APPENDIX B— HYDROLOGICAL ANALYSES

INTRODUCTION

In addition to extensive work conducted to understand the ecological structure and function, and most sensitive environmental values of priority water bodies, determining minimum flows and levels (MFLs) and assessing the status of waterbodies requires substantial hydrological analysis. The main purposes of the hydrological analysis to better understand the impact from groundwater pumping on lake levels and to develop a no- and current-pumping conditions long-term lake levels for MFL determination and assessment.   Several steps were involved in performing the hydrologic analysis for the Lakes Brooklyn and Geneva MFLs determination and assessment, including:

1. Review of available data
2. Long-term rainfall analysis
3. Historical Groundwater pumping impact assessment
4. Development of lake level datasets representing no- and current-pumping conditions
5. Estimating available water (freeboard or deficit).

Figure B-1 shows the flowchart for the hydrological analysis. This document describes the first four steps and associated results. Appendix D includes the description of the last step and associated results.

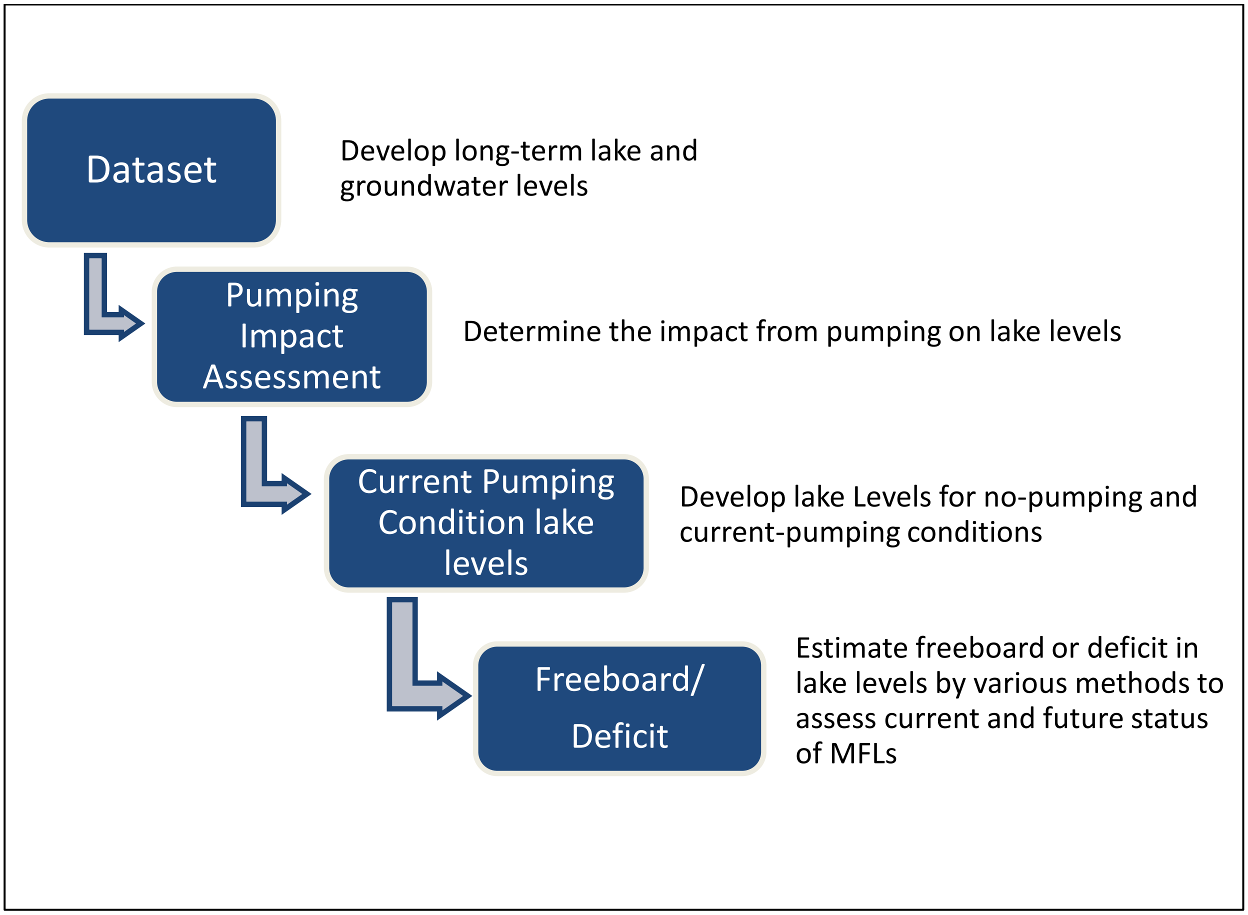

Figure B - 1. Flowchart for hydrological analysis process

SITE DESCRIPTION

Lakes Brooklyn and Geneva are sandhill/sinkhole lakes in southwestern Clay county, adjacent to the city of Keystone Heights, Florida (Figure B-1). They are among the most studied lakes in the District. Lakes Brooklyn and Geneva are part of a chain of lakes in the Upper Etonia Creek Basin (UECB). From highest to lowest elevation, these lakes include; Blue Pond, Lake Lowery, Magnolia Lake, Lake Brooklyn, Lake Keystone, Lake Geneva, and Oldfield Pond and Halfmoon Lake. Halfmoon lake is connected to Etonia Creek through Putnam and Goodson Prairies.

Alligator Creek is an intermittent stream that connects Blue pond, Lake Lowry, Lake Magnolia and Lake Brooklyn (Figure B-2). Alligator Creek provides inflows at the north shore of Lake Brooklyn and, during high water levels, outflow occurs on the southwestern shore of the lake. This outflow drains to Lake Keystone, which discharges to Lake Geneva, and ultimately to Etonia Creek and the St. Johns River (Motz et al 1991).

Surface water inflows are an important part of lake water budgets. The surface water inflow accounts for 81% of Magnolia Lake’s inflow according to Motz (2001) and 71% of Brooklyn Lake’s inflow according to Goodrich (1999). Lake Geneva has been an isolated lake since the 1970s. Inflow from Lake Brooklyn has ceased since then, except for a very brief period in 1998.

The Keystone Heights region sits at the southern end of the Trail Ridge, a formation of relatively high elevation sand hills traversing southern Georgia through northern Florida. The Trail Ridge is an extensive eolian transgressive (former coastal) dune that extends from Keystone Heights into southeastern Georgia (Force and Rich, 1989). Elevations along the Trail Ridge are amongst the highest in northeast Florida. The lakes in the UECB form a chain of decreasing elevation that fosters surface water inflow and sheet flow from the higher elevation lakes into the lower ones (Annable and Motz, 1996). Ground elevation near Keystone Heights declines southward and ranges from 205 ft NAVD88 to 100 ft NAVD88 (Gordu, 2014).

Lakes Geneva and Brooklyn are characterized by a large water level fluctuation range. Stability of lake levels in the UECB vary considerably. Of 121 Florida lakes, for which long term stage data are available, lakes within the UECB are among the most stable (e.g., Blue Pond) and among the most variable (e.g., Lake Brooklyn; Motz et al., 1991). Lake stage in the UECB correlates well with water table depth in the surficial aquifer system (SAS) (Annable 1996). The degree of connection to the aquifer is inconsistent between lakes (Clark, 1964). The connection between the UFA and lakes of the UECB results from sinkhole formation (Schiffer, 1998, Kindinger, 1999). Numerous collapse features lacking restrictive clay horizons have been identified within Lake Brooklyn (SDI 1992). Several field investigations were performed using seismic reflection surveys by Kindinger et al. (1994 and 1998) in the area, which revealed many sinkhole features in the lakes.

A thick, low-permeability confining layer exists throughout the basin, limiting vertical leakage to the UFA. Yobbi & Chappell (1979) studied the hydrology of the UECB by analyzing recharge and relationship between the rainfall and lake and groundwater levels. In this study, net average recharge to the UFA over the entire basin was estimated at 14 to 17 inches per year using water budget calculations. However, many lakes within this basin are sinkhole lakes and have significant connection to the UFA, allowing a significant amount of recharge to the UFA through vertical leakage. Consistent with this general pattern, Epting et al. (2008) classified Lakes Brooklyn and Geneva as isolated / intermittent sinkhole lakes with high leakage to the UFA. This high degree of connectivity between lakes and the UFA result in these lakes being an important recharge source to the UFA (Merritt, 2001, Bentley, 1977). Deevey (1988) estimated leakage from Lake Brooklyn to the UFA at a long-term average rate of approximately 36 inches per year from 1954 to 1986. The seepage from Lake Brooklyn can be very high during wet seasons. Hydraulic seepage meter tests were performed in Brooklyn Lake in a study by Hirsch & Randazzo (2000) to quantify the lake bottom seepage and analyze the factors influencing the lake seepage. The average recharge from Lake Brooklyn to the UFA was calculated in September through November 1997 at a high rate of approximately 100 inches/year. The recharge from Lake Geneva to the UFA, however, is estimated to be relatively modest. Deevey (1988) estimated leakage from Lake Geneva to the UFA at a long-term average rate of approximately 13 inches per year from 1954 to 1986. This indicates that Lake Brooklyn has much higher connection to the UFA than Lake Geneva does.

The UFA is confined and exhibits an elevated potentiometric surface (Annable et al., 1996) in this region. This confinement can restrict recharge from the SAS in areas surrounding the lakes while the lakes themselves act as conduits of infiltration. Thus, the UFA levels and Lakes Brooklyn and Geneva levels strongly influenced each other. Significant recharge to the UFA through these lakes in conjunction with relatively low transmissivity of the UFA has caused a doming of the potentiometric surface in this area.

The UFA horizontal flow direction is generally radially out to the north, west, and east in the study area. However, during dry years, it can be southeast due to impact of low lake levels on the UFA. The SAS horizontal flow direction is generally toward nearby lakes and overall is south in the study area. Vertically, the SAS flow direction is down.

Groundwater is pumped mostly from the UFA for public supply, agriculture, and mining near lakes. In addition to permitted users, a significant number of domestic self-supply water users are near the lakes.

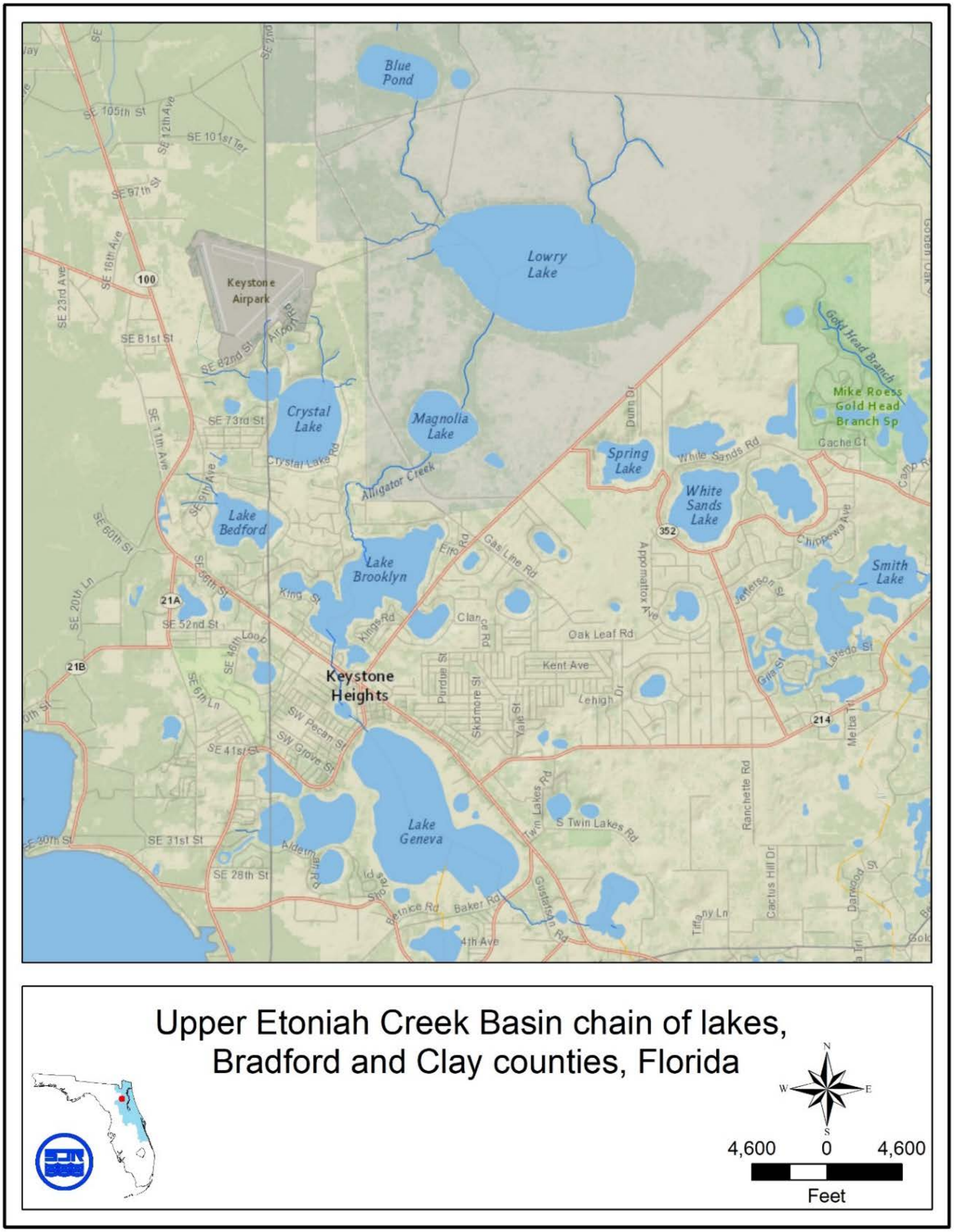

Figure B-2. Site Location Map

REVIEW OF AVAILABLE DATA

Rainfall

A composite rainfall dataset was compiled for Lakes Brooklyn and Geneva, because there is no rainfall gage near Keystone Heights with a long-term rainfall record (Figure B-3). The composite rainfall record was made from the following gauges: several Gainesville NOAA gauges from 1874 to 1989; Lake Brooklyn gauges from 1989 to 1991; Lake Geneva gauges with some additions from Lake Brooklyn from 1991 to 2001; Lake Lily gauges in 2002; and Gold head State Park gauges from 2002 to 2020. Over the long-term record, annual rainfall has ranged from 32.8 to 73.3 inches, and average annual rainfall over the POR is 50.8 inches, with a standard deviation of 8.8 inches.

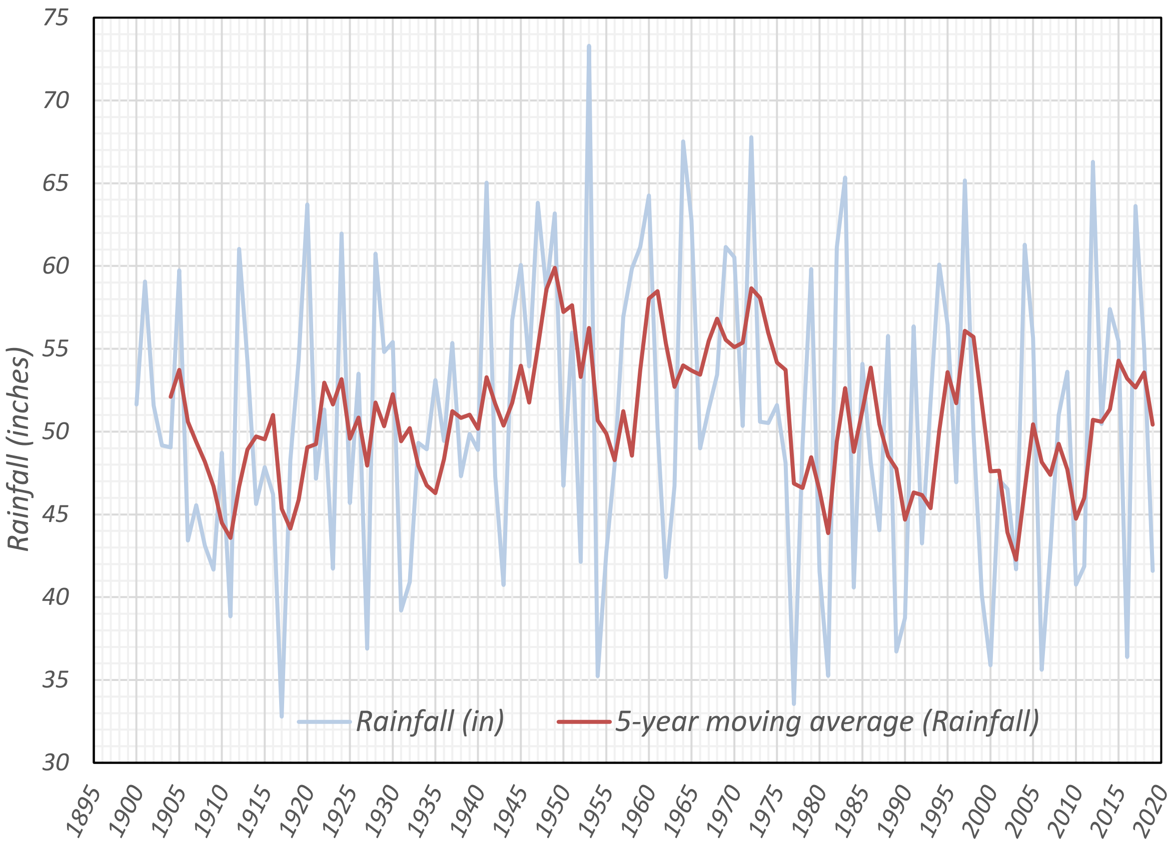

Figure B-3. Annual average rainfall

Water Level

The water level data for both lakes were retrieved from the SJRWMD database. Table B-1 summarizes the available dataset.

Figures B-4 and B-5 show the number of available water level records for Lakes Brooklyn and Geneva respectively. Figure B-6 shows observed water levels for Lakes Brooklyn and Geneva.

Table B-1. Summary of available water level data

Station Number	Station Name	Water Level Period of Record*
3360373	Lake Brooklyn at Keystone Heights	7/17/1957 - Current
11590497	Lake Geneva at Keystone Heights	7/1/1957 –Current

*Before 1957, there was only one measurement available which was in July 1948

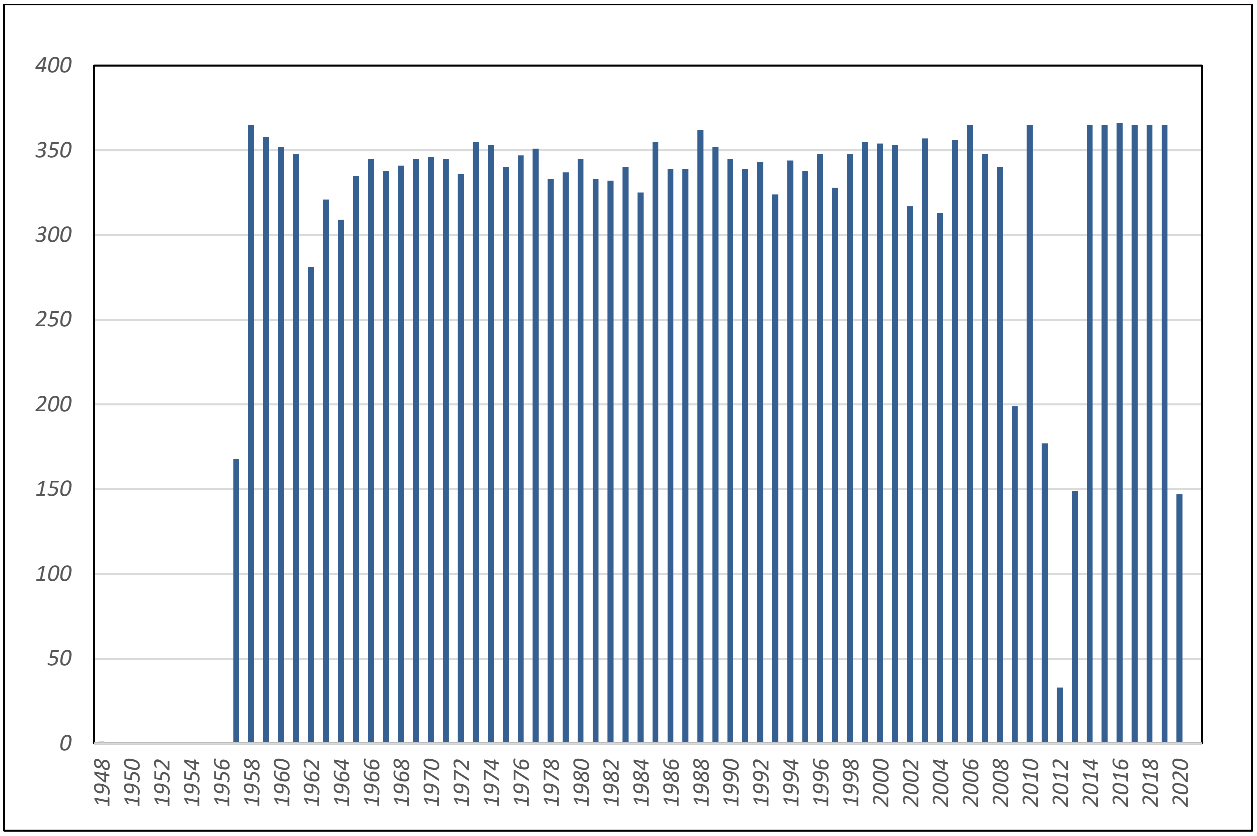

Figure B-4. Lake Brooklyn number of available water level records per year

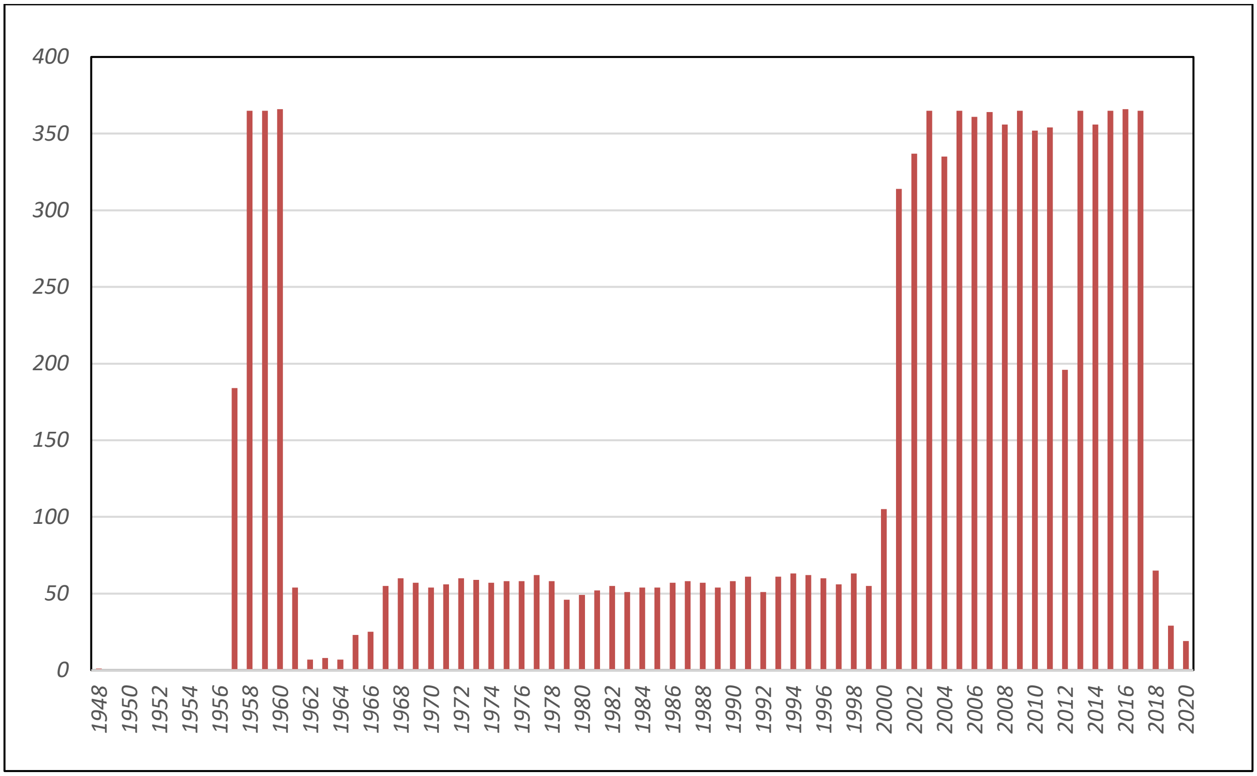

Figure B-5. Lake Geneva number of available water level records per year

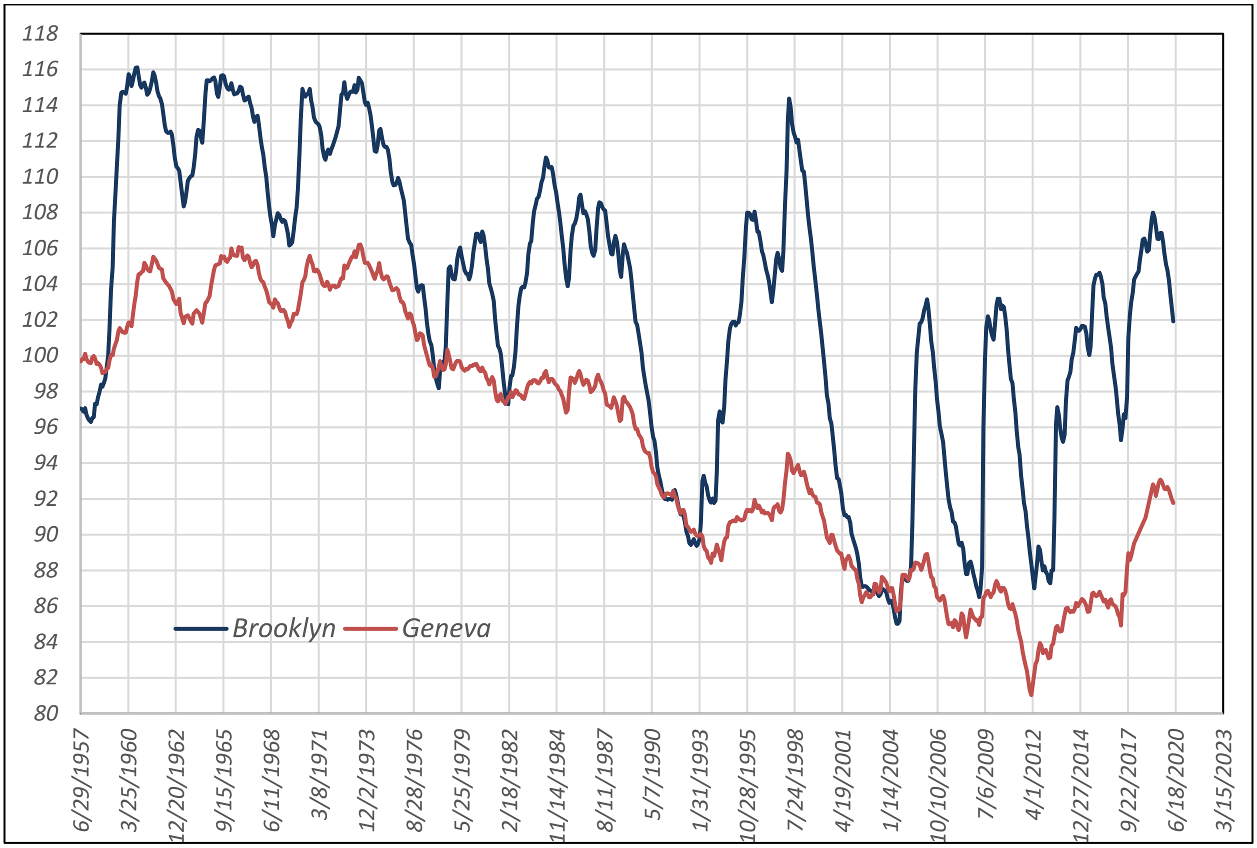

Figure B-6. Lakes Brooklyn and Geneva Water Levels

Lake Brooklyn's hydrograph reflects the influence of periodic surface water inflow and a high connectivity with the UFA. Lake Geneva has a markedly different hydrograph shape, relative to Lake Brooklyn. This is because Lake Geneva is less connected to the UFA and does not receive any surface flows from upstream waterbodies during long periods of low rainfall. The stage fluctuations for Lake Brooklyn (31.4 feet) and Lake Geneva (25.5 feet) are among the largest in Florida. Only 4 percent of 121 Florida lakes studied by Motz et al. (1991) exceeded a 20 feet range of fluctuation.

A summary of water level statistics for both lakes, from 1957 to 2019, is provided in Table B-2. The maximum observed water elevation (116.4 feet, NAVD88) for Lake Brooklyn was recorded in October 1960, weeks after Hurricane Donna passed over Florida. The minimum observed water elevation (85.0 feet, NAVD88) for Lake Brooklyn was recorded in July 2004. The maximum observed water elevation (106.4 feet, NAVD88) for Lake Geneva was recorded in July 1973. The minimum observed water elevation (80.9 feet NAVD88) for Lake Geneva was recorded in June 2012.

Table B-2. Water level (WL) summary statistics for Lakes Brooklyn and Geneva; elevations in NAVD88

Descriptive Statistics	**Brooklyn WL**	**Geneva WL**
Mean	103	95.2
Standard Error	0.1	0.0
Median	104.4	97.2
Standard Deviation	8.6	7.2
Range	31.4	25.5
Minimum	85.0	80.9
Maximum	116.4	106.4

The review of available data indicated that there was sufficient data available from 1957 to present to be used for the MFL analysis. However, because a complete set of regional groundwater pumping data was not available for 2019 and 2020 at the time of the analysis, only the data from 1957 to 2018 was included.

ANALYSIS OF WATER LEVEL DECLINES

Significant downward trends have been observed in Lakes Brooklyn and Geneva water levels over the past 40 to 50 years. The water levels of lakes Brooklyn and Geneva declined approximately 8 and 12 feet, respectively since 1960s. The magnitudes of average water level declines were estimated based on smoothed long-term average levels. Smoothing was required due to the presence of large fluctuations in water levels. Based on spectral analysis, the longest dominant periodic cycles in water levels were determined to be 12 and 15 years for Lakes Brooklyn and Geneva, respectively. Thus, water levels of the lakes were smoothed by loess smoothing technique using 12-year window for Lake Brooklyn and 15-year window for Lake Geneva to estimate the amount of water level decline occurred over the past 40 to 50 years. (Figure B-7 and B-8).

The primary reason why Lake Geneva declined more than lake Brooklyn is that Lake Brooklyn receives a significant amount of flows from the upstream lakes via Alligator Creek and discharges to Lake Geneva through Keystone Lake only during wet periods. However, Lake Geneva has not received any discharge from Brooklyn Lake since 1970s except for a brief period in 1998.

To help with establishing MFLs, the influences of climate (i.e. long-term rainfall variation) and regional groundwater pumping on lake levels were analyzed to understand the primary cause(s) of lake level declines.

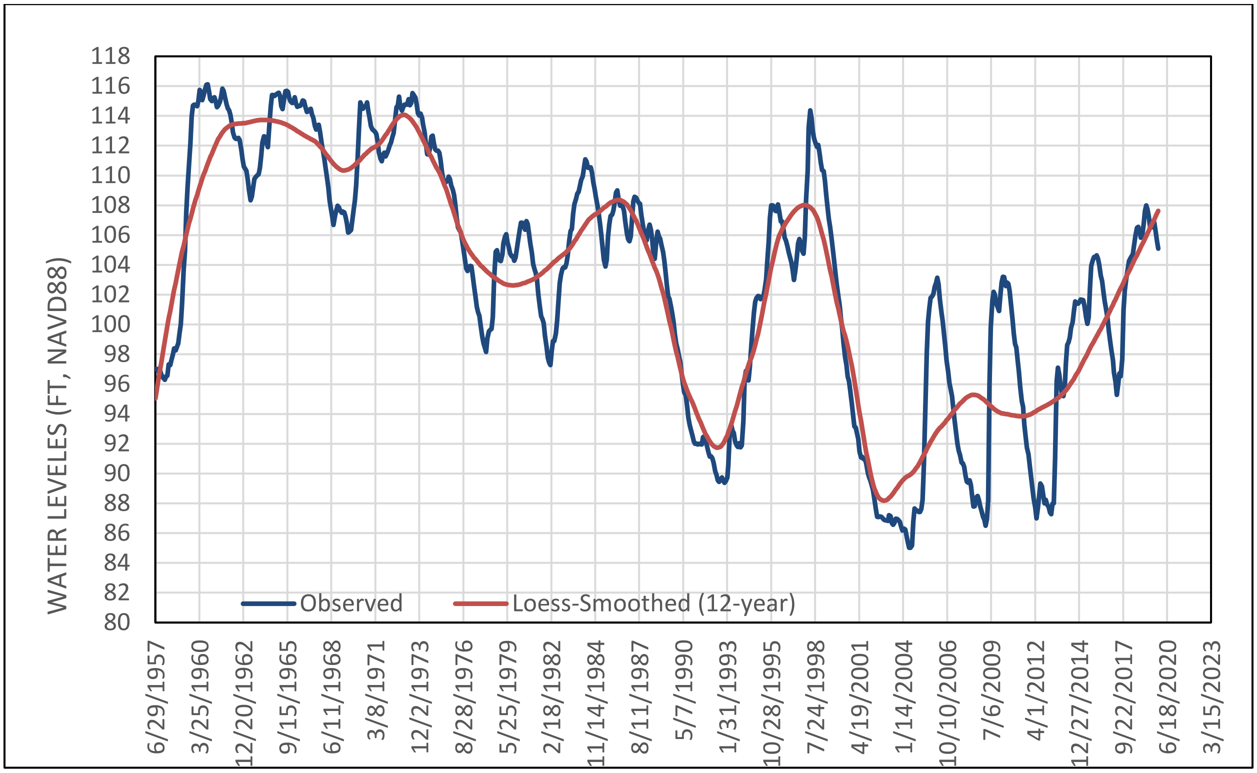

Figure B-7. Lake Brooklyn water levels

Figure B-8. Lake Geneva water levels

Long-term Rainfall Analysis

Analysis of declines in lake levels without understanding the influence of climate (i.e. climatic cycles) on lake system would be difficult. According to Florida Climate Institute, the climatic cycles such as El Nino Southern Oscillations (ENSO), Atlantic Multidecadal Oscillation (AMO) and the Pacific Decadal Oscillation (PDO) have the strongest influence on Florida’s climate variability (Kirtman et al., 2017).

ENSO cycles typically range from 2 to 7 years, PDO cycles typically range from 15 to 25 years and AMO cycles typically range 60 to 70 years (Schlesinger and Ramankutty 1994, Obeysekera et al. 2011 and Kuss and Gurdak 2014). Because of strong relationships of short and long-term climatic cycles such as ENSO and AMO to rainfall, river flows and groundwater levels in Florida (Enfield et al. 2001; Kelly 2004; Kuss and Gurdak 2014), the relationship of the climatic cycles and rainfall with lake level declines was investigated.

AMO is based on the sea surface temperature of the North Atlantic Ocean. The National Oceanic and Atmosphere Administration (NOAA) indicates that rainfall in central and south Florida becomes more plentiful when the Atlantic Ocean is in its warm phase, and droughts are more frequent in the cool phase. Figure B-9 shows the warm and cool phases of the AMO.

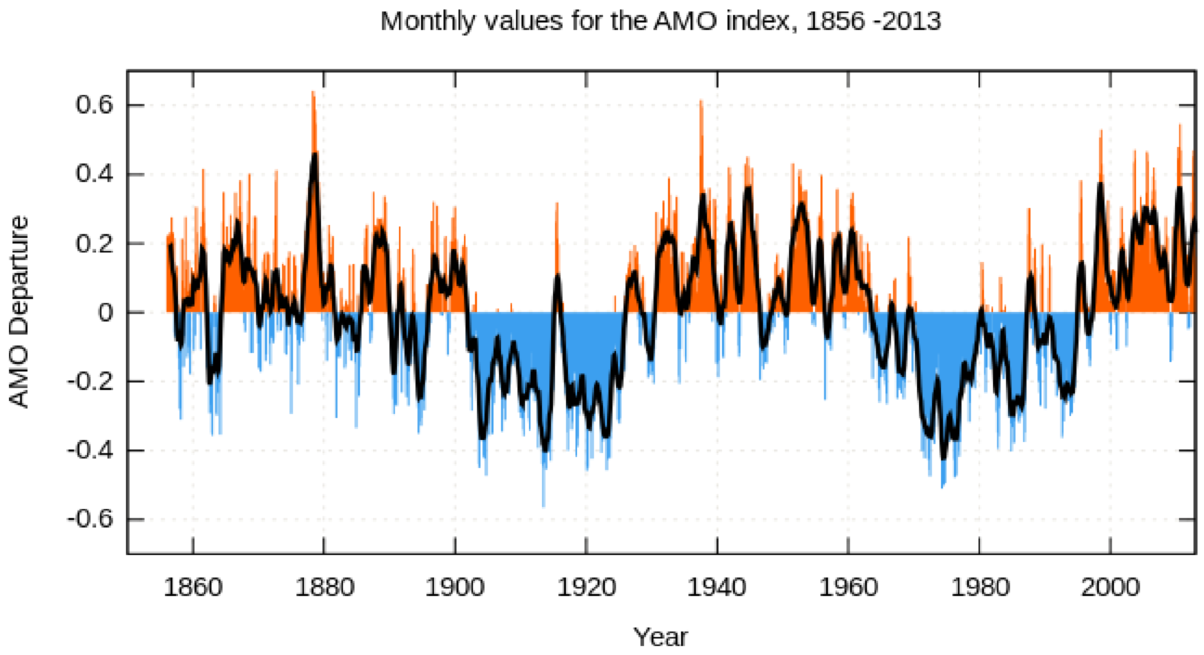

Figure B-9. Atlantic Multidecadal Oscillations

Figure B-10 shows annual rainfall compiled for Keystone Heights region and polynomial trendline. Polynomial trend was provided to better understand the changes in long-term average rainfall. The trend line shown in the figure indicates a potential long-term (about 70 to 80-year) rainfall cycle in which the period from 1945 to 1965 was generally very wet and the periods from 1910 to 1920 and from 1995 to 2005 were generally very dry. The wet and dry periods in long-term rainfall pattern seems to fairly coincide with the warm and cool phases of AMO shown in Figure B-8.

Long-term lake level trends were examined to determine if there is any relationship between the rainfall and climatic cycles and the lake levels. Figure B-10 and B-11 show the Lakes Brooklyn and Geneva monthly levels and polynomial trendlines. Long term trends in Lakes Brooklyn and Geneva levels indicate a cyclic trend like rainfall and AMO cycle. Lake levels were high during the wet period (1945 to 1965) and were low during the dry period (1995 – 2005).

A close examination of the lake level trends showed that lake levels respond slowly to rainfall pattern. As shown in Figure B-9, there has been an increasing trend in rainfall in the region since 2002. A similar increasing trend can be observed in lake levels (Figures B-11 and B-12). However, the increasing trend in Lake Brooklyn levels seems to begin in 2004 - 2005 whereas the increasing trend in Lake Geneva levels seems to begin in 2013 – 2014. It appears that lakes respond to rainfall with a delay of 2 to 10 years. This could be attributed to the effect of storage in the regional aquifer and watershed and the delay in upstream flows reaching the lakes. It is not unexpected to see that Lake Brooklyn responds much quicker than Lake Geneva to recent increase in rainfall trend because Lake Brooklyn has been receiving a significant amount of surface flows from upstream lakes whereas Lake Geneva has been receiving none and mostly driven by groundwater levels.

