
January	-1.32	2.51	0.91	-3.16	-1.57	2.64
February	-0.02	1.97	0.72	-4.64	-1.88	3.86
March	-1.87	2.36	0.86	-5.76	-0.85	5.26
April	-3.57	3.78	1.38	-6.48	-0.76	5.65
May	-4.63	5.61	2.05	-5.83	-0.26	3.06
June	2.77	6.76	2.47	-6.13	-0.60	-5.27
July	2.51	8.05	2.94	-5.61	-1.94	-5.95
August	5.92	6.67	2.43	-4.92	-2.81	-7.30
September	3.56	3.71	1.35	-3.91	-2.31	-2.41
October	-3.55	2.05	0.75	-2.97	-0.84	4.56
November	-2.15	3.15	1.15	-5.27	-1.16	2.37
December	2.13	1.68	0.61	-2.75	-2.29	0.63
Totals	**-0.23**	**48.29**	**17.61**	**-57.42**	**-17.27**	**7.12**

During the course of this study three estimates of groundwater seepage for the Butler Chain were located: SJRWMD's East Central Florida MOD-FLOW model, ERD's seepage monitoring and the conclusion of the water budget. These three values are summarized in **Table 3-4** and commented upon. It is noted that the balance term calculated in this study encompasses error / uncertainty terms as well as a net groundwater flow.

The orders of magnitude of these three estimates are somewhat consistent. If one considers the drought condition, it appears that as the precipitation increases beyond normal (as quantified by the PDSI condition) the seepage flow increases. This explains the difference between the water balance modeling result, representing drought conditions, and the other models' seepage estimates, which are for wetter conditions. All of the estimates are within a factor of 2, which is readily explained by climatic variability.

Table 3-4 – Summary of Seepage Values

Source	Seepage	Units	Comments
SJRWMD's ECF MODFLOW	10.5	inches/year	Model calibrated to 1995 conditions - slightly wet conditions
ERD's Seepage Study	13	inches/2005	Measured specific year - moderately wet conditions
West OC Water Budget	7.1	inches/year	Water budget spans 10 years - near normal conditions

3.8 Conclusions

A monthly water budget was developed for the Lake Butler Chain of Lakes for the period of 1995 to 2005. One of the key water budget components of interest was the contribution of the SAS to the lake system. Due to a lack of SAS, i.e. monitoring well, levels, a residual term was introduced into the water budget. This residual term was, while encompassing a number of sources of uncertainty, primarily intended to be a net groundwater term. This average positive residual term was compared with two other estimates. Given the drought condition, all seepage terms appear to be very consistent, varying within a factor of 2, which is readily explained based on normal climatic variations of such a magnitude.

It is noted that there is a near complete absence of SAS level readings in both basins. This is a critical gap in the available data. ERD was able to physically measure the seepage but there appears to have been no measurements of SAS groundwater levels to be able to correlate the seepage to some head differential. Similarly in the development of the statistical relationship, it was desired to have a consideration of the SAS; however, this was not possible.

There is a need for understanding the localized 3D groundwater flow patterns within this system. This is a fundamental requirement to being able to develop an accurate water budget. In order to understand the 3D groundwater flow patterns it is essential that monitoring wells be located within the basin.

The contribution of groundwater to surface water is empirically known to be significant in many areas of Florida. There have been a number of hydrodynamic models developed of this area, either as a specific study of these basins or else as a component of a more regional effort. However, in all cases these models have either been a groundwater model (SJRWMD's steady state MODFLOW model, SFWMD/SJRWMD transient MODFLOW model) or a surface water model (OCSMD basin study of Cypress Creek Basin, Big Sand Lake Basin and OCEPD water quality model of Butler Chain of Lakes). In all these cases the representation of the interaction of the two domains has been represented as well as the respective models allow.

However it is noted that in all modeling scenarios thus far, there has been none that dynamically represented the interaction between the groundwater and surface water systems. This fact may be less an issue of the model's capability as much as it is an issue of insufficient data for building an appropriate conceptual thence numerical model.

3.9 Recommendations

There are two general recommendations resulting from this study.

- Install piezometers in the SAS in select locations to continually monitor the water table levels;

- Apply analysis and modeling tools, including a range of analysis methods that includes the techniques already applied in this study, up to fully integrated GW-SW modeling using numerical simulators.

There is a lack of SAS monitoring wells located within either basin. These are a fundamental data set required for the estimation of the generalized contribution of the SAS to the lake systems. In order to have a good appreciation of the response of the SAS to rainfall as well as having a means to estimate the SAS flow to the lake systems it is essential to have at least a years worth of SAS water levels. Ideally these records would be spatially distributed around the lake system and include periods of time that encompass both wet and dry periods. Due to various combinations of lake levels/rainfall input/water table levels and the resultant SAS flow the longer and more varied the period of record the more likely one would be able to develop a better appreciation of the SAS response.

In addition, while installing these monitoring wells it would be an ideal time to obtain estimates of hydrogeologic properties as well. For example estimates of the hydraulic conductivity could be obtained and used to refine the values used in the MODFLOW model.

During the development of the water budget, a U.S. Geological Report *Hydrologic Setting, Water Budget, and Preliminary Analysis of Groundwater Exchange at Lake Starr, a Seepage Lake in Polk County Florida* (U.S.G.S. Report 00-4030) was reviewed and provided some guidance in this study. During the period the U.S.G.S. monitored this site, a significant amount of data was collected. These data included SAS water levels, rainfall, stratigraphy and hydrogeological parameters. It is recommended that a similar data collection effort be made in the Butler and Sand Lake Chains.

Another important recommendation is the development of a more detailed model, which includes the SAS response and contribution. There may be several options for this model including an investigative cross sectional / hypothetical model to explore flowpaths and sensitivities. In addition, in more general terms, there are a number of potential choices for model selection, including a more refined spreadsheet/water balance model or an integrated groundwater surface water model.

The Danish Hydrologic Institute (DHI), MIKE SHE/MIKE11 has been applied in a number of locations in Florida and has provided reasonable representation of the interaction between the surface and groundwater domains in some locations. This model is a grid based representation of the overland flow, unsaturated and saturated zones. In addition to collecting SAS water levels, it would be necessary to collect several other spatially varying parameters including but not limited to leakage coefficients in the lake beds in order to estimate the recharge to the UFA.

Another potential option for the generation of an integrated groundwater/surface water model is the application of an Environmental Protection Agency's (EPA) Stormwater Management Model (SWMM) and the United States Geological Survey's

MODFLOW models. These models could be run in an iterative fashion in order to estimate the contribution of the SAS to the lake system.

CDM is currently developing a dynamic interface between USEPA SWMM and USGS MODFLOW, called I-SWMM. CDM's internal research and development funding is being used to develop this interface and it is expected that I-SWMM would be ready to apply to these lake systems in 2009. There could be benefit realized from the fact that both basins currently have their surface water system modeled in SWMM and the groundwater system modeled in MODFLOW. If it is decided to continue on to integrated groundwater/surface water modeling, CDM recommends that this option be explored more fully.

Appendix A

CDM

Memorandum

To: *Meeting Attendees*

From: *Heather Fitzgerald, E.I.*
Doug Moulton, P.E.

Date: *June 15, 2006*

Subject: *Meeting Minutes – South Florida Water Management District Butler and Sand Chains of Lakes Reconnaissance Study Kick-off Meeting*

A meeting was held on May 18, 2006 at the Tibet Butler Reserve to discuss the project goals and data collection efforts of the reconnaissance study. Attending the meeting were the following:

Clyde Dabbs	South Florida Water Management District
Larry Pearson	South Florida Water Management District
Penny Post	Orange County
Kate Kolbo	Reedy Creek Improvement District
Doug Moulton	CDM
Heather Fitzgerald	CDM

- CDM provided the meeting attendees with copies of the project Scope of Services and provided an overview of the project.

- The conveyance system was described by various attendees. It was stated that in order for the system to discharge to the Grand Cypress Swamp water must stage up sufficiently to overtop a berm running along the south end of Lake Sheen. The elevation of this berm was discussed; it was speculated that perhaps it is represented sufficiently in the LiDAR data; additionally it was requested that the Orange County Surveyor obtain spot elevations along it. The LiDAR data obtained from Orange County was reviewed and while there are limited spot elevations provided in the Grand Cypress Swamp it is indicated that they are "obscured".

- Penny stated that the success factor for Orange County in this project is to quantify the groundwater contribution to the Lake Butler Chain. Doug stated that anecdotal information indicates that a hardpan layer is prevalent within the basin and may result in

significant surficial aquifer contribution during times of wet weather. During data collection and evaluation, this theory will be considered.

- Doug stated that CDM was able to obtain the EPA's Stormwater Management Model (SWMM) for the Cypress Creek Drainage Basins as documented in the January 1996 report entitled "Water Quality Model for the Butler Chain of Lakes". Additionally, for another County project, CDM developed a SWMM of the Big Sand Lake Chain of Lakes. Thus the entire project area is currently modeled in SWMM.

- Kate wanted to know what tailwater conditions are used in the Cypress Creek SWMM. Doug stated that currently he did not know but suspected it was a constant elevation. This has since been verified, there is a constant tailwater (99.0 ft NGVD) applied at the downstream end of the SR535 crossing, downstream of the Cypress Creek swamp. It is stated in the above referenced report that this elevation approximates an average water elevation at that point. If this model is used for some component of the water budget estimation, the boundary condition will be set at RCID 's structure S-103A.

- The alert model was discussed in some detail. In general it was felt that having a simple predictive model would fulfill a valid purpose. Being able to predict flooding using a simple model would be useful to provide warning to the residents.

- Evidently the Lake Butler Chain of Lakes normal high water elevation (NHWE) was changed in the early 1980s by the Board of County Commissioners.

- In general it was thought that a public education component would be important. The two main issues that appear to require clarification are: the role of the berm along the southern edge of Lake Sheen as well as the historic water level fluctuation. Many homes may have been built in the area when the lake was at a lower level, thus relatively higher lake levels may be viewed with concern.

- Doug proposed looking at a period of record of stages of the lakes to come up with a statistical analysis of the flooding stages. Kate says that George Cole (previous Orange County Director of Stormwater) made a similar analysis and that Orange County now was in possession of that. Penny said using that analysis would not meet Orange County's expectations since it does not include the groundwater components. Doug's response to this comment was that the groundwater components would come into play during the water budget development. Efforts will be made to get a copy of this analysis during data collection.

- It was stated that there is an USGS ET station on Bay Lake in RCID.

- Data collection efforts were discussed in detail. Outstanding required data/assignments are as follows:

  1. Orange County and RCID will provide rain gage information from Reedy Creek. RCID's gage is linked into USGS, which means it has live data. RCID has three rain gages within the project area. RCID will also provide annual reports for the area. Orange County's rain gage is located on Park and SR 535 (on Lake Sheen). The period of record for this study is defined as 1995 to present. RCID has provided annual summaries of rainfall data. RCID has provided groundwater elevations for monitoring wells in their jurisdiction.

  2. Black and white aerial photographs will be provided by Larry.

  3. Larry will provide Lidar data for Reedy Creek after CDM provides him with the Section, Township, and Range of areas that CDM is missing information on.

  4. CDM will redefine the Cypress Creek drainage basin using ArcHydro tools.

  5. Clyde and Larry will contact Dave Butler and Chris Sweazy at the SFWMD to obtain information on the groundwater basin divides and recharge rates.

  6. Larry will contact the SFWMD permitting depart in order to find out if there are any existing culverts along SR 535 other than the one that is on the south side of the basin. Kate says that the culverts under SR 535, on the south side of the basin, predate the permitting process but has had a flow gage there since the 1960s. Larry has since indicated that the main outfall is the set of twin 60 inch culverts, as noted. However, there is evidence that there are a number of smaller culverts along the length of SR535 from Apopka-Vineland to Chase Road.

  7. Kate says that CDM could use the existing water quality data from the NPDES Permits for RCID.

  8. CDM requested that Orange County to obtain spot elevations of the berm along the southern edge of Lake Sheen.

- At the conclusion of the meeting, the success factors for this project are as follows:

  1. Completion of data collection and development of water budget. If sufficient and appropriate data exists the alert model will be developed.

2. The water budget needs to include a rigorous groundwater component.

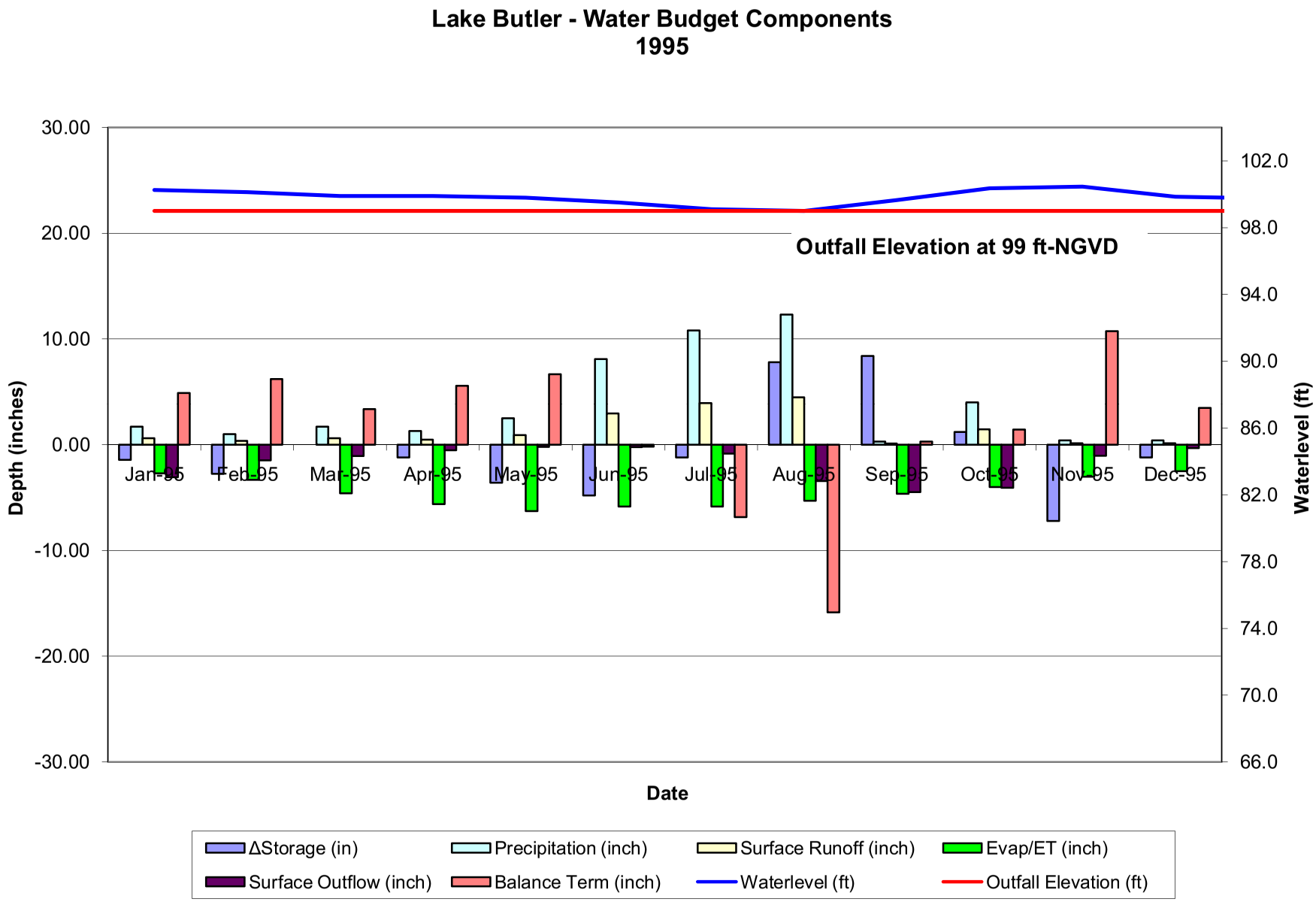
3. Phase I may include the recommendation of installation of a monitoring well in the subsequent phase.

4. The definition of a set of flooding problems for the purposes of this project. It was stated that there could be three levels: flooding of docks, yards/pools, and houses.

5. Efforts will be made to have the report contain graphics that could be used for public education.

In summary, the items listed above were the main points discussed at the meeting. CDM will work with the other meeting attendees in effort to complete the tasks and project goals listed above.

Appendix B


Lake Butler - Water Budget Components
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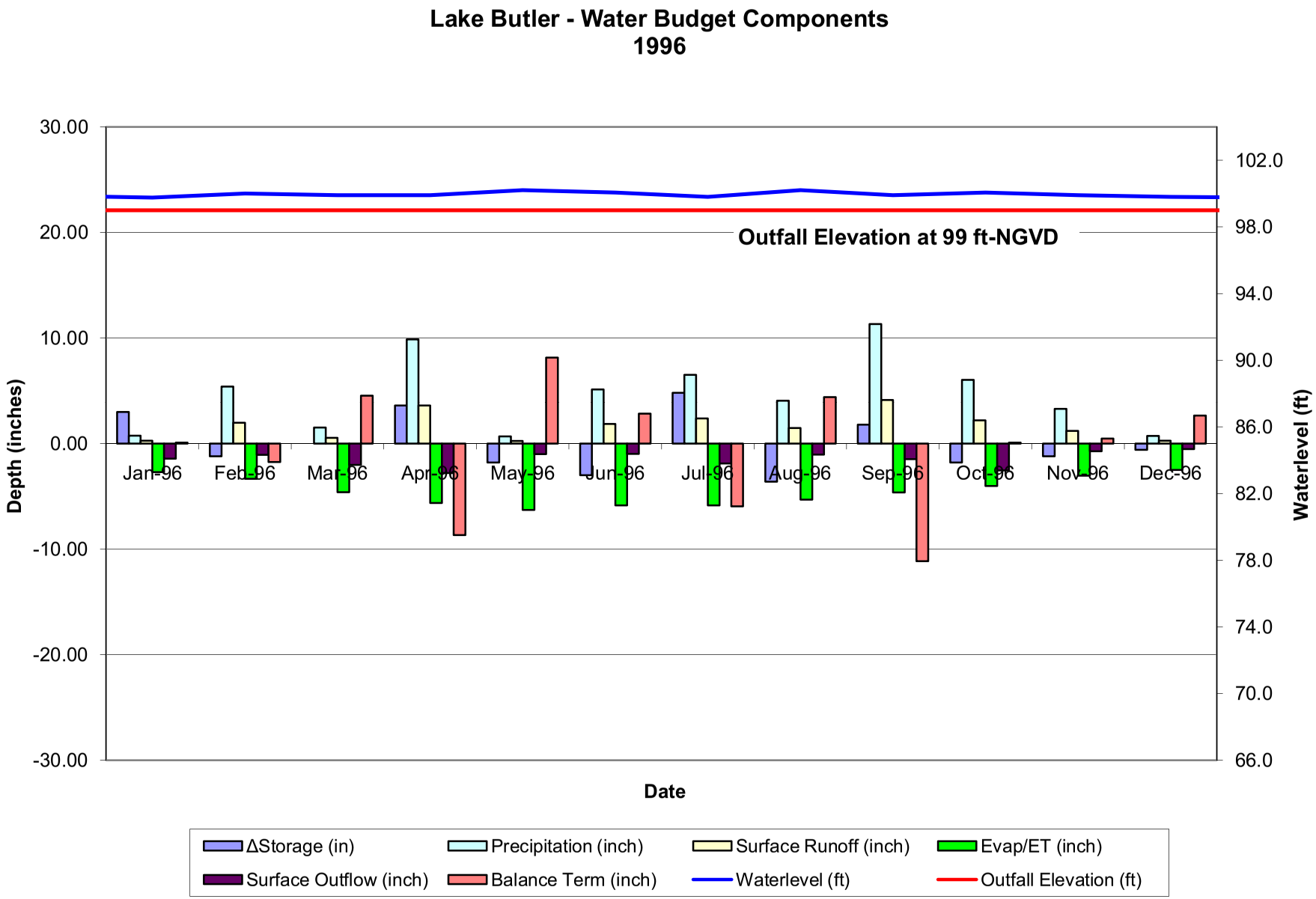
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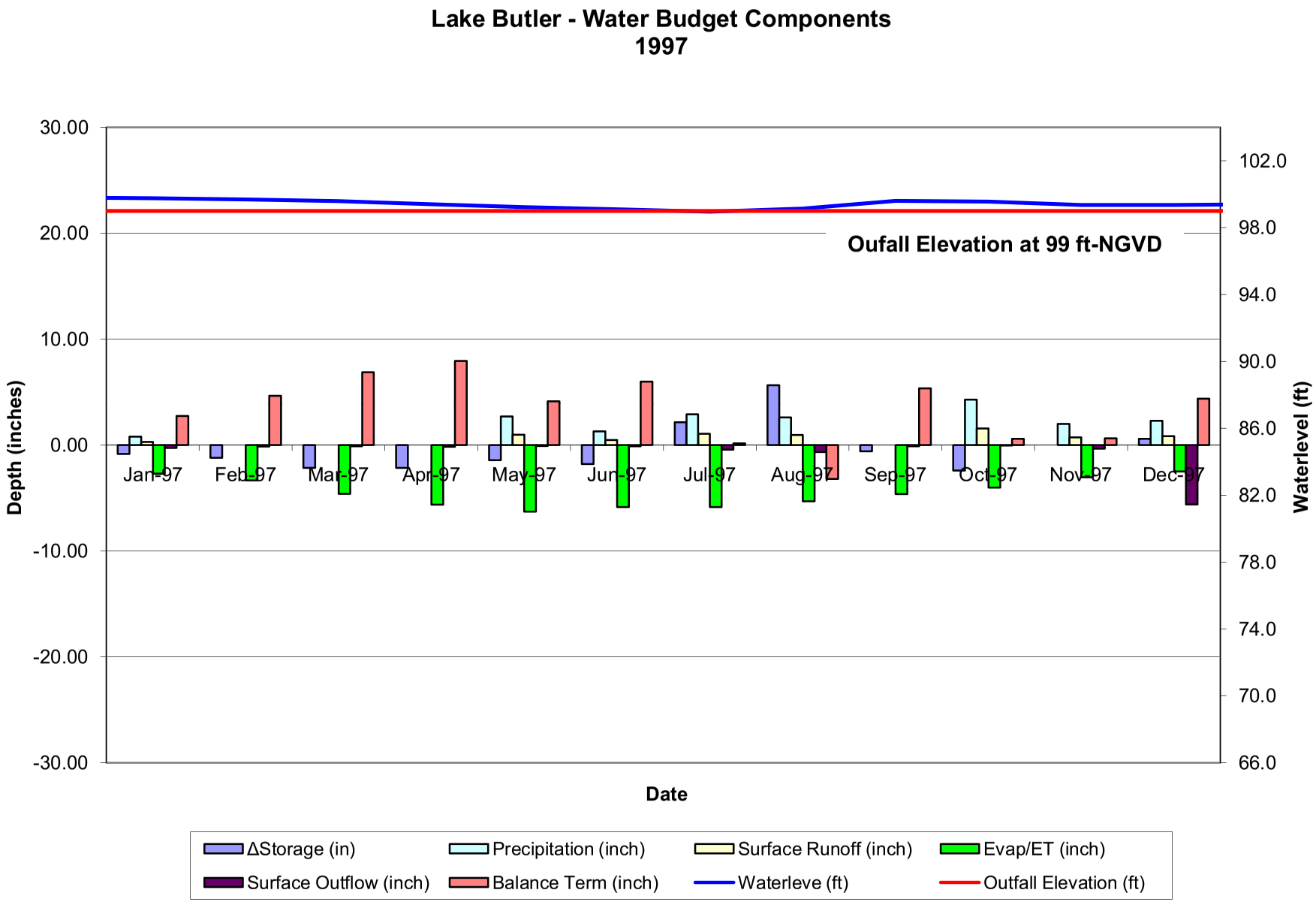
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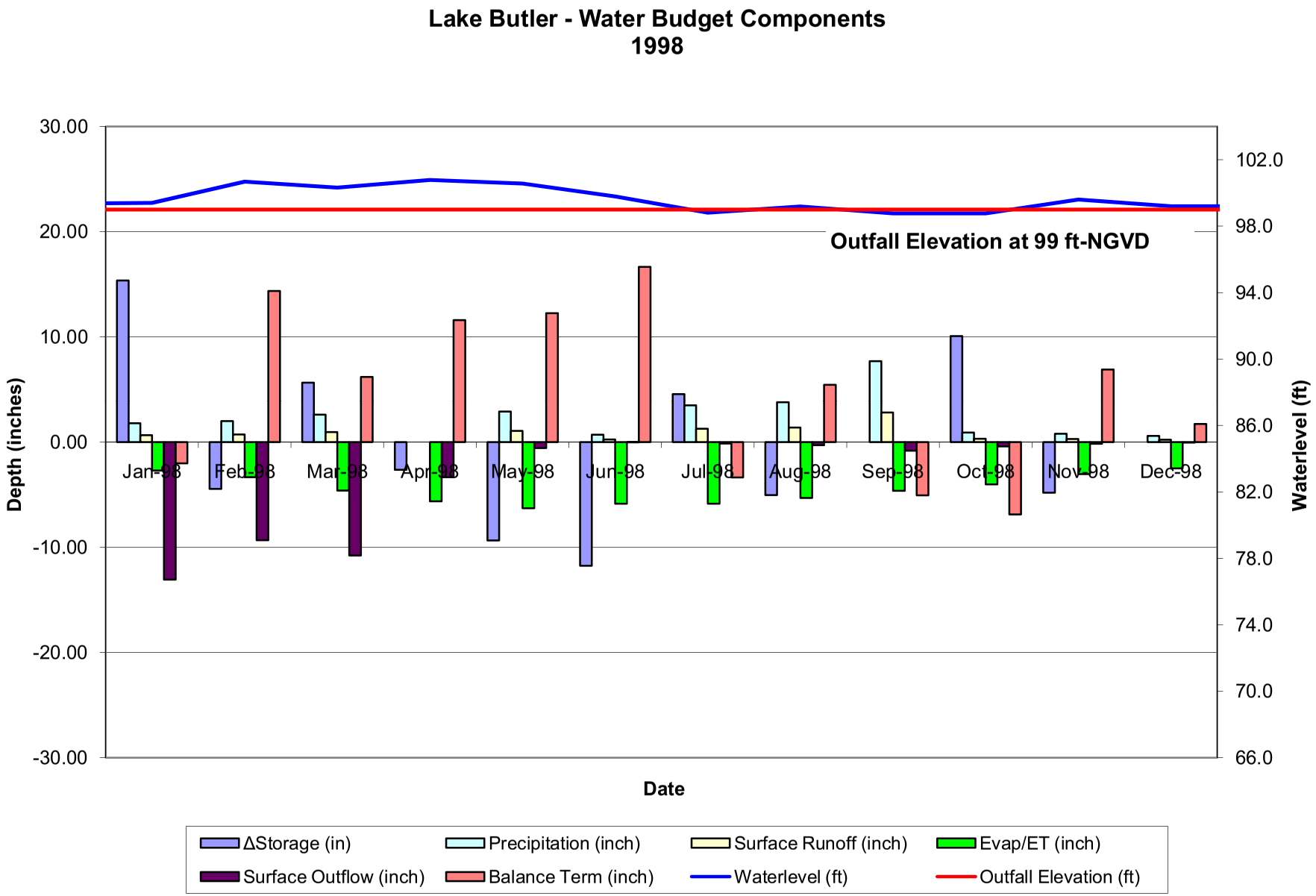
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Waterlevel (ft)
Outfall Elevation at 99 ft-NGVD
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Surface Runoff (inch)
Evap/ET (inch)
Surface Outflow (inch)
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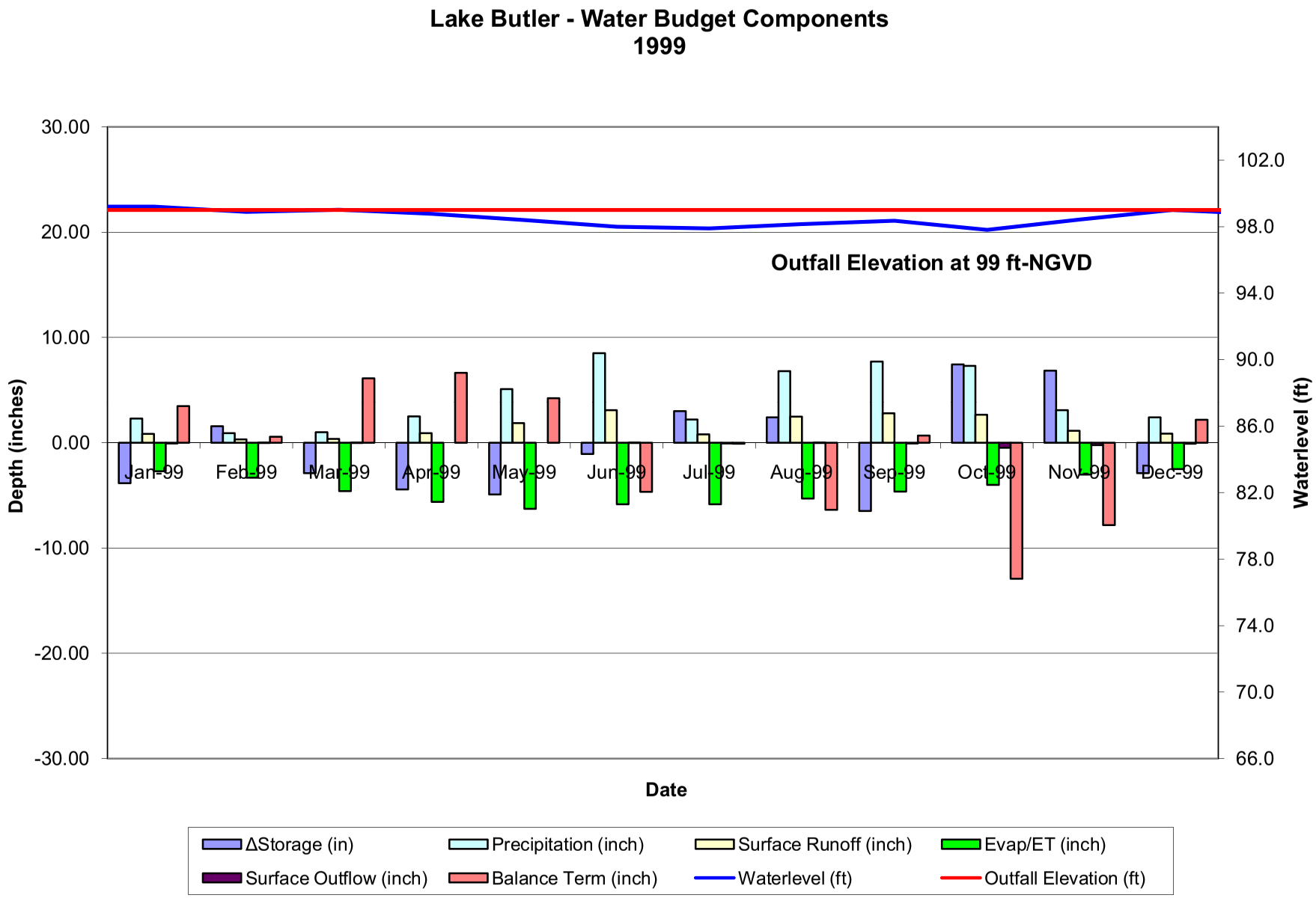
Waterlevel (ft)
Outfall Elevation (ft)