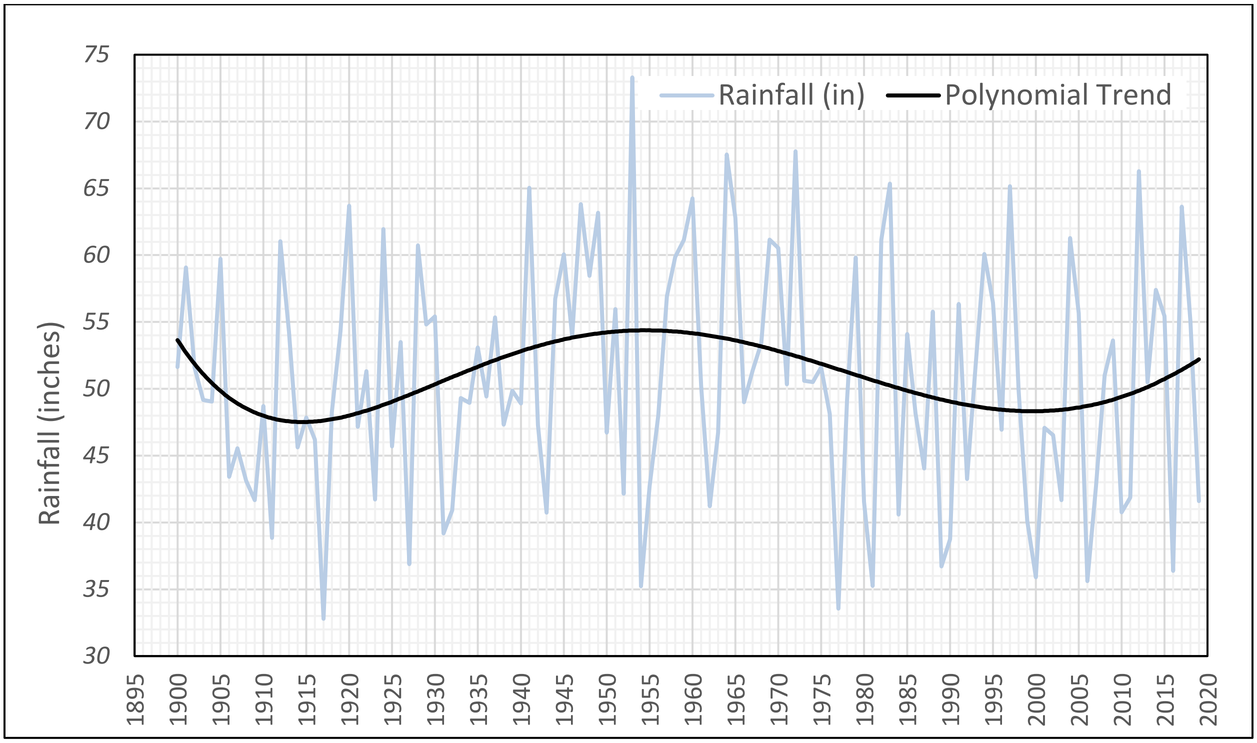

Figure B-10. Long-term rainfall pattern

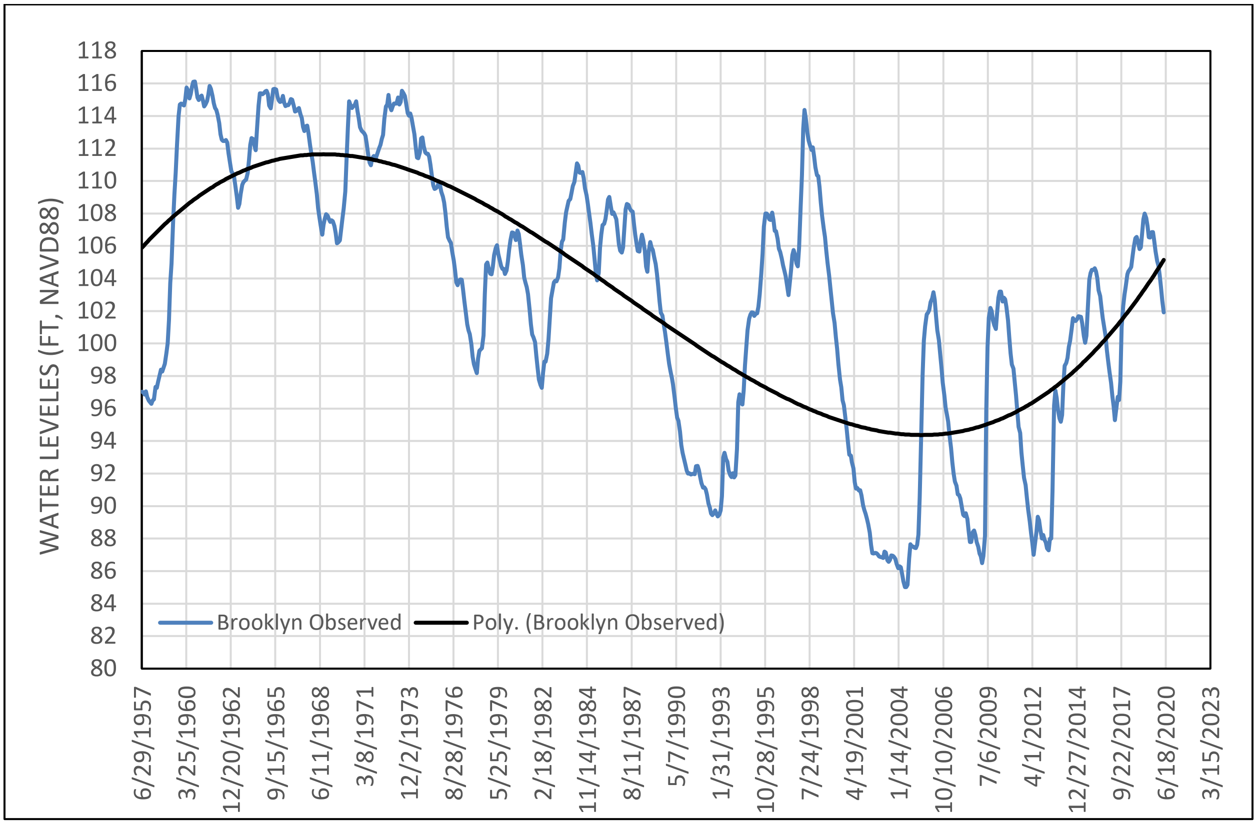

Figure B-11. Long-term trend in Lake Brooklyn levels

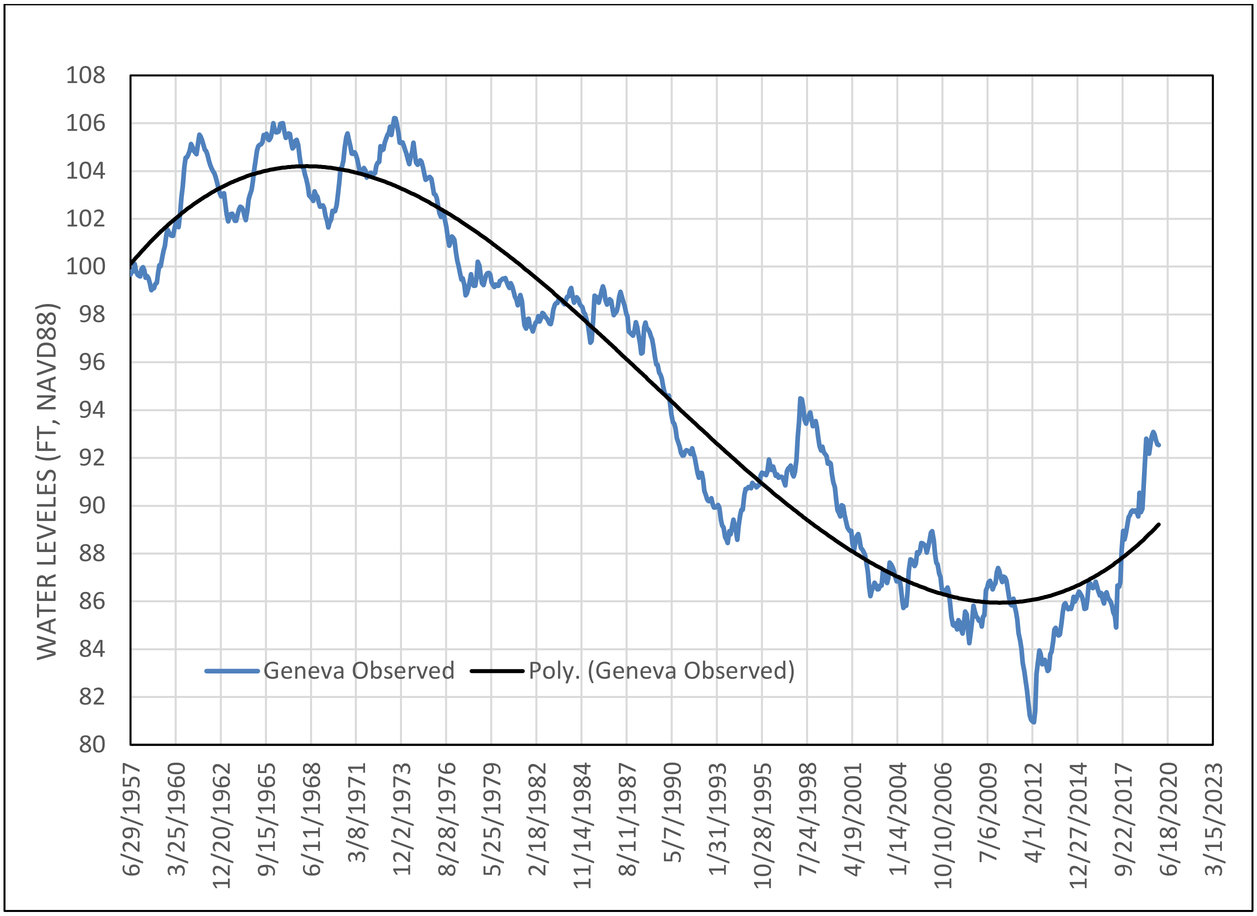

Figure B-12. Long-term trend in Lake Geneva levels

Located within an area of thick sand deposits and being highly connected to the UFA make Lakes Brooklyn and Geneva sensitive to prolonged periods of below average rainfall. Because of this physiographic setting, cumulative (i.e., back to back) years of below average rainfall makes the landscape very dry, contributing to reduction in surface water inflows and recharge to groundwater, causing declines in groundwater levels. This results in lower lake levels. From the 1930s to the early 1970s, there was a cumulative rainfall surplus of approximately 150 inches (Figure B-13). From the early 1970s to 2012, there was a rainfall deficit of approximately 105 inches. This period of reduced surface water inflows and recharge corresponds to a period of water level decline at Lakes Brooklyn and Geneva. This suggests that there is a close relationship between back-to-back years of below or above average rainfall and water levels at these lakes. This also suggests that it may take many years of above average rainfall to offset the effect of prolonged periods of drought on these lakes.

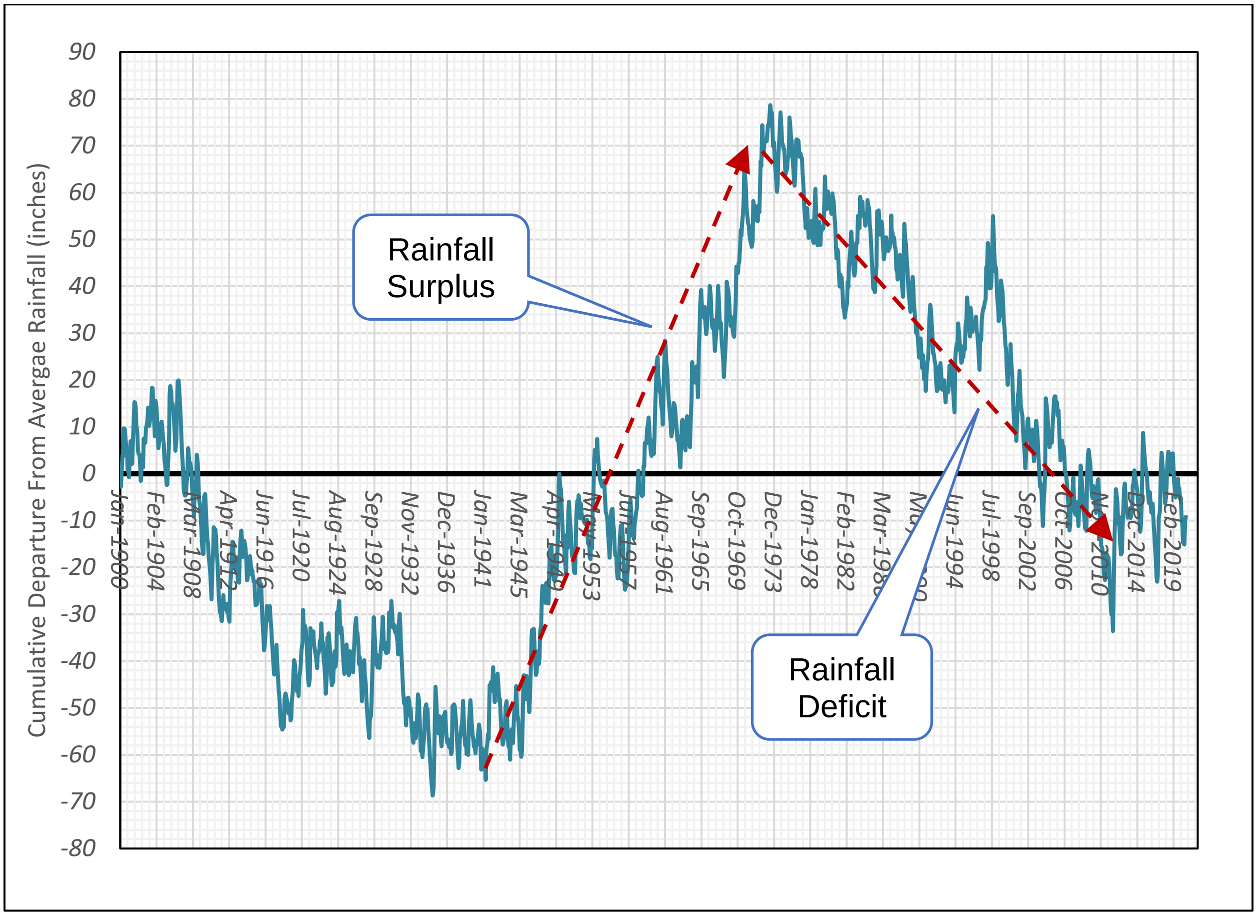

Figure B-13. Cumulative departure from average rainfall

Standardized Precipitation Index (SPI) results also support these findings. The SPI is a widely used index for characterizing meteorological drought on a range of timescales. On short timescales, the SPI is closely related to soil moisture, while at longer timescales, the SPI can be related to groundwater and reservoir storage (Keyantash, 2018). An SPI graph was developed using a composite of Gainesville and local Keystone Heights rainfall data (Figure B-14). As shown in the figure, a wet period (blue areas) was observed from the late 1940s to the late 1970s, followed by several severe dry periods (red areas) after the late 1970s. The latter is the same period when water levels at Lakes Brooklyn and Geneva declined significantly.

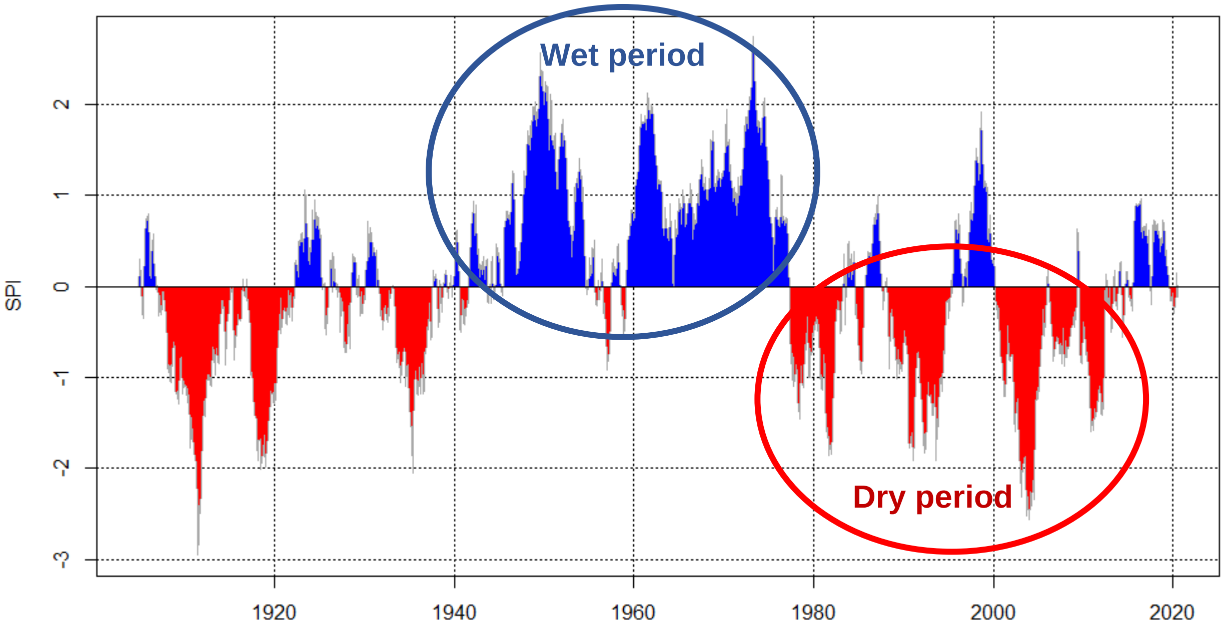

Figure B-14. Long-term 60-month Standard Precipitation Index

A comprehensive body of literature also corroborates that there is a strong correlation between lake levels and rainfall with increasing levels correlated with above average annual rainfall, and declining water levels correlated with below average annual rainfall (Yobbi and Chappell 1979, Motz et al. 1991, Robison 1992, Motz et al. 1994, Motz et al. 1995). Clark et al. (1963) conducted a study focusing on Brooklyn Lake in 1963 after the Brooklyn Lake water level declined approximately 20 feet in 3 years. The purpose of the study was to determine the reason for the steep decline in the lake levels. A water budget analysis was performed, and the study concluded that more than 3 years of drought in conjunction with high rates of leakage caused the 20 feet of declines in lake levels.

Historical Groundwater Pumping Impact Assessment

Lakes Brooklyn and Geneva have developed from collapse or subsidence sinkholes, creating a high degree of connection to the UFA. This makes them sensitive to any adverse changes in the groundwater system. In addition, because these lakes are located at the intersection of several groundwater basins in North Florida, they are also vulnerable to potential impact from regional groundwater pumping. Therefore, potential impact to Lakes Brooklyn and Geneva not only from local pumping but also from regional pumping were assessed.

Groundwater Use

To estimate the impact on lake levels from pumping, monthly groundwater use data was compiled for Alachua, Clay, Duval, Putnam and Bradford counties from 1957 to 2018 (see Figure B-15). The pumping in 2019 and 2020 was not included because complete datasets of 2019 and 2020 pumping were not available at the time of analysis. The five counties were selected because the groundwater use in these counties could potentially impact the groundwater levels near lakes Brooklyn and Geneva most based on regional groundwater modeling efforts such as Northeast Florida (NEF) and North Florida Southeast Georgia (NFSEG) regional groundwater models. It should also be noted that the groundwater pumping within five counties was only used as a proxy to understand the variation of regional groundwater pumping from 1957 to 2018. The impact of groundwater pumping on lake levels were assessed based the entire groundwater pumping within the NFSEG model domain.

The data included actual groundwater use reported by the consumptive use permit holders and estimated groundwater use for domestic self-supply and small agricultural use. As shown in Figure B-15, the total groundwater use in these counties reached its highest in 1988 (323 mgd) and declined until 1994. It increased again till 2006 (302 mgd) and has declined about 20% after 2006. The average groundwater use over the past five years (2014 – 2018) is approximately 238 mgd, which is similar to groundwater use in the early 1970s.

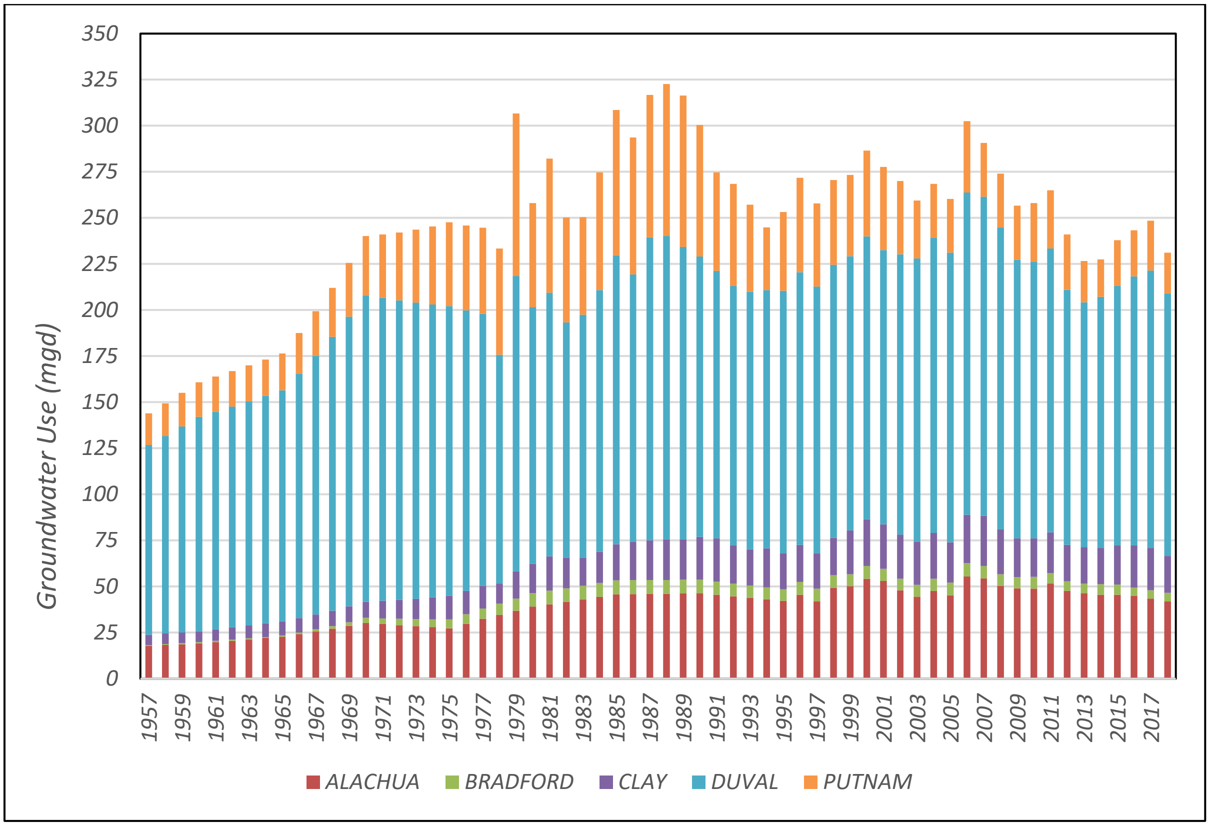

Figure B-15. Estimated historical groundwater uses in Alachua, Bradford, Clay, Duval and Putnam Counties

Groundwater Modeling

Keystone Heights Subregional Transient Model

The hydrologic system of Lakes Geneva and Brooklyn is very complex. Both lakes have strong interaction with the UFA and are heavily dependent on the flows from upstream lakes. Thus, a model simulating both groundwater and surface water system and their interaction was needed to better understand the relationship between the lakes and the groundwater system and the influence of climate and groundwater pumping. As a result, Keystone Heights subregional transient model (KHTM v1.0) was initially developed by Tetra Tech in 2017 and later updated and called KHTM v2.0 (SJRWMD, 2020). See attached for details regarding the updates to the KHTM. KHTM was developed using MODFLOW-NWT including lake and stream packages so that it can fully simulate the interaction between the groundwater and surface water features such as lakes and streams as well as change in lake levels and stream flows due to change in rainfall, ET and pumping. KHTM was calibrated to match monthly groundwater and lake levels as well as stream flows from 1995 to 2014. The model was later extended to simulate monthly water levels and flows up to 2018 and back to 1957.

North Florida Southeast Georgia Groundwater Model

Although KHTM v2.0 is fully capable of simulating local groundwater pumping near Lakes Brooklyn and Geneva, it cannot simulate the effect of regional groundwater pumping due to its limited model domain. It is common modeling practice to develop a refined local model such as KHTM v2.0 for a limited but critical area of concern and use a regional model to adjust lateral boundary conditions for simulation of regional groundwater pumping and recharge effects. Therefore, North Florida and South Georgia regional groundwater model (NFSEG) was used in conjunction with KHTM v2.0 for groundwater pumping impact assessment. SJRWMD and SRWMD have been jointly developing NFSEG model encompassing most of North Florida and South Georgia and some parts of South Carolina. The latest version of the model (NFSEG v1.1) has recently been completed (Durden et al. 2019). NFSEG v1.1 is a steady-state model which was calibrated to match average water levels and flows in 2001 and 2009.

Figure B-16 shows the boundaries of both NFSEG and KHTM models.

Estimated historical impact on lake levels

NFSEG v1.1 and KHTM v2.0 were used to estimate the impacts of groundwater pumping on lake levels. The KHTM v2.0 simulates monthly lake levels from 1957 to 2018. The NFSEG v1.1 was used to adjust the KHTM v2.0 lateral boundary conditions, which were set as general head boundaries (GHBs), to simulate the effects of regional pumping on lake levels.

Because the NFSEG v1.1 is a steady-state model, it does not produce drawdowns resulting from regional pumping on a monthly time step. To overcome this issue, a methodology was developed to estimate the impact of regional pumping on lake levels for every month from 1957 to 2018.

The first step was to adjust all monthly time steps of lateral boundaries of the KHTM using the same drawdown set obtained from the steady-state simulation of NFSEG model. This means that KHTM would simulate the same regional pumping condition for the entire simulation period which was from 1957 to 2018. Because the NFSEG model was calibrated under 2001 and 2009 hydrologic and pumping conditions only, by removing all the pumping and human-induced recharge wells in the model, two sets of drawdown estimates were obtained. The first set represented the total drawdown resulted from 2001 pumping condition and the second set represented the total drawdown resulted from 2009 pumping condition.

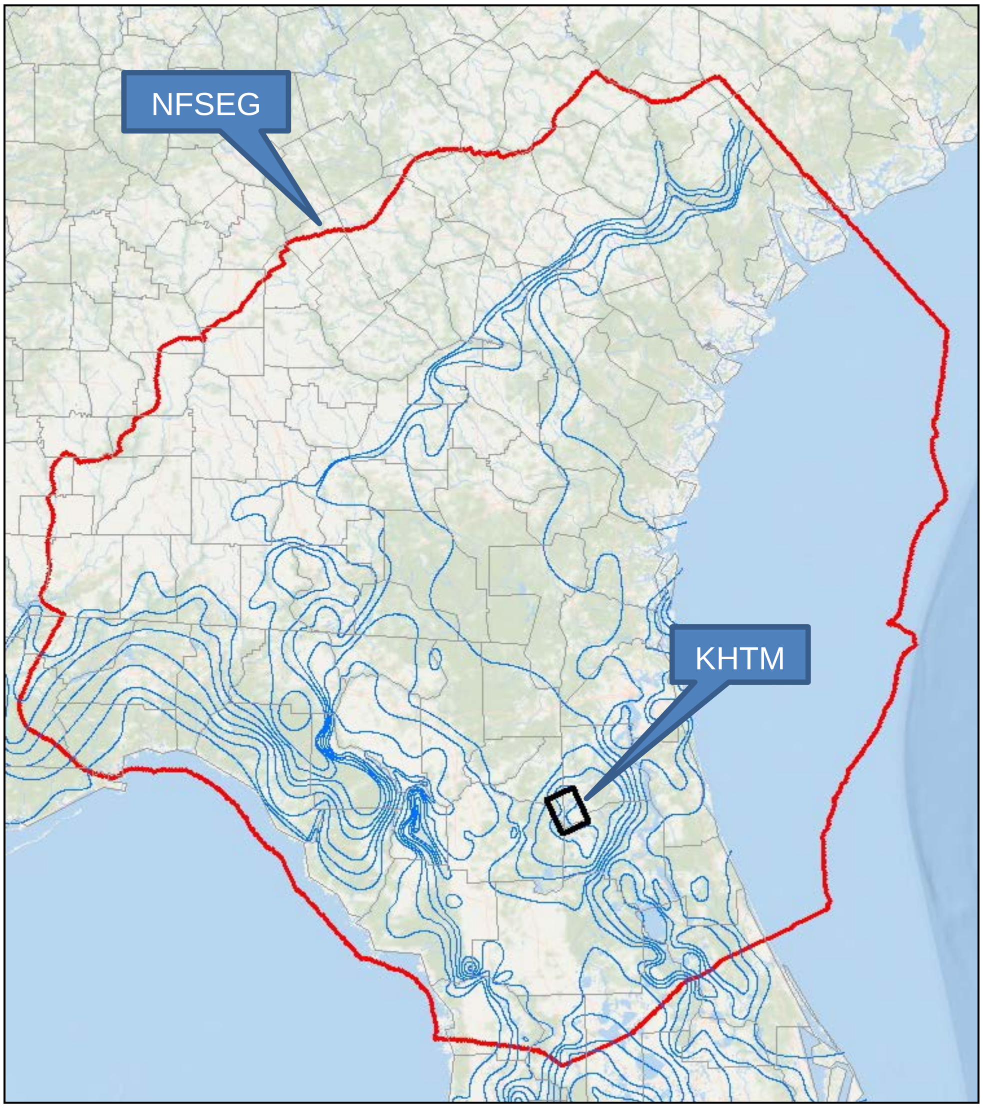

Figure B-16. NFSEG and KHTM model boundaries

Then, two KHTM simulations were performed. The first simulation was performed by adjusting all monthly lateral boundary elevations using the same 2001 drawdown dataset and the second simulation was performed by adjusting all monthly lateral boundary elevations using the same 2009 drawdown dataset. The adjustment was calculated for each GHB cell and applied to GHBs on cell-by-cell basis. The UFA elevations along GHBs were increased by from approximately 5 to 11 feet for 2001 pumps-off simulation and from approximately 4 to 9 feet for 2009 pumps-off simulation. Because regional pumping in 2001 was higher than that in 2009, the amount of adjustments applied to GHBs are higher for 2001 pumps-off simulation (Figure B-17).

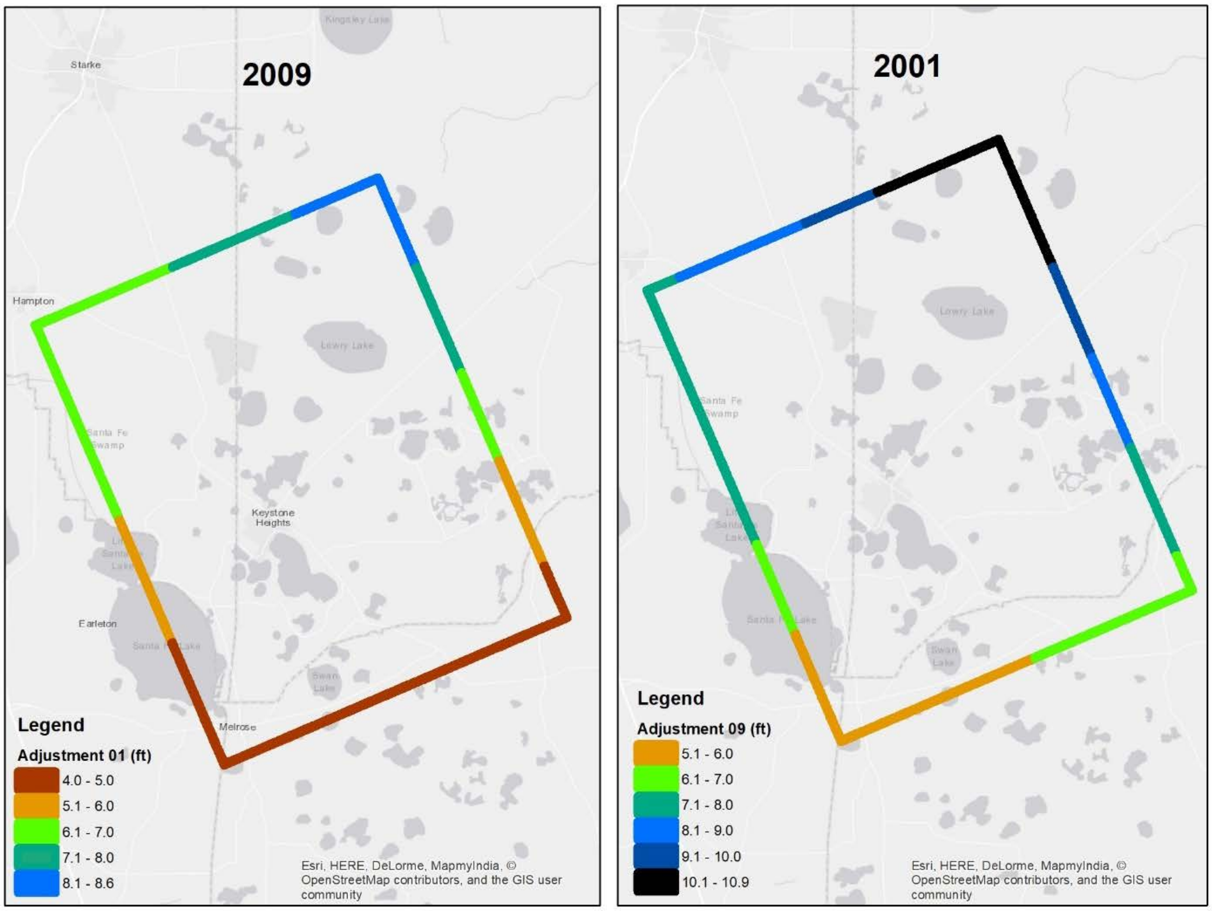

Figure B-17. KHTM GHB adjustment based on NFSEG 2001 and 2009 pumps-off simulations

It should be noted that the pumping in KHTM was not removed in these simulations to prevent any possible “double-count” since all pumping within NFSEG model domain including those near Keystone Heights were already removed in the NFSEG pumps-off simulations mentioned above. As a result, two lake level time series were generated for each lake. Figures B-18 and B-19 show the simulated levels of lakes Brooklyn and Geneva respectively. Because the regional pumping in 2001 was higher than the regional pumping in 2009, the simulated lake levels for 2001 pumps-off condition is higher than those for 2009 pumps-off condition.

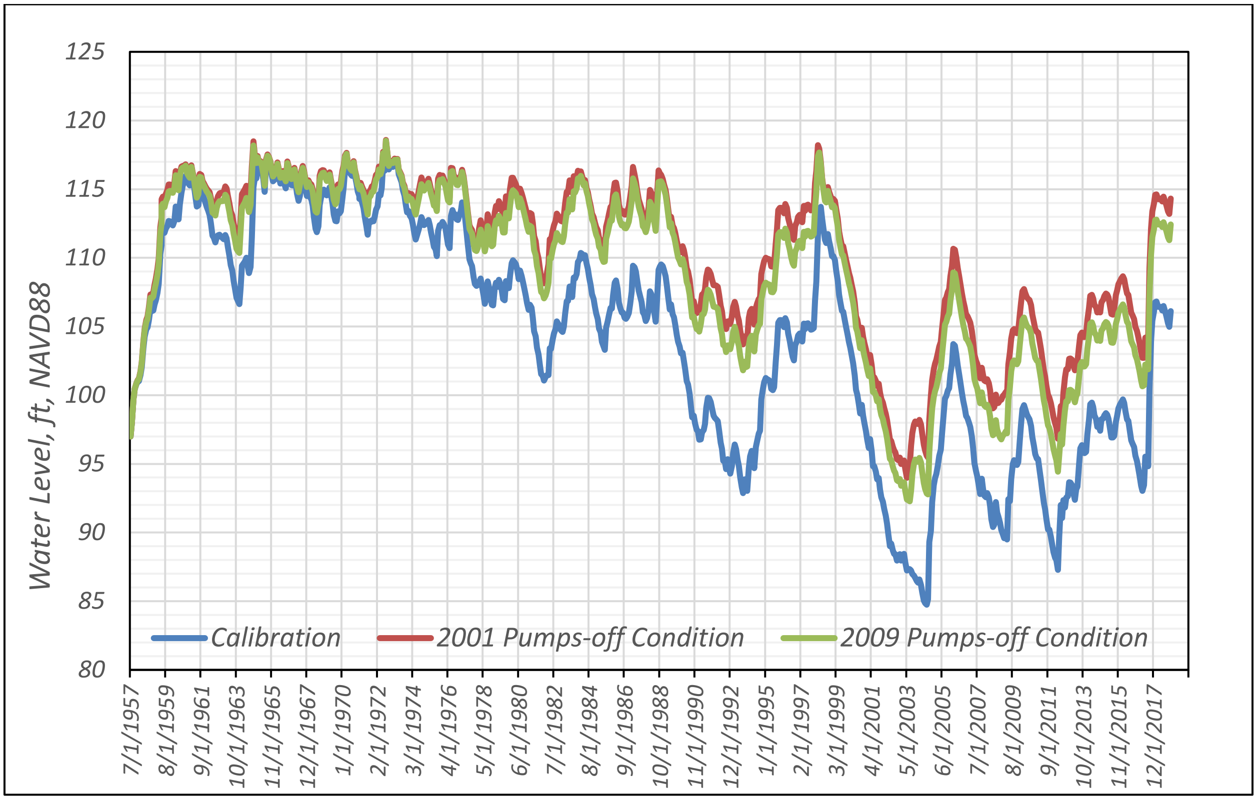

Figure B-18. Simulated Lake Brooklyn levels generated from KHTM

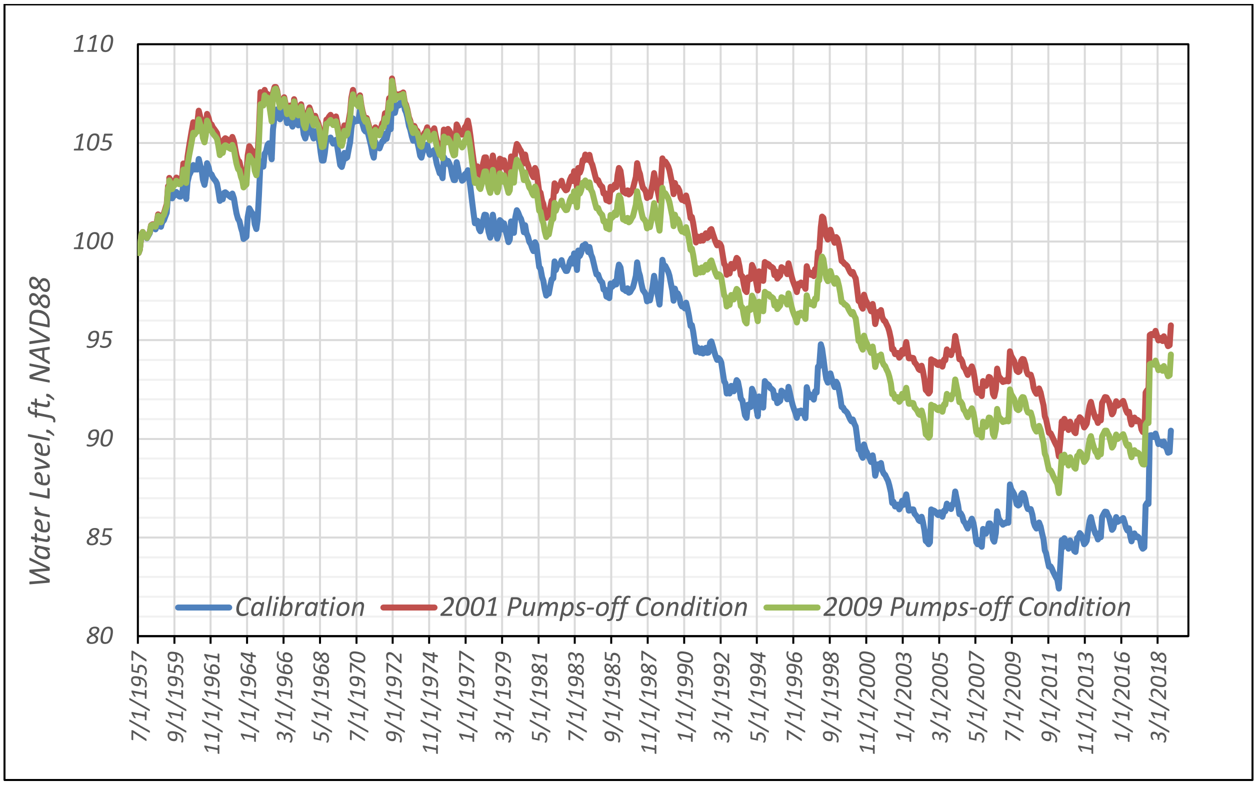

Figure B-19. Simulated Lake Geneva levels generated from KHTM

Because regional pumping has been changing over time as shown in Figure B-15, the next step was to develop a linear relationship between the regional groundwater pumping and change in simulated lake levels to accurately reflect the effect of change in pumping over time on lake levels.

To develop the relationship, the following NFSEG/KHTM simulations were performed so that a wide range of pumping conditions can be included in the regression analysis.

- 2001 pumping
- 2001 pumping decreased by 25%
- 2001 pumping decreased by 50%
- 2001 pumping decreased by 75%
- 2001 pumping increased by 25%
- 2001 pumps-off
- 2009 Pumping
- 2009 pumping decreased by 25%
- 2009 pumping decreased by 50%
- 2009 pumping decreased by 75%
- 2009 pumping increased by 25%
- 2009 pumps-off

Linear relationships were developed using the output of KHTM model for each month separately. KHTM is a transient model and simulated a variety of hydrologic conditions including dry, average and wet conditions. Because linear relationships were developed monthly, each relationship will be unique to the hydrological condition (dry, wet, or average) it was derived from. Since each linear relationship was used to make predictions only for the month which it was derived from, potential effect of non-linearity due to different hydrologic conditions was minimized. After review of the simple linear regression developed for each month, we noticed that adding Brooklyn lake levels as another predictor would greatly improve the fit between the model-simulated and the predicted lake level changes due to pumping. Therefore, we built a multiple linear regression using both pumping and lake Brooklyn levels as predictors for each month.