Lake Butler - Water Budget Components
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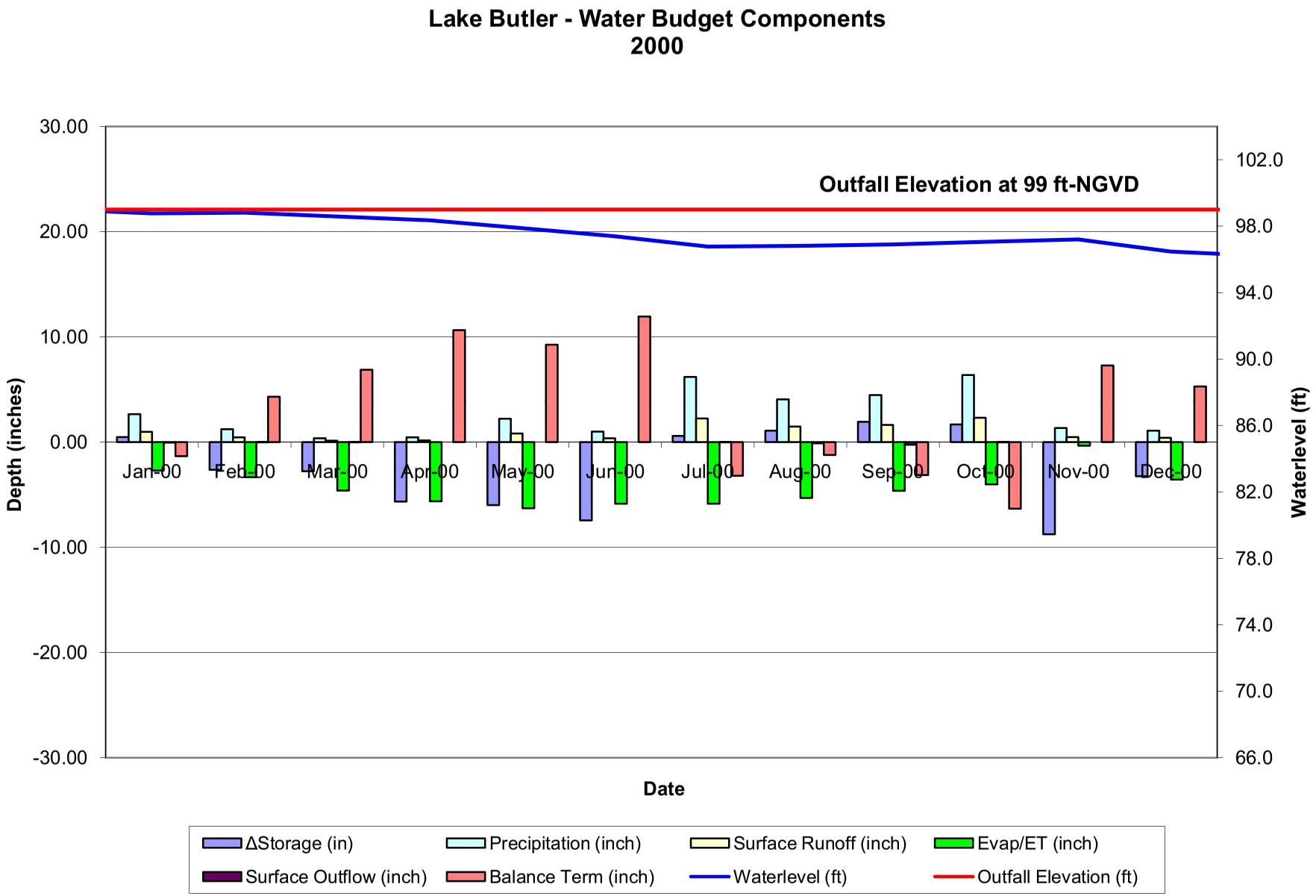
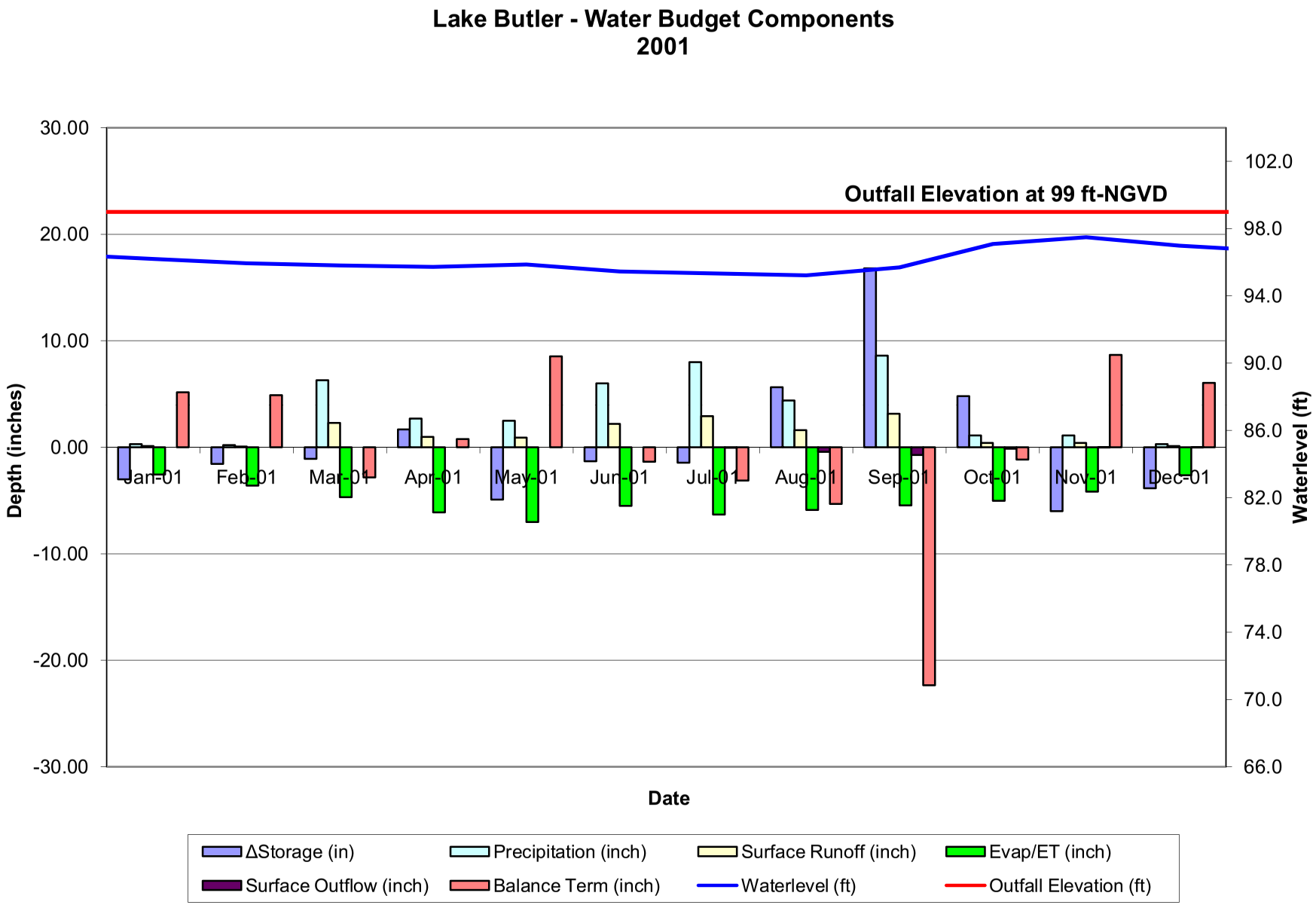
-20.00
-30.00
Depth (inches)
102.0
98.0
94.0
90.0
86.0
82.0
78.0
74.0
70.0
66.0
Waterlevel (ft)
Outfall Elevation at 99 ft-NGVD
Jan-99
Feb-99
Mar-99
Apr-99
May-99
Jun-99
Jul-99
Aug-99
Sep-99
Oct-99
Nov-99
Dec-99
Date
ΔStorage (in)
Precipitation (inch)
Surface Runoff (inch)
Evap/ET (inch)
Surface Outflow (inch)
Balance Term (inch)
Waterlevel (ft)
Outfall Elevation (ft)


Lake Butler - Water Budget Components
2000
Outfall Elevation at 99 ft-NGVD
30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
Depth (inches)
102.0
98.0
94.0
90.0
86.0
82.0
78.0
74.0
70.0
66.0
Waterlevel (ft)
Jan-00
Feb-00
Mar-00
Apr-00
May-00
Jun-00
Jul-00
Aug-00
Sep-00
Oct-00
Nov-00
Dec-00
Date
ΔStorage (in)
Precipitation (inch)
Surface Runoff (inch)
Evap/ET (inch)
Surface Outflow (inch)
Balance Term (inch)
Waterlevel (ft)
Outfall Elevation (ft)


Lake Butler - Water Budget Components
2001
Outfall Elevation at 99 ft-NGVD
30.00
20.00
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-30.00
Depth (inches)
102.0
98.0
94.0
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82.0
78.0
74.0
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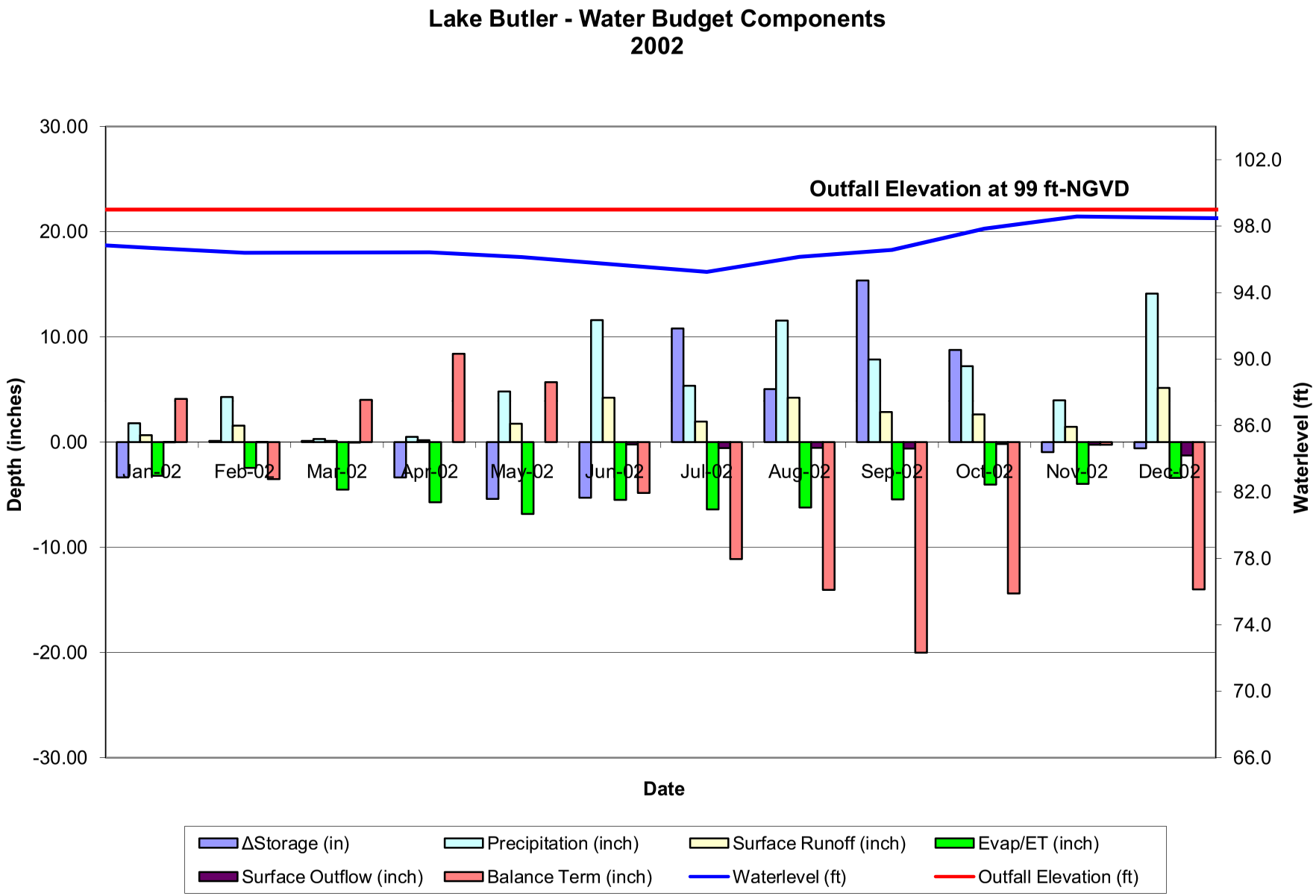
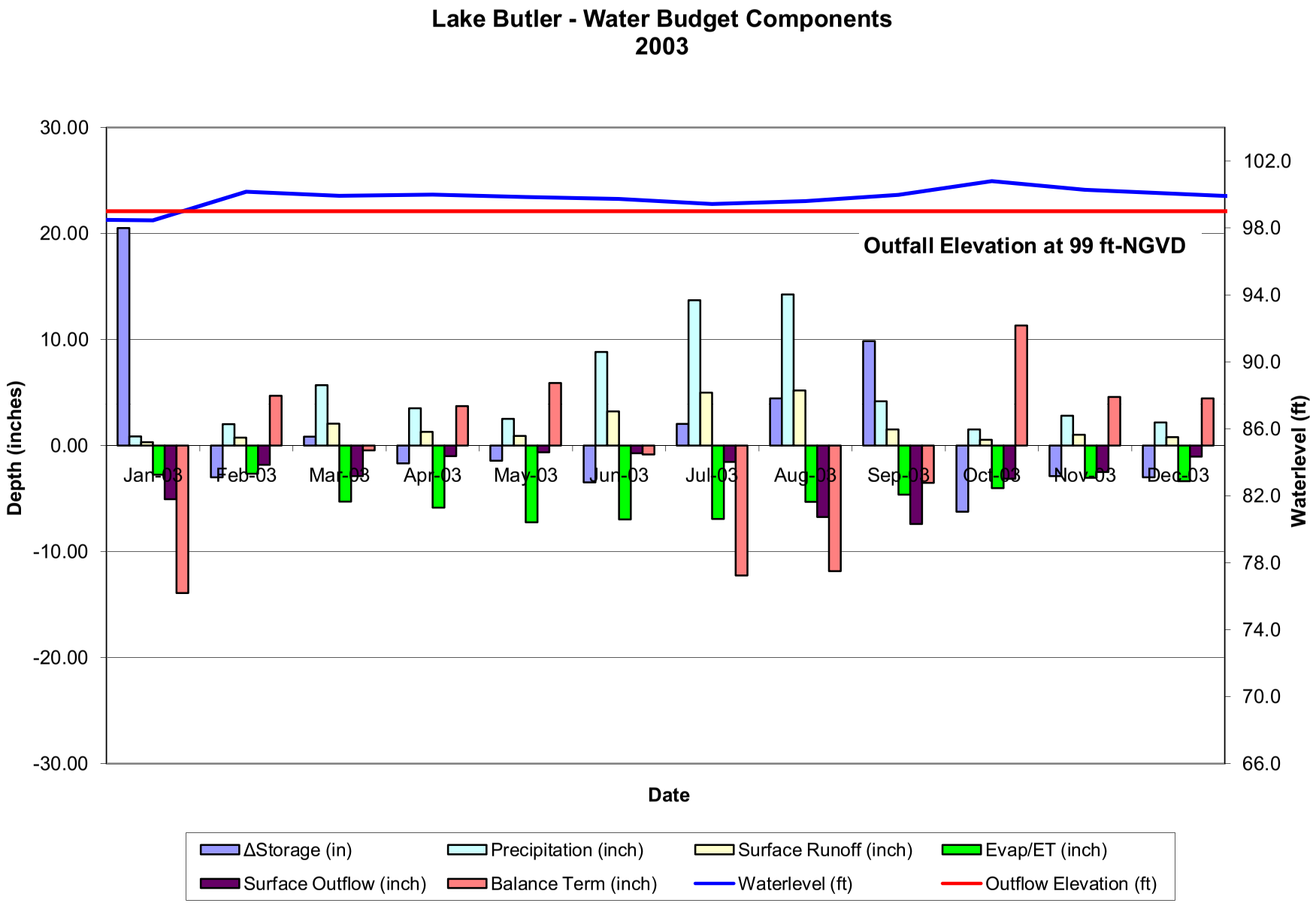
66.0
Waterlevel (ft)
Jan-01
Feb-01
Mar-01
Apr-01
May-01
Jun-01
Jul-01
Aug-01
Sep-01
Oct-01
Nov-01
Dec-01
Date
ΔStorage (in)
Precipitation (inch)
Surface Runoff (inch)
Evap/ET (inch)
Surface Outflow (inch)
Balance Term (inch)
Waterlevel (ft)
Outfall Elevation (ft)