The following equation was used to develop a multiple linear regression for each month for each lake from 1957 to 2018.

$$LDD_k = A_k + B_k\, Q_k + C_k\, BrL_k$$

Where

LDD_k: Lake drawdown (feet) in month k

A_k = Intercept in month k

B_k and C_k: Regression coefficients

Q_k : 12-month moving average of total pumping (mgd) in month k for five counties listed in Figure B-14

BrL_k: Simulated Brooklyn Lake levels in month k

k : months from 7/1957 thru 12/2018

The relationship was developed for each month because the relationship between pumping and the resulting impact on lake levels could be different under different hydrologic conditions (e.g., during wet conditions, impact may be offset by surface water flows and surface runoff, etc.) and at different lake levels (e.g., change in lake storage and seepage to the UFA could be different).

The data shown in Figures B-18 and B-19 and total groundwater pumping simulated in NFSEG model for the five counties discussed in the previous section were used for development of linear monthly relationship. Using the monthly linear relationships, the monthly impact to lake levels resulted from pumping from 1957 to 2018 was estimated (see Figures B-20 and B-21). It should be noted that the groundwater pumping in five counties were considered only as proxy to develop the linear relationship and capture the variation of regional pumping over time. The NFSEG groundwater model simulations included pumping for the entire model domain.

The magnitude of groundwater impact to lakes is dependent on not only the magnitude of groundwater pumping but also the amount of surface water flows coming from the upstream lakes. The impact of pumping on lake levels during a dry period could be considerably higher than the impact of pumping on lake levels during a wet period for the same amount of pumping because of lack of surface water flows and runoff. Thus, although the amount of regional pumping in 1960s was not negligible, the impact of groundwater pumping on both lakes was relatively low. The groundwater impact had been largely offset by the amount of surface water flows coming from the upstream lakes during that period.

Lake Brooklyn has been continuously receiving surface water flows from the upstream lakes. However, after 1973, the amount of surface flows coming from the upstream lakes to Lake Brooklyn has declined and varied due largely to rainfall deficit. Because of this, the groundwater impact to lake Brooklyn has varied and become more pronounced after 1973.

Lake Geneva has not received any surface flow from Lake Brooklyn since 1973 except for a very brief period in 1998. As a result, the variation in groundwater impact on Lake Geneva has been less after 1973, compared to Lake Brooklyn. However, like Lake Brooklyn, the magnitude of groundwater impact on Lake Geneva levels has become more pronounced since then. In short, the groundwater pumping impact to both lakes has increased significantly after 1973 due to not only increase in regional groundwater pumping but also reduction in surface water flows and runoff, which have exacerbated the impact.

It should also be noted that the groundwater pumping impact on lakes has recently (since 2007) declined due to reduction in regional pumping as shown in Figures B-20 and B-21.

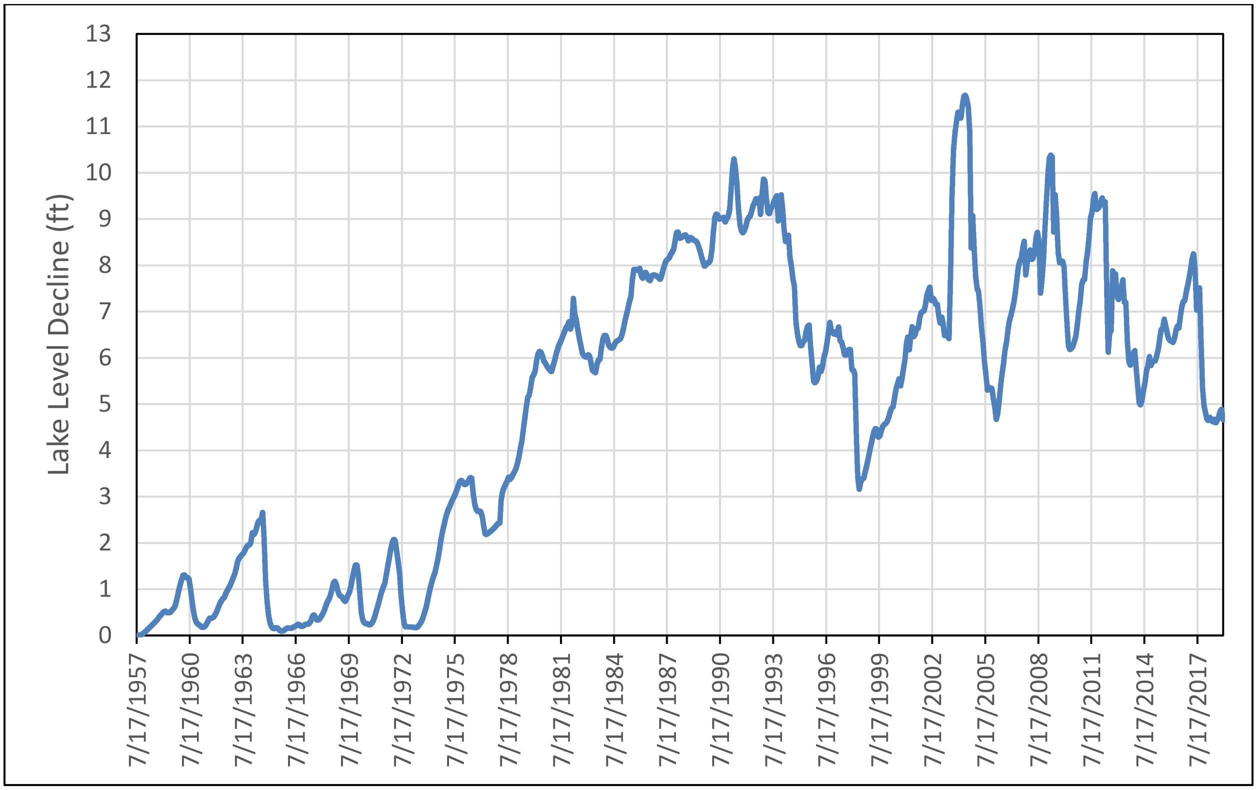

Figure B-20. The estimated impact of historical groundwater pumping on Lake Brooklyn levels

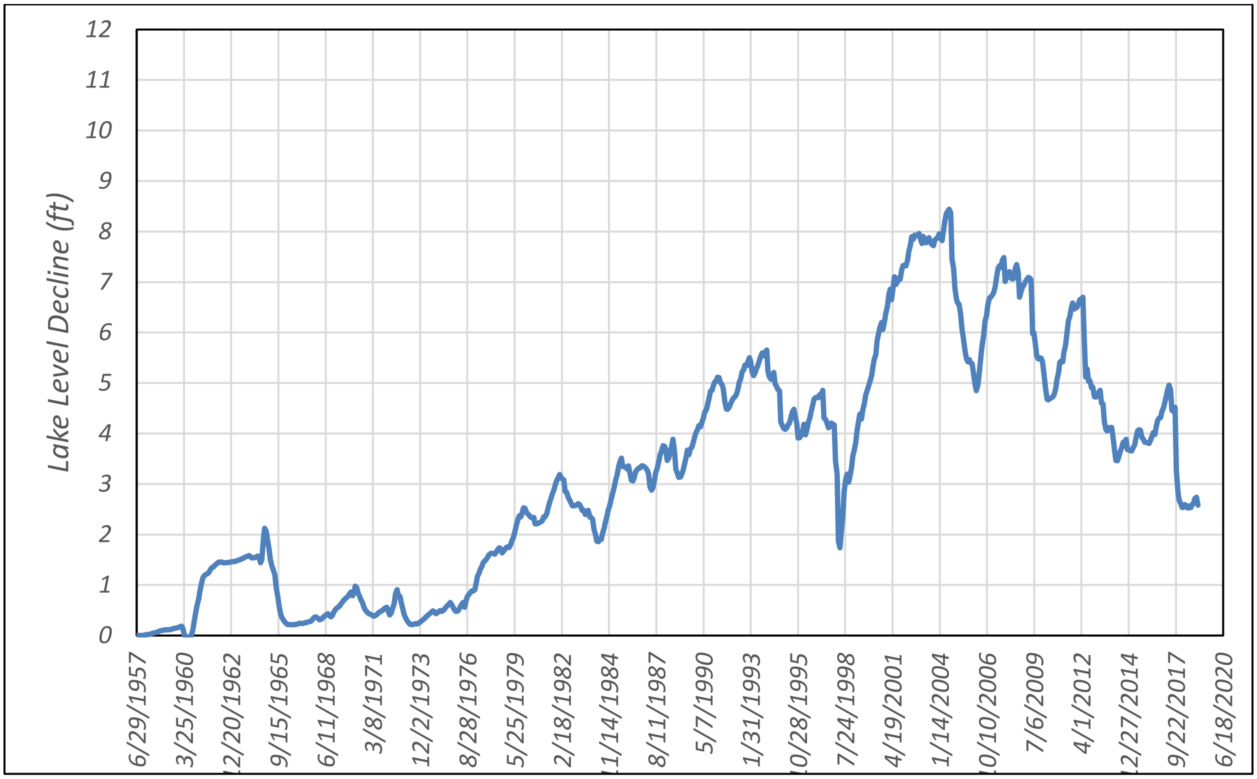

Figure B-21. The estimated impact of historical groundwater pumping on Lake Geneva levels

Discussion

Our analysis of long-term water level declines indicated that both long-term rainfall deficits and regional groundwater pumping have played critical roles in lowering lake levels over the past 40-50 years. The groundwater pumping impact to both lakes has increased considerably after 1973 due to not only increase in regional groundwater pumping but also reduction in surface water flows and runoff resulting from rainfall deficit which have exacerbated the impact. However, the groundwater pumping impact on lake levels has declined over the past five years due to approximately 20% reduction in regional pumping. Our analysis also suggests that it may take many years of above average rainfall to offset the effect of prolonged periods of drought on these lakes.

DEVELOPMENT OF LAKE LEVEL DATASETS FOR MFL ANALYSIS

The current and future status of minimum levels developed for Lake Brooklyn and Geneva need to be assessed. The objective of the current status assessment is to determine whether the Lake minimum levels are being achieved under the current pumping condition. Because of our limited understanding of possible future climatic conditions and difficulties in predicting future lake levels using global climate model forecasts, historical lake levels were considered to be the best available data and were adjusted for groundwater pumping impact to assess the current status of minimum levels.

Lake Brooklyn and Geneva MFL determinations and assessment are based on lake level datasets representative of current-pumping and no-pumping conditions (no-pumping condition and current-pumping condition lake levels). The no-pumping condition lake levels constitute a reference hydrologic condition in which lakes were not under the influence of any groundwater pumping for the period from 1957 to 2018. The adjustment of historical lake levels requires considering the effect of current groundwater pumping on lake levels not only for the recent years but also for the entire period of record (from 1957 to 2018). Thus, the current-pumping condition lake levels represent a reference hydrologic condition in which lakes were under the influence of current groundwater pumping constantly for the period from 1957 to 2018. Current groundwater pumping is defined as the average groundwater pumping from 2014 to 2018. An average of the past five years (from 2014 to 2018) of groundwater pumping was used to calculate the current-pumping condition so that it is more representative of the most recent average groundwater demand condition. The years 2019 and 2020 were not included because regional pumping data were not available at the time of this analysis.

The first step in developing the current-pumping condition lake levels, which in this case is the “average 2014-2018 pumping condition” lake levels, is to develop a “no-pumping condition” lake level dataset. The “no-pumping condition” lake level dataset was developed by adding an estimate of impact due to historical pumping (i.e., change in lake levels due to pumping) to each month in the observed record from 1957 to 2018. The “current-pumping condition” lake level dataset was developed by subtracting an estimate of impact due to current (average 2014-2018) pumping from the no-pumping lake levels in each month from 1957 to 2018.

“No-pumping condition” lake levels

The impacts from pumping as shown in Figures B-20 and B-21 were added to the monthly means of the observed lake level data to create a “no pumping condition” lake level dataset for Lakes Brooklyn and Geneva. These lake levels constitute a reference hydrologic condition of the lakes in which the impact from groundwater pumping is assumed to be minimal. The monthly datasets were later disaggregated into daily lake levels by linear interpolation.

"Current-pumping condition" lake levels

To develop the current-pumping-condition lake level dataset, the impact of current pumping on lake levels needs to be estimated. As previously discussed in Section 2.2, multiple linear regressions were developed to estimate the impact of pumping on lake levels for each month from 1957 to 2018. Using the linear monthly relationships and the average 2011-2018 pumping (about 238 mgd), a monthly time series of impact dataset was developed for each lake (Figures B-22 and B-23).

To generate current-pumping condition levels for each lake, the impacts from the average 2011-2018 pumping shown in Figures B-22 and B-23 were subtracted from the no-pumping condition lake levels. Figures B-24 and B-25 show both no-pumping and current-pumping conditions lake levels for Lakes Brooklyn and Geneva, respectively. The monthly datasets were later disaggregated into daily lake levels by linear interpolation.

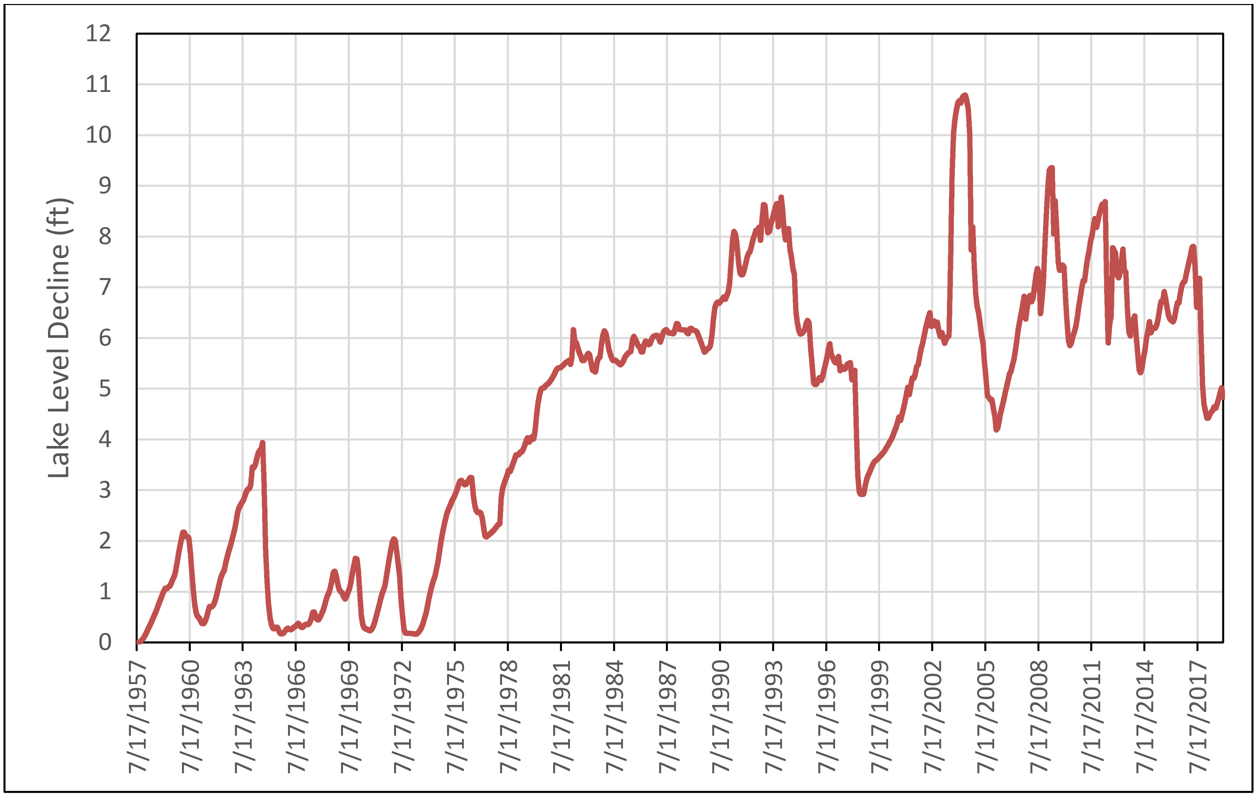

Figure B-22. The estimated impact of current groundwater pumping on Lake Brooklyn levels

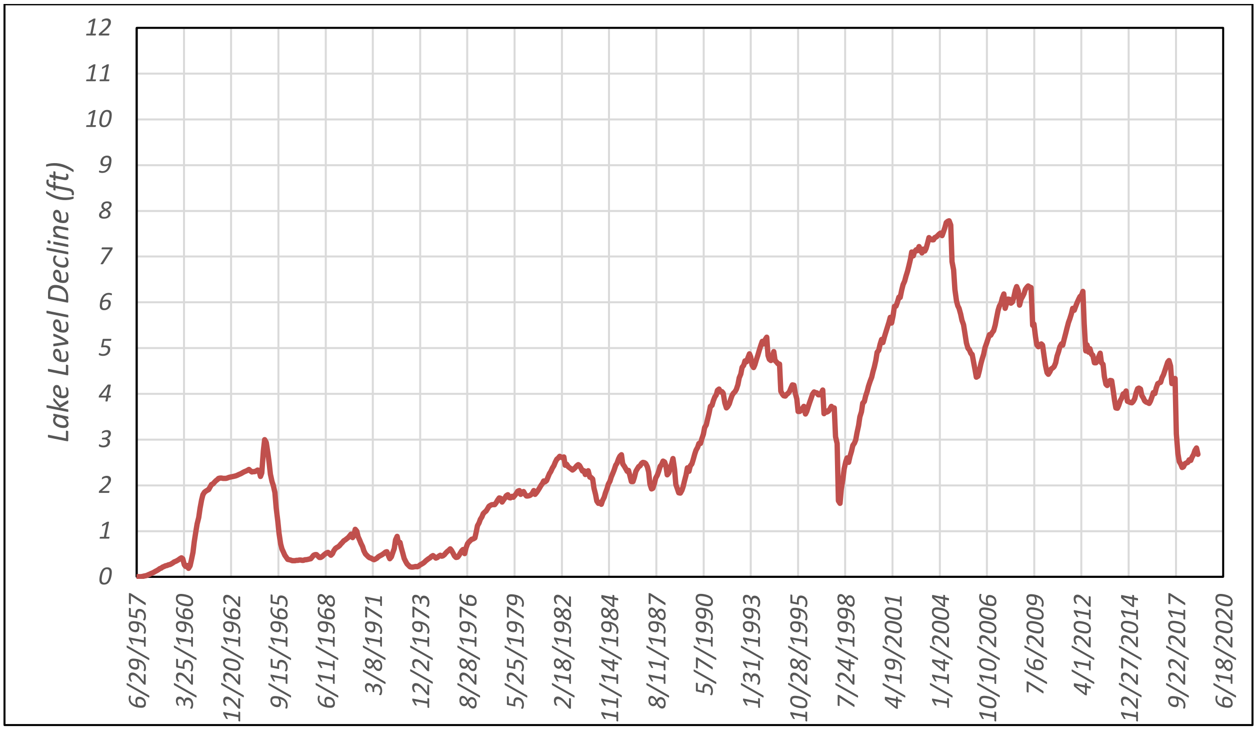

Figure B-23. The estimated impact of current groundwater pumping on Lake Geneva levels

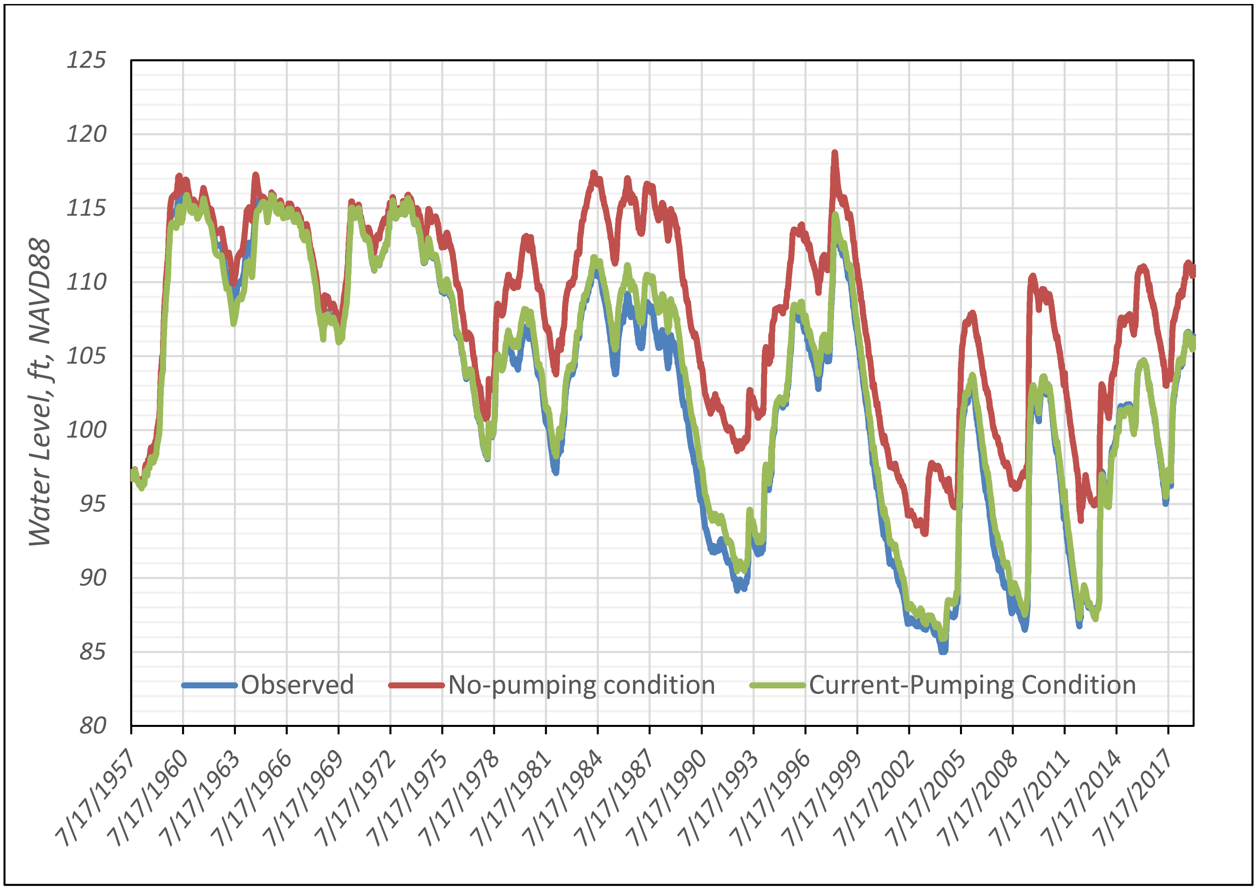

Figure B-24. The estimated no-pumping and current-pumping condition levels for Lake Brooklyn

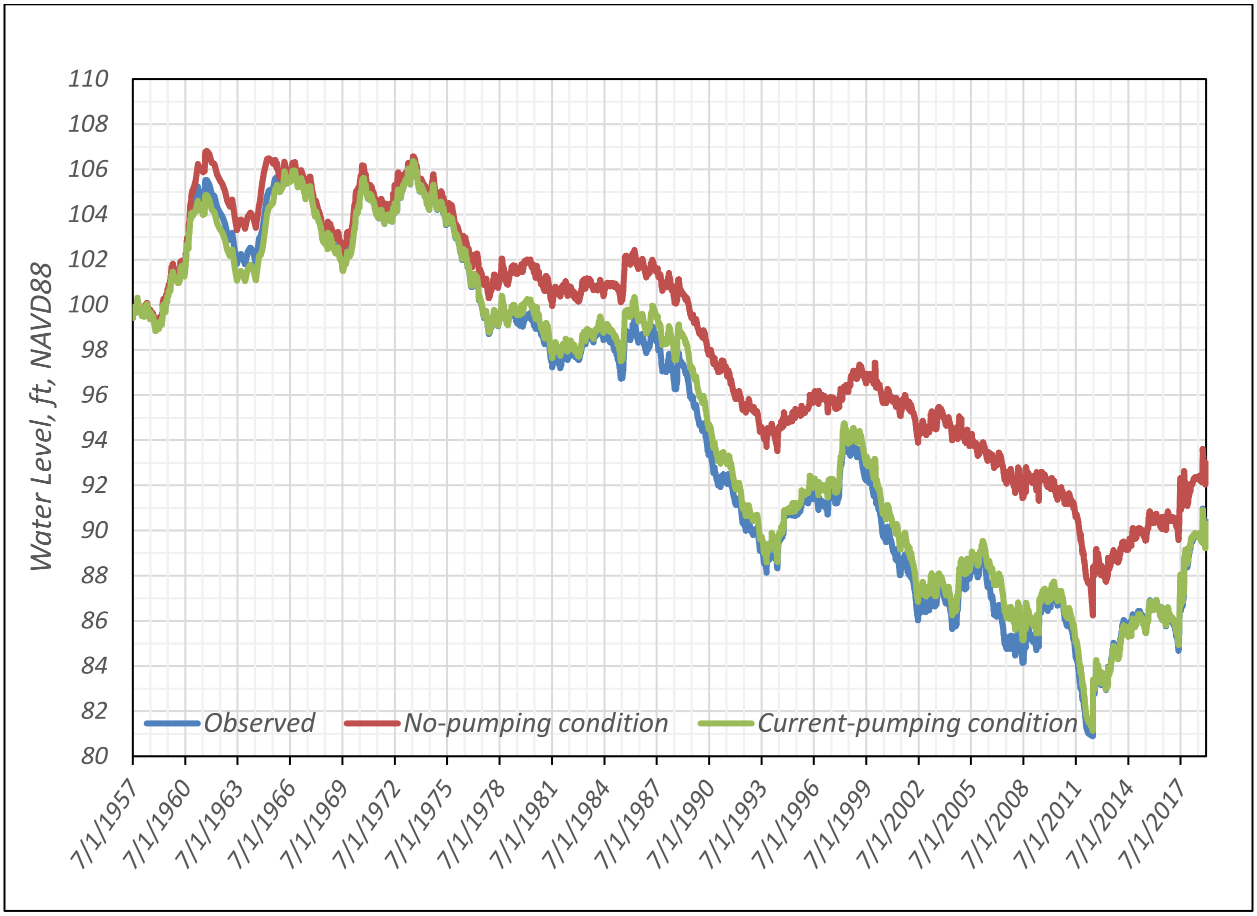

Figure B-25. The estimated no-pumping and current-pumping condition levels for Lake Geneva

The current-pumping condition lake levels represent a reference hydrologic condition of the lakes in which the total regional groundwater pumping impacting the lakes is constant from 1957 to 2018 at a rate of averaged pumping from 2014 to 2018. Assuming climatic, rainfall, and other conditions present from 1957 to 2018 are repeated over the next 58 years, the current-pumping condition lake levels would reflect the future condition of the lake levels if the average regional groundwater pumping does not change from 2014-2018 condition. Because of our limited understanding of possible future climatic conditions and uncertainties in global climate model predictions, using historical conditions to generate current-pumping condition lake levels is reasonable. Therefore, the no-pumping and current-pumping condition lake level datasets shown in Figures B-24 and B-25 were used to determine and evaluate the MFLs at Lakes Brooklyn and Geneva.

Several MFL criteria require lake levels being expressed as exceedance probabilities. Percent exceedance can be defined as the percent of the time a specified level will be equaled or exceeded over the period of record and be calculated as follows:

$$P = 100 * [m / (n + 1)]$$

Where P = Percent of time that a specified level will be equaled or exceeded

m = the rank of the specified level

n = the total number of level data over period of record

Figures B-26 and B-27 show exceedance probability curves of water levels for Lakes Brooklyn and Geneva, respectively.

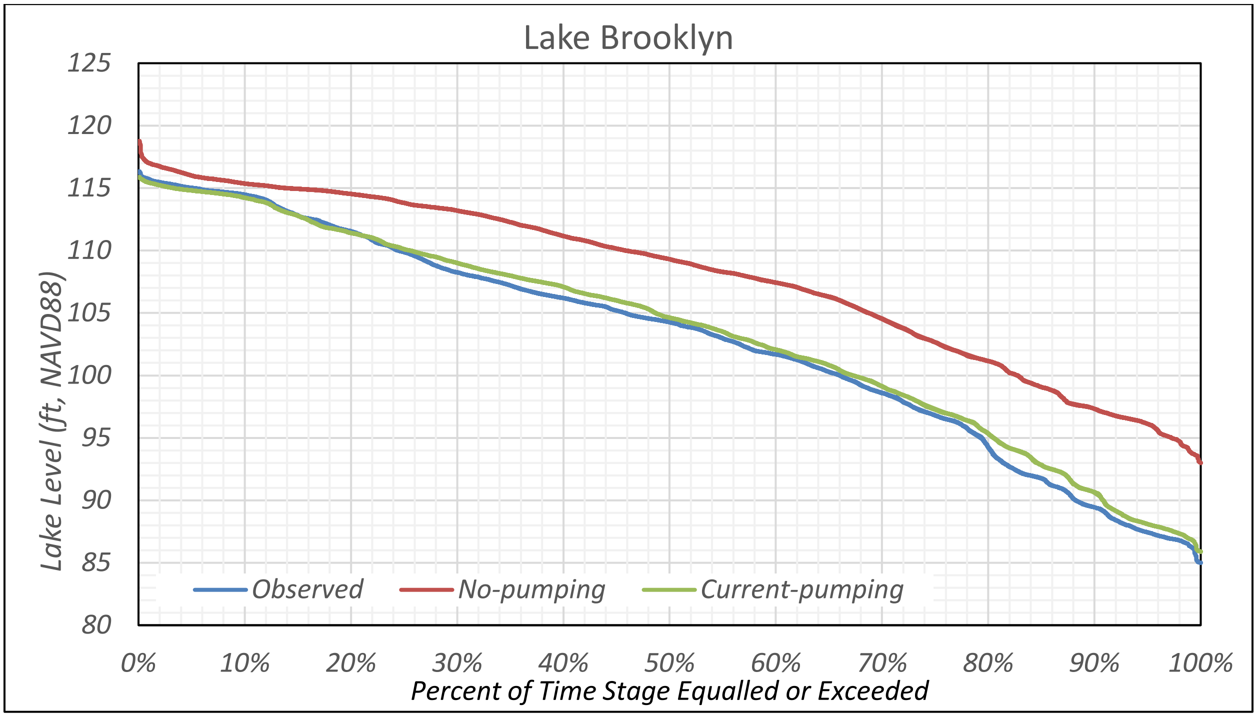

Figure B-24. Exceedance probability curve of Lake Brooklyn levels

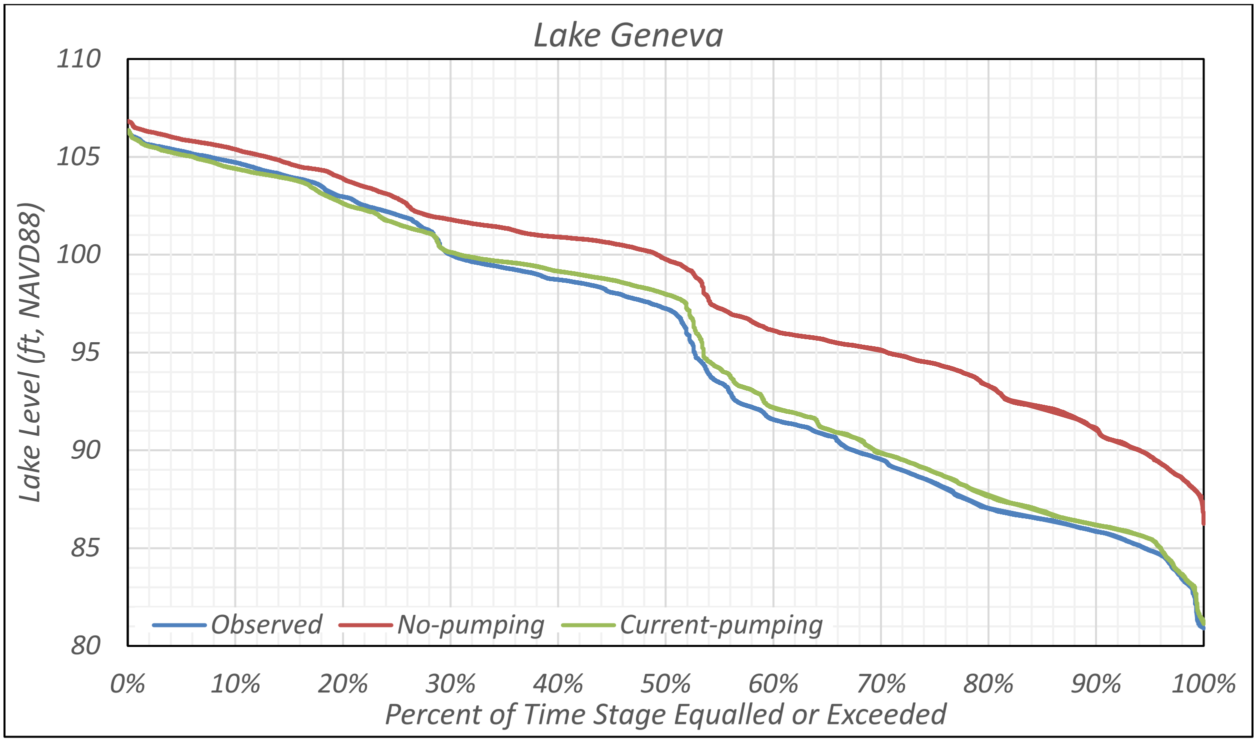

Figure B-25. Exceedance probability curve of Lake Geneva levels

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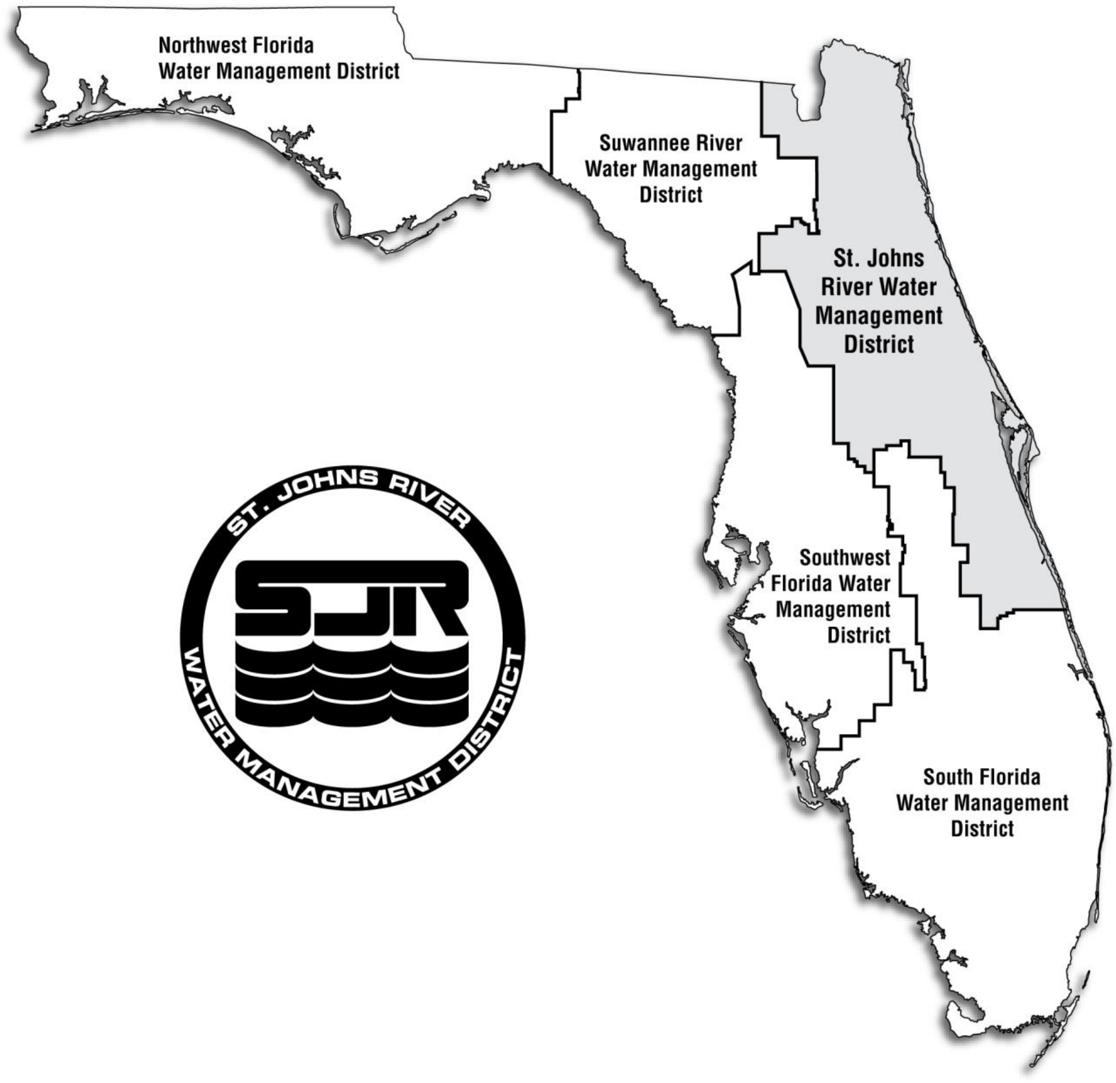
KEYSTONE HEIGHTS TRANSIENT GROUNDWATER MODEL VERSION 2.0

By:
Lanie Meridth, M.S.
Paul Bremner, Ph.D.
Wei Jin, Ph.D., P.E.
Fatih Gordu, P.E.
Michelle Brown, P.E.
Sherry Brandt-Williams, Ph.D.

St. Johns River Water Management District
Palatka, Florida

2020


Northwest Florida Water Management District
Suwannee River Water Management District
St. Johns River Water Management District
Southwest Florida Water Management District
South Florida Water Management District

EXECUTIVE SUMMARY

The Keystone Heights transient groundwater flow model (KHTM) was initially developed in 2017 (KHTM v1.0) and later updated in late 2019 with recently collected high-resolution bathymetry data for Lake Brooklyn and Lake Geneva (KHTM v1.1) by Tetra Tech for the St. Johns River Water Management District (SJRWMD). The purpose of the model was to develop a tool for hydrologic simulation of a chain of lakes, primarily Lakes Brooklyn and Geneva, in the Upper Etonia Creek Basin for Minimum Flows and Levels (MFL) applications. The KHTM was calibrated to the period of 1995 to 2014 and later extended back to 1957. SJRWMD subsequently expanded the simulation period from 2014 to 2018 and recalibrated the model, herein referred to as KHTM v2.0, with the primary objectives being: **1)** to improve the model's ability to match observed Lake Brooklyn levels that had degraded after bathymetry updates and **2)** to enhance the model's ability to match low observed water levels (< 95 feet NAVD88) at Lake Brooklyn while also maintaining pre-defined calibration criteria.

The automated parameter estimation tool (PEST) was used for recalibration. A relatively small subset of the parameters used in KHTM v1.0 calibration were selected to vary during the KHTM v2.0 model recalibration process. The selected parameters included lakebed leakance and hydraulic conductivity parameters assigned to Lake Brooklyn. SJRWMD also modified the formulation of lakebed leakance at Lake Brooklyn using an analytical approximation of the Heaviside step-function so that higher lakebed leakance can be assigned to sinkhole features. This approach is consistent with seismic investigations at Lake Brooklyn indicating the presence of multiple karst collapse features in deeper portions of the lake that are more hydraulically connected to the Upper Floridan Aquifer (UFA) than shallower regions, indicative of sharp discontinuities in leakance across the lakebed area (SDI, 1992).

To evaluate whether the goals of the recalibration effort were achieved, the KHTM v1.0 and v1.1 calibration results (included in this report) were compared to KHTM v2.0 results. The KHTM v2.0 met all pre-defined calibration criteria and produced equivalent or improved calibration statistics to KHTM v1.0 and v1.1. Additionally, KHTM v2.0 simulated lake levels at Lake Brooklyn closer to measurement values than KHTM v1.0 and v1.1 during 1995 to 2004, where degradation occurred following bathymetry updates. Therefore, the first goal of recalibration was achieved. The match to modeled Lake Brooklyn lake level targets improved over those from KHTM v1.0 and v1.1, shown by a decrease in MAE and an improved match to observed high- and low level periods. Therefore, the second goal of the recalibration effort was also achieved.

Overall, KHTM v2.0 met its model objectives while maintaining, and in some cases improving, the quality of calibration achieved by KHTM v1.0. Furthermore, the reconceptualization of the distribution of lakebed leakance beneath Lake Brooklyn, where greater leakance occurs in deep areas of the lake characterized by collapse features, is a closer approximation to our understanding of the system acquired from hydrogeologic data and therefore an improvement in model conceptualization.

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CHAPTER 1. INTRODUCTION

The Keystone Heights transient groundwater flow model version 1.0 (KHTM v1.0) was previously developed in 2017 by Tetra Tech for the St. Johns River Water Management District (SJRWMD) for Minimum Flows and Levels (MFL) applications, which was calibrated to match observations for the period of 1995 to 2014 (Tetra Tech, 2017). The model domain and major surface hydrologic features represented in the model are illustrated in **Figure 1**. A monthly long-term simulation was also developed by Tetra Tech to extend the simulation period back to July 1957, which retained the calibration period of 1995 to 2014. In late 2019, the District contracted Tetra Tech to update the model with recently collected high-resolution bathymetry data for Lake Brooklyn and Lake Geneva, and to perform model calibration via a limited number of PEST iterations. One of the objectives of the contracted work was to improve the model's ability to match observed Lake Brooklyn water levels, particularly those below 95 feet (NAVD88) if possible. After performing a limited number of PEST calibrations, Tetra Tech (2019) concluded that the previously calibrated KHTM v1.0 model parameters were still the preferred set, despite a degradation in model calibration performance caused by model updates. Tetra Tech (2019) also concluded that the updated model, herein referred to as KHTM v1.1, generally did not perform as well as KHTM v1.0 in matching the highest and lowest observed lake levels at Lake Brooklyn, particularly during the period between 1995 and 2004 (**Figure 2**).

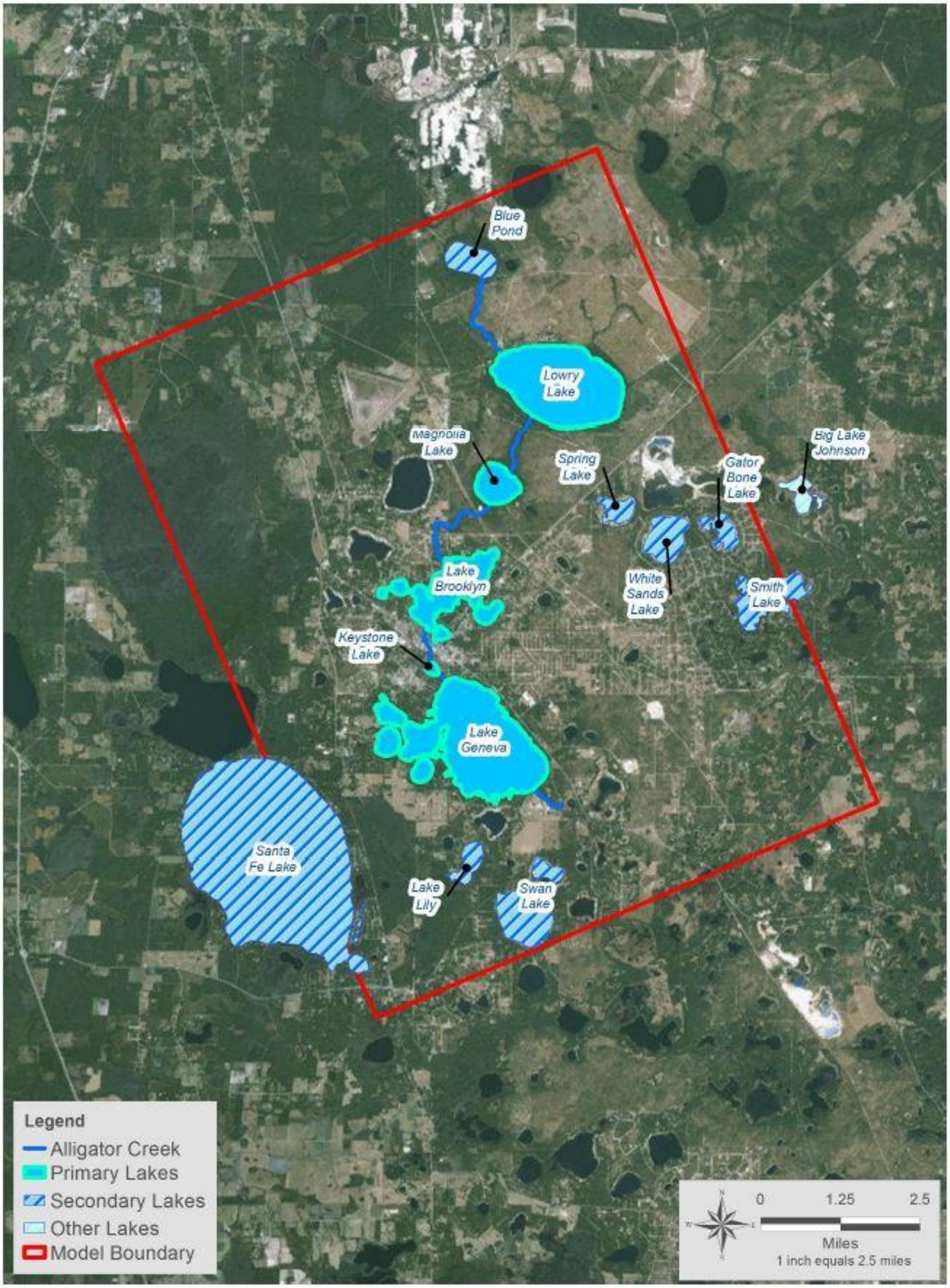

Figure 1. Model domain and major surface hydrologic features. Figure from Tetra Tech (2017).

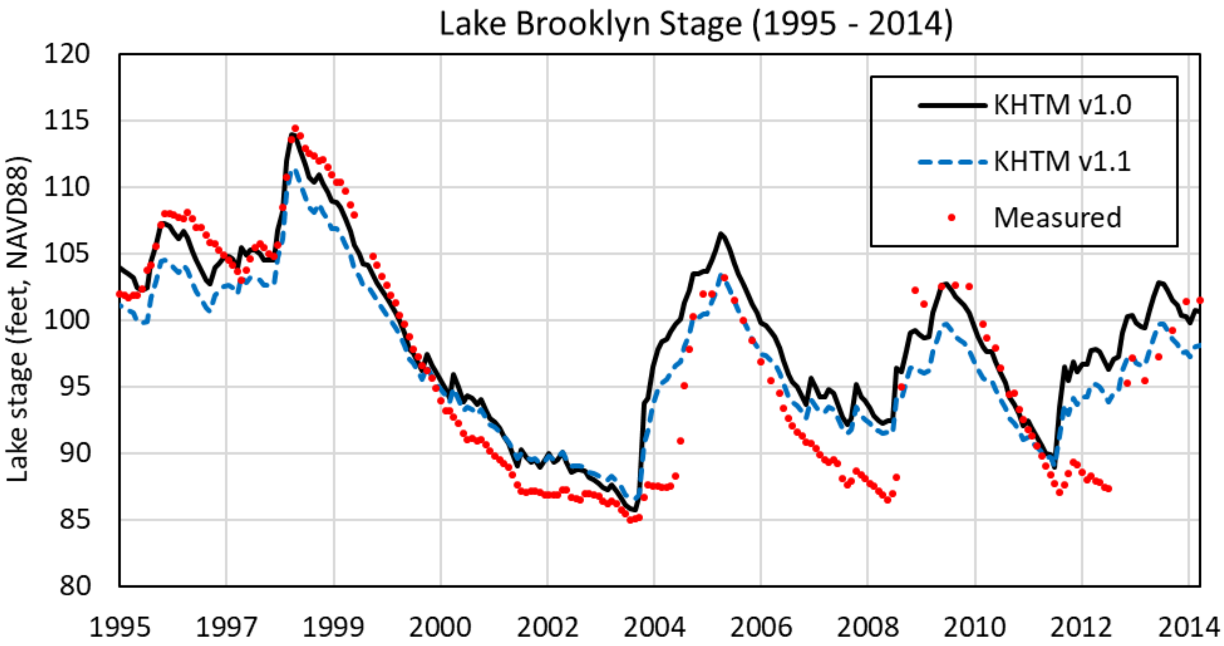

Figure 2. Simulated lake level at Lake Brooklyn during the calibration period for KHTM v1.0 (green) and KHTM v1.1 (black) compared to measured values (red).

SJRWMD subsequently modified the PEST calibration scheme and performed additional recalibrations. The primary goals of recalibration were: **1)** to improve overall model calibration statistics and improve the model's ability to match observed Lake Brooklyn levels that had degraded in the early part of the calibration period (1995 to 2004) and **2)** to enhance the model's ability to match low observed water levels (< 95 feet NAVD88) at Lake Brooklyn while also maintaining pre-defined calibration criteria summarized in **Table 1**. SJRWMD's recalibration process and results are summarized in the following sections. SJRWMD's recalibrated model will herein be referred to as KHTM v2.0.

Table 1. Calibration metric goals for the four main calibration target groups.

Target Type	**Calibration Metric**	**Metric Goal**
Groundwater Levels	Mean Absolute Error	**≤ 5 feet**
Lake Water Levels	Mean Absolute Error	**≤ 2 feet**
Monthly Average Streamflow	(Mean Absolute Error) ÷ Range	**≤ 10%**
Vertical Head Differences	(Mean Absolute Error) ÷ Range	**≤ 10%**

CHAPTER 2. MODEL RECALIBRATION

The KHTM v1.1 model used for SJRWMD's recalibration effort incorporated all bathymetric updates but retained the KHTM v1.0 calibrated parameter values. Two parameters were redefined, and one additional parameter was introduced during the recalibration process that are explained in detail in the following sections. The calibration period of 1995 to 2014 was retained.

RECALIBRATION TARGETS

All calibration targets included in KHTM v1.0 and adjustments made to the weights of calibration targets to improve the ability to match lower water levels at Lake Brooklyn in KHTM v1.1 were retained. The reweighting approach included modifications to the weights of a small number of Lake Brooklyn water level targets to emphasize extreme observed levels, lows and highs, within the calibration period (Tetra Tech, 2019).

RECALIBRATION PARAMETERS

A relatively small subset of PEST parameters (5 out of 208) related to Lake Brooklyn were selected to vary during the recalibration. These parameters were selected in order to focus recalibration on improving the model fit at Lake Brooklyn without degrading overall model performance. The five varied parameters included the following:

- *Kh_BlwB*: Parameter defining horizontal hydraulic conductivity for the zone between the lakebed and the top of the Upper Floridan Aquifer (UFA) beneath Lake Brooklyn; parameter as defined in KHTM v1.0.
- $kxkz_B$: Anisotropy ratio defined for the zone between the lakebed and the top of the UFA beneath Lake Brooklyn; parameter as defined in KHTM v1.0.
- $LAKLK_B$: Shallow lakebed leakance for Lake Brooklyn; parameter redefined in this recalibration.
- *Bratio*: Lakebed leakance term defining the ratio of deep-to-shallow lakebed leakance for Lake Brooklyn, i.e., the deep lakebed leakance equals the product of *Bratio* and $LAKLK_B$; parameter redefined in the recalibration.
- $DepthC_B$: A lakebed leakance term introduced for KHTM v2.0 defining the critical cell depth for Lake Brooklyn. This threshold defines where a deep or shallow lakebed leakance is applied in the MODFLOW lake (LAK) package. The critical depth is defined from the top of model layer 1. If a cell's depth is smaller than $DepthC_B$, the cell is a shallow cell with shallow lakebed leakance; otherwise, the cell is a deep cell with deep lakebed leakance; newly introduced parameter in the recalibration.

Other PEST parameters, aside from the five parameters identified above, remained fixed and were assigned either parameter values estimated from the calibration of KHTM v1.0 or minor adjustments made during model updates of KHTM v1.1 (i.e. the minimum lakebed leakance for all lakes, fixed at 1.00E-8 day^{-1}).

LAKEBED LEAKANCE REFORMULATION

For Lake Brooklyn, SJRWMD implemented a reformulation of lakebed leakance, a function of hydraulic conductivity and lakebed sediment thickness that affects the rate of flow between the aquifer and the lake. Lake Brooklyn lakebed leakance in KHTM v1.0 was varied as a function of lake depth so that deeper portions of the lake could have a higher leakance than shallower areas (Tetra Tech, 2017). However, this approach was somewhat limited in that it utilized a continuous approximation for lakebed leakance as a function of lake cell depth and leakance parameter. Thus, the leakance parameter could not be discretely adjusted in the deeper portions to simulate highly permeable sinkhole features. To overcome this limitation, SJRWMD modified the approach for KHTM v2.0 by calculating lakebed leakance using an analytical approximation of the Heaviside step-function (**Equation 1**), whose value is zero for negative arguments (x<0), one for positive arguments (x>0), and where a large k (e.g., 1000) corresponds to a sharper transition at x=0.

$$H(x) \approx \frac{1}{2} + \frac{1}{2} tanh\, kx \tag{1}$$

The application of the Heaviside approximation to the calculation of cell lakebed leakance at Lake Brooklyn is shown in **Equation 2**. The approach used to calculate lakebed leakance at the other primary lakes in the model remained unchanged from KHTM v1.0. The formula was constructed so that the transition at x=0 occurs at the critical depth in the model, *DepthC_B*, estimated by PEST. All equation terms used in the lakebed leakance calculation are described below:

$$LAKLK_i = LAKLK_B \left\{ 1 + 0.5(Bratio - 1) \left[1 + tanh\left(1000 \frac{Depth_i - DepthC_B}{Dmax_B} \right) \right] \right\} \tag{2}$$

where

- i is an integer representing a model cell beneath the lake in the LAK package.
- $LAKLK_i$ = lakebed leakance [day^{-1}] assigned to model cell i in the LAK package.
- $LAKLK_B$ = shallow lakebed leakance [day^{-1}] estimated by PEST for Lake Brooklyn. This term represents the lakebed leakance assigned to cells with a depth above the critical depth.
- *Bratio* = ratio of deep over shallow lakebed leakance estimated by PEST for Lake Brooklyn.
- $Depth_i$ = model cell depth from top of layer 1 [feet].
- $Dmax_B$ = maximum model cell depth from top of layer 1 for Lake Brooklyn, equal to 41.522 feet.
- $DepthC_B$ = critical depth from top of layer 1 estimated by PEST for Lake Brooklyn [feet].

Figure 3 conceptually illustrates the application of **Equation 2** to Lake Brooklyn in the model. For a given lake cell in the model, shaded blue in **Figure 3**, the cell depth and maximum depth are defined relative to the top of layer 1. Applying **Equation 2**, model lake cells with a cell depth greater than $DepthC_B$ (defined as deep cells) were assigned the deep lakebed leakance value, whereas those with a cell depth less than $DepthC_B$ (defined as shallow cells) were assigned the shallow lakebed leakance value in the LAK package. As an example, let us assume that the $LAKLK_B$, $DepthC_B$, $Dmax_B$, and *Bratio* are 1.00E-4 day^{-1}, 25 feet, 40 feet, and 10, respectively. For a given lake cell, *i*, with a cell depth of 20 feet (less than $DepthC_B$), $LAKLK_i$ is equivalent to the shallow lakebed leakance value ($LAKLK_B$) of 1.00E-4 day^{-1}. For another lake cell with a depth greater than $DepthC_B$, 30 feet, $LAKLK_i$ is equivalent to 1.00E-3 day^{-1}, or the product of $LAKLK_B$ and *Bratio*, and represents the "deep" leakance value. This approach is consistent with seismic investigations at Lake Brooklyn that have indicated the presence of multiple karst collapse features in deeper portions of the lake that are more hydraulically connected to the UFA than shallower regions, indicative of sharp discontinuities in leakance across the lakebed area (SDI, 1992).

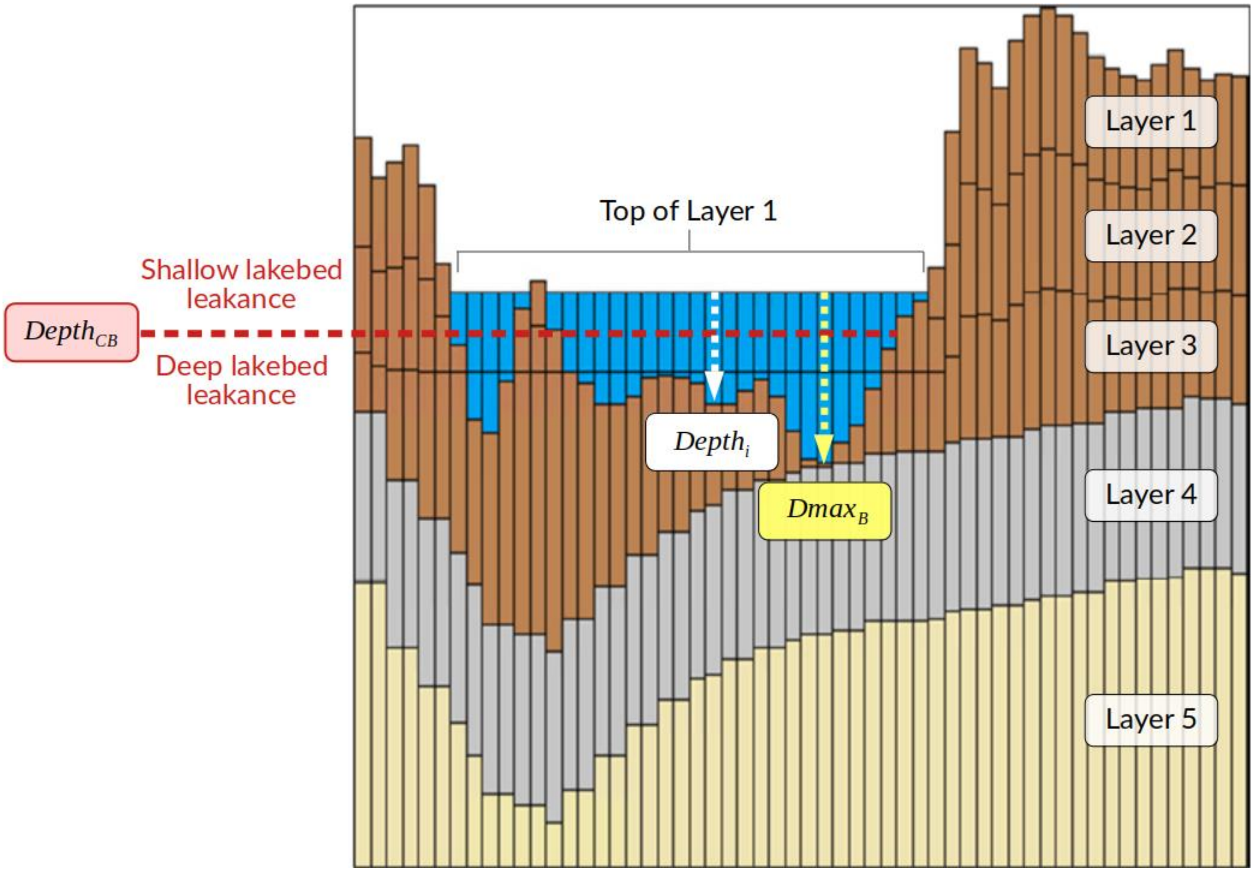

Figure 3. Representative cross-section of the model grid showing Lake Brooklyn (blue), the surficial aquifer system (SAS, layers 1-3, brown), intermediate confining unit (ICU, layer 4, gray), and the intermediate aquifer system (IAS, layer 5, tan). Leakance terms represented in Equation 2 are labeled. Figure modified from Tetra Tech, 2017 (Figure 4C).

CHAPTER 3. RECALIBRATION RESULTS

The parameter estimation software PEST++ (a USGS maintained variant of PEST; Doherty, 2016) was used to perform automated calibration of KHTM v2.0. Each PEST iteration took approximately 3-4 days to complete and a total of 12 PEST iterations were run on a cluster of approximately 27 remote agents. The best parameter set was identified and is summarized in **Table 2**, along with the upper and lower bounds used in automated calibration. Only parameters modified for recalibration are listed in **Table 2.** For additional parameter values and documentation see the KHTM v1.0 model report (Tetra Tech, 2017).

Table 2. Calibrated parameter values which were modified from KHTM v1.0, along with their respective upper and lower bounds imposed in PEST++ during the recalibration process.

Parameter Name	Parameter Description	Units	Calibrated Value	Lower Bound	Upper Bound
$LAKLK_B$	Lakebed Leakance (Brooklyn)	day^{-1}	6.82E-4	1.00E-8	10
Kh_BlwB	Kh below Brooklyn	feet/day	0.62	0.0001	100
$kxkz_B$	Kh/Kv ratio below Brooklyn	-	1.51	0.001	50
Bratio	Deep/shallow lakebed leakance ratio (Brooklyn)	-	1058.81	0.001	1.00E6
$DepthC_B$	Critical depth (Brooklyn)	feet	26.55	0	41.522

To evaluate whether the first goal of recalibration was achieved, the KHTM v1.1 calibration results were compared against KHTM v2.0 results. Likewise, where relevant to the second objective of this recalibration, reported KHTM v1.0 calibration results were also compared against the KHTM v2.0 results. In addition to model recalibration, KHTM v2.0 incorporated updates to bathymetric data, model layer elevations, and inactive or active cell assignments as compared to KHTM v1.0. These updates affected simulated groundwater levels and lake levels in the model (as shown in KHTM v1.1 results) and are thus also reflected in the statistics reported for KHTM v2.0. More detailed discussions comparing KHTM v2.0 model results to those reported from KHTM v1.0 and v1.1 are provided in Chapter 5 of this report.

For the calculation of KHTM v2.0 calibration statistics, error was defined as the subtraction of the measured target value from the modeled target value. Error statistics included both mean error (ME) and mean absolute error (MAE). All statistics were calculated within the defined calibration period (January 1995 to December 2014) and excluded zero-weighted targets in PEST, as well as synthetic targets representing high water table wetland areas in the surficial aquifer. **Tables 3 - 5** present the calibration statistics for KHTM v2.0 alongside those for KHTM v1.0 and KHTM v1.1. The statistics for KHTM v1.0 and KHTM v1.1 included in this report were sourced from each respective model report, where available. The final KHTM v2.0 calibrated parameter set resulted in calibration metric values that met all the predefined metric goals for the main calibration target groups highlighted in **Table 3**.

Table 3. Calibration metric goals and results for KHTM v1.0, v1.1, and v2.0.

Target Type	Calibration Metric	Metric Goal	Metric Result		
			KHTM v1.0[a]	KHTM v1.1[b]	KHTM v2.0
Groundwater levels	Mean error (feet)	-	0.04	0.73	1.27
	Mean absolute error (feet)	≤ 5 feet	3.75	3.76	3.65
	Range in observations (feet)	-	111.71	111.71	111.71
	MAE ÷ Range (%)	-	3.4%	4.51%	4.47%
Lake water levels	Mean error (feet)	-	-0.17	0.16	0.24
	Mean absolute error (feet)	≤ 2 feet	1.42	1.36	1.21
	Range in observations (feet)	-	50.87	50.87	50.87
	MAE ÷ Range (%)	-	2.8%	2.67%	2.37%
Monthly average streamflow	Mean error (cfd)	-	-9.364E+04	-8.554E+04	-8.428E+04
	Mean absolute error (cfd)	-	9.924E+04	9.558E+04	9.549E+04
	Range in observations (cfd)	-	3.336E+06	3.336E+06	3.336E+06
	MAE ÷ Range (%)	≤ 10%	3.0%	2.87%	2.86%
Vertical head differences	Mean error (feet)	-	-3.80	-3.13	-0.75
	Mean absolute error (feet)	-	4.63	5.12	4.57
	Range in observations (feet)	-	55.45	55.45	55.45
	MAE ÷ Range (%)	≤ 10%	8.3%	9.24%	8.24%

[a] KHTM v1.0 metric statistics reported in Tetra Tech (2017).
[b] KHTM v1.1 metric statistics were not reported in Tetra Tech (2019). but were calculated here for comparison.

GROUNDWATER LEVELS

The major aquifer systems in the model domain include the surficial aquifer system (SAS), Upper Floridan aquifer (UFA), and Lower Floridan aquifer (LFA). **Table 4** includes groundwater level target statistics during the calibration period within the major aquifer systems in the model. Groundwater level statistics reported for KHTM v1.0 and v1.1 were included for comparison. The reported KHTM v1.1 groundwater level statistics included zero-weighted and synthetic targets located in the SAS, but these were not included in KHTM v1.0 and v2.0. To provide a direct comparison with KHTM v1.0 and v2.0, the KHTM v1.1 SAS groundwater statistics were recalculated with the zero-weighted and synthetic targets removed.

Table 4. Tabulated groundwater head target statistics for KHTM v1.0, v1.1, and v2.0.

Target Group	KHTM v1.0		KHTM v1.1		KHTM v2.0	
	ME (feet)	MAE (feet)	ME (feet)	MAE (feet)	ME (feet)	MAE (feet)
SAS	-1.32	4.77	0.87[a]	6.13[a]	0.79	4.48
			-0.20[b]	4.60[b]		
UFA	1.80	2.46	2.02	2.64	1.93	2.56
LFA	1.24	1.42	1.47	1.63	1.44	1.61

[a]KHTM v1.1 statistics in Tetra Tech (2019) report included zero-weighted and synthetic targets in the SAS.
[b]KHTM v1.1 statistics recalculated without zero-weighted and synthetic SAS targets.

LAKE LEVELS

Table 5 presents lake level calibration statistics during the calibration period at the primary lakes in the model**,** as well as for lake level target measurements below 95 feet (NAVD88) at Lake Brooklyn. The latter was included to evaluate model performance during low level periods. **Table 5** also includes statistics from KHTM v1.0 and v1.1 for direct comparison. Note that an evaluation of Lake Brooklyn low level targets was not reported for KHTM v1.0 or v1.1, but were calculated and added for comparison purposes. **Figures 4 - 9** compare the simulated lake levels to measured values.

The MAE at Lake Brooklyn and Lake Geneva was 2.12 feet and 0.73 feet, respectively. The MAE of the low level periods at Lake Brooklyn was larger in magnitude relative to the MAE calculated using all available lake level measurements. The MAE at Lake Lowry and Lake Magnolia was less than 1 foot in magnitude, while the MAE at Keystone Lake was 2.86 feet (**Table 5**). The range in observed levels at the primary lakes during the calibration period were lowest at Lake Lowry, where lake level fluctuated by approximately 4 feet (**Figure 4**), while the range in observed levels were highest at Lake Brooklyn, where lake level fluctuated by approximately 30 feet (**Figure 6**). Relative to Lake Brooklyn, there was less fluctuation in lake level during the calibration period at Lake Geneva (**Figure 8**), where the observed level fluctuated by approximately 14 feet. No measured data was available at Keystone Lake after the year 2003 (**Figure 7**), or at Geneva West during the calibration period (**Figure 9**).

Table 5. Lake level target mean error (ME) and mean absolute error (MAE) for KHTM v1.0, v1.1, and v2.0.

Target Group	KHTM v1.0		KHTM v1.1		KHTM v2.0	
	ME (feet)	MAE (feet)	ME (feet)	MAE (feet)	ME (feet)	MAE (feet)
Lowry	0.19	0.33	0.28	0.36	0.28	0.36
Magnolia	-0.38	0.89	0.01	0.75	0.01	0.75
Brooklyn	1.52	2.88	0.51	2.82	0.83	2.12
**Brooklyn below 95 feet*	3.64	3.67	2.95	3.10	2.19	2.52
Keystone	-0.53	2.80	-0.19	2.84	-0.07	2.86
Geneva	-0.32	0.82	0.03	0.72	-0.01	0.73

*Only targets with a measured level below the given lake level threshold were used to compute error statistics. Brooklyn low level statistics were not originally reported for KHTM v1.0 and v1.1 but were calculated and included for comparison.

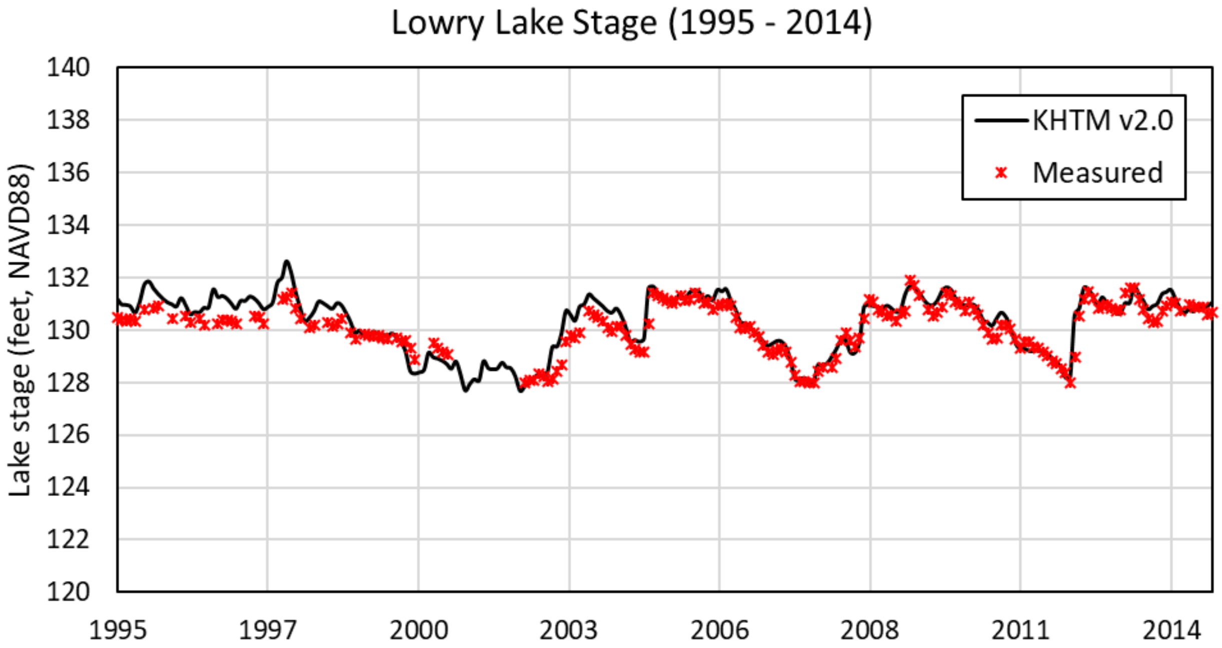

Figure 4. Measured (red) and simulated (black) lake level at Lowry Lake during the calibration period.

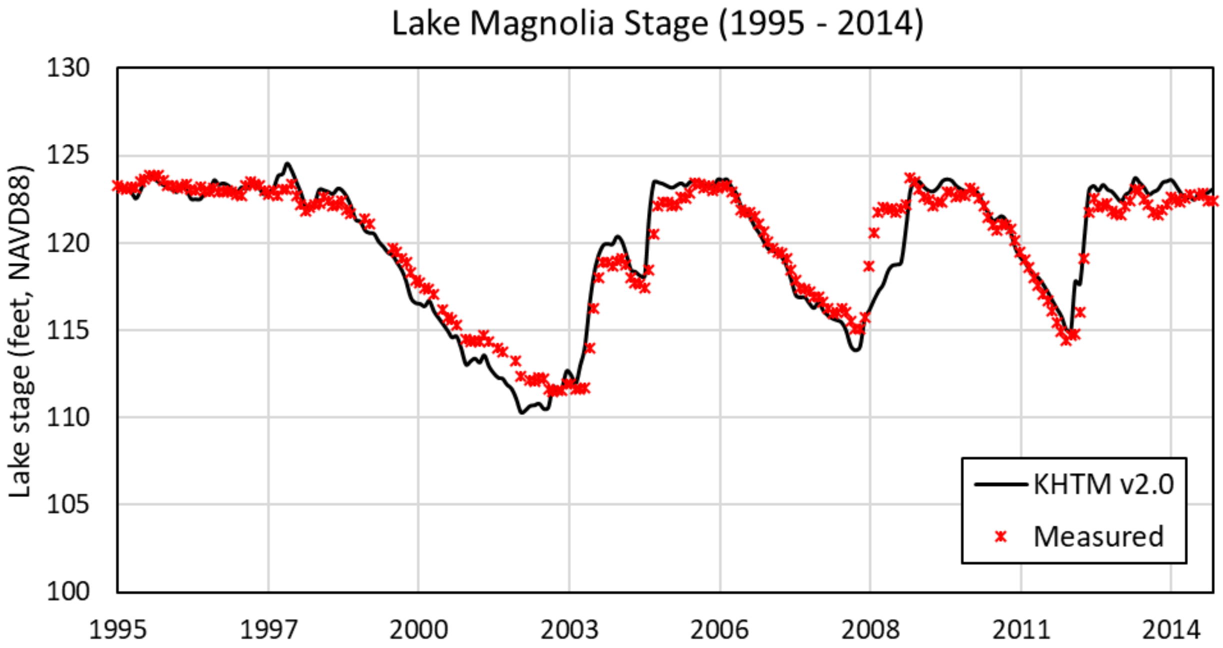

Figure 5. Measured (red) and simulated (black) lake level at Lake Magnolia during the calibration period.

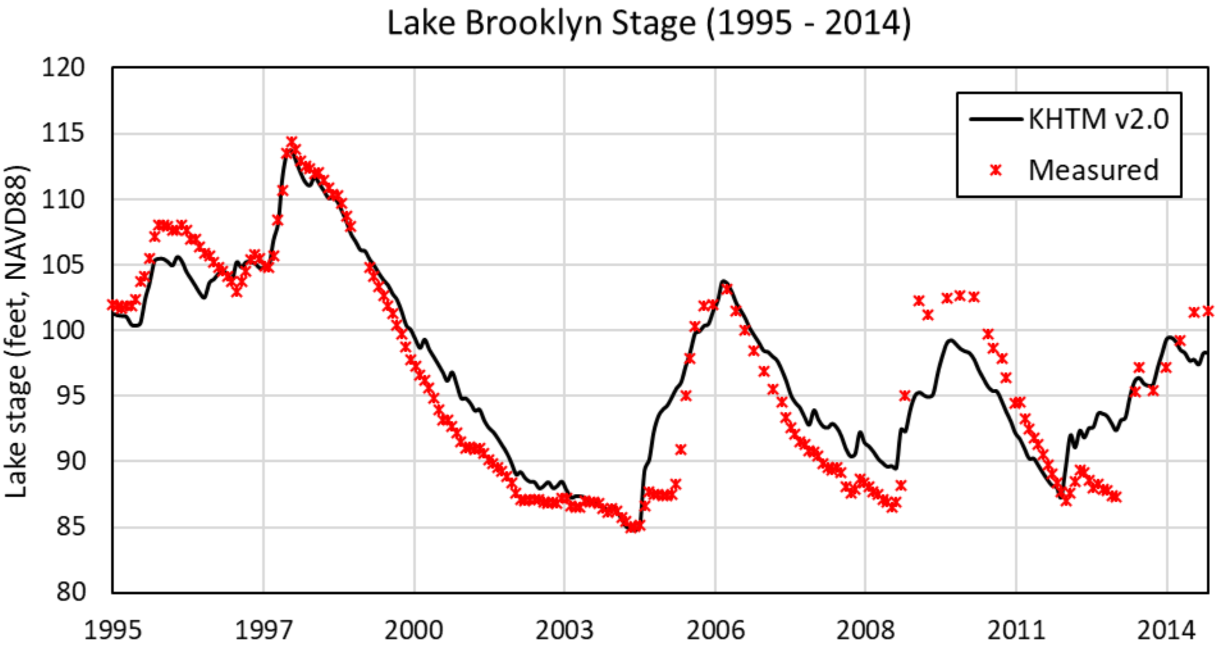

Figure 6. Measured (red) and simulated (black) lake level at Lake Brooklyn during the calibration period.

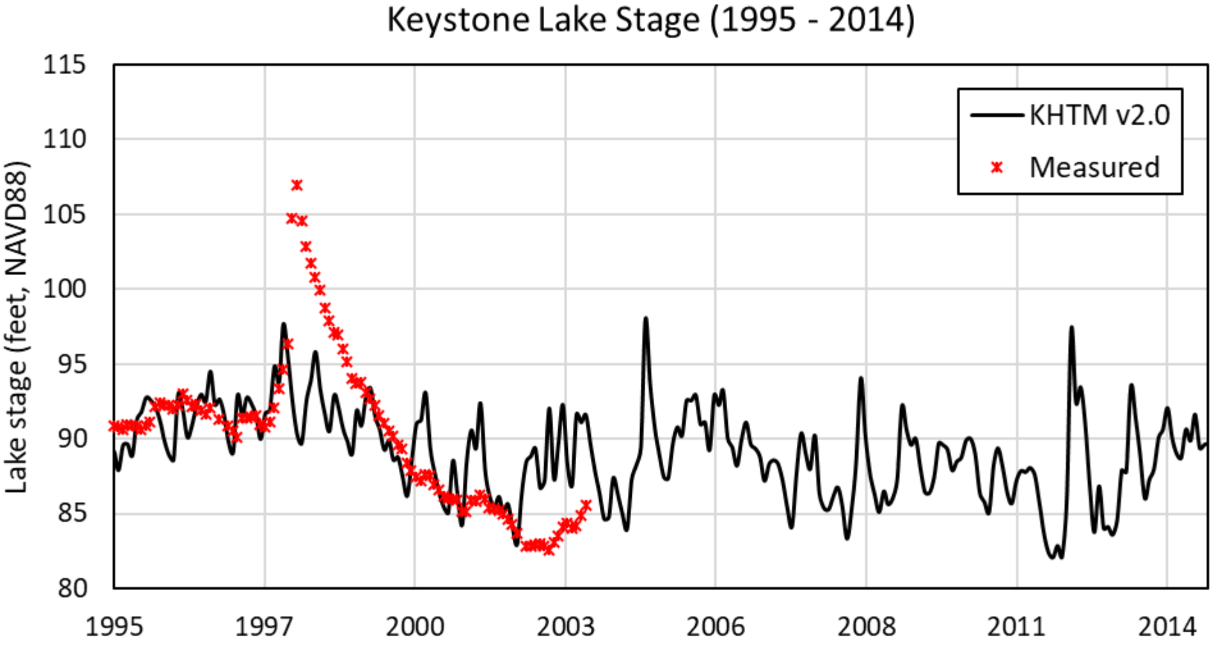

Figure 7. Measured (red) and simulated (black) lake level at Keystone Lake during the calibration period. No lake level measurements were available at Keystone Lake following the year 2003.

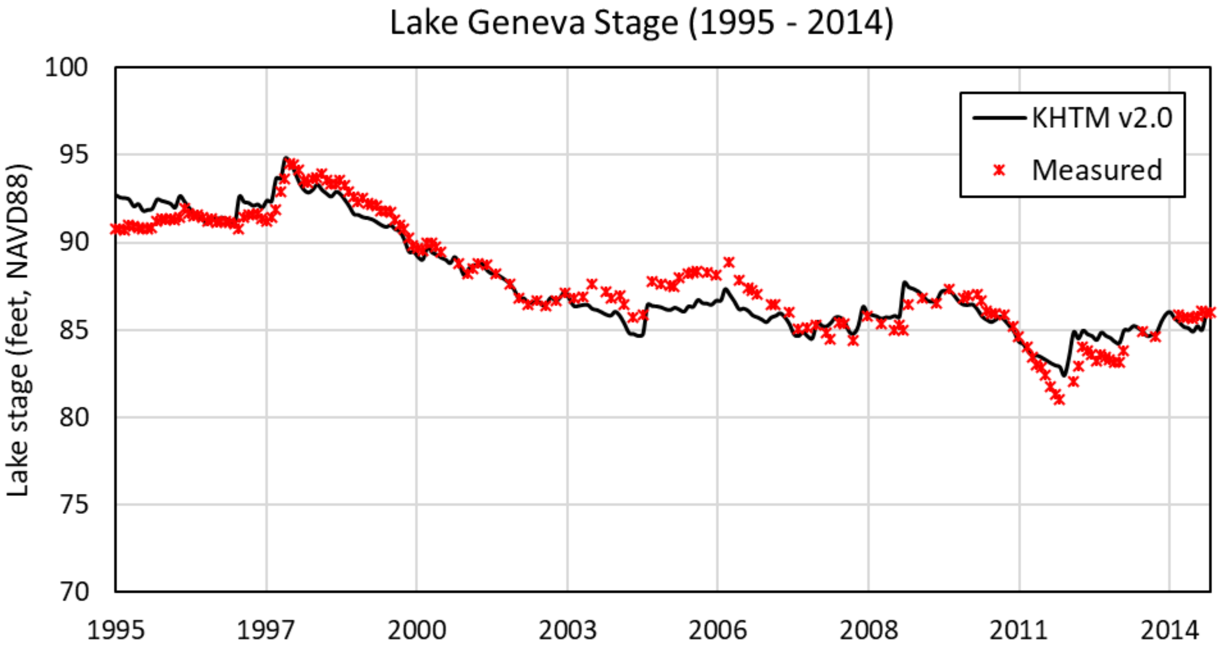

Figure 8. Measured (red) and simulated (black) lake level at Lake Geneva during the calibration period.