Lake Butler - Water Budget Components
2002
Outfall Elevation at 99 ft-NGVD
30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
Depth (inches)
102.0
98.0
94.0
90.0
86.0
82.0
78.0
74.0
70.0
66.0
Waterlevel (ft)
Jan-02
Feb-02
Mar-02
Apr-02
May-02
Jun-02
Jul-02
Aug-02
Sep-02
Oct-02
Nov-02
Dec-02
Date
ΔStorage (in)
Precipitation (inch)
Surface Runoff (inch)
Evap/ET (inch)
Surface Outflow (inch)
Balance Term (inch)
Waterlevel (ft)
Outfall Elevation (ft)


Lake Butler - Water Budget Components
2003
Outfall Elevation at 99 ft-NGVD
Depth (inches)
Waterlevel (ft)
Date
30.00
20.00
10.00
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Jan-03
Feb-03
Mar-03
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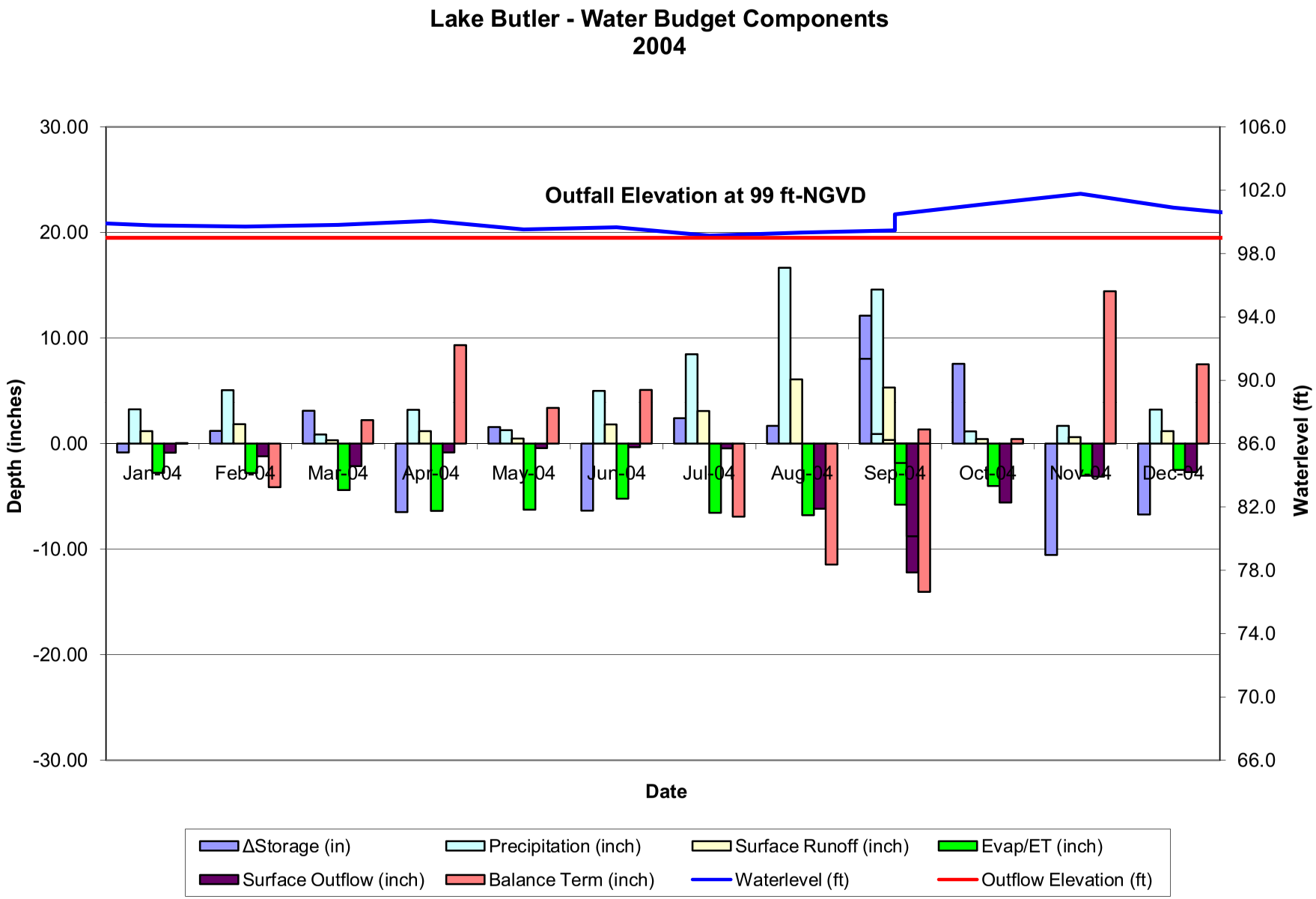
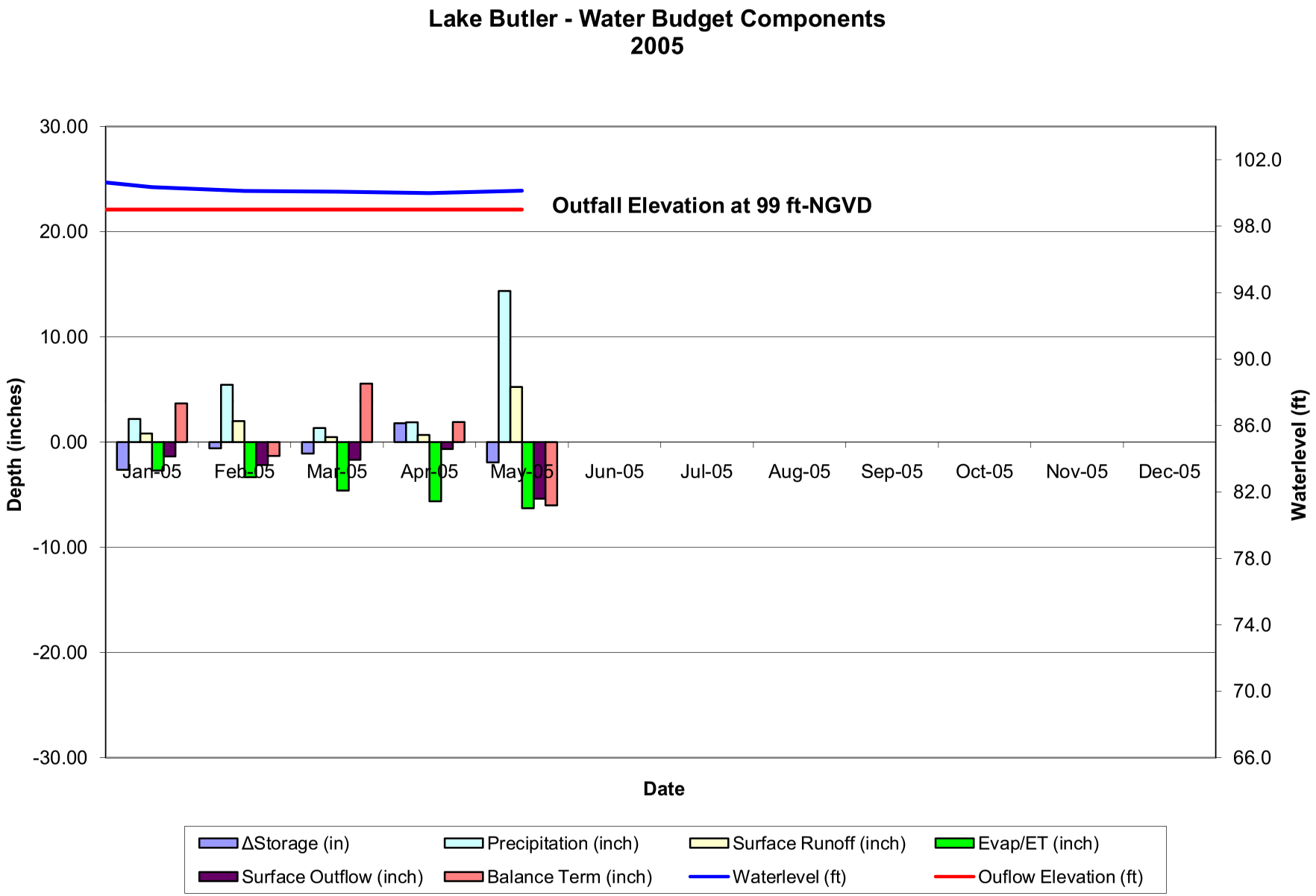
May-03
Jun-03
Jul-03
Aug-03
Sep-03
Oct-03
Nov-03
Dec-03
ΔStorage (in)
Precipitation (inch)
Surface Runoff (inch)
Evap/ET (inch)
Surface Outflow (inch)
Balance Term (inch)
Waterlevel (ft)
Outflow Elevation (ft)


Lake Butler - Water Budget Components
2004
Outfall Elevation at 99 ft-NGVD
30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
Depth (inches)
106.0
102.0
98.0
94.0
90.0
86.0
82.0
78.0
74.0
70.0
66.0
Waterlevel (ft)
Jan-04
Feb-04
Mar-04
Apr-04
May-04
Jun-04
Jul-04
Aug-04
Sep-04
Oct-04
Nov-04
Dec-04
Date
ΔStorage (in)
Precipitation (inch)
Surface Runoff (inch)
Evap/ET (inch)
Surface Outflow (inch)
Balance Term (inch)
Waterlevel (ft)
Outflow Elevation (ft)


Lake Butler - Water Budget Components
2005
Outfall Elevation at 99 ft-NGVD
30.00
20.00
10.00
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-10.00
-20.00
-30.00
Depth (inches)
102.0
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94.0
90.0
86.0
82.0
78.0
74.0
70.0
66.0
Waterlevel (ft)
Jan-05
Feb-05
Mar-05
Apr-05
May-05
Jun-05
Jul-05
Aug-05
Sep-05
Oct-05
Nov-05
Dec-05
Date
ΔStorage (in)
Precipitation (inch)
Surface Runoff (inch)
Evap/ET (inch)
Surface Outflow (inch)
Balance Term (inch)
Waterlevel (ft)
Ouflow Elevation (ft)

Appendix C

Appendix C
Response to Orange County Comments

September 20, 2006

Doug Moulton, P.E.

2301 Maitland Center Parkway, Suite 300

Maitland, FL 32751

Subject: **Butler and Big Sand Lake Chain of Lakes Reconnaissance**

Dear Mr. Moulton:

As part of the subject task I have reviewed the draft section you emailed to me on September 18, 2006, and the following are my comments.

1. Why doesn't the graph for Lake Butler show all of year 2005 water budget components? Does the MODFLOW model have applicable 2005 data?
   Response: The original data set obtained from Orange County for the lake levels and rainfall ended in May 2005; these data were used as the basis for the present analysis. In general, the most significant of the graphs is the average values, presented as Figure 3-8. The MODFLOW model is a steady-state model; as such the input and outputs are indications of the average condition.

2. It was thought that there was an outfall from Tibet Butler under Winter Garden Road. The figure doesn't show one, so it's assumed it was determined that there isn't one. Can there be a small narrative paragraph on this?
   Response: The existence of an outfall from Lake Tibet Butler under Winter Garden Road was neither proved nor disproved. In fact, permit review from the South Florida Water Management District indicated that this outfall may exist. In the water balance analysis it was necessary to attempt to quantify the outflow as accurately as possible. The major outfall, at the south end of the Cypress Creek Swamp, has been monitored for a significant period of time, thus it was possible to estimate a volume associated with this outfall. The volume associated with the secondary outflows should be considered as a source of potential error in the "balancing term."