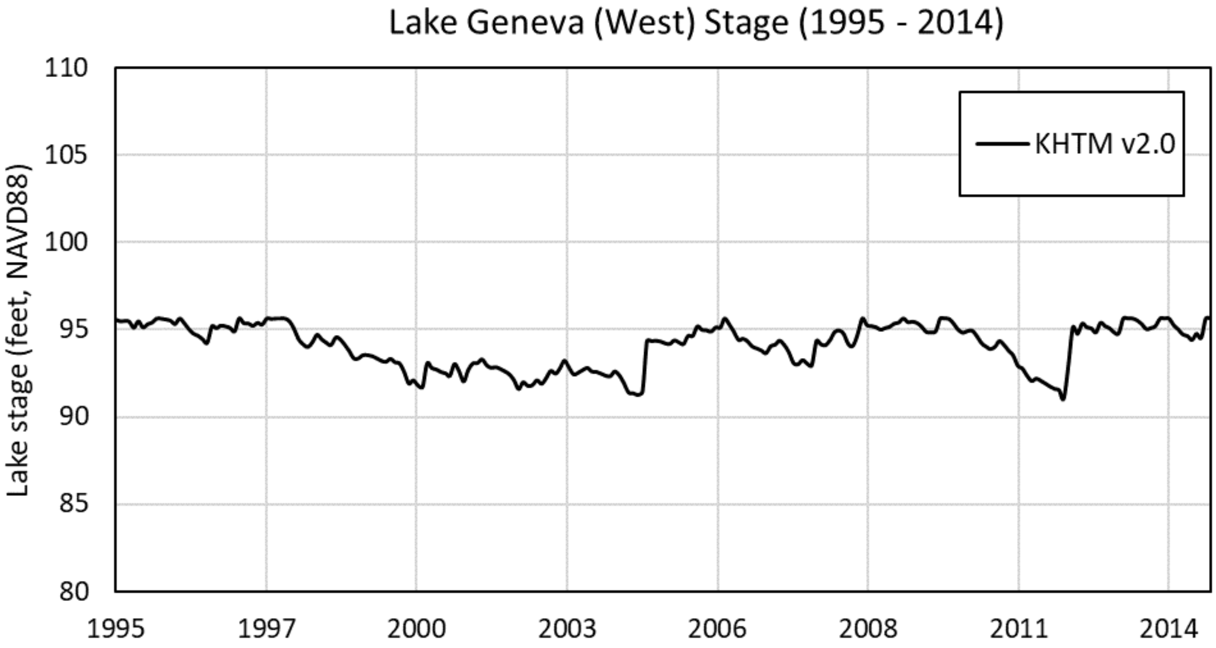

Figure 9. Simulated lake level at Lake Geneva West during the calibration period. No measured data was available at Geneva West during the calibration period.

LEAKANCE AND LEAKAGE

The following sections report simulated leakance values and leakage rates at the primary lakes represented in the model and compare those results to prior estimates from literature. Lakebed leakance (also referred to as conductance per unit area), a function of hydraulic conductivity and lakebed sediment thickness that affects the rate of flow between the aquifer and the lake, was reformulated during model recalibration and is reported as a function of cell depth and lake level at Lake Brooklyn. In this report, the leakance term representing the combined leakance of all model layers between the lakebed the top of the UFA beneath each lake is referred to as composite leakance. Leakage is the vertical volumetric flow rate of water from the lake to the aquifer and reported in units of inches per year after dividing by the simulated lake area.

Lakebed Leakance

The spatial distribution of lakebed leakance at Lake Brooklyn as a result of applying the Heaviside approximation (**Equation 2**) and PEST estimated leakance parameter values (**Table 2**) is shown in **Figure 10**. Deep lake cells, defined as those cells with a depth greater than the $DepthC_B$ of 26.55 feet (**Table 2**), were assigned the PEST estimated lakebed leakance of 0.72 day^{-1} in the LAK package. These cells are shown by the darkest blue color in **Figure 10**. Shallow lake cells, defined as those with a depth less than $DepthC_B$, were assigned a lakebed leakance of 6.82E-4 day^{-1} in the LAK package from the PEST estimated $LAKLK_B$ shallow leakance value. These cells are shown by the lightest blue color in **Figure 10**. Lakebed leakance as a function of model lake cell depth at Lake Brooklyn is shown in **Figure 11**. The transition from shallow to deep lakebed leakance in the model occurs at $DepthC_B$ (red dashed line in **Figure 11**). Next, Lake Brooklyn average lakebed leakance as a function of lake level was calculated by averaging lakebed leakance values from cells with a bottom elevation below each lake level using **Equation 3** and the results are displayed graphically in **Figure 12.** For a given lake level, only lake cells with a bottom elevation below that level were used to calculate the average lakebed leakance for Lake Brooklyn (**Equation 3**). As an example, at a level of 95 feet NAVD88, 163 out of 444 lake cells have a bottom lake elevation below 95 feet NAVD88, therefore n = 163 in **Equation 3**. For a given lake level in **Figure 12**, a combination of shallow and deep leakance cells were used to compute the average lakebed leakance, until approximately 90 feet (NAVD88) or less, where only those lake model cells assigned the maximum lakebed leakance (0.72 day^{-1}) remain active in the model.

For a given lake level (h_s)

$$\overline{LAKLK_B} = \frac{1}{n}\sum_{i=1}^{n} LAKLK_i \qquad (3)$$

where

- $\overline{LAKLK_B}$ is the average lakebed leakance at Lake Brooklyn at a given level, h_s.
- i is a model lake cell with a bottom elevation < h_s.
- n is the total number of cells with a bottom elevation < h_s
- $LAKLK_i$ is the lakebed leakance assigned to model cell i in the LAK package.

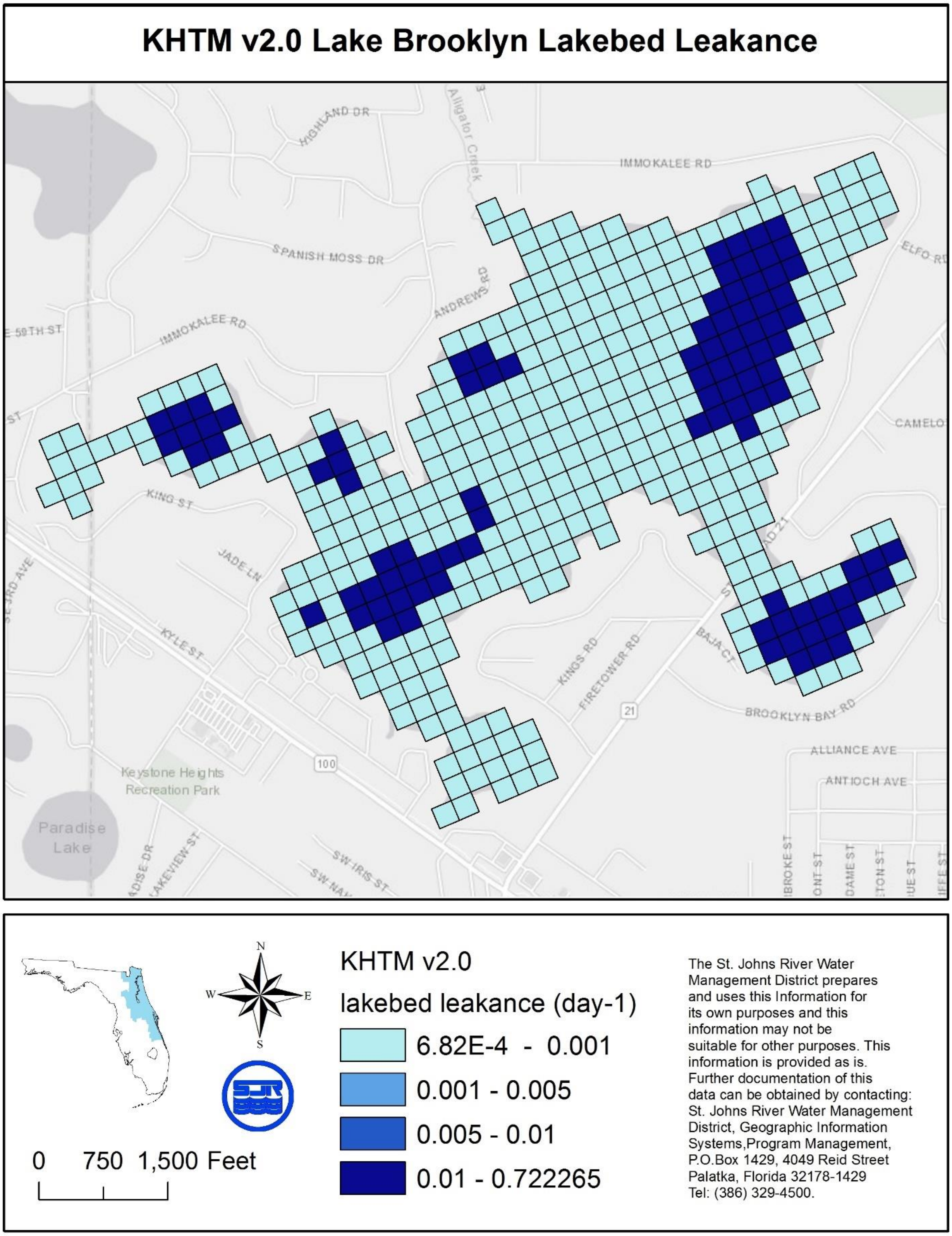

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Figure 10. Spatial distribution of lakebed leakance at Lake Brooklyn. Each square represents an individual lakebed model cell.

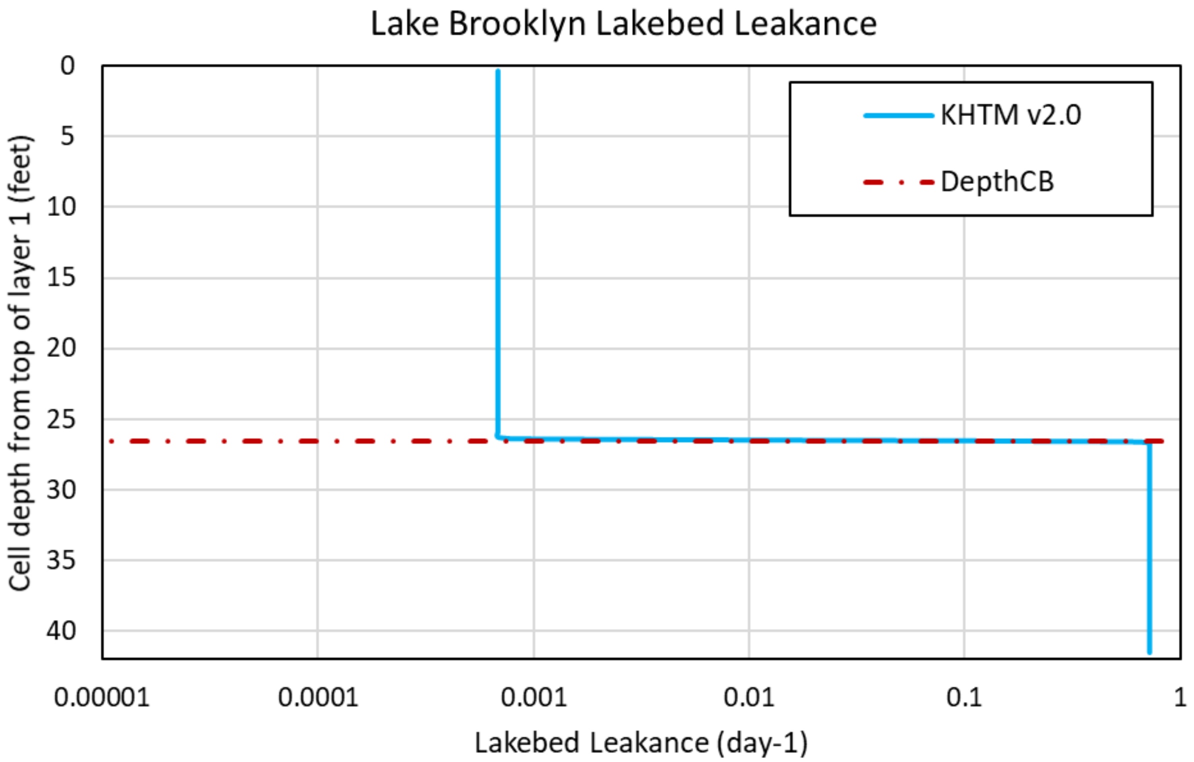

Figure 11. Lakebed leakance as a function of lake depth at Lake Brooklyn. These values were assigned to individual cells representing the bottom of Lake Brooklyn. DepthCB is shown in red. Lake cell depth shown along the vertical axis for clarity.

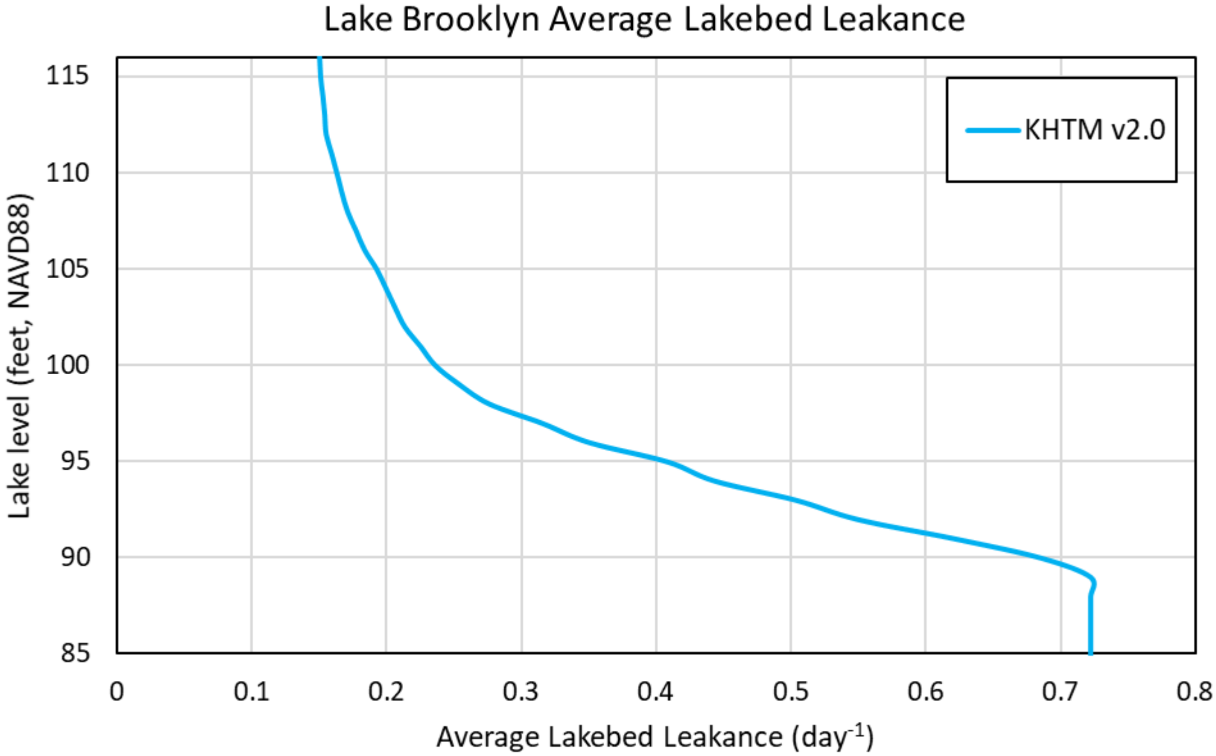

Figure 12. Average lakebed leakance as a function of lake level at Lake Brooklyn. The averages were calculated by averaging all lakebed leakance values from cells with a bottom elevation below a given lake level. Lake level shown along vertical axis for clarity.

Composite Leakance

Continuing a step further, the composite leakance between the lakebed and the top of the UFA were calculated at each cell, *i*, beneath each primary lake in the model using **Equation 4**. This approach calculated a composite leakance between the lakebed and the UFA, which includes the SAS, Upper Confining Unit (UCU), Intermediate Aquifer System (IAS), and the Lower Confining Unit (LCU). The leakance term for an individual model layer was calculated by dividing the model layer's vertical hydraulic conductivity by the model layer thickness. **Figure 13** shows the spatial distribution of model cell composite leakance at Lake Brooklyn. Darker shades of blue indicate areas with higher composite leakance between the lakebed and the UFA.

$$COMP_{LK_i} = \frac{1}{\frac{1}{LAKLK_i} + \frac{1}{SAS_{LK_i}} + \frac{1}{UCU_{LK_i}} + \frac{1}{IAS_{LK_i}} + \frac{1}{LCU_{LK_i}}} \tag{4}$$

where

- i is a model cell representing a lake in the LAK package
- $COMP_{LKi}$ is the composite leakance (day^{-1}) for model cell i
- $LAKLK_i$ is the lakebed leakance (day^{-1}) assigned in the LAK package
- SAS_{LKi} is the SAS model layer leakance (day^{-1})
- UCU_{LKi} is the UCU model layer leakance (day^{-1})
- IAS_{LKi} is the IAS model layer leakance (day^{-1})
- LCU_{LKi} is the LCU model layer leakance (day^{-1})

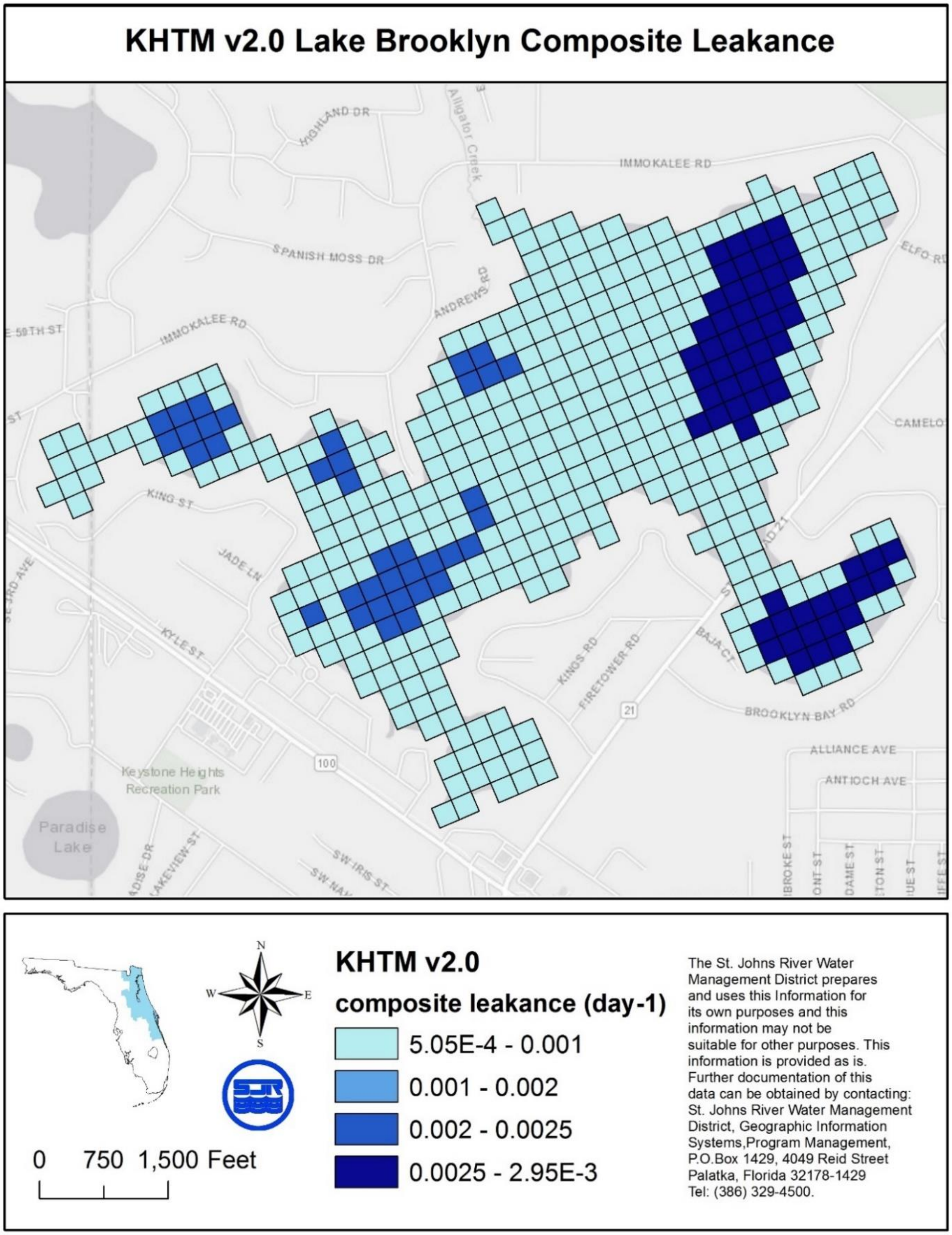

Figure 13. Spatial distribution of composite leakance (day-1) at model lake package cells representing Lake Brooklyn.

Average Composite Leakance: Method 1

In order to compare to prior estimates of leakance values available at each lake, an average composite leakance at each lake needs to be calculated using the model. The first method used to calculate an average composite leakance value averaged the composite leakance using **Equation 4** at all model grid cells assigned to the lake in the LAK package. This method is consistent with the approach used to calculate simulated leakance at each lake in KHTM v1.0 and would be most representative of a high stage condition in which all model cells in the lake are active. The average model composite leakance values calculated using this approach are compared to equivalent values reported for KHTM v1.0 in **Table 6**.

Table 6. Average simulated composite leakance calculated using all model lake package cells comprising each primary lake, reflecting a high stage condition in which all lake cells are active (see Figure 13 for distribution at Lake Brooklyn). Values are compared to reported values for KHTM v1.0.

Lake	Average Simulated Composite Leakance (day^{-1})[a]	
	KHTM v1.0	KHTM v2.0
Lowry	1.68×10^{-4}	1.68×10^{-4}
Magnolia	4.83×10^{-4}	4.83×10^{-4}
Brooklyn	1.00×10^{-3}	9.68×10^{-4}
Keystone	2.37×10^{-2}	2.37×10^{-2}
Geneva (East)	3.25×10^{-4}	3.31×10^{-4}
Geneva West	3.96×10^{-4}	3.96×10^{-4}

[a] Composite leakance averaged over all model cells comprising each primary lake.

Average Composite Leakance: Method 2

A second approach to calculate the simulated composite leakance was implemented in which the average composite leakance at each lake was calculated for a range of lake levels simulated during the calibration period. This approach takes into account the variability in hydrologic conditions and lake level at each lake observed during the calibration period, and thus provides a more accurate representation of the average composite leakance at each lake to compare with prior estimates. For a given lake level, **Equation 5** was applied to calculate the average composite leakance, $COMP_{LK_{lake}}$, at each lake by averaging the model cell composite leakances for all cells possessing a bottom lake elevation below the lake level.

For a given lake level (h_s)

$$\overline{COMP_{LK_{lake}}} = \frac{1}{n}\sum_{i=1}^{n} COMP_{LK_i} \tag{5}$$

where

- $\overline{\boldsymbol{COMP_{LK_{lake}}}}$ is the average composite leakance for a lake at a given lake level, h_s.
- i is a model lake cell with a bottom elevation < h_s.
- n is the total number of cells with a bottom elevation < h_s
- $\boldsymbol{COMP_{LK_i}}$ is the composite leakance at model cell i.

The result yields a range of average simulated composite leakance for each primary lake corresponding to the range in lake levels simulated during the calibration period. This range can be directly compared with prior ranges of estimated leakance, as shown in **Table 7**. **Figure 14** shows the variation in average composite leakance at Lake Brooklyn with changes in lake level, as well as the minimum and maximum estimated leakances, for comparison. For Lake Brooklyn, the simulated average composite leakance approaches its maximum value at minimum stage shown in **Figure 14**, where deep lake cells with higher lakebed leakance values are active.

Table 7. Range of simulated average composite leakance corresponding to the range in simulated lake level during the calibration period for each primary lake in KHTM v2.0. Ranges are compared to prior estimates of leakance for each lake. See Figure 14 for the variation in average composite leakance with lake level at Lake Brooklyn.

Lake	Range of Estimated Leakance (day^{-1})	Range of Simulated Lake Level (feet)	Range of Average Simulated Composite Leakance (day^{-1})*
Lowry	2.51 x 10^{-4} - 2.95 x 10^{-4}	128 - 133	1.68 x 10^{-4} - 1.71 x 10^{-4}
Magnolia	3.10 x 10^{-4} - 5.91 x 10^{-4}	110 - 125	4.83 x 10^{-4} - 5.01 x 10^{-4}
Brooklyn	9.61 x 10^{-4} - 2.60 x 10^{-3}	85 - 114	9.75 x 10^{-4} - 2.73 x 10^{-3}
Keystone	None	82 - 98	2.38 x 10^{-2} - 2.38 x 10^{-2}
Geneva (East)	1.76 x 10^{-4} - 8.07 x 10^{-4}	82 - 95	3.84 x 10^{-4} - 5.52 x 10^{-4}
Geneva West		91 - 96	3.98 x 10^{-4} – 4.01 x 10^{-4}

*For a given lake level, only lake cells with a bottom elevation below that level were used to calculate the average leakance.

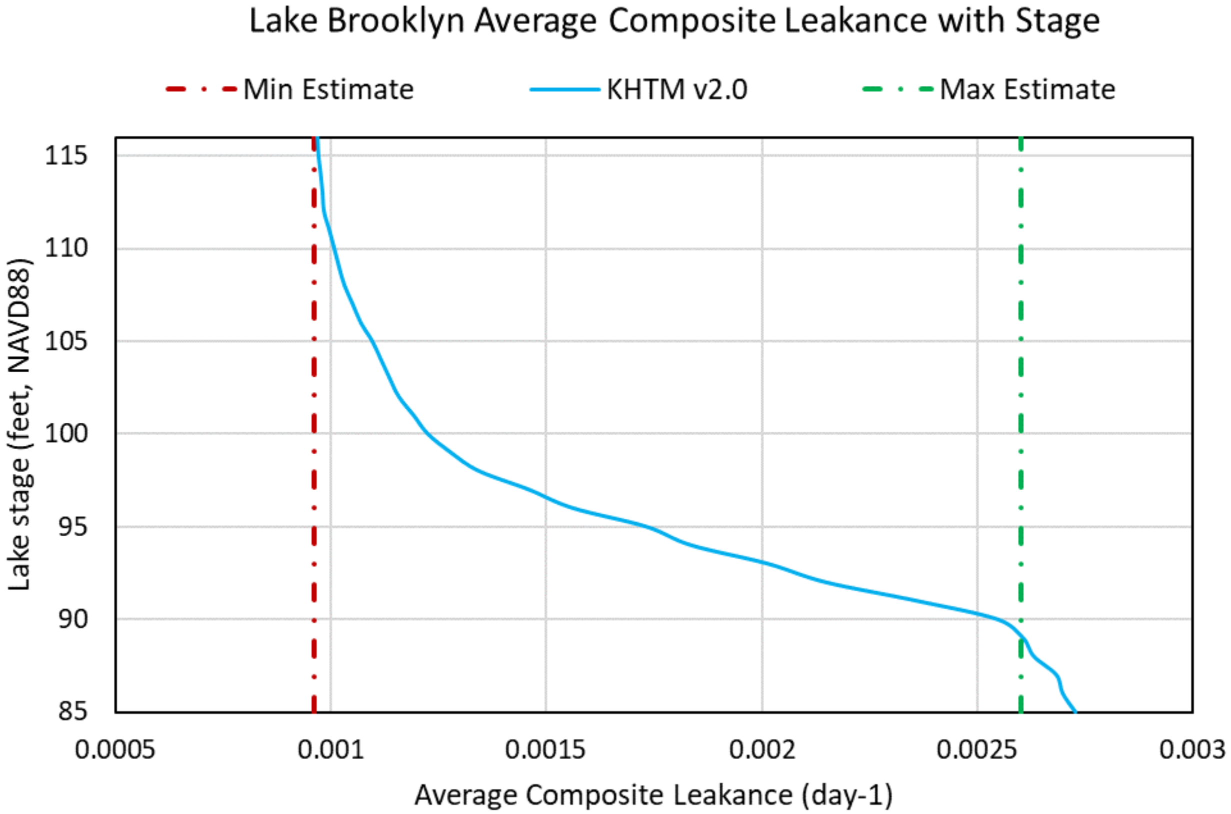

Figure 14. Average composite leakance (day-1) at Lake Brooklyn for a given lake level. For comparison, the minimum and maximum estimated leakances are also included. Lake level is shown along vertical axis for clarity.

Leakage

Lake leakage rates were estimated by several studies for Lakes Lowry, Magnolia, Brooklyn, Keystone, and Geneva for various periods during the first three years of calibration (January 1995 to December 1997) using water balance approaches (Tetra Tech, 2017). Simulated lake leakage rates from the lake were calculated for each monthly stress period in the model. Simulated lake area was estimated for each stress period based upon simulated lake level at each lake using stage-volume-area relationship tables recently updated with refined bathymetric data (Tetra Tech, 2019). The simulated lake area was used to convert volumetric lake leakage rates (units of cubic feet per day) to units of inches per year in order to compare with prior estimates. The average and range of monthly simulated lake leakage rates between 1995 to 1997 are compared to prior estimates in **Table 8.** Two sets of leakage results are reported for KHTM v1.0 for comparison with KHTM v2.0 in **Table 8**. These include average leakage rates reported in the KHTM v1.0 modeling effort (Tetra Tech, 2017), as well as recalculated average leakage rates using simulated volumetric rates (in cubic feet per day), updated stage-area tables, and simulated lake level results for each stress period from KHTM v1.0. Leakage rates were recalculated for KHTM v1.0 by SJRWMD to be consistent with the methodology used to compute the 1995-1997 leakage rates for KHTM v2.0, and therefore provide values for direct comparison. The range of leakage rates was not reported for KHTM v1.0 but was calculated by SJRWMD and included alongside KHTM v2.0 ranges to provide a consistent metric to compare with the range of published estimates for each lake.

Table 8. 1995 - 1997 leakage rates compared to prior estimates for KHTM v1.0 and KHTM v2.0.

Lake	1995-1997 Leakage Rate Estimates (in/yr)	Simulated 1995-1997 Leakage Rate (in/yr)				
		Average			Range	
		KHTM v1.0[a]	KHTM v1.0[b]	KHTM v2.0[b]	KHTM v1.0[b]	KHTM v2.0[b]
Lowry	58 – 68	31.8	30.9	30.6	29 – 33	29 – 33
Magnolia	60 – 113	65.0	65.8	64.8	62 – 69	61 – 68
Brooklyn	73 – 98	84.6	83.7	79.4	68 – 103	69 – 97
Keystone*	None	181.6	430.3	403.9	188 – 587	193 – 587
Geneva (East)	7.4 – 10.2	11.4	14.2	14.1	11 – 17	11 – 18
Geneva West*			10.3	10.2	8 - 12	8 – 12

* No prior leakage estimates are available at Keystone Lake or Geneva West.

[a] Leakage rates as reported in the KHTM v1.0 report (see Tetra Tech, 2017).

[b] Leakage rates calculated using simulated volumetric rates, simulated lake levels, and updated stage-area tables.

CHAPTER 4. EXTENDED LONG-TERM (XLT) SIMULATION

SJRWMD extended the KHTM v1.1 long-term (LT) simulation model input files to the end of December 2018 (**Appendix A**). No changes were made to the LT model inputs previously developed for the period July 1957 through December 2014. The KHTM v2.0 recalibrated parameter set (**Table 2**) was used to run the monthly extended long-term (XLT) simulation (July 1957 – December 2018) one time (no further PEST iterations) to evaluate the model's performance to predict historical and recent lake levels at the primary lakes. **Figures 15 – 19** show the extended long-term simulated lake levels at lakes Lowry, Magnolia, Brooklyn, Keystone, and Geneva compared to measured values. Likewise, **Figure 20** shows the simulated lake level at Lake Geneva West, however no measured data was available to compare against during this period.

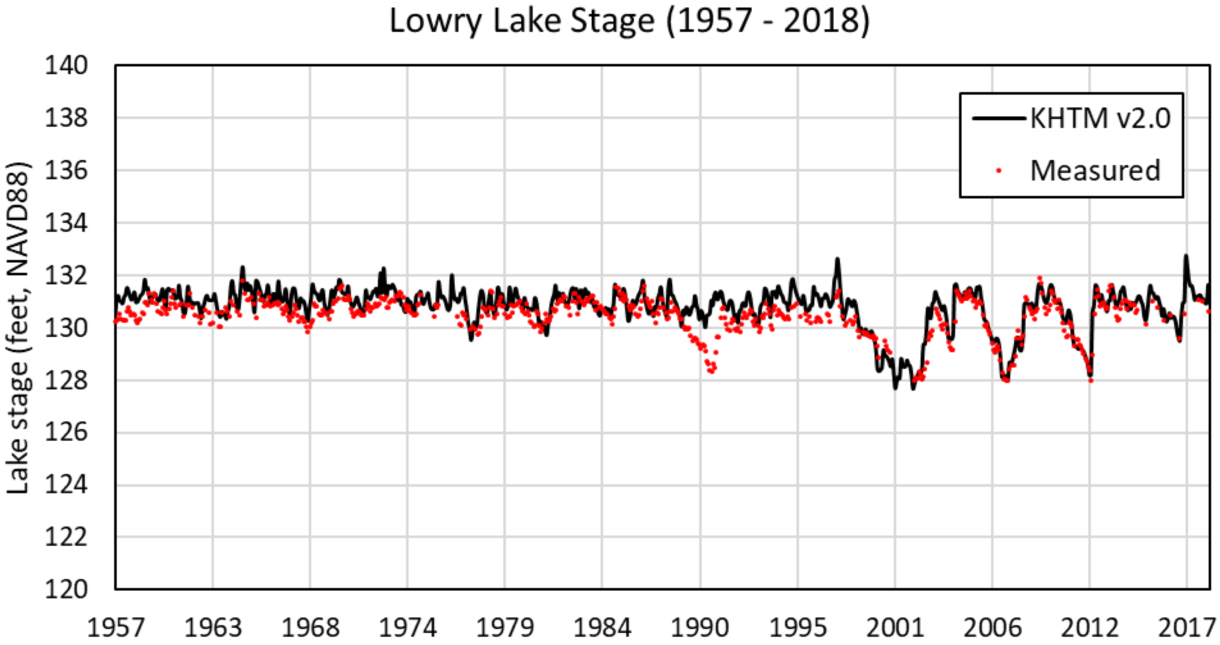

Figure 15. Extended long-term measured (red) and simulated (black) level at Lake Lowry.

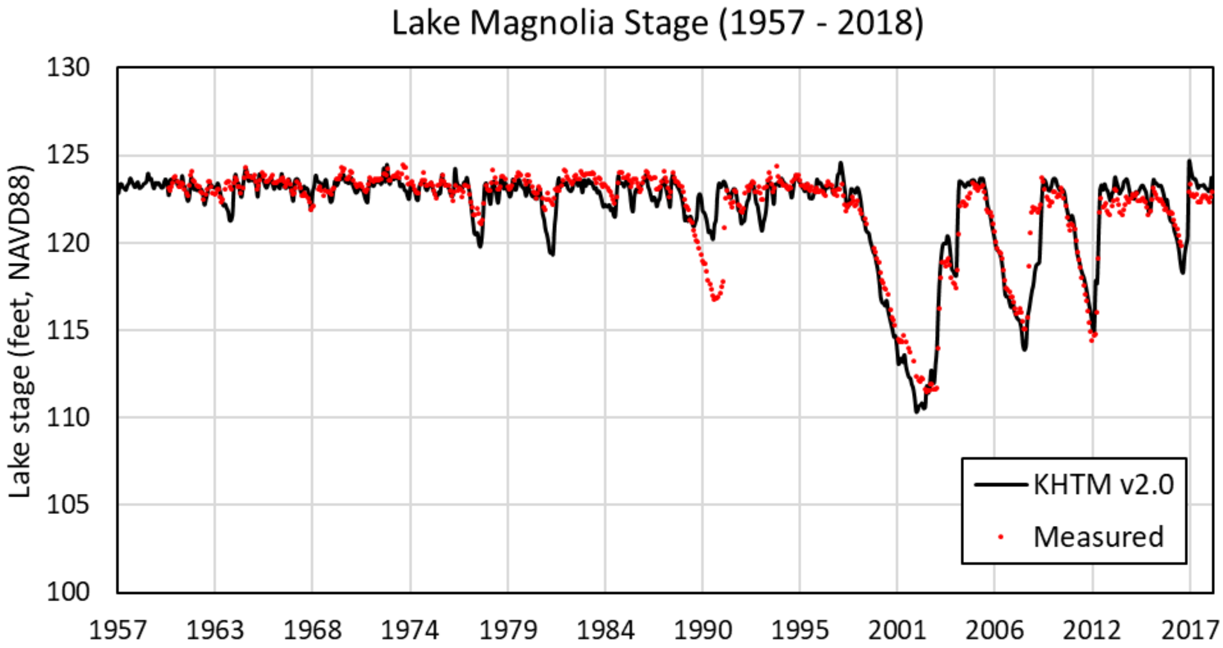

Figure 16. Extended long-term measured (red) and simulated (black) level at Lake Magnolia.

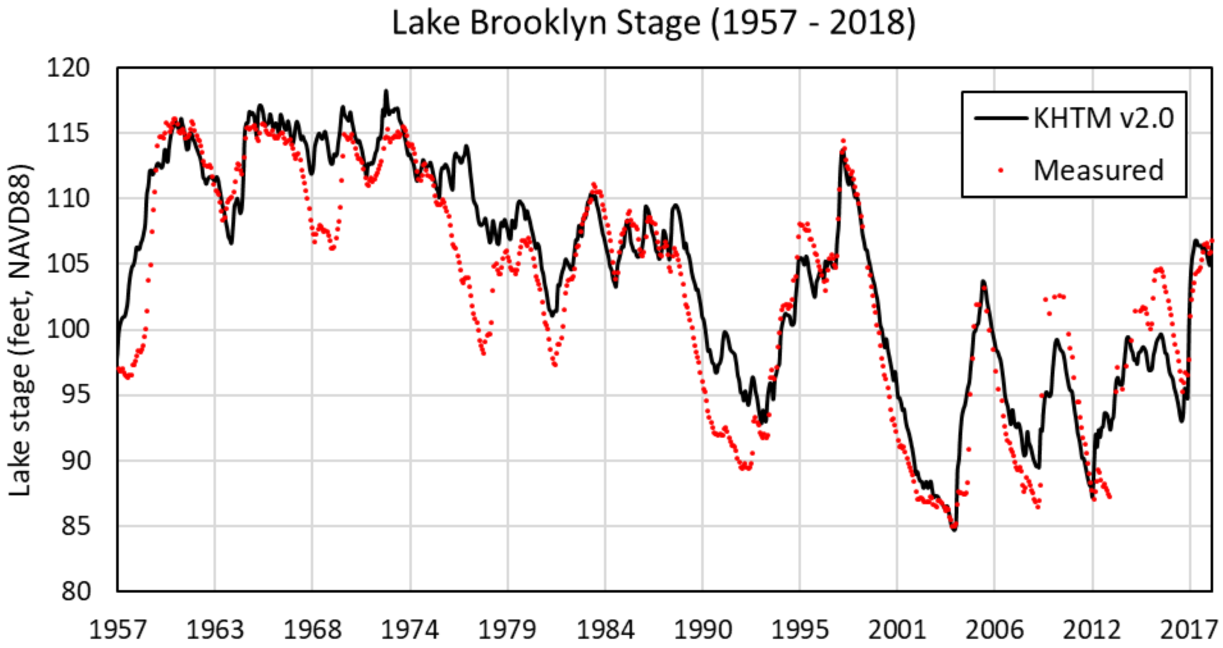

Figure 17. Extended long-term measured (red) and simulated (black) level at Lake Brooklyn.

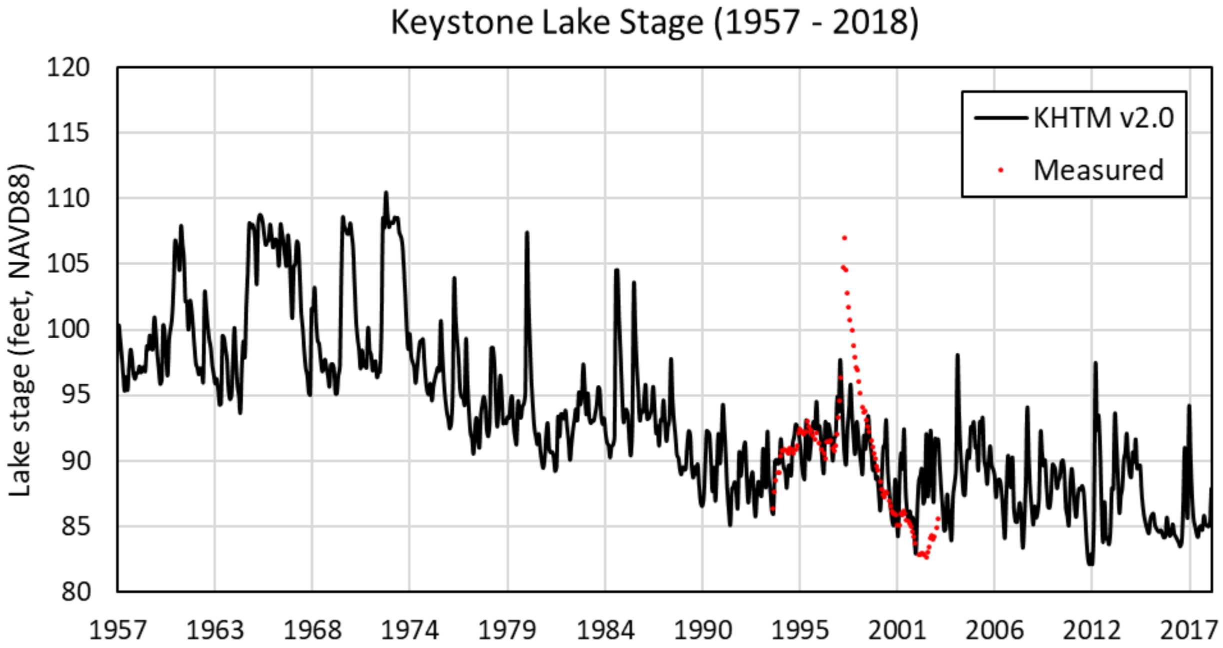

Figure 18. Extended long-term measured (red) and simulated (black) level at Keystone Lake.

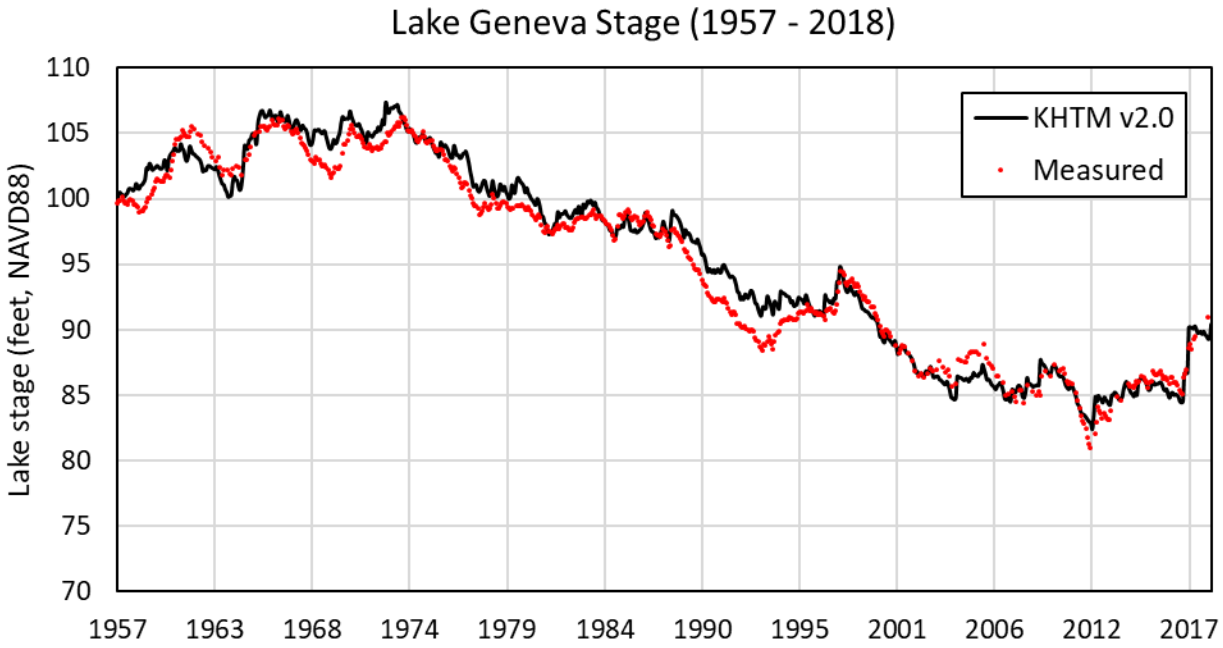

Figure 19. Extended long-term measured (red) and simulated (black) level at Lake Geneva.

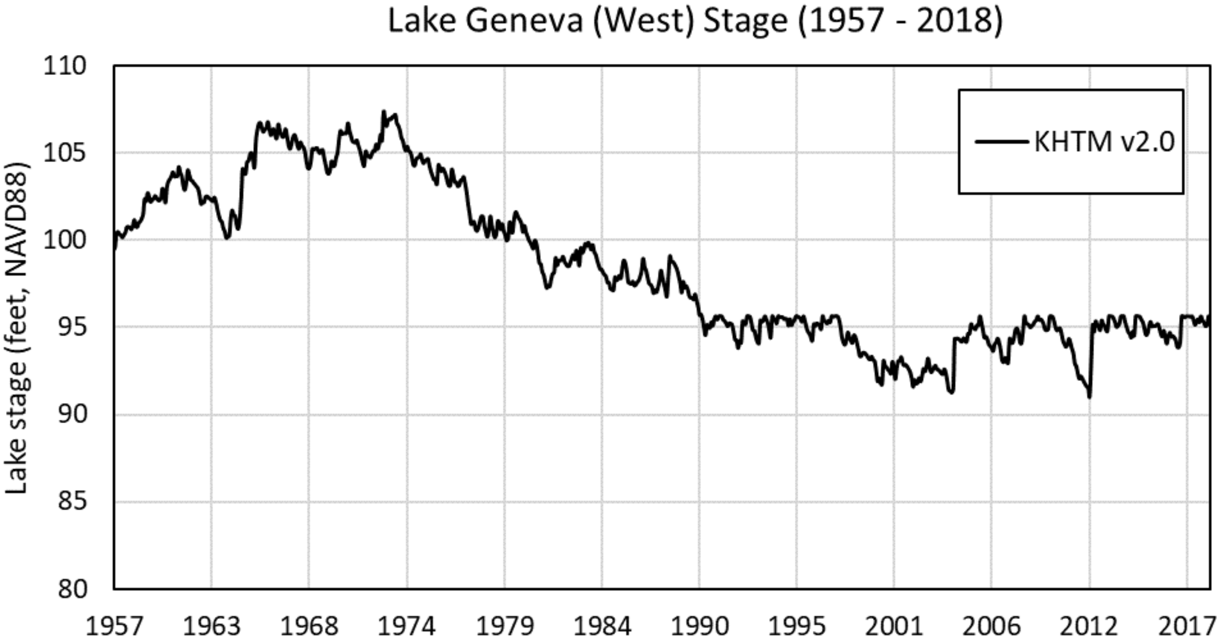

Figure 20. Extended long-term simulated lake level at Lake Geneva West. No measured data was available to compare against during this period.

Annual average lake water budgets for each year in the KHTM v2.0 XLT simulation (1957 – 2018) were calculated in units of cubic feet per day for the primary lakes in the model and are provided in **Appendix B**. Annual average volumetric rates (units of cubic feet per day) were converted to units of inches per year by dividing by the annual average lake area, calculated from simulated monthly level and stage-area relationships defined for each primary lake (Tetra Tech, 2019). Annual average lake water budgets converted to units of inches per year are provided in **Appendix C**. **Figure 21** shows the annual average inflows and outflows at Lake Brooklyn for the XLT simulation period in units of inches per year.

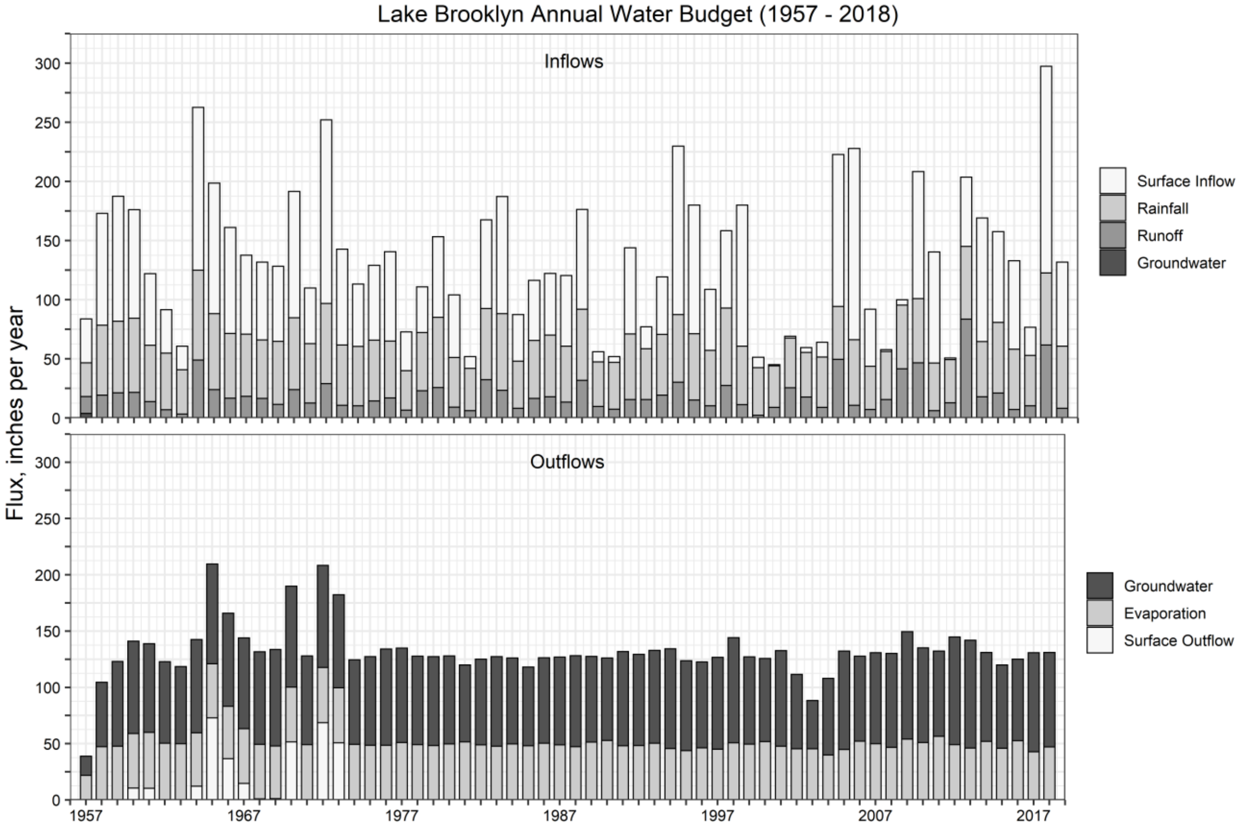

Figure 21. Lake Brooklyn annual water budget for the XLT simulation period. Inflows (top) and outflows (bottom) at Lake Brooklyn are in units of inches per year.

CHAPTER 5. DISCUSSIONS

To evaluate KHTM v2.0 model prediction performance, model results were compared to available estimates, pre-defined metric goals (**Table 1**), and available hydrogeologic information. In addition, to determine if the goals of the recalibration effort were achieved, KHTM v2.0 results were compared to those reported for KHTM v1.0 and v1.1. Simulated leakance and lake leakage rates are also discussed to evaluate the effects of reformulating lakebed leakance during model recalibration.

EVALUATION OF KHTM V2.0 MODEL CALIBRATION PERFORMANCE

The calibration performance of the model was evaluated by comparing simulated groundwater and lake levels to observed data and defined calibration metric goals.

Groundwater Levels

Overall, the model simulated groundwater levels well in the SAS (MAE = 4.48 feet), UFA (MAE = 2.56 feet), and LFA (MAE = 1.61 feet) with a MAE below the calibration criterion of 5 feet in each major aquifer (**Table 4**). The ME exceeded zero for all major aquifers in the model, suggesting that the model, on average, overestimated head in these aquifers. However, this bias was minor (ME < 2 feet) compared to the range in observations of groundwater level targets in the model domain, which exceeded 100 feet.

Lake Levels

At lakes Lowry, Magnolia, and Geneva, the model simulated lake level targets within <1-foot MAE from observations (**Table 5**). The model also closely matched the temporal fluctuation in level during the calibration period at Lake Lowry (**Figure 4**), Lake Magnolia (**Figure 5**), and Lake Geneva (**Figure 8**) very well. Compared to the other primary lakes in the model, the MAE was higher at Lake Brooklyn and Keystone Lake during the calibration period (**Table 5**) and exceeded the metric goal of ≤ 2 feet for all modeled lake level targets by <1 foot. Although the simulated Lake Brooklyn levels deviated from measured levels, particularly during low level periods, the temporal pattern of fluctuation in level was captured overall (**Figure 6**). Furthermore, the MAE at Lake Brooklyn (MAE = 2.12 feet) was small relative to the ~30-foot fluctuation in observed level during the calibration period (**Figure 6**). Isolating the low level-only periods at Lake Brooklyn (< 95 feet NAVD88), the MAE increased compared to the MAE calculated over the entire the calibration period (**Table 5**). However, same as for the entire calibration period, the model captured the temporal fluctuation in level well during low water periods, particularly the low level event prior to Hurricane Frances in September 2004 (**Figure 6**). Few measurements of lake level exist at Keystone Lake during the calibration period with which to gauge model performance, although for the periods where measured data are available, the model generally captured the overall trend of lake level more closely than the magnitude of the level (**Figure 7**). The ME was near zero at Lake Magnolia (ME = 0.01 feet), Keystone Lake (ME = -0.07 feet), and Lake Geneva (ME = -0.01 feet) suggesting that the model was, on average, neither underestimating nor overestimating level at these lakes. On the other hand, the ME at lakes Lowry (ME = 0.28 feet) and Brooklyn (ME = 0.83 feet) indicated that the model overestimated level at these lakes, although by less than 1 foot on average (**Table 5**).

EVALUATION OF RECALIBRATION OBJECTIVES

The primary goals of recalibration were **1)** to improve the model's ability to match observed Lake Brooklyn levels that had degraded in the early part of the calibration period (1995 to 2004) and **2)** to enhance the model's ability to match low observed water levels (< 95 feet NAVD88) at Lake Brooklyn while also maintaining pre-defined calibration criteria summarized in **Table 1**. **Figure 22** compares simulated lake level at Lake Brooklyn during the calibration period in KHTM v1.0, v1.1, and v2.0. KHTM v2.0 approximated lake level at Lake Brooklyn closer to measurement values than KHTM v1.0 and v1.1, particularly during 1995 to 2004, where degradation occurred following bathymetric updates in KHTM v1.1. Thus, the first goal of the recalibration effort was achieved. For the second objective, KHTM v2.0 performed better in matching low levels at Lake Brooklyn as shown in **Table 5** as a result of recalibration. The MAE of lake levels below 95 feet at Lake Brooklyn decreased from 3.67 feet (KHTM v1.0) to 3.10 feet following bathymetry updates (KHTM v1.1) and 2.52 feet after recalibration (KHTM v2.0). Comparison of KHTM v2.0 and KHTM v1.1 calibration statistics indicated that the overall model performance was significantly improved. The MAE of groundwater levels decreased from 3.76 to 3.65 feet and the MAE of lake levels decreased from 1.36 to 1.21 feet (**Table 3**). The MAE percentage of the observed range in data for streamflow, vertical head differences, and lake water levels decreased in KHTM v2.0, which suggests an improved match to the observed data for these groups over KHTM v1.1 (**Table 3**). Based upon the totality of calibration metric results, KHTM v2.0 maintained, or improved upon, the calibration quality achieved by KHTM v1.1. Therefore, the second goal of the recalibration effort was also achieved. More detailed comparisons of changes in simulated groundwater and lake levels as a result of recalibration are described in the sections below.

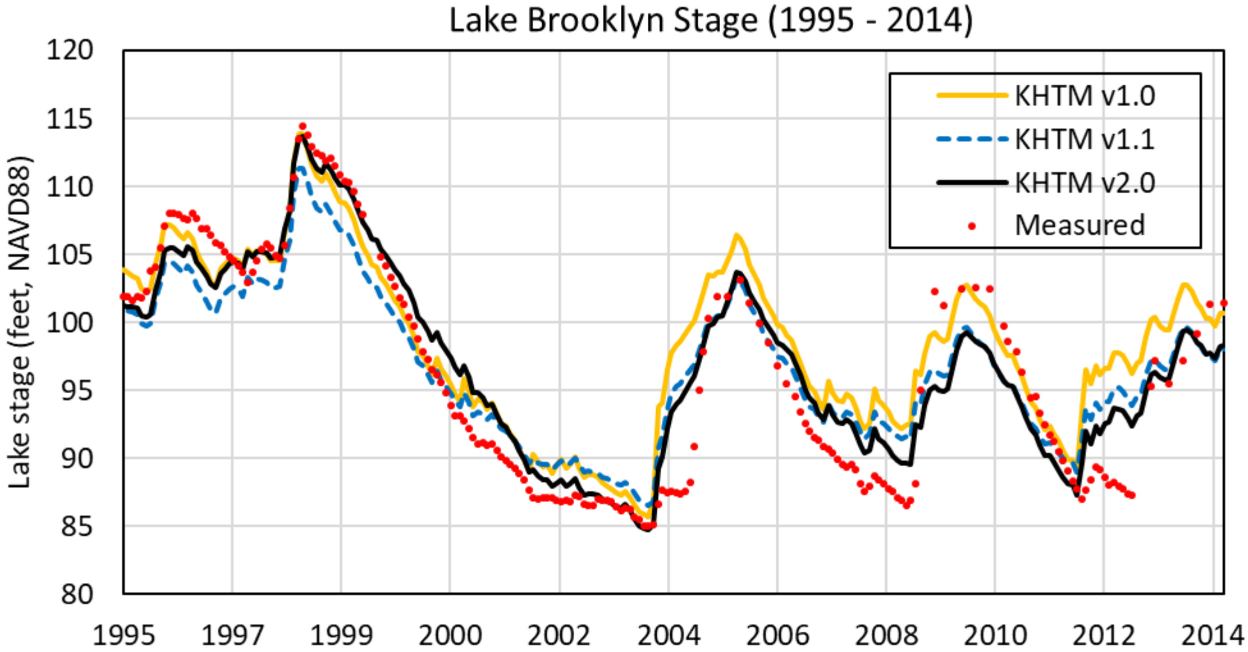

Figure 22. Comparison of simulated lake level at Lake Brooklyn in KHTM v1.0 (yellow solid line), KHTM v1.1 (blue dashed line) and KHTM v2.0 (black solid line) to measured values (red points). Results were generated from the LT model for v1.0 and the XLT model for v2.0.

Groundwater Levels

The simulation of groundwater levels in the SAS improved following model recalibration. When comparing statistics in the SAS, following removal of synthetic SAS targets, the MAE decreased from 4.77 feet (KHTM v1.0) to 4.48 feet (KHTM v2.0) (**Table 4**). Groundwater levels in the SAS changed from being underestimated, on average, in KHTM v1.0 (ME = -1.32 feet) and KHTM v1.1 (ME = -0.20 feet) to overestimated (ME = 0.79 feet) following recalibration (**Table 4**). The MAE in the UFA increased following bathymetric updates from 2.46 feet (KHTM v1.0) to 2.64 feet (KHTM v1.1), however, this was reduced following recalibration to 2.56 feet (**Table 4**). The MAE in the LFA also increased following bathymetric updates from 1.42 feet (KHTM v1.0) to 1.63 feet (KHTM v1.1) and was also reduced after recalibration to 1.61 feet (**Table 4**). Based on these results, the overall ability of the model to predict groundwater levels in the major aquifers improved in KHTM v2.0 following degradation that occurred in the UFA and LFA in KHTM v1.1.

Lake Levels

There was no change in calibration statistics at Lake Lowry or Lake Magnolia between KHTM v1.1 and v2.0 (**Table 5**). Compared to KHTM v1.0, overestimation of level at Lake Lowry increased from ME = 0.19 feet (KHTM v1.0) to ME = 0.28 feet (KHTM v1.1. and v2.0), although the MAE only increased by 0.03 feet (**Table 5**). Whereas the model underestimated level at Lake Magnolia in KHTM v1.0 (ME = -0.38), the ME was approximately zero in KHTM v1.1 and v2.0, suggesting that the model, on average, neither underestimated nor overestimated level at this lake. There was also a decrease in the MAE at Lake Magnolia from 0.89 feet (v1.0) to 0.75 feet (v1.1 and v2.0) (**Table 5**). The near zero

MEs at Lake Magnolia, Keystone Lake, and Lake Geneva are an improvement from higher magnitude ME values at these lakes in KHTM v1.0 (**Table 5**). Overall, the simulation of lake level at Lake Brooklyn improved following recalibration compared to both KHTM v1.0 and v1.1. Throughout the calibration period, lake level, on average, remained overestimated in KHTM v2.0, although by a lesser magnitude than the previous model versions. The MAE at Lake Brooklyn decreased from 2.82 feet in KHTM v1.1 to 2.12 feet following recalibration, which is an improvement from the MAE of 2.88 feet in KHTM v1.0 (**Table 5**). Likewise, the model's ability to match low levels at Lake Brooklyn significantly improved following recalibration. After bathymetric updates in KHTM v1.1, the MAE below a level of 95 feet at Lake Brooklyn decreased from 3.67 feet in KHTM v1.0 to 3.10 feet in KHTM v1.1 (**Table 5**). Recalibration further improved the model's ability to match levels below 95 feet by reducing the MAE to 2.52 feet in KHTM v2.0 (**Table 5**). The low level events in 2004 and 2008-2009 were more closely approximated by KHTM v2.0 than either previous versions of the model (**Figure 22**). The recalibrated model was also able to capture high level events very well, particularly in 1998 (**Figure 22**). The XLT simulation generally matched historical and recent lake levels well at the primary lakes (**Figure 15 - 19**), particularly considering the data limitations during the period prior to the start of calibration (1957 – 1994) (Tetra Tech, 2017). The model generally matched observed levels at Lakes Brooklyn (**Figure 17**) and Geneva (**Figure 19**), particularly during the rise in water levels that occurred following Hurricane Irma in September 2017. Additionally, the model matched long-term observed lake levels at Lake Lowry (**Figure 15)** and Magnolia (**Figure 16**) very well.

LEAKANCE AND LEAKAGE

The spatial distribution of cells assigned the maximum lakebed leakance value at Lake Brooklyn (those with a depth greater than $DepthC_B$; dark blue shaded cells in **Figure 10**) match well with regions of karst collapse features identified via high-resolution seismic profiling of the lake (**Figure 23**). These collapse regions were interpreted as having a greater degree of connection to the UFA and, thus, the potential for higher rates of leakage through the lakebed to the UFA. It should be noted that the lake water level was low at the time the seismic survey was conducted, and much of the lake bottom was exposed. The seismic survey was only conducted in the remaining pools, or the deeper portions of the lake (SDI, 1992; Jeff Davis, PG, personal communication). The reformulation of lakebed leakance embodied the concept of deeper (collapsed) portions of the lakebed having a higher leakance value. However, the depth at which leakance increased was estimated independently through model calibration because it was not known. Therefore, the general agreement between the model assigned high lakebed leakance areas (**Figure 10**) and the regions interpreted as collapse features (**Figure 23)** is significant because the transition between low (shallow areas) and high (deep areas) lakebed leakance was controlled by the critical depth PEST parameter $DepthC_B$. This adds confidence to both KHTM v2.0 and to the interpretation that these areas have different hydraulic properties than surrounding regions of the lake. The variation of lakebed leakance at Lake Brooklyn as a function of cell depth (**Figure 11**) and lake level (**Figure 12**) are also in agreement with the interpretation that distinct hydraulic properties exist in regions characterized by greater depth in the model.

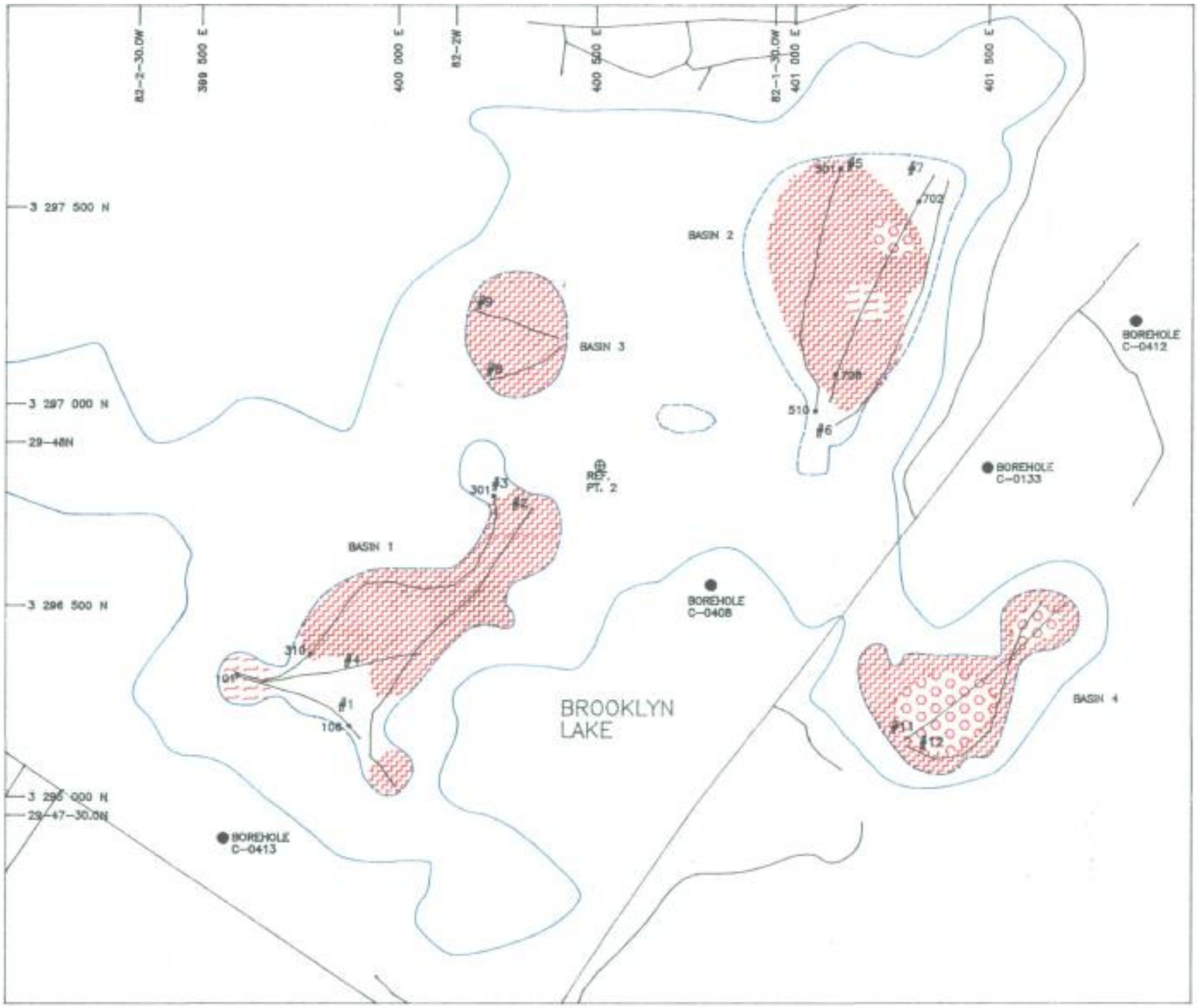

Figure 23. Regions of karst collapse features at Lake Brooklyn (shaded in red) interpreted from high resolution seismic profiling (From Figure 5-7-1; SDI, 1992).

The range in simulated composite leakance for a given range of lake levels generally agreed well with prior estimates of leakance (**Table 7**). The range of simulated composite leakance fell within the estimated range for all primary lakes except Lake Lowry (**Table 7**). The ranges of simulated composite leakance at Lake Magnolia and Lake Brooklyn matched the estimated ranges very well (**Table 7**). The average composite leakance as a function of lake level at Lake Brooklyn matched very well with the range of estimated leakances, exceeding the maximum estimated leakance value by approximately 1.3E-04 day^{-1} at a level of 85 feet (**Figure 14**). The model shows general agreement between simulated 1995-1997 leakage rates and prior estimates (**Table 8**). Rather than a single value for each lake, the range in simulated leakage rates was used as the primary metric to evaluate model results since estimates vary widely between different studies for the 1995-1997 time period. The simulated 1995-1997 leakage rates at Lake Magnolia and Lake Brooklyn agreed well with estimated leakage rates (**Table 8**). No prior estimates of leakage were available for Geneva West, therefore estimates for Geneva were used for both lakes Geneva and Geneva West in evaluating model results. The range in simulated leakage at Lake Geneva West (8 to 12 in/yr) agreed more closely with the range of prior estimates (7.4 to 10.2 in/yr), while the range in simulated leakage at Lake Geneva (11 to 18 in/yr) exceeded the estimated range (**Table 8**). The model underestimated leakage at Lake Lowry compared to prior estimates (**Table 8**). Simulated leakage rates were highest at Keystone Lake (**Table 8**), however, no prior estimates were available at the time of this report to evaluate these simulated leakages. High leakage rates at Keystone Lake may be necessary in order to compensate for high runoff rates to the lake, which in turn reduce overflow to Lake Geneva (Tetra Tech, 2017). Although no data was available at Keystone Lake, the model reasonably simulated leakage rates at the other primary lakes in the model for the 1995-1997 period (**Table 8**).

Improvement of simulated low levels at Lake Brooklyn were directly tied to modifications of its lakebed leakance. The modifications were a significant change from the previous treatment of lakebed leakance at Lake Brooklyn used in both KHTM v1.0 and v1.1. The spatial distribution of lakebed leakance in KHTM v2.0 more closely approximates the system (see **Figure 23**) than KHTM v1.0, in which lakebed leakance varied continuously as a function of depth across the lakebed area (**Figure 24**). The maximum assigned lakebed leakance value at Lake Brooklyn increased from 0.016 day^{-1} in KHTM v1.0 to 0.72 day^{-1} in KHTM v2.0. Due to the reformulation of lakebed leakance, the simulated composite leakance averaged over the entire lake area at Lake Brooklyn decreased from 1.00E-3 day^{-1} (v1.0) to 9.68E-4 day^{-1} (v2.0) (**Table 6**). For all other lakes in the model, the formulation of lakebed leakance was unchanged from KHTM v1.0, and the simulated average composite leakance values did not fluctuate between KHTM v2.0 and v1.0 (**Table 6**).

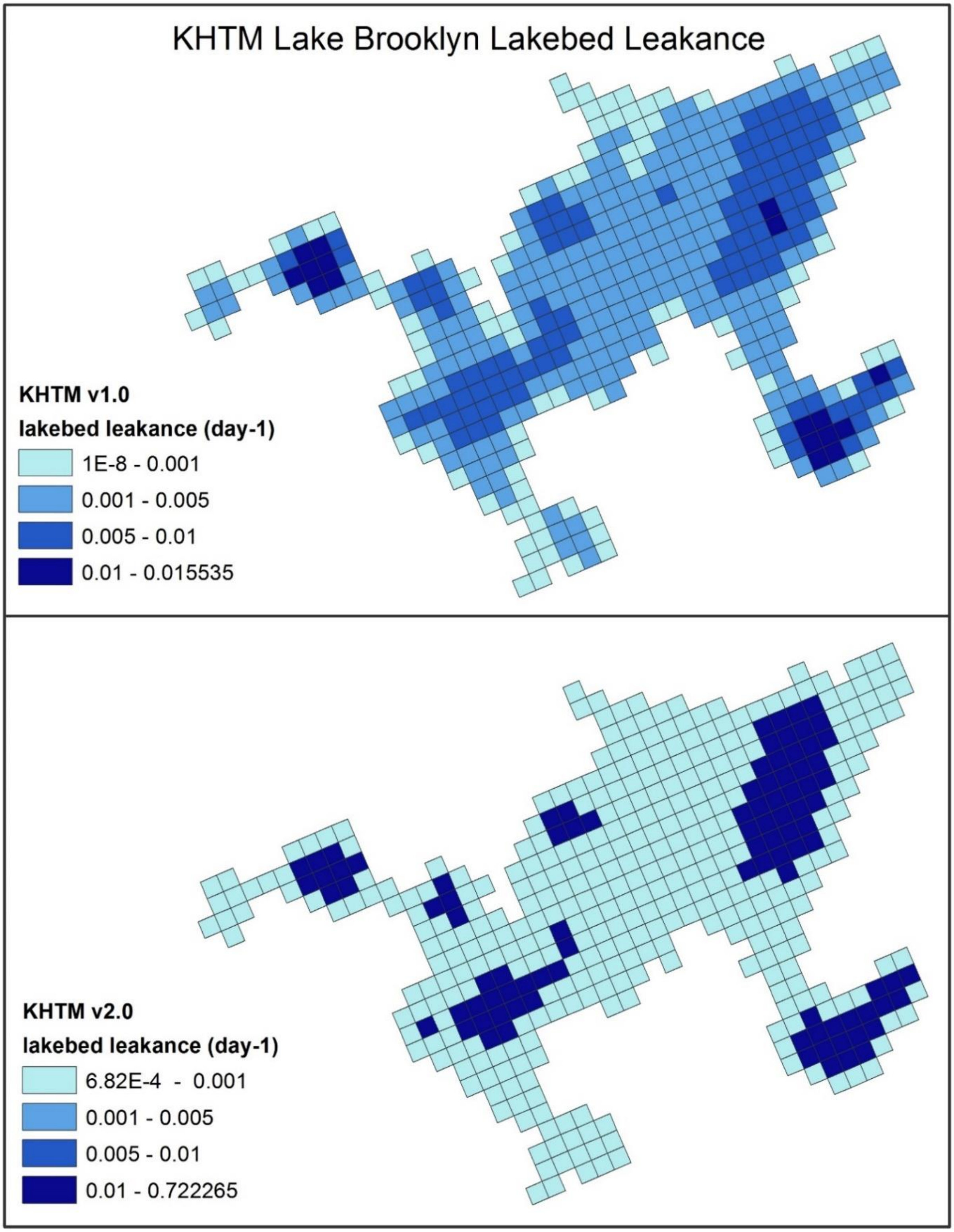

Figure 24. Spatial distribution of lakebed leakance at Lake Brooklyn in KHTM v1.0 (top) and KHTM v2.0 (bottom, simplified from Figure 10).

CHAPTER 6. CONCLUSIONS

The KHTM v1.0 was updated by Tetra Tech (2019) to incorporate high resolution bathymetry data available at lakes Brooklyn and Geneva (KHTM v1.1), and then subsequently recalibrated by SJRWMD (KHTM v2.0). The primary goals of recalibration were **1)** to improve overall model performance for simulating Lake Brooklyn levels, which had degraded in the early part of the calibration period (1995 to 2004) after bathymetry update and **2)** to enhance the model's ability to match low observed water levels (< 95 feet NAVD88) at Lake Brooklyn while also maintaining pre-defined calibration criteria summarized in **Table 1**. Both objectives were accomplished by this recalibration effort. Automated model calibration was performed by using PEST++, and the recalibration focused on a small subset of parameters that were determined to influence level at Lake Brooklyn. The calibration period of 1995 to 2014, as well as all calibration targets from KHTM v1.0, were retained for the recalibration. Lakebed leakance at Lake Brooklyn was reformulated using an approximation of the Heaviside step function, where model lake cells with a cell depth greater than the PEST estimated *critical depth* were assigned the deep lakebed leakance value. Likewise, lake cells with a cell depth less than *critical depth* were assigned the shallow lakebed leakance value in the LAK package. This conceptualization agrees with seismic investigations at Lake Brooklyn that interpreted these deeper regions of the lake as having a greater degree of connection with the UFA.

Comparison of KHTM v2.0 with KHTM v1.1 calibration indicated that the overall model performance significantly improved. The KHTM v2.0 met all pre-defined calibration criteria and produced equivalent or improved calibration statistics to KHTM v1.0 and v1.1. Additionally, KHTM v2.0 simulated lake levels at Lake Brooklyn closer to measurement values than KHTM v1.0 and v1.1 during 1995 to 2004, where degradation occurred following bathymetry updates. Therefore, the first goal of recalibration was achieved. Overall, the model simulated groundwater levels very well in the major aquifer systems, meeting the MAE calibration criterion of 5 feet in the SAS, UFA, and LFA. The model simulated lake levels at the primary lakes reasonably well, particularly at Lakes Lowry, Magnolia, and Geneva, where the MAE was below 1 foot. The match to modeled Lake Brooklyn lake level targets improved over those from KHTM v1.0 and v1.1, shown by a decrease in MAE and an improved match to observed high and low level periods. The model simulated levels reasonably well at all primary lakes outside of the calibration period and was able to capture the observed rise in lake level at Lake Brooklyn and Geneva following Hurricane Irma in September 2017. The model achieved agreement between the ranges of estimated and simulated composite leakances at all primary lakes, particularly at Lake Brooklyn, where the average composite leakance as a function of lake level matched very well with prior estimates. Additionally, the model showed general agreement between simulated 1995-1997 leakage rates and prior estimates, particularly at Lake Brooklyn where the range of simulated leakage rates more closely approximates the estimated range, compared to KHTM v1.0. As a result of recalibration, KHTM v2.0 performed better than KHTM v1.0 in matching low levels at Lake Brooklyn. Therefore, the second goal of the recalibration effort was also achieved.

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APPENDIX A - EXTENSION OF THE KEYSTONE HEIGHTS LONG-TERM SIMULATION MODEL

INTRODUCTION

The Keystone Heights transient groundwater flow model (KHTM) was previously developed for the St. Johns River Water Management District for Minimum Flows and Levels (MFL) applications (Tetra Tech, 2017). The KHTM was calibrated to match observations during the 1995 to 2014 period. A monthly long-term simulation, referred to as KHTM long-term (LT) simulation, was then developed to extend the calibrated KHTM simulation period back to July 1957, while retaining the calibration period between 1995 to 2014 (Tetra Tech, 2017). The District further extended the long-term simulation period to December 2018, referred to as the KHTM extended long-term (XLT) simulation. The addition of 48 monthly stress periods to the LT simulation, corresponding to the time period between January 2015 to December 2018, was performed to update the model with current data that has become available following initial model development. The added stress periods in the XLT simulation also fall outside of the model calibration period years, and thus provide an opportunity to test the model's prediction performance outside of calibration conditions. As part of this effort, the District updated all the model input files needed to run the LT simulation out to December 2018. The methodology and input data used to extend the model input files was kept as consistent as possible with the approach implemented by Tetra Tech (2017) during development of the LT simulation input files. This document summarizes the model input updates that were performed to extend the long-term simulation.

KHTM MODFLOW INPUT FILES

This section summarizes the updates made to the KHTM inputs required to run the XLT simulation and post-process model results. This effort required updates to both MODFLOW input files and pre- and post-processing scripts required to generate input files and extract model results. The input files and scripts that required revision were initially identified and described by Tetra Tech in a technical memorandum delivered to the District (Tetra Tech, 2019).

Discretization (DIS) File

The number of stress periods, the monthly time interval for which all inputs are constant, identified in the MODFLOW input file 'Keystone Tr_LT.dis' was increased from 690 to 738. The length of each added stress period was set to the number of days in the respective month of the year. The number of time steps in each added stress period was set to 5, and a time step multiplier of 1.2 was applied, consistent with the discretization of the previous stress periods in the LT model. The additional 48 stress periods added to the model were simulated as transient, or 'TR' in the DIS file.

General Head Boundary (GHB) Package

For each added stress period, groundwater heads were defined in two stages along lateral boundaries in the Upper Floridan Aquifer (UFA), following the methodology used to develop the LT simulation input files (Tetra Tech, 2017). For the first stage, groundwater heads in each GHB perimeter cell were defined for the months of May and September for the years 2015 to 2017 using spatially interpolated heads from UFA potentiometric surfaces available from the Florida Geological Survey (FGS). The following processing steps were performed in ArcGIS 10.6.1 to accomplish this:

- UFA potentiometric surface 10-foot contour intervals were converted to point features using the GIS tool 'Feature Vertices to Points'
- The points were converted from NGVD29 to the vertical datum NAVD88 using VERTCON offsets (NAVD88 = NGVD29 + offset). The GIS tool 'Extract Values to Points' was used to determine the offset for each vertex of the FGS UFA contour map. The points were then clipped to a 25-mile buffer zone around the KHTM model grid. A 25-mile buffer was chosen to reduce GIS processing time for spatial interpolation while still capturing the regional groundwater level patterns in the vicinity of the model domain.
- The point features were used as input in the 'Topo to Raster' GIS interpolation tool. The cell size was set to the 76.2-meter grid cell size. The model grid centroid of the GHB cells were used to extract values from the raster to assign UFA heads to the GHB model cells for layer 7.

The second stage of the process estimated GHB UFA head values for the remaining months in each added year of the XLT simulation, excluding May and September, since the potentiometric surfaces were available for these months. The calculation of GHB UFA head values for months without an UFA potentiometric surface were calculated as described in the following paragraphs, and followed the methodology established during development of the LT simulation (Tetra Tech, 2017).