3. Should more lake levels in the chains be monitored: **Response: From the limited data available, the Butler Chain of Lakes lake levels appears to equilibrate from north to south. Based upon a review of the connectivity, it seems likely that lakes in the northern most portion of the system (e.g. Lake Cresent) tend to be somewhat disconnected from the overall system. It is noted, however, that these lakes make up a relatively small proportion of the overall surface area of the system. Thus the current monitoring in the Butler Chain seems adequate. In the Sand Lake Chain, there tends to be the potential for a significant head difference between Spring Lake and the remainder of the system to the south. Currently Orange County maintains a permanent lake level and rainfall station on Spring Lake; in recent times lake level information on Big Sand Lake has also been collected. It is recommended that a permanent lake level monitoring station be established on Big Sand Lake.**

4. Can you go into more detail on the runoff coefficient? For pervious and impervious, 0.05 and 0.70, respectively, seems low. **Response: Various sources were consulted to determine a surface water response in the Butler Chain of Lakes. The most specific information was found in the United States Geological Survey (USGS) report 2005-5052 *Hydrology and Water Quality of Lakes and Streams in Orange County, Florida* in which the average surface water runoff was indicated to be a relatively low 1.1 inches per year. Based upon this estimate and published runoff coefficients the values of 0.05 and 0.70 were selected to estimate the runoff. Additional qualitative justification for using these relatively low values include the general agreement that this chain of lakes is located in a relatively high Upper Floridan Recharge area, thus one would expect low runoff.**

5. Provide the lake areas. **Response: The lake areas are provided in the following table. The source of these areas is the Orange County Lake GIS coverage.**

Basin	Lake Name	Area (acres)
Butler Lake Chain		
	LAKE BUTLER	1743.7
	LAKE TIBET BUTLER	1125.8
	LAKE DOWN	919.0
	LAKE SHEEN	571.5
	LAKE CRESCENT	203.1
	LAKE BESSIE	167.5
	LAKE BLANCHE	142.4
	LAKE CHASE	141.3
	LAKE LOUISE	137.0
	POCKET LAKE	127.3
	LAKE BURDEN	124.9
	LAKE ESTES	68.0
	LAKE ISLEWORTH	57.5
	LAKE WILLIAM DAVIS	44.8
	LAKE RHEA	12.1
	LAKE STORY	11.7
	LAKE BRENDA	11.3
	LAKE BURDEN	9.6
	LAKE VALERIAN	4.4
	LAKE MITZI	3.0
	LOST COVE	2.0
	UNNAMED LAKE	0.7
Sand Lake Chain		
	BIG SAND LAKE	872.4
	LITTLE SAND LAKE	194.6
	LAKE WILLIS	125.2
	SPRING LAKE	111.6
	LAKE SERENE	39.9
	LAKE SLOAT	29.6
	BOO BOO LAKE	18.5
	LAKE EVE	18.4
	LAKE TUCKER	14.7
	LAKE CROWELL	14.6
	BIG SAND LAKE	12.6

6. Discuss the pros and cons of the different models that can be used in the recommendation. In addition, a table may also be useful. A figure or table showing the locations of the recommended piezometers would be useful.

Response: As there are both currently surface and groundwater models for this area, the recommendation was to develop an integrated surface water – groundwater model. There are four possible models that could be used: DHI's MIKE SHE/MIKE 11, running interative simulations of MODFLOW and SWMM, ICPR with PercPak, or using this area as a pilot area for the development of a dynamic interface between SWMM and MODFLOW. The following table provides a comparison of the pros and cons of these various model combinations. Also the following figure presents publically owned parcels adjacent to both lake systems. These areas could serve to site potential piezometers locations.

Integrated Model Comparison		
Model	***Pros***	***Cons***
MIKE SHE/11	Industry standard	Cost of license
	Fully dynamic	Complexity of use
	Fully integrated	Data requirements
	Potential to represent all components of hydrological cycle	Model would need to be developed
SWMM/MODFLOW	Public domain	Model runs need to be manually iterative
	Both models currently exist	No explicit representation of unsaturated zone
	Both models fully dyanamic	
ICPR w PercPak	Industry standard for stormwater modeling in Central Florida	Would need to upgrade ICPR license
	ICPR model exists for basin	Only models seepage out of lakes, no mechanism for seepage into lakes
HSPF	Public domain	Data intensive
	Model of system exists	HSPF portion of model would need to be developed
		Backwater effects are difficult to model
ISWMM	R&D project projected to have a dynamic interface between SWMM - EXTRAN block and MODFLOW	No explicit representation of unsaturated zone
	Public domain	
	R&D project - potential for additional cost sharing	
	Both models currently exist	

If you have any questions, please feel free to contact me at (407) 836-7747.

Sincerely,

Penny R. Post, P.E., CFM, Senior Engineer

cc: Mark V. Massaro, P.E., Deputy Director, Public Works Department
M. Krishnamurthy, Ph.D., P.E., CFM, Manager, Stormwater Management Division
Rodney J. Lynn, P.E., CFM, Chief Engineer, Stormwater Management Division

Appendix D

Appendix D
PDSI Lake Level Indicator

D.1 Introduction

In section 3 an introduction to the Palmer Drought Severity Index (PDSI) was presented. To reiterate, this index is a measure of the soil moisture deficit, which to a large extent is the difference between rainfall and evapotranspiration (ET), also taking into account moisture contained in soil storage. The range of PDSI values range from 5 to -5; the positive numbers representing "wet" conditions; the negative numbers representing "drought" conditions; zero representing "average" conditions.

It is asserted that it is possible to make use of the PDSI to predict the water levels of a lake system.

Originally the PDSI was developed as an agricultural aid to estimate the amount of irrigation that would be required to satisfy crop demands. In general, a PDSI of 0 indicates that the atmospheric input is sufficient to satisfy the local ET demand; essentially a "break even" condition as far as the water budget is concerned.

If the PDSI is indicating a drought condition (i.e. < 0), then atmospheric input is insufficient to satisfy the ET demand. In order to satisfy this demand, terrestrial sources (i.e. existing soil moisture and available surface water) will need to be used. If there is a persistent drought the available terrestrial sources will become depleted.

Conversely, if the PDSI is indicating a wet condition (i.e. >0), then atmospheric input is more than sufficient to satisfy the ET demand. In this case, the excess atmospheric input would initially be used to recharge any of the terrestrial sources that were depleted in any previous drought months. With a persistent wet period eventually the terrestrial water would become excessive and potentially flooding conditions would occur.

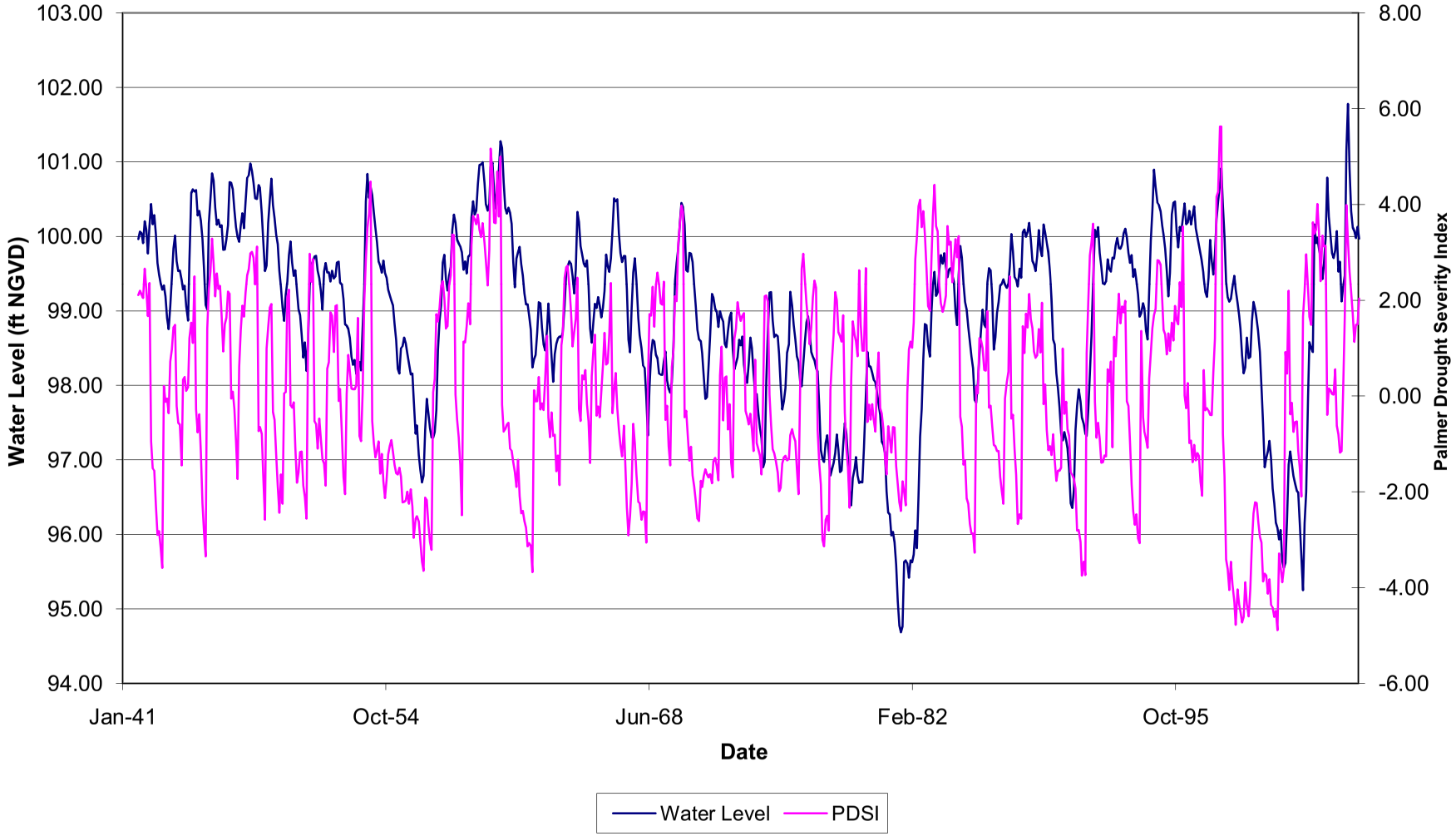
The reader is referred to the original publication for further details regarding this index. *Research Paper No. 45 Meteorological Drought* written by Wayne C. Palmer of the Office of Climatology, U.S. Weather Bureau, Washington, D.C. February 1965.

D.2 Methodology

It is intended to indicate that it is possible to make use of a calculated PDSI to provide a means to estimate the response of a water body to climatological inputs.

The period of record of Lake Butler levels (November 1941 to May 2005) was downloaded from the South Florida Water Management District's (SFWMD) DBHydro database. The PDSI was downloaded for a similar period from the following website:
http://www.ncdc.noaa.gov/oa/climate/onlineprod/drought/main.html. These two data sets were plotted together as line scatter plots and are presented as **Figure D-1**,

Figure D-1
Butler Lake WL vs PDSI



the whole period of record, and **Figures D-2 to D-6**, the whole period of record divided into shorter periods (approximately 13 year periods). The subset figures were reviewed visually to determine any potential trends.

Three conditions were considered:

- Lake levels rising to problem levels,
- Lake levels falling to problem levels, and
- Lake levels remaining at a non-problematic level.

In order to assess the relationship between the lake levels and the PDSI, it is necessary to make an arbitrary ranking of the lake levels. As noted previously, the outfall elevation, to the southwest into the Cypress Creek Swamp has been estimated at 99.0 feet National Geodetic Vertical Datum (NGVD). From Orange County's Lake Index the Normal High Water Elevation (NHWE) is 99.5 feet NGVD. Based upon these two values the following is suggested:

- Very high > 101 feet NGVD,
- High between 100 and 101 feet NGVD,
- Average between 99 and 100, and
- Low < 99 feet NGVD.

It is also necessary to define those periods of time in which significant impacts to the surface waters occur. Based upon the review of the time series plots it appears that if a general PDSI condition persists for approximately 6 months; this appears to be sufficiently long to have impacts to surface waters. This duration is, very likely, a function of a variety of factors, including, but not limited to, the active storage within the lake system, the soil storage in the tributary basins, and the amount and timing of the contribution from the SAS.