Monthly groundwater levels from 8 UFA wells (Hydron 02241171, 02251181, 02301221, 07851742, 31502845, 32644070, 32694101, 70078104) in the model domain were used to calculate a monthly mean UFA groundwater level from 2015 to 2018. The monthly mean water level in September of a given year was used as a baseline to estimate the difference in water level for the months of October to April of the subsequent year. Similarly, the monthly mean water level in May of a given year was used as a baseline to estimate the difference in water level for the months of June to August of the same year. Next, the water level differences were subtracted from UFA head values extracted from the potentiometric surfaces (May or September) of a given year to estimate GHB heads. For example, assuming an average UFA water level from well data in May 2015 of 80 feet and an average UFA water level in June 2015 of 78 feet, the average difference in water level between these time periods is equal to 2 feet (difference in UFA water level is equal to May UFA water level subtracted by June UFA water level). To estimate the GHB UFA heads in the model for the model stress period representing June 2015, the average water level difference of 2 feet was subtracted from the May 2015 potentiometric surface estimated UFA heads at each GHB cell location. This process was repeated for each added stress period in the XLT simulation where an UFA potentiometric surface was not available.

At the time of assembling the data, the UFA potentiometric surface estimates for the year 2018 were unavailable. Therefore, UFA heads at each GHB cell were estimated for the year 2018 by using the potentiometric surfaces available for the year 2017 and observed groundwater level data. For example, to estimate UFA head values at GHB cells for May 2018, the average difference in observed groundwater levels between May 2017 and May 2018 was calculated. This average difference was subtracted from the May 2017 extracted UFA head values at each GHB cell in order to define the UFA head for May 2018. Similarly, the average difference in observed groundwater levels between September 2017 and September 2018 was subtracted from the September 2017 extracted UFA head values at each GHB cell to define the UFA head during September 2018. For the months of October to December 2018, the monthly mean water level in September 2017 was used as a baseline to estimate the difference in water level. For the months of June to August 2018, the monthly mean water level in May 2017 was used as a baseline to estimate the difference in water level. Then, as was done previously, differences in UFA groundwater level relative to either May or September 2017 water levels were subtracted from the UFA head values extracted from the respective 2017 potentiometric surfaces.

To validate this approach, the processes described above were performed for the year 2014, and then compared to the groundwater heads assigned in the GHB long-term simulation MODFLOW package (Tetra Tech, 2017). The residual GHB heads for the months of May to December of 2014 were evaluated by calculating the mean, maximum, and average residual UFA head across all GHB lateral boundary cells (**Table A-1**). Differences in groundwater head relative to the original GHB package could arise from any of the following sources: datum conversion to NAVD88, GIS processing steps, or processing of observation well data. The evaluation of residual groundwater heads revealed no temporal bias in assignment of heads with the methods described above, as seen in **Table A-1**. A similar maximum, minimum, and average residual head was observed for each month in 2014. Furthermore, the largest average residual head in the month of August of 0.5 feet was a small percentage (0.6%) of the average observed groundwater level in that month of 79 feet. Thus, it was determined that the methods used for assignment of GHB lateral heads were satisfactory for the XLT simulation.

Table A-1 : Maximum, minimum and average difference in assigned GHB head in the UFA in 2014.

Stress Period	Max of residual (feet)	Min of residual (feet)	Average of residual (feet)
May-2014	1.77	-3.00	0.3
Jun-2014	1.76	-3.00	0.3
Jul-2014	1.78	-2.99	0.3
Aug-2014	1.98	-2.78	0.5
Sep-2014	1.81	-2.68	0.2
Oct-2014	1.74	-2.75	0.1
Nov-2014	1.76	-2.73	0.2
Dec-2014	1.75	-2.74	0.1

For all perimeter GHB cells in the Lower Floridan Aquifer (LFA), groundwater heads were assumed to be 1.5 feet higher than the heads assigned to the overlying UFA, as described in the KHTM model report (Tetra Tech, 2017).

Lake (LAK) Package

Precipitation and evaporation inputs were defined for the added stress periods for all primary lakes in the model. No locally gauged estimates of rainfall from Lake Brooklyn and Geneva were available within the extended model time period (2015 – 2018). Therefore, rainfall rates were assigned using monthly precipitation data available on a 2x2 km grid from gauge adjusted NEXRAD. An area-weighted average monthly precipitation rate was calculated for lakes Lowry, Brooklyn, and Geneva using each active lake cell boundary. Consistent with the calibration period, the same precipitation rates from Lake Lowry were also assigned to Lake Magnolia, and those from Lake Brooklyn to Keystone Lake. A separate area weighted average rainfall rate was calculated for Lake Geneva (including the area of Lake Geneva West) and applied to both lakes in the lake package. To be consistent with the current model inputs, all primary lakes in the model were assigned an equivalent evaporation rate time series calculated from gridded monthly potential evaporation (PET) data from NLDAS.

Cumulative surface inflow rates for all primary lakes were estimated using SCS curve number (CN) based runoff rates, which require specifying daily rainfall, an antecedent moisture condition (AMC) threshold, lake basin area, and runoff curve numbers (see Tetra Tech, 2017 for additional documentation). This approach was previously used to estimate runoff for only Lake Brooklyn, Geneva and Geneva West (Tetra Tech, 2017). For the other primary lakes in the model – Lake Lowry, Magnolia, and Keystone – HSPF runoff was used to estimate surface inflows (Tetra Tech, 2017). Daily rainfall for each lake was defined using area-weighted gauge adjusted NEXRAD rainfall data. This dataset is consistent with the monthly average rainfall that was input into the LAK package described above. AMC thresholds were defined using 5-day rolling antecedent cumulative rainfall, in which the dormant season (October-February) thresholds varied between 0.5 inches (dry and average) to 1.0 inches (average and wet), and the growing season (March – September) thresholds varied between 1.4 and 2.0 inches, respectively. Lake basin areas were defined from SSAR models (Table 12 from Robison, 2011). For the calibration period, PEST was used to estimate a curve number for lakes Brooklyn, Geneva, and Geneva West, resulting in curve numbers of 79, 75, and 76, respectively. To apply a curve number to the other primary lakes in the model during the extended model period, the curve numbers for lakes Brooklyn, Geneva, and Geneva West were averaged (CN = 76.67) and applied to the other lakes to estimate runoff. For Lake Lowry, incoming flows from Alligator Creek (Hydron ID 72051622) and the surficial spring north of the lake (Hydron ID 72041620) were added to the curve number estimated runoff.

To validate this approach for the extended model period, the procedures described above were reproduced for the year 2014 and compared to the currently assigned lake package inputs in the LT simulation for the same year (Tetra Tech, 2017). The difference between the existing and NEXRAD area-weighted precipitation rates for lakes Lowry, Brooklyn, and Geneva for each month is shown in **Figure A-1**. Deviations from the existing rates are [≤ ±0.010], on the order of 2% of each month's average rainfall rate. Next, the District evaluated the method of estimating runoff using the CN approach for lakes Lowry, Magnolia, and Keystone, which used HSPF estimated runoff during the calibration period. The difference in runoff between these methods is plotted for the year 2014 in **Figure A-2**. The difference ranges between -0.75 and 2.95 cfs for these three lakes.

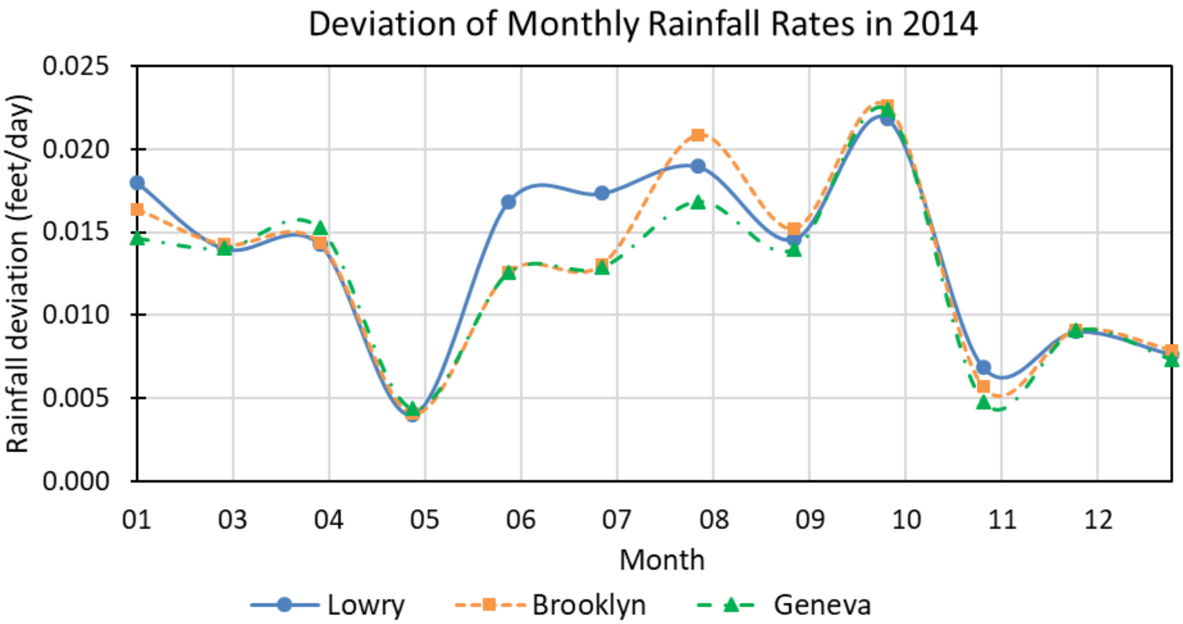

Figure A-1. Deviation in rainfall rate for lakes Lowry, Brooklyn, and Geneva between existing 2014 lake package rainfall and NEXRAD area-weighted rainfall.

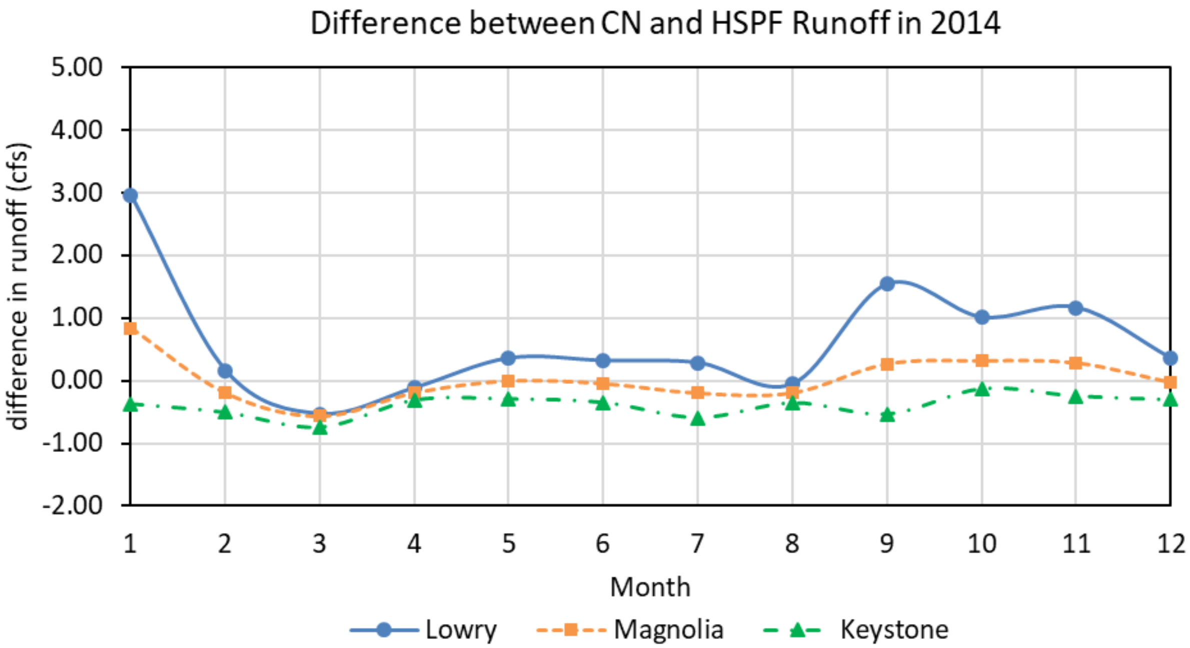

Figure A-2. Deviation in runoff rate for lakes Lowry, Magnolia, and Keystone between the 2014 curve number estimated runoff and HSPF runoff.

Output Control (OC) Option

The output control file was extended to 738 stress periods. MODFLOW head and budget files were saved for the last time step of the added stress periods.

River (RIV) Package

Lake stages for the secondary lakes in the model, represented using the RIV package (see Tetra Tech, 2017 for additional documentation), were updated using observed stage data where available. If no observed stage information was available at a lake, observed data of nearby lakes were used to estimate stage using either time constant offsets or stage correlation by simple linear regression. **Table A-2** includes the secondary waterbodies that were represented in the RIV package and identifies the method used to define stage for each waterbody. Observed stage data from the following lakes was used to define stages of secondary lakes in the RIV package: Big Lake Johnson (Hydron ID 03270361), Blue Pond (Hydron ID 72021626), Lake Lowry (Hydron ID 02261194), Lake Brooklyn (Hydron ID 03360373), Lake Geneva (Hydron ID 11590497), Lake Magnolia (Hydron ID 01830088) and Swan Lake (Hydron ID 04630910). The time constant stage offsets for an individual lake were determined from available overlapping time series data or from the previously defined offsets in the LT simulation RIV package. Stage data available at Big Lake Johnson (outside of model domain) was used to estimate stage at the following lakes within the model domain based on a simple linear regression (R2 > 0.94): Gator Bone Lake, White Sands, Spring Lake, Smith Lake. Stage data at Swan Lake was used to estimate stage at Lake Lily using a simple linear regression (R2 > 0.98). Stage in the portion of Alligator Creek at Blue Pond and Lake Lowry was defined using stage measurements available at each cell location. Stage in the portion of Alligator Creek between Blue Pond and Lake Lowry was defined by spatially interpolating stage in between measured stage at Blue Pond and Lake Lowry for each added stress period, while maintaining the stage offset for each downstream model cell that was applied in the LT simulation.

The minimum stage for any river cell in layers 1-3 was set equivalent to the bottom elevation for that layer. After stages were assigned based on observed data or estimated using constant offsets or correlation to nearby lakes, stages below the bottom elevation for each layer were set equal to the bottom elevation. Approximately 17% of all river package boundary cells represented model-wide in layers 1 through 3 required adjustment to the bottom elevation for a layer after stages were initially estimated.

Table A-2. Secondary waterbodies represented in the model by the RIV package and the method used to estimate stage for each model cell representing the waterbody.

Waterbody Name	Method Used to Define Lake Stage in RIV package
Blue Pond	Hydron ID 72071626
North of Blue Pond	Hydron ID 72071626
Stevens Lake	Hydron ID 72071626 - 13.96 feet offset
Perch Pond	Hydron ID 72071626 + 6.84 feet offset
Alligator Creek	Stage offset between Hydron ID 72071626 and 02261194
Crystal Lake	Hydron ID 01830088 - 14.1 feet offset
Pond West of Crystal Lake	Hydron ID 01830088 + 1.78 feet offset
Lost Pond	Hydron ID 01830088 - 13.8 feet offset
Lake Bedford	Hydron ID 03360373 - 8.3 feet offset
Pond North of Bedford	Hydron ID 03360373 + 14.75 feet offset
Bolt Lake	Hydron ID 03360373 + 7.39 feet offset
Silver Lake	Hydron ID 03360373 + 5.01 feet offset
Paradise Lake	Hydron ID 03360373 - 6.39 feet offset
Little Lake Geneva	Hydron ID 03360373 – 14.4 feet offset
Pond East of Brooklyn	Layer Bottom Elevation
Santa Fe Lake	Hydron ID 11590497 + 54.0 feet offset
Indian Lake	Hydron ID 11590497 + 21.17 feet offset
Twin Lakes	Hydron ID 11590497 - 14.61 feet offset
Lake Hutchinson	Hydron ID 11590497
Oldfield Pond	Hydron ID 11590497 - 7.78 feet offset
Lake Opal	Hydron ID 11590497 + 15.43 feet offset
Swan Lake	Hydron ID 04630910
Serena Lake	Hydron ID 04630910
Halfmoon Lake	Hydron ID 04630910
Lake Lilly	Hydron ID 04630910 * 0.927 + 24.798 (R^2 = 0.9841)
Echo Lake	Lake Lilly*0.23 + Swan Lake*0.77
Spring Lake	Hydron ID 03270361*1.13 - 10.81 (R^2 = 0.9804)

Waterbody Name	**Method Used to Define Lake Stage in RIV package**
White Sands Lake	Hydron ID 03270361*0.98 - 4.42 (R^2 = 0.9725)
Gator Bone Lake	Hydron ID 03270361*0.90 + 1.82 (R^2 = 0.9408)
Smith Lake	Hydron ID 03270361*0.88 + 2.46 (R^2 = 0.9635)
Bull Pond	Smith Lake + 2.0 feet offset
Lake Washington	Smith Lake + 1.79 feet offset
Long Lake	Smith Lake + 2.78 feet offset
Silver Sands Lake	Smith Lake + 1.96 feet offset
Lake Margie	Smith Lake + 0.65 feet offset
Deer Springs Lake	Spring Lake + 1.45 feet offset
Vulcan Pond	Constant stage of 143.8 feet
Bundy Lake	Constant stage of 80 feet

Streamflow Routing (SFR) Package

The SFR package required specification of runoff, precipitation, potential evaporation, and inflow rates for five SFR segments defined in the model (Tetra Tech, 2017). Precipitation rates for individual segments were assigned the same precipitation rates as the lake package, following previous methodology. The area weighted rainfall assigned to lakes Lowry and Magnolia was applied to SFR segments 1, 2, and 3. Segment 4 was assigned the same precipitation rates as lakes Brooklyn and Keystone. Segment 5 was assigned the same precipitation rates as Lake Geneva and Geneva West. To be consistent with the approach applied in the LT simulation input files, the potential evaporation rates applied to the primary lakes were also applied to the SFR segments in the model. Inflow and runoff rates were set equal to 0 for all stress periods, following the approach used in the LT SFR input file.

Well (WEL) Package

Groundwater withdrawal rates for all domestic self-supply (DSS), consumptive use permit (CUP) and non-CUP agricultural wells in the model domain were extended through 2018 using previously established methodology (Tetra Tech, 2017). The total monthly withdrawal for the added stress periods appears consistent with the withdrawal from the model during most of the calibration period, ranging from 2 – 3.3 MGD (**Figure A-3**).

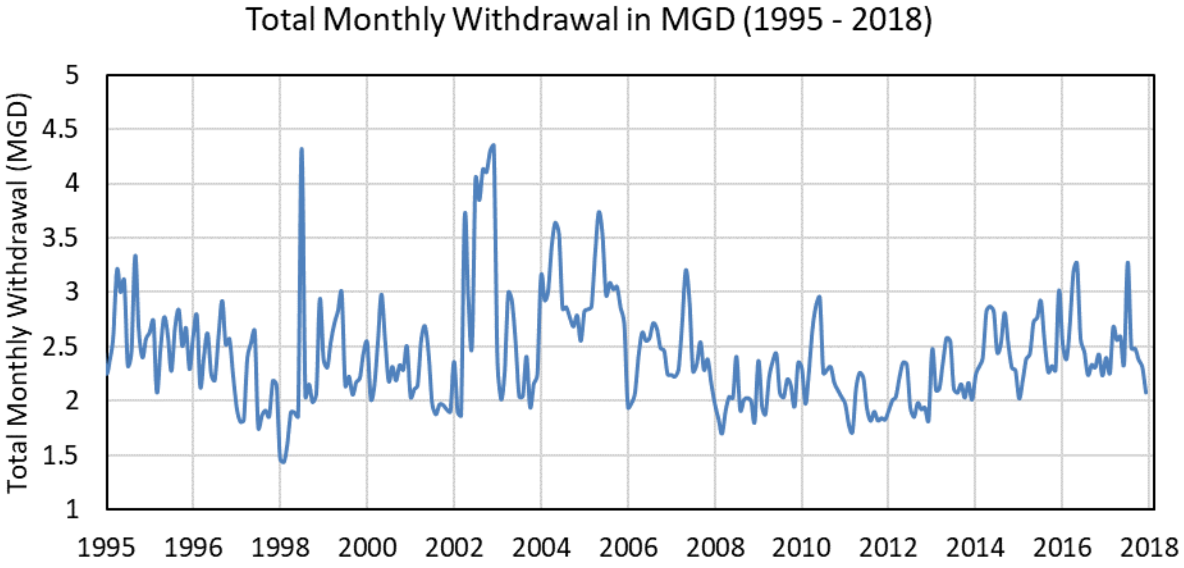

Figure A-3. Total monthly withdrawal from within the KHTM domain (1995 – 2018).

Recharge (RCH) and Evapotranspiration (EVT) Packages

The RCH and EVT packages were extended through 2018 using monthly average recharge and maximum saturated ET rates from HSPF model results. To be consistent with the calibration period, the PEST estimated recharge rate multiplier of 0.77533 was also applied to the added stress periods in the RCH package. No multiplier was applied to the EVT package specified rates. Recharge and ET rates in areas containing primary and secondary lakes, as well as areas with extinction depths of zero, were all assigned a rate of zero, following the approach used during the calibration period (Tetra Tech, 2017).

ADDITIONAL KHTM INPUTS

Additional programs were updated in order to accommodate the added stress periods for all pre and post-processing steps required to generate MODFLOW input files and execute the XLT simulation. The source code for the Fortran program ‘*CurveNumberCalcs.f90*’, which calculates a runoff rate based on curve number, was updated and recompiled to perform the calculation for the added stress periods. All input and control files associated with this program were also updated with the information and/or input data necessary to estimate runoff for all primary lakes through the end of 2018. Several updates of PEST template (.tpl) files were required to generate MODFLOW package input files that extended through the end of the added stress periods. Template files that were updated included: the GHB, LAK, SFR, and RIV packages. Windows batch files and associated input files created for the purpose of post-processing model results were also updated to generate output files reflecting the new extended long-term simulation period.

CONCLUSION

The District performed an update to the MODFLOW input files and additional files required to extend and run the existing KHTM long-term simulation out to the end of December 2018. In updating all required files, the District followed the methodology established in previous documentation of the KHTM development (Tetra Tech, 2017) and as described by Tetra Tech in a technical memorandum delivered to the District (Tetra Tech, 2019).

REFERENCES

Tetra Tech, Inc., 2017. *Keystone Heights Transient Groundwater Flow Modeling for Evaluation of Minimum Flows and Levels.* Final report prepared in conjunction with Jones Edmunds & Associates, Inc. for St. Johns Water Management District. September.

Tetra Tech, Inc., 2019. *Keystone Heights Long-Term Simulation Input Update Summary (Final).* Technical memorandum prepared in conjunction with Jones Edmunds & Associates, Inc. for St. Johns Water Management District. October.

Appendix B - Annual Lake Water Budget Tables in Cubic Feet Per Day (CFD) (1957-2018)

Table B-1. Lake Lowry annual water budget. All rates are in units of cubic feet per day and 1957 results reflect July - December only.

	INFLOW			OUTFLOW		
Year	**Rainfall**	**From Alligator Creek, Runoff & Spring**	**From Groundwater**	**Evaporation**	**To Groundwater**	**To Alligator Creek**
1957*	7.67E+05	6.62E+05	2.62E+04	5.84E+05	3.24E+05	2.70E+05
1958	7.62E+05	6.66E+05	2.65E+04	6.02E+05	3.29E+05	4.79E+05
1959	7.79E+05	6.96E+05	2.85E+04	6.06E+05	3.29E+05	5.98E+05
1960	8.00E+05	6.82E+05	2.99E+04	6.17E+05	3.26E+05	5.51E+05
1961	6.07E+05	6.52E+05	3.29E+04	6.30E+05	3.15E+05	3.81E+05
1962	6.08E+05	5.99E+05	3.14E+04	6.42E+05	3.18E+05	2.57E+05
1963	4.72E+05	5.71E+05	3.08E+04	6.26E+05	3.27E+05	1.50E+05
1964	9.78E+05	9.00E+05	2.62E+04	6.11E+05	3.52E+05	8.11E+05
1965	8.16E+05	6.98E+05	3.32E+04	6.11E+05	3.39E+05	6.66E+05
1966	6.96E+05	6.74E+05	3.69E+04	5.91E+05	3.25E+05	5.30E+05
1967	6.68E+05	6.57E+05	3.73E+04	6.20E+05	3.18E+05	4.05E+05
1968	6.32E+05	6.62E+05	3.64E+04	6.17E+05	3.30E+05	3.84E+05
1969	6.81E+05	6.84E+05	3.77E+04	5.95E+05	3.43E+05	4.01E+05
1970	7.71E+05	6.89E+05	3.93E+04	6.19E+05	3.43E+05	6.42E+05
1971	6.39E+05	6.47E+05	3.78E+04	6.25E+05	3.31E+05	3.10E+05
1972	8.62E+05	9.54E+05	3.93E+04	6.23E+05	3.44E+05	8.43E+05
1973	6.44E+05	6.63E+05	4.29E+04	6.18E+05	3.26E+05	4.71E+05
1974	6.42E+05	6.02E+05	3.98E+04	6.30E+05	3.24E+05	3.30E+05
1975	6.56E+05	6.63E+05	4.03E+04	6.21E+05	3.36E+05	3.85E+05
1976	6.10E+05	7.64E+05	4.01E+04	6.18E+05	3.48E+05	4.29E+05
1977	4.25E+05	6.04E+05	4.15E+04	6.42E+05	3.47E+05	1.74E+05
1978	6.25E+05	6.57E+05	3.60E+04	6.24E+05	3.71E+05	2.88E+05
1979	7.61E+05	6.45E+05	3.51E+04	6.18E+05	3.75E+05	4.04E+05
1980	5.27E+05	6.51E+05	3.48E+04	6.26E+05	3.72E+05	3.01E+05
1981	4.46E+05	5.56E+05	3.40E+04	6.45E+05	3.63E+05	7.21E+04
1982	7.77E+05	7.25E+05	2.84E+04	6.24E+05	3.90E+05	4.38E+05
1983	8.32E+05	7.51E+05	3.03E+04	6.09E+05	3.82E+05	5.33E+05
1984	4.97E+05	5.88E+05	3.26E+04	6.24E+05	3.59E+05	2.63E+05
1985	6.33E+05	6.90E+05	2.85E+04	6.21E+05	3.65E+05	2.98E+05
1986	6.64E+05	6.51E+05	2.99E+04	6.39E+05	3.71E+05	3.09E+05
1987	5.97E+05	6.28E+05	3.15E+04	6.13E+05	3.73E+05	3.44E+05

	INFLOW			OUTFLOW		
Year	**Rainfall**	**From Alligator Creek, Runoff & Spring**	**From Groundwater**	**Evaporation**	**To Groundwater**	**To Alligator Creek**
1988	7.77E+05	7.08E+05	2.92E+04	6.08E+05	3.81E+05	4.78E+05
1989	4.78E+05	5.59E+05	3.17E+04	6.45E+05	3.70E+05	9.56E+04
1990	4.90E+05	5.82E+05	2.85E+04	6.57E+05	3.80E+05	9.89E+04
1991	7.17E+05	6.66E+05	2.59E+04	6.13E+05	4.08E+05	3.70E+05
1992	5.46E+05	6.09E+05	2.51E+04	6.08E+05	4.04E+05	1.45E+05
1993	6.56E+05	5.82E+05	2.31E+04	6.31E+05	4.10E+05	1.98E+05
1994	7.65E+05	8.49E+05	2.02E+04	6.16E+05	4.26E+05	5.44E+05
1995	6.45E+05	8.51E+05	2.09E+04	5.76E+05	4.18E+05	5.58E+05
1996	6.58E+05	6.69E+05	2.15E+04	5.89E+05	4.02E+05	3.19E+05
1997	6.65E+05	7.77E+05	2.05E+04	5.75E+05	4.08E+05	4.02E+05
1998	6.16E+05	1.02E+06	2.08E+04	6.41E+05	4.05E+05	7.58E+05
1999	5.18E+05	3.62E+05	2.26E+04	6.20E+05	3.77E+05	5.97E+04
2000	5.00E+05	3.33E+05	2.35E+04	6.38E+05	3.64E+05	0.00E+00
2001	5.64E+05	3.26E+05	2.27E+04	5.78E+05	3.65E+05	0.00E+00
2002	7.21E+05	3.04E+05	2.09E+04	5.62E+05	3.72E+05	0.00E+00
2003	7.04E+05	6.96E+05	1.54E+04	5.73E+05	4.35E+05	2.05E+05
2004	7.43E+05	6.34E+05	1.64E+04	6.04E+05	4.25E+05	2.70E+05
2005	7.42E+05	8.79E+05	1.64E+04	5.84E+05	4.35E+05	5.88E+05
2006	4.93E+05	4.33E+05	1.93E+04	6.52E+05	3.97E+05	2.08E+05
2007	5.42E+05	3.12E+05	2.17E+04	6.19E+05	3.63E+05	0.00E+00
2008	6.64E+05	7.10E+05	1.59E+04	5.90E+05	4.10E+05	8.20E+04
2009	6.93E+05	9.18E+05	1.30E+04	6.90E+05	4.38E+05	4.52E+05
2010	5.51E+05	7.29E+05	1.38E+04	6.25E+05	4.28E+05	3.82E+05
2011	5.81E+05	3.51E+05	1.55E+04	7.04E+05	3.96E+05	1.12E+04
2012	7.65E+05	8.74E+05	1.31E+04	6.39E+05	4.18E+05	2.69E+05
2013	6.11E+05	7.37E+05	1.14E+04	6.05E+05	4.40E+05	3.53E+05
2014	6.68E+05	7.67E+05	1.24E+04	6.55E+05	4.25E+05	3.57E+05
2015	6.22E+05	7.78E+05	1.15E+04	6.00E+05	4.14E+05	3.80E+05
2016	6.52E+05	6.69E+05	2.63E+04	6.19E+05	3.75E+05	3.49E+05
2017	7.73E+05	1.09E+06	7.37E+03	6.27E+05	4.16E+05	6.52E+05
2018	6.41E+05	8.79E+05	6.30E+03	5.97E+05	4.20E+05	5.05E+05
AVG	**6.52E+05**	**6.69E+05**	**2.63E+04**	**6.19E+05**	**3.75E+05**	**3.49E+05**

Table B-2. Lake Magnolia annual water budget. All rates are in units of cubic feet per day and 1957 results reflect July - December only.

	INFLOW				OUTFLOW		
Year	**Rainfall**	**Runoff**	**From Alligator Creek**	**From Groundwater**	**Evaporation**	**To Groundwater**	**To Alligator Creek**
1957*	1.26E+05	4.50E+04	2.91E+05	0.00E+00	9.61E+04	1.05E+05	2.60E+05
1958	1.26E+05	3.15E+04	4.95E+05	0.00E+00	9.94E+04	1.07E+05	4.38E+05
1959	1.29E+05	5.08E+04	6.18E+05	1.24E-02	1.01E+05	1.07E+05	5.96E+05
1960	1.33E+05	4.82E+04	5.70E+05	4.76E+00	1.02E+05	1.05E+05	5.41E+05
1961	9.98E+04	4.19E+04	4.00E+05	3.55E+01	1.03E+05	9.97E+04	3.46E+05
1962	9.95E+04	2.43E+04	2.72E+05	2.35E+01	1.05E+05	1.01E+05	1.86E+05
1963	7.62E+04	2.00E+04	1.63E+05	3.97E+01	1.01E+05	1.01E+05	9.34E+04
1964	1.62E+05	6.52E+04	8.25E+05	8.20E-03	1.01E+05	1.17E+05	7.82E+05
1965	1.36E+05	3.43E+04	6.90E+05	2.27E+01	1.01E+05	1.08E+05	6.61E+05
1966	1.15E+05	4.55E+04	5.52E+05	6.51E+01	9.77E+04	1.02E+05	5.20E+05
1967	1.10E+05	4.65E+04	4.25E+05	8.01E+01	1.02E+05	1.00E+05	3.77E+05
1968	1.04E+05	6.29E+04	4.04E+05	5.47E+01	1.01E+05	1.06E+05	3.63E+05
1969	1.12E+05	3.34E+04	4.21E+05	4.41E+01	9.74E+04	1.10E+05	3.48E+05
1970	1.28E+05	3.48E+04	6.65E+05	6.04E+01	1.03E+05	1.09E+05	6.36E+05
1971	1.05E+05	3.46E+04	3.29E+05	6.28E+01	1.02E+05	1.05E+05	2.49E+05
1972	1.44E+05	1.56E+05	8.68E+05	4.43E+01	1.04E+05	1.11E+05	9.48E+05
1973	1.07E+05	6.24E+04	4.90E+05	1.14E+02	1.02E+05	1.02E+05	4.66E+05
1974	1.06E+05	2.25E+04	3.48E+05	8.68E+01	1.03E+05	1.03E+05	2.71E+05
1975	1.08E+05	3.50E+04	4.04E+05	6.34E+01	1.02E+05	1.08E+05	3.33E+05
1976	1.01E+05	8.59E+04	4.49E+05	3.83E+01	1.02E+05	1.13E+05	4.17E+05
1977	6.63E+04	3.70E+04	1.93E+05	8.99E+01	1.01E+05	1.05E+05	1.68E+05
1978	1.01E+05	5.28E+04	3.04E+05	7.48E+00	1.02E+05	1.25E+05	1.67E+05
1979	1.25E+05	2.34E+04	4.21E+05	0.00E+00	1.02E+05	1.24E+05	3.33E+05
1980	8.67E+04	6.46E+04	3.17E+05	0.00E+00	1.03E+05	1.21E+05	2.65E+05
1981	6.98E+04	1.34E+04	8.52E+04	1.73E+01	1.01E+05	1.08E+05	3.40E+04
1982	1.27E+05	6.70E+04	4.51E+05	0.00E+00	1.02E+05	1.33E+05	3.25E+05
1983	1.38E+05	5.40E+04	5.52E+05	0.00E+00	1.01E+05	1.26E+05	5.00E+05
1984	8.14E+04	1.89E+04	2.76E+05	1.67E+00	1.02E+05	1.14E+05	1.99E+05
1985	1.03E+05	7.00E+04	3.10E+05	0.00E+00	1.01E+05	1.18E+05	2.37E+05
1986	1.09E+05	4.54E+04	3.25E+05	0.00E+00	1.04E+05	1.22E+05	2.48E+05
1987	9.81E+04	3.28E+04	3.62E+05	0.00E+00	1.00E+05	1.21E+05	2.93E+05
1988	1.28E+05	4.20E+04	4.94E+05	0.00E+00	1.00E+05	1.26E+05	4.21E+05
1989	7.56E+04	1.06E+04	1.11E+05	3.81E+00	1.03E+05	1.14E+05	3.04E+04
1990	7.75E+04	2.22E+04	1.11E+05	0.00E+00	1.04E+05	1.21E+05	7.67E+03

	INFLOW				**OUTFLOW**		
Year	**Rainfall**	**Runoff**	**From Alligator Creek**	**From Groundwater**	**Evaporation**	**To Groundwater**	**To Alligator Creek**
1991	1.17E+05	2.52E+04	3.84E+05	0.00E+00	1.00E+05	1.42E+05	2.28E+05
1992	8.72E+04	2.64E+04	1.58E+05	0.00E+00	9.73E+04	1.33E+05	4.15E+04
1993	1.05E+05	2.04E+04	2.08E+05	0.00E+00	1.01E+05	1.35E+05	1.07E+05
1994	1.26E+05	2.84E+04	5.55E+05	0.00E+00	1.01E+05	1.47E+05	4.28E+05
1995	1.07E+05	2.37E+04	5.71E+05	0.00E+00	9.51E+04	1.38E+05	4.74E+05
1996	1.08E+05	3.13E+04	3.32E+05	0.00E+00	9.62E+04	1.32E+05	2.36E+05
1997	1.10E+05	3.44E+04	4.13E+05	0.00E+00	9.45E+04	1.36E+05	3.15E+05
1998	1.01E+05	4.27E+04	7.68E+05	0.00E+00	1.05E+05	1.31E+05	7.02E+05
1999	8.08E+04	1.77E+04	7.18E+04	0.00E+00	9.73E+04	1.14E+05	3.95E+04
2000	6.72E+04	1.99E+04	9.56E+03	0.00E+00	8.61E+04	9.48E+04	0.00E+00
2001	6.85E+04	2.46E+04	1.01E+04	0.00E+00	7.04E+04	8.82E+04	0.00E+00
2002	8.19E+04	4.22E+04	1.07E+04	0.00E+00	6.41E+04	7.97E+04	0.00E+00
2003	8.58E+04	4.11E+04	2.16E+05	0.00E+00	7.01E+04	1.13E+05	0.00E+00
2004	1.10E+05	5.14E+04	2.81E+05	0.00E+00	8.93E+04	1.42E+05	1.28E+05
2005	1.23E+05	3.98E+04	6.00E+05	0.00E+00	9.67E+04	1.48E+05	5.11E+05
2006	7.84E+04	2.40E+04	2.18E+05	0.00E+00	1.04E+05	1.23E+05	1.93E+05
2007	7.42E+04	2.45E+04	1.04E+04	0.00E+00	8.52E+04	1.01E+05	0.00E+00
2008	8.22E+04	3.86E+04	9.18E+04	0.00E+00	7.32E+04	1.04E+05	0.00E+00
2009	1.08E+05	2.91E+04	4.59E+05	0.00E+00	1.08E+05	1.51E+05	2.08E+05
2010	9.04E+04	2.49E+04	3.92E+05	0.00E+00	1.02E+05	1.45E+05	3.06E+05
2011	8.58E+04	2.48E+04	1.92E+04	0.00E+00	1.04E+05	1.17E+05	0.00E+00
2012	1.07E+05	6.77E+04	2.76E+05	0.00E+00	8.93E+04	1.35E+05	8.58E+04
2013	1.00E+05	2.93E+04	3.61E+05	0.00E+00	9.89E+04	1.53E+05	2.45E+05
2014	1.09E+05	3.12E+04	3.66E+05	0.00E+00	1.07E+05	1.39E+05	2.59E+05
2015	1.01E+05	1.24E+04	3.88E+05	0.00E+00	9.78E+04	1.36E+05	2.65E+05
2016	8.20E+04	2.08E+04	1.42E+05	0.00E+00	1.05E+05	1.27E+05	8.25E+04
2017	1.19E+05	1.00E+05	6.56E+05	0.00E+00	9.42E+04	1.29E+05	5.74E+05
2018	1.06E+05	1.63E+04	5.13E+05	0.00E+00	9.84E+04	1.42E+05	3.93E+05
AVG	**1.04E+05**	**3.95E+04**	**3.63E+05**	**1.56E+01**	**9.81E+04**	**1.19E+05**	**2.89E+05**

Table B-3. Lake Brooklyn annual water budget. All rates are in units of cubic feet per day and 1957 results reflect July - December only.