D.3 Observations

Based upon the visual review of the plots the following generalizations were made:

- When the PDSI drops precipitously, the lake levels tend to follow suit. As an example, consider the 8 month period from June 1942 to February 1943 (Figure D-2). The PDSI dropped almost 6 points, from 2.36 (moderately wet) to -3.59 (severe drought). The lake level dropped approximately 1.7 feet from an elevation of 100.44 NGVD to a low of 98.76 feet NGVD. One could also consider the 11 month period from July of 1984 to May of 1985 (Figure D-5). The PDSI dropped 6.6 points from 3.34 (very wet) to -3.27 (severe drought). The lake level dropped approximately 2.1 feet from an elevation of 99.87 feet NGVD to 97.77 feet NGVD.

Figure D-2
Butler Lake WL vs PDSI

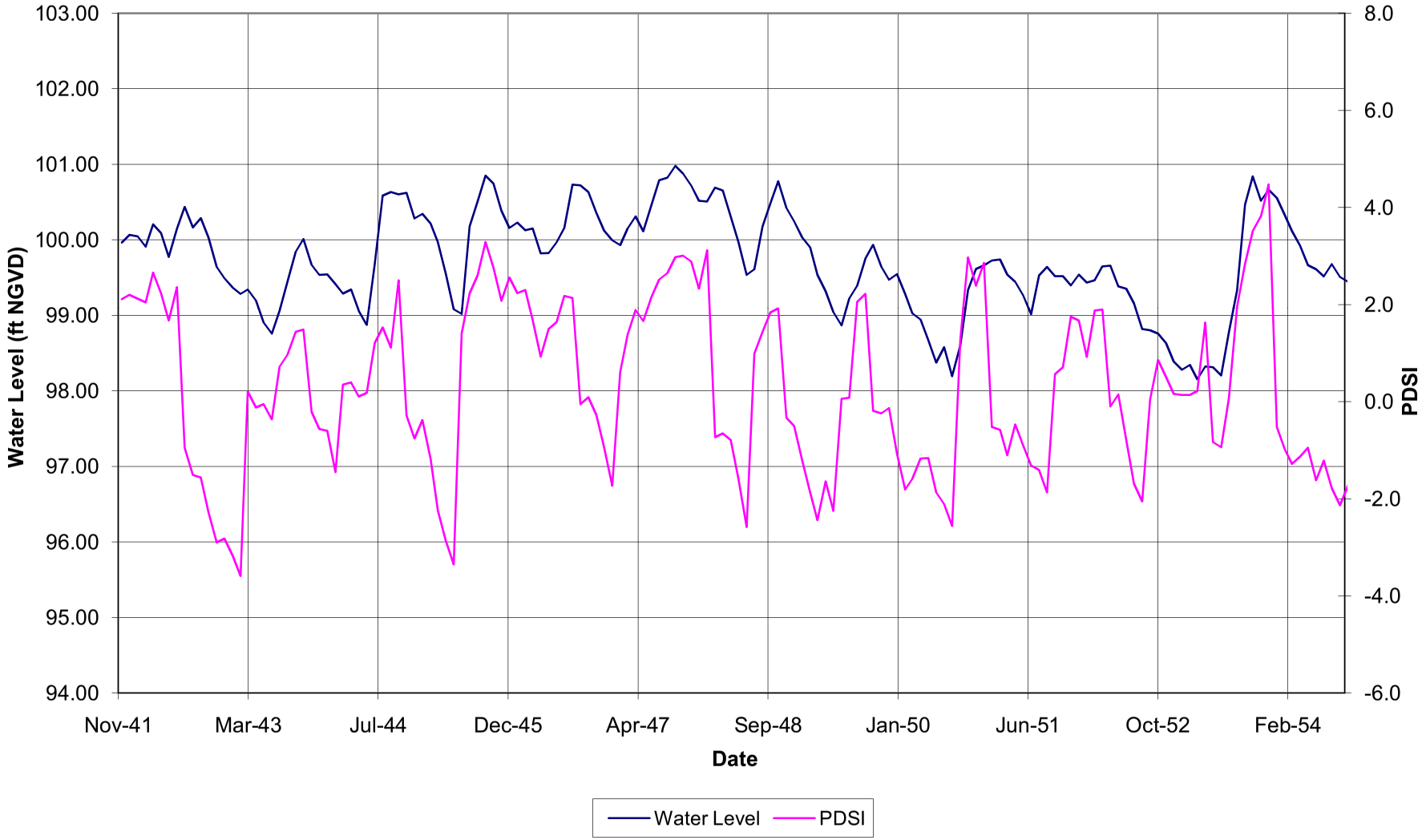


Figure D-3
Butler Lake WL vs PDSI

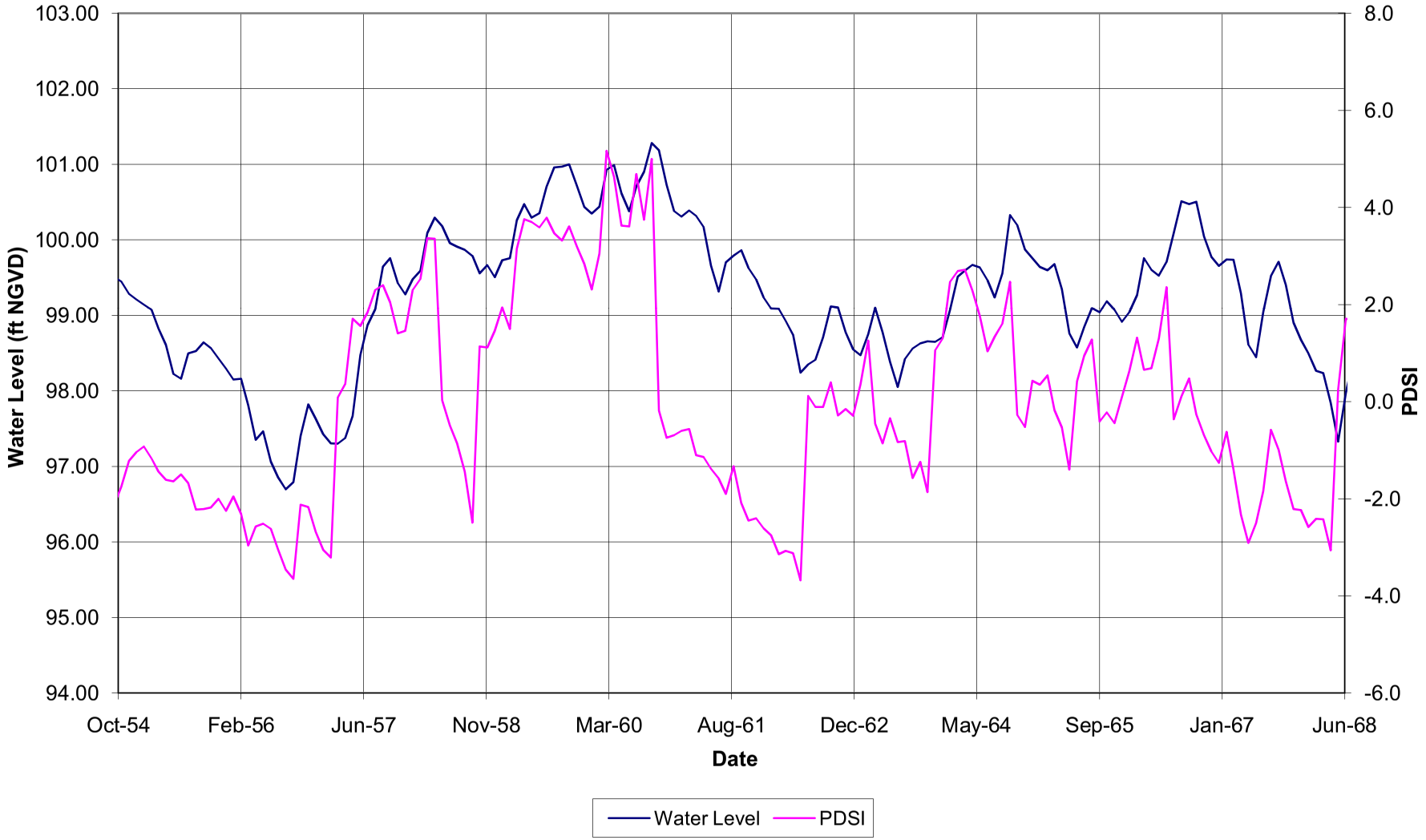


Figure D-4
Butler Lake WL vs PDSI

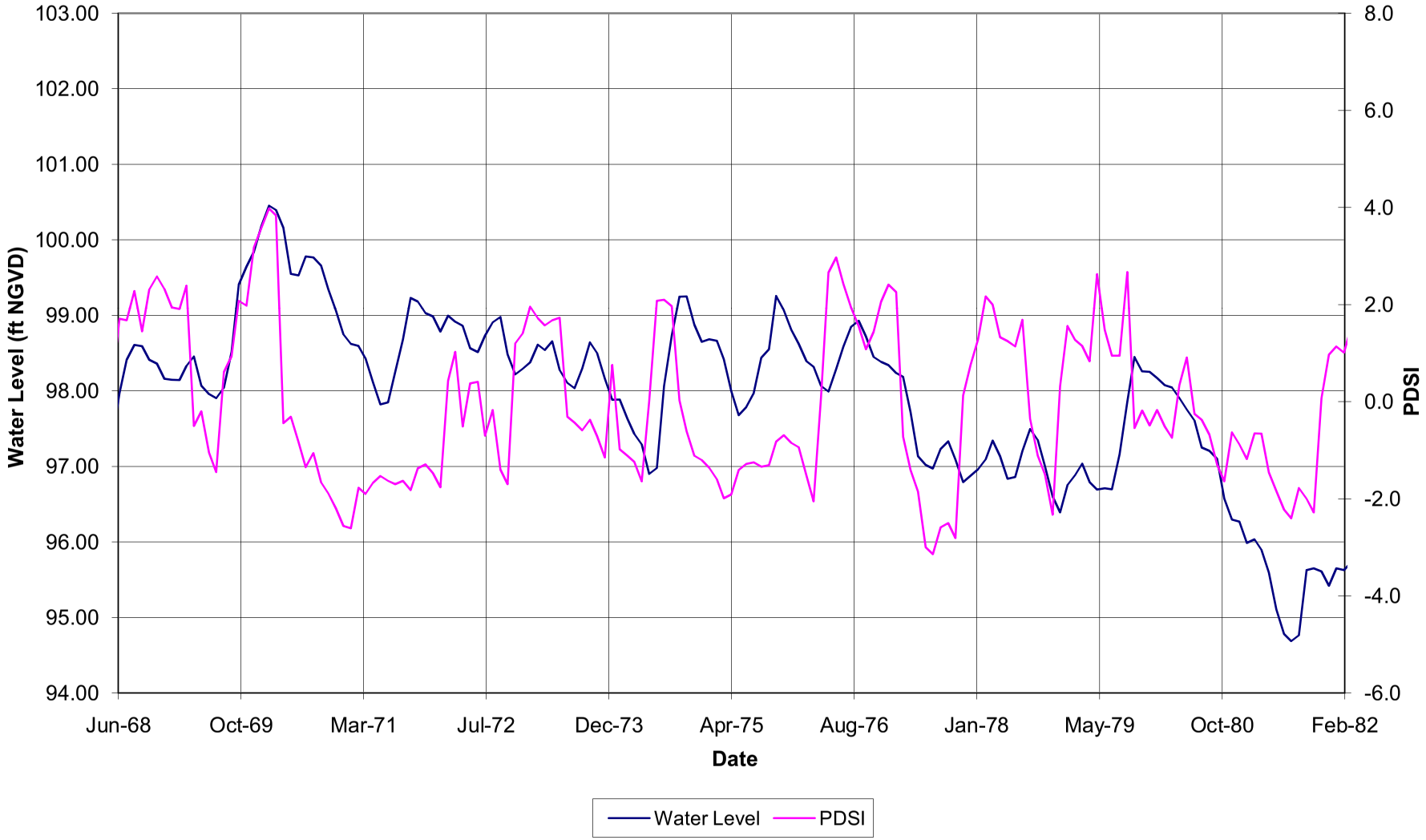


Figure D-5
Butler Lake WL vs PDSI

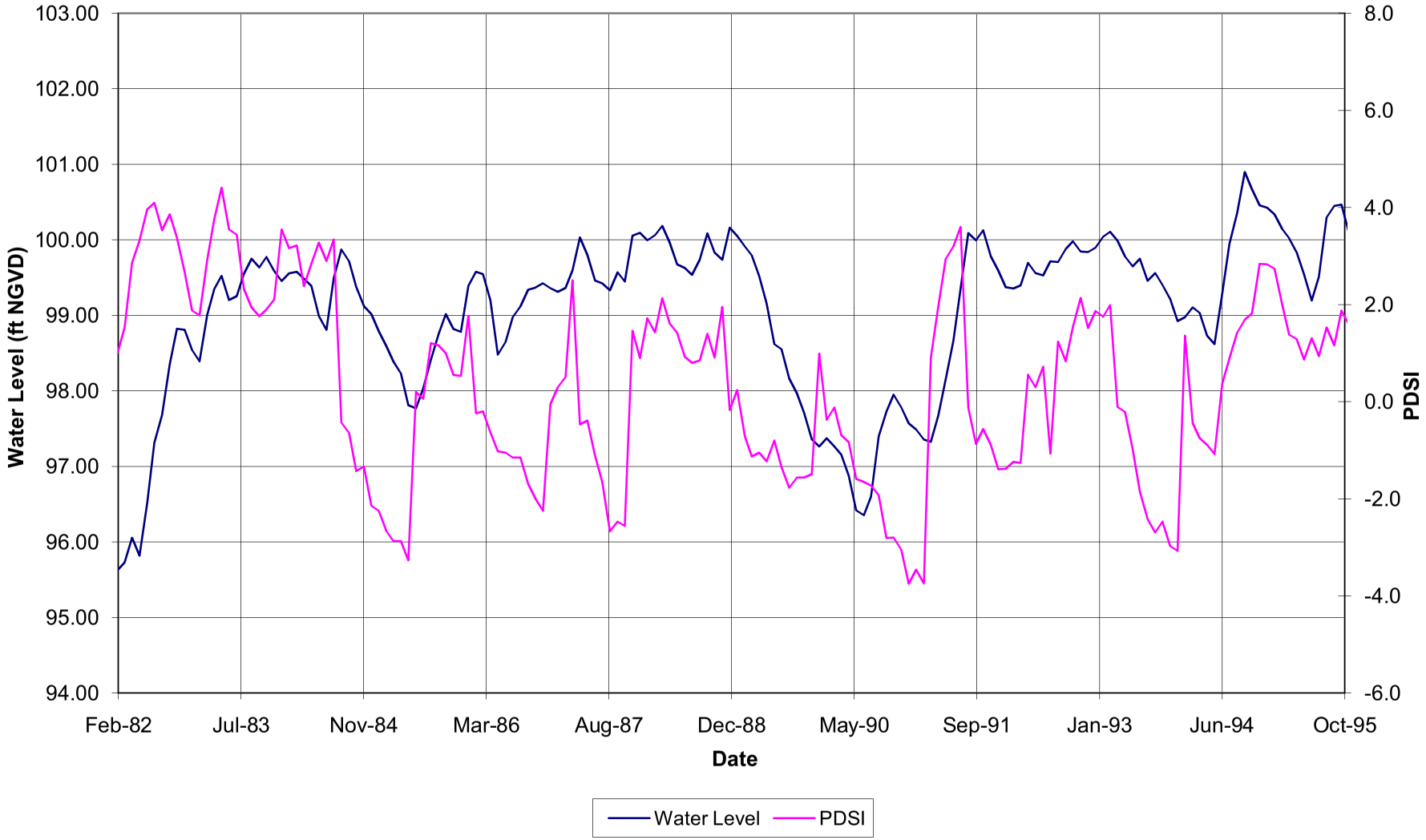
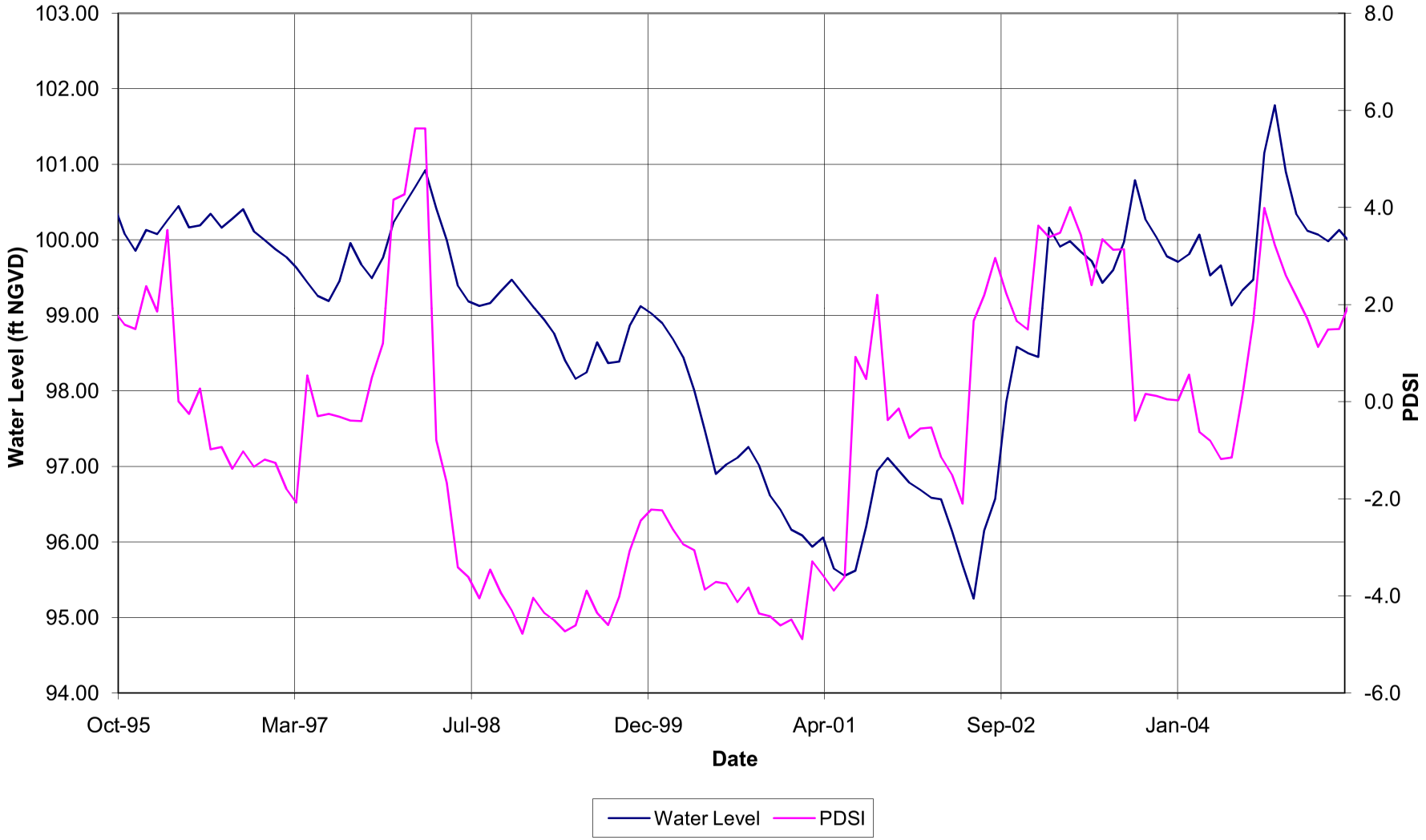


Figure D-6
Butler Lake WL vs PDSI



- When the PDSI stays persistently low, the lake levels drop or stay low. As an example consider the 3 year period from June 1998 to June 2001 (Figure D-6). The PDSI has an average value of -3.83 (severe drought); a minimum value of -4.89(extreme drought); a maximum value of -2.22 (moderate drought). During this period the lake level drops 5.3 feet from a high of 100.92 feet NGVD to a low of 95.62 feet NGVD.

- When the PDSI jumps precipitously, the lake levels follow suit. However, it is noted that there appears to be a lake level limit which is approximately 101.0 feet NGVD. This is somewhat consistent with the control level. Recall that the outfall from the system is at approximately 99.0 feet NGVD; once the outfall is fully functional, that is the lake is overtopping along the length of the natural weir, there will be a significant control exerted over the upper limit of the lake level. As an example of this type of jump consider the 7 month period from May 1945 to September 1945 (Figure D-2). The PDSI jumped 6.6 points from -3.35 (severe drought) to 3.29 (very wet).

- When the PDSI stays persistently high, the lake level tends to stay high and follow the PDSI trends. Again, it is likely that at high lake levels there would be a significant outflow from the lake system. As an example consider the 18 month period from April 1959 to September 1960 (Figure D-3). The PDSI was consistently high with an average of 3.7 (very wet); a minimum of 2.3 (moderately wet); and a high of 5.2 (extremely wet). The lake level during the same period stayed consistently high with an average elevation of 100.7 feet NGVD; a minimum of 100.3 feet NGVD; and a maximum of 101.3 feet NGVD.

As has been noted, when the lake levels are dropping there tends to be little to no control of the lowest elevation; with the possible exception of contribution from the surrounding aquifer. Conversely, when the lake levels are rising there tends to be an ultimate control which caps the increase in the range of 101.0 feet NGVD.

These observations were generalized in **Table D-1**, below. This table is based up the categorization of the lake level discussed previously; as well as a persistence of a hydrologic condition for a minimum of 6 months.

This table can provide a reasonable first cut at an alert model in which one monitors the lake level and the calculated PDSI. This will provide a reasonable estimate of the general trend of the lake.

Table D-1 – PDSI and Lake Level Relationship

PDSI Condition	Lake Level Condition			
	Very High	**High**	**Average**	**Low**
Sudden/Dramatic Rise (from "drought" to "wet")	Unlikely combination	Alert	Alert	Warning
Persistently High	Alert	Alert	Warning	Warning
Persistently Average	On Guard	On Guard	On Guard	Relax
Persistently Low	On Guard	On Guard	Relax	Relax
Sudden/Dramatic Drop (from "wet" to "drought")	On Guard	On Guard	Relax	Unlikely combination

As an example, consider the recent history of Lake Butler, from January 2000 to February 2008 as shown in **Figure D-7**. It has been asserted in this memo that by considering the PDSI it is possible to have an indication of the overall trends of the lake levels. These most recent data seem to bear this out.

If table D-1 is also considered, from January 2000 to approximately May 2001, the lake level is "low" and the PDSI is "persistently low", according to the table one can "relax" as far as flooding is concerned.

From May 2001 to September 2001, the PDSI rises precipitously thus one should be guarded, however, as the lake level started low, the stage increases approximately 1.7 feet, which is a significant rise, but not enough to cause problems.

Contrast then, with the period between May 2002 and August 2003 when the PDSI also rises precipitously and tends to stay high. In this same period, the lake level rises approximately 5.5 feet, resulting in a very high stage. This more pronounced response may be a function of a loss of soil storage during the pervious period when the PDSI also increases. This speculation regarding the loss of soil storage is borne out during the period September 2003 to June 2004, when the PDSI drops precipitously, however the reduction in lake stage is moderate staying in the high to average levels. This period would be representative of a high lake level with a persistently low PDSI, thus one should remain "on guard."

From this period, the PDSI rises precipitously from June 2004 to September 2004; the lake level rises to virtually the highest level in this period of record. Based on Table D-1, this would be a situation when one should be "alert."

It is obvious, when considering the comparative plots shown in this appendix, that there are some timing issues to consider. If there is a lot of storage in a lake system, one would have to consider a time lag between the PDSI and the lake level. Similarly,

if a system tends to have a lot of contribution from the groundwater system, the volume and rate of the contribution will also play a role in defining the lag time.

The PDSI is an indicator of the available water to satisfy various demands. When the PDSI is high, there is an excess of water; when the PDSI is low, there is a deficit of water. Thus, it is an ideal indicator for lake level increases or decreases. In general, it would necessary to invest a significant effort in determining a relationship between the lakes of interest and the PDSI. It appears that the PDSI could play in important role in water resources management.