	INFLOW				OUTFLOW		
Year	**Rainfall**	**Runoff**	**From Alligator Creek**	**From Groundwater**	**Evaporation**	**To Groundwater**	**To Alligator Creek**
1957*	2.27E+05	1.14E+05	2.95E+05	3.08E+04	1.75E+05	1.36E+05	0.00E+00
1958	2.97E+05	9.73E+04	4.73E+05	0.00E+00	2.37E+05	2.87E+05	0.00E+00
1959	3.69E+05	1.29E+05	6.41E+05	0.00E+00	2.90E+05	4.57E+05	0.00E+00
1960	4.04E+05	1.39E+05	5.89E+05	0.00E+00	3.12E+05	5.27E+05	6.84E+04
1961	3.10E+05	8.99E+04	3.94E+05	0.00E+00	3.22E+05	5.12E+05	6.86E+04
1962	2.96E+05	4.43E+04	2.28E+05	0.00E+00	3.13E+05	4.48E+05	0.00E+00
1963	2.17E+05	1.91E+04	1.16E+05	0.00E+00	2.89E+05	3.97E+05	0.00E+00
1964	4.62E+05	2.98E+05	8.38E+05	0.00E+00	2.88E+05	5.04E+05	7.52E+04
1965	4.27E+05	1.61E+05	7.35E+05	0.00E+00	3.20E+05	5.90E+05	4.86E+05
1966	3.61E+05	1.11E+05	5.92E+05	0.00E+00	3.06E+05	5.47E+05	2.43E+05
1967	3.43E+05	1.21E+05	4.37E+05	0.00E+00	3.18E+05	5.27E+05	9.58E+04
1968	3.15E+05	1.06E+05	4.19E+05	0.00E+00	3.08E+05	5.23E+05	6.83E+03
1969	3.41E+05	7.38E+04	4.06E+05	0.00E+00	2.99E+05	5.48E+05	8.52E+03
1970	4.02E+05	1.59E+05	7.08E+05	0.00E+00	3.22E+05	5.93E+05	3.42E+05
1971	3.17E+05	8.05E+04	2.98E+05	0.00E+00	3.11E+05	4.98E+05	2.74E+01
1972	4.47E+05	1.92E+05	1.02E+06	0.00E+00	3.24E+05	5.98E+05	4.53E+05
1973	3.35E+05	7.05E+04	5.32E+05	0.00E+00	3.20E+05	5.44E+05	3.34E+05
1974	3.13E+05	6.46E+04	3.29E+05	0.00E+00	3.08E+05	4.68E+05	0.00E+00
1975	3.16E+05	8.94E+04	3.90E+05	0.00E+00	3.00E+05	4.85E+05	0.00E+00
1976	2.99E+05	1.06E+05	4.71E+05	0.00E+00	3.03E+05	5.32E+05	0.00E+00
1977	2.01E+05	4.03E+04	1.97E+05	0.00E+00	3.08E+05	5.04E+05	0.00E+00
1978	2.70E+05	1.27E+05	2.13E+05	0.00E+00	2.71E+05	4.32E+05	0.00E+00
1979	3.31E+05	1.44E+05	3.80E+05	0.00E+00	2.70E+05	4.40E+05	0.00E+00
1980	2.39E+05	5.26E+04	3.01E+05	0.00E+00	2.83E+05	4.45E+05	0.00E+00
1981	1.72E+05	3.02E+04	4.85E+04	0.00E+00	2.49E+05	3.28E+05	0.00E+00
1982	2.88E+05	1.55E+05	3.59E+05	0.00E+00	2.34E+05	3.65E+05	0.00E+00
1983	3.55E+05	1.28E+05	5.40E+05	0.00E+00	2.61E+05	4.35E+05	0.00E+00
1984	2.28E+05	4.67E+04	2.27E+05	0.00E+00	2.85E+05	4.36E+05	0.00E+00
1985	2.47E+05	8.41E+04	2.57E+05	0.00E+00	2.43E+05	3.53E+05	0.00E+00
1986	2.78E+05	9.64E+04	2.79E+05	0.00E+00	2.70E+05	4.06E+05	0.00E+00
1987	2.59E+05	7.37E+04	3.28E+05	0.00E+00	2.69E+05	4.27E+05	0.00E+00
1988	3.30E+05	1.74E+05	4.61E+05	0.00E+00	2.59E+05	4.42E+05	0.00E+00
1989	1.98E+05	5.12E+04	4.60E+04	0.00E+00	2.70E+05	4.00E+05	0.00E+00
1990	1.59E+05	2.99E+04	2.00E+04	0.00E+00	2.13E+05	2.94E+05	0.00E+00

	INFLOW				**OUTFLOW**		
Year	**Rainfall**	**Runoff**	**From Alligator Creek**	**From Groundwater**	**Evaporation**	**To Groundwater**	**To Alligator Creek**
1991	1.93E+05	5.48E+04	2.55E+05	0.00E+00	1.68E+05	2.92E+05	0.00E+00
1992	1.23E+05	4.48E+04	5.27E+04	0.00E+00	1.39E+05	2.32E+05	0.00E+00
1993	1.24E+05	4.68E+04	1.17E+05	0.00E+00	1.22E+05	1.99E+05	0.00E+00
1994	1.78E+05	9.51E+04	4.45E+05	0.00E+00	1.43E+05	2.77E+05	0.00E+00
1995	2.52E+05	6.90E+04	4.90E+05	0.00E+00	1.97E+05	3.60E+05	0.00E+00
1996	2.28E+05	5.03E+04	2.51E+05	0.00E+00	2.25E+05	3.71E+05	0.00E+00
1997	3.29E+05	1.39E+05	3.30E+05	0.00E+00	2.27E+05	4.12E+05	0.00E+00
1998	3.03E+05	6.90E+04	7.30E+05	0.00E+00	3.12E+05	5.71E+05	0.00E+00
1999	2.17E+05	1.29E+04	4.71E+04	0.00E+00	2.66E+05	4.17E+05	0.00E+00
2000	1.39E+05	3.58E+04	3.28E+03	0.00E+00	2.05E+05	2.92E+05	0.00E+00
2001	1.03E+05	6.33E+04	3.84E+03	0.00E+00	1.18E+05	2.09E+05	0.00E+00
2002	5.23E+04	2.49E+04	5.75E+03	0.00E+00	6.33E+04	9.21E+04	0.00E+00
2003	4.58E+04	9.59E+03	1.34E+04	0.00E+00	4.88E+04	4.60E+04	0.00E+00
2004	4.97E+04	5.55E+04	1.43E+05	0.00E+00	4.45E+04	7.60E+04	0.00E+00
2005	1.84E+05	3.56E+04	5.35E+05	0.00E+00	1.48E+05	2.89E+05	0.00E+00
2006	1.53E+05	3.04E+04	2.02E+05	0.00E+00	2.20E+05	3.16E+05	0.00E+00
2007	1.03E+05	3.97E+04	4.11E+03	0.00E+00	1.27E+05	2.06E+05	0.00E+00
2008	9.54E+04	7.40E+04	8.20E+03	0.00E+00	8.31E+04	1.48E+05	0.00E+00
2009	1.12E+05	9.56E+04	2.20E+05	0.00E+00	1.11E+05	1.95E+05	0.00E+00
2010	1.36E+05	2.11E+04	3.16E+05	0.00E+00	1.72E+05	2.82E+05	0.00E+00
2011	7.07E+04	2.49E+04	2.74E+03	0.00E+00	1.10E+05	1.47E+05	0.00E+00
2012	1.01E+05	1.37E+05	9.62E+04	0.00E+00	8.06E+04	1.57E+05	0.00E+00
2013	1.13E+05	4.38E+04	2.54E+05	0.00E+00	1.12E+05	2.33E+05	0.00E+00
2014	2.09E+05	7.42E+04	2.69E+05	0.00E+00	1.83E+05	2.76E+05	0.00E+00
2015	1.76E+05	2.49E+04	2.58E+05	0.00E+00	1.59E+05	2.56E+05	0.00E+00
2016	1.40E+05	3.44E+04	7.81E+04	0.00E+00	1.73E+05	2.38E+05	0.00E+00
2017	1.93E+05	1.97E+05	5.56E+05	0.00E+00	1.36E+05	2.80E+05	0.00E+00
2018	2.77E+05	4.30E+04	3.73E+05	0.00E+00	2.48E+05	4.41E+05	0.00E+00
AVG	**2.38E+05**	**8.28E+04**	**3.17E+05**	**2.53E+02**	**2.26E+05**	**3.69E+05**	**3.55E+04**

Table B-4. Keystone Lake annual water budget. All rates are in units of cubic feet per day and 1957 results reflect July - December only.

	INFLOW				OUTFLOW		
Year	**Rainfall**	**Runoff**	**From Alligator Creek**	**From Groundwater**	**Evaporation**	**To Groundwater**	**To Alligator Creek**
1957*	9.69E+03	4.44E+04	0.00E+00	0.00E+00	7.22E+03	4.60E+04	0.00E+00
1958	7.89E+03	3.38E+04	0.00E+00	0.00E+00	6.35E+03	3.30E+04	0.00E+00
1959	1.01E+04	4.56E+04	0.00E+00	0.00E+00	7.85E+03	4.94E+04	0.00E+00
1960	1.14E+04	4.54E+04	6.62E+04	0.00E+00	8.65E+03	8.60E+04	6.70E+03
1961	1.00E+04	4.36E+04	6.61E+04	0.00E+00	1.04E+04	1.03E+05	2.54E+04
1962	8.46E+03	4.56E+04	0.00E+00	0.00E+00	8.40E+03	4.71E+04	0.00E+00
1963	5.07E+03	3.71E+04	0.00E+00	0.00E+00	6.80E+03	3.77E+04	0.00E+00
1964	1.20E+04	4.71E+04	7.32E+04	0.00E+00	6.97E+03	7.60E+04	1.97E+04
1965	1.45E+04	3.50E+04	4.78E+05	0.00E+00	1.09E+04	1.94E+05	3.27E+05
1966	1.24E+04	4.48E+04	2.38E+05	0.00E+00	1.06E+04	1.67E+05	1.21E+05
1967	1.13E+04	4.15E+04	9.27E+04	0.00E+00	1.07E+04	1.31E+05	1.72E+04
1968	9.35E+03	4.90E+04	6.26E+03	0.00E+00	8.18E+03	6.10E+04	0.00E+00
1969	7.43E+03	2.82E+04	7.86E+03	0.00E+00	6.39E+03	3.93E+04	0.00E+00
1970	1.30E+04	3.32E+04	3.34E+05	0.00E+00	1.08E+04	1.66E+05	1.96E+05
1971	8.14E+03	4.00E+04	0.00E+00	0.00E+00	7.85E+03	4.70E+04	0.00E+00
1972	1.32E+04	9.59E+04	4.46E+05	0.00E+00	9.70E+03	1.41E+05	3.78E+05
1973	1.11E+04	5.17E+04	3.29E+05	0.00E+00	1.07E+04	1.48E+05	2.55E+05
1974	7.77E+03	2.67E+04	0.00E+00	0.00E+00	7.50E+03	3.48E+04	0.00E+00
1975	7.18E+03	3.65E+04	0.00E+00	0.00E+00	6.44E+03	3.79E+04	0.00E+00
1976	7.27E+03	5.30E+04	0.00E+00	0.00E+00	7.28E+03	5.28E+04	0.00E+00
1977	3.53E+03	2.96E+04	0.00E+00	0.00E+00	5.05E+03	2.98E+04	0.00E+00
1978	6.14E+03	5.14E+04	0.00E+00	0.00E+00	5.98E+03	5.05E+04	0.00E+00
1979	6.57E+03	2.74E+04	0.00E+00	0.00E+00	5.46E+03	3.23E+04	0.00E+00
1980	6.22E+03	7.52E+04	0.00E+00	0.00E+00	7.41E+03	6.84E+04	4.37E+03
1981	2.69E+03	1.57E+04	0.00E+00	0.00E+00	3.99E+03	1.62E+04	0.00E+00
1982	5.92E+03	3.00E+04	0.00E+00	0.00E+00	4.90E+03	3.16E+04	0.00E+00
1983	7.37E+03	4.60E+04	0.00E+00	0.00E+00	5.44E+03	4.19E+04	0.00E+00
1984	4.46E+03	2.52E+04	0.00E+00	0.00E+00	5.59E+03	2.83E+04	0.00E+00
1985	7.30E+03	6.88E+04	0.00E+00	0.00E+00	6.27E+03	6.86E+04	0.00E+00
1986	7.16E+03	5.70E+04	0.00E+00	0.00E+00	6.45E+03	5.65E+04	0.00E+00
1987	5.26E+03	3.39E+04	0.00E+00	0.00E+00	5.41E+03	3.70E+04	0.00E+00
1988	7.01E+03	3.47E+04	0.00E+00	0.00E+00	5.22E+03	3.71E+04	0.00E+00
1989	2.85E+03	1.61E+04	0.00E+00	0.00E+00	3.80E+03	1.59E+04	0.00E+00
1990	2.89E+03	2.64E+04	0.00E+00	0.00E+00	3.90E+03	2.70E+04	0.00E+00

	INFLOW				OUTFLOW		
Year	**Rainfall**	**Runoff**	**From Alligator Creek**	**From Groundwater**	**Evaporation**	**To Groundwater**	**To Alligator Creek**
1991	4.76E+03	3.69E+04	0.00E+00	0.00E+00	3.99E+03	3.98E+04	0.00E+00
1992	3.07E+03	3.46E+04	0.00E+00	0.00E+00	3.43E+03	3.28E+04	0.00E+00
1993	3.70E+03	2.90E+04	0.00E+00	0.00E+00	3.56E+03	2.81E+04	0.00E+00
1994	4.38E+03	3.53E+04	0.00E+00	0.00E+00	3.48E+03	3.50E+04	0.00E+00
1995	4.74E+03	3.26E+04	0.00E+00	0.00E+00	3.67E+03	3.33E+04	0.00E+00
1996	4.32E+03	3.68E+04	0.00E+00	0.00E+00	4.17E+03	3.43E+04	0.00E+00
1997	5.97E+03	3.93E+04	0.00E+00	0.00E+00	3.92E+03	3.84E+04	0.00E+00
1998	5.53E+03	3.60E+04	0.00E+00	0.00E+00	4.88E+03	4.18E+04	0.00E+00
1999	3.53E+03	2.72E+04	0.00E+00	0.00E+00	4.09E+03	2.78E+04	0.00E+00
2000	2.84E+03	2.74E+04	0.00E+00	0.00E+00	3.80E+03	2.89E+04	0.00E+00
2001	3.07E+03	3.18E+04	0.00E+00	0.00E+00	3.40E+03	3.22E+04	0.00E+00
2002	2.82E+03	4.23E+04	0.00E+00	0.00E+00	3.26E+03	3.61E+04	0.00E+00
2003	3.12E+03	4.10E+04	0.00E+00	0.00E+00	3.29E+03	4.72E+04	0.00E+00
2004	4.43E+03	4.63E+04	0.00E+00	0.00E+00	3.85E+03	4.32E+04	0.00E+00
2005	4.85E+03	4.44E+04	0.00E+00	0.00E+00	3.89E+03	4.15E+04	0.00E+00
2006	2.93E+03	2.89E+04	0.00E+00	0.00E+00	3.86E+03	3.23E+04	0.00E+00
2007	2.99E+03	3.19E+04	0.00E+00	0.00E+00	3.56E+03	3.40E+04	0.00E+00
2008	4.10E+03	3.82E+04	0.00E+00	0.00E+00	3.55E+03	3.91E+04	0.00E+00
2009	4.19E+03	3.93E+04	0.00E+00	0.00E+00	3.92E+03	3.75E+04	0.00E+00
2010	2.85E+03	3.02E+04	0.00E+00	0.00E+00	3.51E+03	3.15E+04	0.00E+00
2011	2.44E+03	3.39E+04	0.00E+00	0.00E+00	3.97E+03	3.37E+04	0.00E+00
2012	5.71E+03	5.23E+04	0.00E+00	0.00E+00	4.51E+03	5.05E+04	0.00E+00
2013	3.73E+03	3.58E+04	0.00E+00	0.00E+00	3.64E+03	3.51E+04	0.00E+00
2014	4.38E+03	3.94E+04	0.00E+00	0.00E+00	3.73E+03	3.86E+04	0.00E+00
2015	3.78E+03	2.66E+03	0.00E+00	5.87E+00	3.40E+03	7.40E+03	0.00E+00
2016	2.98E+03	3.91E+03	0.00E+00	2.74E+01	3.66E+03	3.55E+03	0.00E+00
2017	5.10E+03	2.53E+04	0.00E+00	1.60E+01	3.70E+03	2.58E+04	0.00E+00
2018	3.78E+03	5.07E+03	2.74E+01	1.64E+02	3.34E+03	3.56E+03	0.00E+00
AVG	**6.15E+03**	**3.74E+04**	**3.48E+04**	**3.47E+00**	**5.63E+03**	**5.09E+04**	**2.20E+04**

Table B-5. Lake Geneva annual water budget. All rates are in units of cubic feet per day and 1957 results reflect July - December only.

	INFLOW					OUTFLOW			
Year	**Rainfall**	**From Lake Hutchinson & Runoff**	**From Alligator Creek**	**From Lake Geneva West**	**From Ground-water**	**Evapo-ration**	**To Ground-water**	**To Lake Geneva West**	**To Surface Water**
1957*	7.65E+05	1.16E+05	0.00E+00	8.74E+04	2.40E+01	5.82E+05	1.65E+05	0.00E+00	0.00E+00
1958	7.72E+05	8.62E+04	0.00E+00	6.90E+04	1.38E+01	6.10E+05	1.76E+05	0.00E+00	0.00E+00
1959	8.14E+05	1.34E+05	0.00E+00	8.20E+04	5.38E+00	6.35E+05	2.02E+05	0.00E+00	0.00E+00
1960	8.49E+05	1.57E+05	1.77E+03	8.28E+04	2.66E+00	6.55E+05	2.12E+05	0.00E+00	0.00E+00
1961	6.50E+05	9.22E+04	1.77E+04	5.51E+04	6.09E+00	6.75E+05	2.04E+05	1.18E+03	0.00E+00
1962	6.42E+05	3.96E+04	0.00E+00	3.47E+04	1.31E+01	6.78E+05	1.96E+05	0.00E+00	0.00E+00
1963	4.86E+05	1.50E+04	0.00E+00	2.33E+04	2.12E+01	6.46E+05	1.99E+05	0.00E+00	0.00E+00
1964	1.02E+06	3.29E+05	1.37E+04	1.82E+05	6.74E+00	6.33E+05	2.33E+05	0.00E+00	0.00E+00
1965	8.95E+05	2.01E+05	2.91E+05	8.32E+04	0.00E+00	6.71E+05	2.77E+05	2.01E+04	1.87E+05
1966	7.71E+05	1.37E+05	1.02E+05	1.05E+05	4.19E-01	6.54E+05	2.58E+05	0.00E+00	2.79E+05
1967	7.35E+05	1.22E+05	1.07E+04	9.12E+04	1.04E+00	6.82E+05	2.45E+05	0.00E+00	8.21E+04
1968	6.88E+05	1.00E+05	0.00E+00	7.06E+04	2.38E-01	6.73E+05	2.63E+05	0.00E+00	4.26E+03
1969	7.38E+05	6.59E+04	0.00E+00	5.36E+04	2.58E-01	6.45E+05	2.78E+05	0.00E+00	1.92E+02
1970	8.50E+05	1.89E+05	1.68E+05	9.72E+04	0.00E+00	6.83E+05	2.95E+05	4.33E+03	1.73E+05
1971	6.98E+05	8.36E+04	0.00E+00	5.88E+04	0.00E+00	6.83E+05	2.63E+05	0.00E+00	1.06E+04
1972	9.49E+05	2.14E+05	3.52E+05	1.04E+05	0.00E+00	6.86E+05	2.95E+05	7.27E+03	2.88E+05
1973	7.16E+05	9.70E+04	2.36E+05	9.82E+04	1.03E+00	6.86E+05	2.75E+05	0.00E+00	4.55E+05
1974	6.98E+05	5.87E+04	0.00E+00	4.53E+04	4.23E+00	6.86E+05	2.48E+05	0.00E+00	3.56E+02
1975	7.06E+05	8.42E+04	0.00E+00	6.44E+04	3.24E+00	6.69E+05	2.62E+05	0.00E+00	0.00E+00
1976	6.52E+05	1.01E+05	0.00E+00	7.48E+04	1.12E+00	6.61E+05	2.77E+05	0.00E+00	0.00E+00
1977	4.41E+05	3.35E+04	0.00E+00	3.69E+04	4.99E+00	6.70E+05	2.71E+05	0.00E+00	0.00E+00
1978	6.35E+05	1.18E+05	0.00E+00	8.99E+04	5.27E+00	6.34E+05	2.68E+05	0.00E+00	0.00E+00
1979	7.68E+05	1.38E+05	0.00E+00	1.00E+05	5.17E+00	6.24E+05	2.50E+05	0.00E+00	0.00E+00
1980	5.36E+05	5.04E+04	1.37E+02	4.44E+04	4.19E+00	6.36E+05	2.34E+05	0.00E+00	0.00E+00
1981	4.27E+05	2.67E+04	0.00E+00	3.21E+04	1.33E+01	6.19E+05	2.01E+05	0.00E+00	0.00E+00
1982	7.39E+05	1.48E+05	0.00E+00	1.09E+05	3.90E+00	5.95E+05	2.36E+05	0.00E+00	0.00E+00
1983	8.05E+05	1.14E+05	0.00E+00	8.74E+04	4.17E+00	5.89E+05	2.29E+05	0.00E+00	0.00E+00
1984	4.85E+05	4.32E+04	0.00E+00	4.06E+04	1.20E+01	6.08E+05	2.05E+05	0.00E+00	0.00E+00
1985	5.82E+05	7.23E+04	0.00E+00	6.12E+04	1.51E+01	5.72E+05	1.88E+05	0.00E+00	0.00E+00
1986	6.17E+05	8.74E+04	0.00E+00	7.07E+04	1.49E+01	5.94E+05	2.02E+05	0.00E+00	0.00E+00
1987	5.57E+05	6.41E+04	0.00E+00	5.73E+04	3.04E+01	5.71E+05	2.00E+05	0.00E+00	0.00E+00
1988	7.20E+05	1.67E+05	0.00E+00	1.20E+05	1.46E+01	5.64E+05	2.12E+05	0.00E+00	0.00E+00
1989	4.38E+05	4.55E+04	0.00E+00	4.67E+04	1.14E+01	5.94E+05	2.11E+05	0.00E+00	0.00E+00

	INFLOW					OUTFLOW			
Year	**Rainfall**	**From Lake Hutchinson & Runoff**	**From Alligator Creek**	**From Lake Geneva West**	**From Ground-water**	**Evapo-ration**	**To Ground-water**	**To Lake Geneva West**	**To Surface Water**
1990	4.18E+05	2.47E+04	0.00E+00	1.90E+04	1.45E+01	5.58E+05	2.06E+05	0.00E+00	0.00E+00
1991	5.77E+05	4.58E+04	0.00E+00	4.04E+04	3.64E+00	4.93E+05	2.13E+05	0.00E+00	0.00E+00
1992	4.10E+05	4.48E+04	0.00E+00	0.00E+00	3.90E+00	4.57E+05	1.83E+05	0.00E+00	0.00E+00
1993	4.72E+05	4.36E+04	0.00E+00	1.41E+04	1.70E+00	4.53E+05	1.63E+05	0.00E+00	0.00E+00
1994	5.48E+05	8.93E+04	0.00E+00	9.80E+04	3.73E-01	4.40E+05	1.66E+05	0.00E+00	0.00E+00
1995	4.62E+05	3.01E+04	0.00E+00	1.76E+04	1.55E+01	4.16E+05	1.46E+05	0.00E+00	0.00E+00
1996	3.87E+05	3.50E+04	0.00E+00	1.35E+04	4.48E+01	4.19E+05	1.13E+05	0.00E+00	0.00E+00
1997	5.41E+05	1.21E+05	0.00E+00	1.32E+05	3.65E+01	4.13E+05	1.28E+05	0.00E+00	0.00E+00
1998	4.20E+05	3.64E+04	0.00E+00	5.13E+04	9.85E+01	4.91E+05	1.38E+05	0.00E+00	0.00E+00
1999	3.36E+05	1.89E+04	0.00E+00	0.00E+00	8.14E+01	4.42E+05	1.01E+05	0.00E+00	0.00E+00
2000	3.08E+05	2.90E+04	0.00E+00	0.00E+00	1.19E+01	4.13E+05	9.89E+04	0.00E+00	0.00E+00
2001	3.48E+05	2.79E+04	0.00E+00	0.00E+00	0.00E+00	3.58E+05	1.05E+05	0.00E+00	0.00E+00
2002	2.63E+05	2.38E+04	0.00E+00	0.00E+00	2.74E-02	3.08E+05	9.29E+04	0.00E+00	0.00E+00
2003	2.88E+05	1.18E+04	0.00E+00	0.00E+00	2.66E+01	2.92E+05	8.44E+04	0.00E+00	0.00E+00
2004	3.11E+05	6.15E+04	0.00E+00	0.00E+00	6.62E+01	2.79E+05	6.28E+04	0.00E+00	0.00E+00
2005	3.64E+05	2.25E+04	0.00E+00	0.00E+00	1.02E+02	2.93E+05	6.16E+04	0.00E+00	0.00E+00
2006	2.55E+05	2.90E+04	0.00E+00	1.10E+04	2.90E+02	3.25E+05	4.44E+04	0.00E+00	0.00E+00
2007	2.63E+05	3.26E+04	0.00E+00	0.00E+00	1.52E+02	2.82E+05	4.90E+04	0.00E+00	0.00E+00
2008	2.95E+05	6.39E+04	0.00E+00	1.91E+04	2.64E+01	2.76E+05	7.30E+04	0.00E+00	0.00E+00
2009	3.81E+05	7.53E+04	0.00E+00	6.63E+04	1.51E+01	3.59E+05	8.30E+04	0.00E+00	0.00E+00
2010	2.71E+05	1.92E+04	0.00E+00	2.47E+03	5.10E+01	3.21E+05	6.55E+04	0.00E+00	0.00E+00
2011	1.81E+05	1.78E+04	0.00E+00	0.00E+00	1.24E+02	2.96E+05	4.11E+04	0.00E+00	0.00E+00
2012	2.95E+05	1.10E+05	0.00E+00	0.00E+00	4.48E+01	2.54E+05	5.27E+04	0.00E+00	0.00E+00
2013	2.58E+05	4.33E+04	0.00E+00	1.62E+04	3.38E+01	2.63E+05	5.73E+04	0.00E+00	0.00E+00
2014	3.37E+05	6.63E+04	0.00E+00	4.36E+04	1.07E+02	2.99E+05	4.77E+04	0.00E+00	0.00E+00
2015	2.93E+05	8.77E+03	0.00E+00	2.47E+03	9.63E+01	2.88E+05	4.38E+04	0.00E+00	0.00E+00
2016	2.46E+05	3.14E+04	0.00E+00	0.00E+00	6.46E+01	2.98E+05	3.63E+04	0.00E+00	0.00E+00
2017	4.38E+05	1.82E+05	0.00E+00	1.89E+05	2.85E+01	3.12E+05	7.01E+04	0.00E+00	0.00E+00
2018	4.38E+05	4.14E+04	0.00E+00	3.40E+04	0.00E+00	3.81E+05	1.00E+05	0.00E+00	0.00E+00
AVG	**5.34E+05**	**7.90E+04**	**1.94E+04**	**5.18E+04**	**2.88E+01**	**5.08E+05**	**1.70E+05**	**5.72E+02**	**2.41E+04**

Table B-6. Lake Geneva West annual water budget. All rates are in units of cubic feet per day and 1957 results reflect July - December only.

	INFLOW				**OUTFLOW**		
Year	**Rainfall**	**Runoff**	**From Alligator Creek**	**From Groundwater**	**Evaporation**	**To Groundwater**	**To Alligator Creek**
1957*	2.37E+05	1.20E+05	0.00E+00	3.62E+03	1.81E+05	2.47E+04	8.77E+04
1958	2.42E+05	9.74E+04	0.00E+00	2.16E+03	1.91E+05	3.74E+04	6.90E+04
1959	2.61E+05	1.33E+05	0.00E+00	1.31E+03	2.04E+05	4.89E+04	8.21E+04
1960	2.75E+05	1.44E+05	0.00E+00	1.00E+03	2.12E+05	5.37E+04	8.29E+04
1961	2.13E+05	9.12E+04	1.21E+03	1.16E+03	2.20E+05	5.19E+04	5.51E+04
1962	2.06E+05	4.21E+04	0.00E+00	1.42E+03	2.18E+05	4.77E+04	3.47E+04
1963	1.53E+05	1.74E+04	0.00E+00	1.59E+03	2.04E+05	4.58E+04	2.33E+04
1964	3.26E+05	3.31E+05	0.00E+00	9.79E+02	2.02E+05	5.90E+04	1.83E+05
1965	3.03E+05	1.71E+05	2.01E+04	4.49E+02	2.27E+05	7.82E+04	8.33E+04
1966	2.64E+05	1.10E+05	0.00E+00	5.98E+02	2.23E+05	7.20E+04	1.05E+05
1967	2.49E+05	1.22E+05	0.00E+00	7.06E+02	2.31E+05	6.65E+04	9.13E+04
1968	2.30E+05	1.07E+05	0.00E+00	6.86E+02	2.24E+05	6.96E+04	7.07E+04
1969	2.44E+05	7.27E+04	0.00E+00	7.07E+02	2.13E+05	7.25E+04	5.36E+04
1970	2.90E+05	1.67E+05	4.33E+03	5.28E+02	2.33E+05	8.12E+04	9.73E+04
1971	2.33E+05	8.53E+04	0.00E+00	5.75E+02	2.28E+05	7.14E+04	5.88E+04
1972	3.23E+05	2.04E+05	7.27E+03	4.98E+02	2.33E+05	8.12E+04	1.04E+05
1973	2.45E+05	7.10E+04	0.00E+00	6.29E+02	2.35E+05	7.52E+04	9.82E+04
1974	2.32E+05	6.18E+04	0.00E+00	8.58E+02	2.28E+05	6.52E+04	4.54E+04
1975	2.32E+05	9.30E+04	0.00E+00	8.61E+02	2.20E+05	6.73E+04	6.44E+04
1976	2.13E+05	1.12E+05	0.00E+00	7.55E+02	2.16E+05	7.08E+04	7.49E+04
1977	1.40E+05	3.84E+04	0.00E+00	9.32E+02	2.13E+05	6.52E+04	3.69E+04
1978	1.99E+05	1.32E+05	0.00E+00	9.14E+02	1.99E+05	6.17E+04	9.01E+04
1979	2.41E+05	1.53E+05	0.00E+00	9.31E+02	1.95E+05	5.80E+04	1.01E+05
1980	1.68E+05	5.57E+04	0.00E+00	8.92E+02	1.99E+05	5.52E+04	4.45E+04
1981	1.30E+05	3.02E+04	0.00E+00	9.41E+02	1.88E+05	4.29E+04	3.21E+04
1982	2.25E+05	1.65E+05	0.00E+00	5.79E+02	1.81E+05	4.96E+04	1.09E+05
1983	2.46E+05	1.29E+05	0.00E+00	6.90E+02	1.80E+05	5.06E+04	8.75E+04
1984	1.49E+05	4.78E+04	0.00E+00	9.71E+02	1.86E+05	4.57E+04	4.06E+04
1985	1.75E+05	8.22E+04	0.00E+00	7.99E+02	1.72E+05	3.83E+04	6.13E+04
1986	1.86E+05	9.86E+04	0.00E+00	7.58E+02	1.79E+05	4.16E+04	7.08E+04
1987	1.68E+05	7.23E+04	0.00E+00	1.01E+03	1.72E+05	4.04E+04	5.73E+04
1988	2.17E+05	1.85E+05	0.00E+00	8.01E+02	1.70E+05	4.33E+04	1.20E+05
1989	1.32E+05	5.15E+04	0.00E+00	7.23E+02	1.78E+05	4.15E+04	4.68E+04
1990	1.24E+05	2.82E+04	0.00E+00	4.36E+02	1.66E+05	3.47E+04	1.90E+04

	INFLOW				OUTFLOW		
Year	**Rainfall**	**Runoff**	**From Alligator Creek**	**From Groundwater**	**Evaporation**	**To Groundwater**	**To Alligator Creek**
1991	1.78E+05	5.26E+04	0.00E+00	2.93E+02	1.53E+05	3.54E+04	4.00E+04
1992	1.30E+05	4.92E+04	0.00E+00	2.27E+02	1.44E+05	3.12E+04	0.00E+00
1993	1.59E+05	4.85E+04	0.00E+00	2.00E+02	1.52E+05	3.30E+04	1.40E+04
1994	1.90E+05	9.95E+04	0.00E+00	2.00E+02	1.52E+05	3.55E+04	9.55E+04
1995	1.58E+05	3.48E+04	0.00E+00	2.19E+02	1.42E+05	3.41E+04	1.74E+04
1996	1.33E+05	3.93E+04	0.00E+00	2.49E+02	1.43E+05	2.96E+04	1.33E+04
1997	1.87E+05	1.32E+05	0.00E+00	2.36E+02	1.42E+05	3.26E+04	1.28E+05
1998	1.32E+05	4.14E+04	0.00E+00	4.58E+02	1.52E+05	2.63E+04	5.03E+04
1999	1.06E+05	2.14E+04	0.00E+00	3.70E+02	1.40E+05	2.02E+04	0.00E+00
2000	1.01E+05	3.33E+04	0.00E+00	1.91E+02	1.35E+05	1.75E+04	0.00E+00
2001	1.24E+05	3.21E+04	0.00E+00	1.53E+02	1.27E+05	2.05E+04	0.00E+00
2002	1.03E+05	2.68E+04	0.00E+00	1.42E+02	1.18E+05	1.85E+04	0.00E+00
2003	1.19E+05	1.42E+04	0.00E+00	1.95E+02	1.21E+05	2.10E+04	0.00E+00
2004	1.40E+05	6.86E+04	0.00E+00	1.72E+02	1.25E+05	2.05E+04	0.00E+00
2005	1.70E+05	2.63E+04	0.00E+00	2.14E+02	1.38E+05	3.04E+04	0.00E+00
2006	1.21E+05	3.34E+04	0.00E+00	1.89E+02	1.54E+05	2.85E+04	1.10E+04
2007	1.31E+05	3.75E+04	0.00E+00	1.40E+02	1.41E+05	2.56E+04	0.00E+00
2008	1.54E+05	7.24E+04	0.00E+00	1.42E+02	1.43E+05	3.39E+04	1.83E+04
2009	1.81E+05	8.44E+04	0.00E+00	1.45E+02	1.70E+05	3.58E+04	6.38E+04
2010	1.28E+05	2.22E+04	0.00E+00	1.42E+02	1.51E+05	3.25E+04	2.19E+03
2011	9.29E+04	2.00E+04	0.00E+00	1.01E+02	1.54E+05	2.25E+04	0.00E+00
2012	1.67E+05	1.22E+05	0.00E+00	9.02E+01	1.44E+05	2.78E+04	0.00E+00
2013	1.47E+05	4.74E+04	0.00E+00	1.01E+02	1.49E+05	3.64E+04	1.62E+04
2014	1.78E+05	7.29E+04	0.00E+00	1.18E+02	1.59E+05	3.38E+04	4.25E+04
2015	1.49E+05	1.07E+04	0.00E+00	8.22E+01	1.46E+05	3.28E+04	2.47E+03
2016	1.28E+05	3.63E+04	0.00E+00	1.64E+01	1.55E+05	3.01E+04	0.00E+00
2017	2.08E+05	1.99E+05	0.00E+00	0.00E+00	1.52E+05	3.35E+04	1.82E+05
2018	1.70E+05	4.66E+04	0.00E+00	0.00E+00	1.47E+05	3.43E+04	3.32E+04
AVG	**1.86E+05**	**8.27E+04**	**5.36E+02**	**5.76E+02**	**1.77E+05**	**4.41E+04**	**5.15E+04**

APPENDIX C - ANNUAL LAKE WATER BUDGET IN INCHES PER YEAR (IPY) (1957-2018)

Table C-1. Lake Lowry annual water budget. All rates are in units of inches per year and 1957 results reflect July - December only.

	INFLOW			OUTFLOW		
Year	**Rainfall**	**From Alligator Creek, Runoff & Spring**	**From Groundwater**	**Evaporation**	**To Groundwater**	**To Alligator Creek**
1957*	30.43	26.26	1.04	23.17	12.87	10.71
1958	59.87	52.31	2.08	47.26	25.88	37.62
1959	61.16	54.64	2.24	47.59	25.85	46.98
1960	62.97	53.69	2.36	48.61	25.68	43.42
1961	47.77	51.30	2.59	49.59	24.81	29.98
1962	47.91	47.16	2.48	50.59	25.06	20.24
1963	37.27	45.10	2.43	49.45	25.83	11.84
1964	76.99	70.88	2.06	48.14	27.71	63.84
1965	64.04	54.84	2.61	48.00	26.59	52.32
1966	54.72	52.95	2.90	46.41	25.53	41.63
1967	52.60	51.69	2.94	48.78	25.05	31.90
1968	49.87	52.24	2.88	48.71	26.08	30.31
1969	53.54	53.82	2.97	46.77	26.97	31.51
1970	60.58	54.13	3.09	48.60	26.92	50.47
1971	50.34	50.90	2.98	49.24	26.08	24.44
1972	67.80	75.00	3.09	49.02	27.08	66.29
1973	50.65	52.13	3.38	48.56	25.62	37.01
1974	50.53	47.38	3.13	49.60	25.53	25.97
1975	51.60	52.16	3.17	48.89	26.46	30.32
1976	48.13	60.24	3.17	48.75	27.46	33.86
1977	33.57	47.75	3.28	50.74	27.44	13.73
1978	49.24	51.79	2.83	49.16	29.23	22.69
1979	59.84	50.73	2.76	48.59	29.52	31.74
1980	41.59	51.43	2.75	49.43	29.40	23.74
1981	35.27	44.01	2.69	51.08	28.72	5.70
1982	61.11	57.02	2.23	49.02	30.69	34.46
1983	65.38	58.97	2.38	47.82	30.02	41.88
1984	39.30	46.51	2.58	49.32	28.41	20.76
1985	49.86	54.42	2.24	48.94	28.81	23.52
1986	52.32	51.26	2.36	50.31	29.20	24.35
1987	47.08	49.50	2.48	48.33	29.37	27.15

	INFLOW			**OUTFLOW**		
Year	**Rainfall**	**From Alligator Creek, Runoff & Spring**	**From Groundwater**	**Evaporation**	**To Groundwater**	**To Alligator Creek**
1988	61.25	55.84	2.30	48.00	30.05	37.72
1989	37.76	44.19	2.50	51.02	29.22	7.56
1990	38.75	46.01	2.25	51.94	30.06	7.82
1991	56.41	52.40	2.04	48.24	32.12	29.08
1992	43.21	48.19	1.99	48.14	32.01	11.48
1993	51.81	45.91	1.82	49.82	32.39	15.59
1994	60.09	66.72	1.59	48.40	33.48	42.72
1995	50.73	66.88	1.65	45.26	32.84	43.84
1996	51.94	52.78	1.70	46.51	31.77	25.22
1997	52.30	61.09	1.62	45.25	32.13	31.61
1998	48.46	80.00	1.63	50.44	31.87	59.67
1999	40.99	28.63	1.79	49.10	29.84	4.73
2000	40.04	26.70	1.88	51.07	29.15	0.00
2001	45.63	26.36	1.84	46.76	29.51	0.00
2002	58.35	24.63	1.69	45.48	30.11	0.00
2003	55.56	54.91	1.21	45.18	34.33	16.17
2004	58.81	50.16	1.30	47.78	33.67	21.41
2005	58.29	69.04	1.29	45.81	34.11	46.16
2006	38.99	34.22	1.52	51.55	31.41	16.46
2007	43.67	25.14	1.74	49.84	29.24	0.00
2008	52.66	56.34	1.26	46.80	32.50	6.50
2009	54.52	72.19	1.03	54.30	34.48	35.51
2010	43.38	57.41	1.09	49.21	33.73	30.13
2011	46.06	27.81	1.23	55.83	31.41	0.89
2012	60.90	69.60	1.04	50.90	33.30	21.40
2013	48.09	58.01	0.90	47.66	34.61	27.78
2014	52.62	60.38	0.98	51.54	33.45	28.12
2015	48.96	61.25	0.90	47.23	32.59	29.89
2016	51.70	53.02	2.09	49.07	29.76	27.66
2017	60.93	86.20	0.58	49.48	32.82	51.42
2018	50.38	69.10	0.50	46.93	32.98	39.65
AVG	**51.23**	**52.47**	**2.08**	**48.44**	**29.37**	**27.53**

Table C-2. Lake Magnolia annual water budget. All rates are in units of inches per year and 1957 results reflect July - December only.

	INFLOW				OUTFLOW		
Year	**Rainfall**	**Runoff**	**From Alligator Creek**	**From Groundwater**	**Evaporation**	**To Groundwater**	**To Alligator Creek**
1957*	30.45	10.85	70.10	0.00	23.18	25.37	62.78
1958	59.89	15.00	235.58	0.00	47.27	50.86	208.23
1959	61.29	24.08	292.65	0.00	47.63	50.55	282.47
1960	63.08	22.94	271.31	0.00	48.62	49.97	257.29
1961	47.79	20.05	191.52	0.02	49.52	47.72	165.41
1962	47.86	11.67	131.04	0.01	50.46	48.82	89.36
1963	37.33	9.79	79.95	0.02	49.53	49.43	45.75
1964	76.90	30.89	391.20	0.00	47.94	55.30	370.50
1965	64.25	16.25	326.66	0.01	48.03	51.22	313.29
1966	54.82	21.62	262.05	0.03	46.40	48.53	246.83
1967	52.72	22.23	202.83	0.04	48.76	47.75	180.20
1968	50.01	30.18	193.74	0.03	48.60	50.83	174.06
1969	53.49	15.97	201.42	0.02	46.59	52.68	166.43
1970	60.82	16.51	315.13	0.03	48.67	51.66	301.49
1971	50.28	16.59	157.74	0.03	49.11	50.25	119.36
1972	67.94	73.69	409.44	0.02	49.05	52.26	446.94
1973	50.82	29.75	233.46	0.05	48.59	48.55	222.10
1974	50.59	10.81	167.06	0.04	49.61	49.28	129.76
1975	51.61	16.73	193.47	0.03	48.75	51.87	159.52
1976	48.31	41.15	214.97	0.02	48.80	54.34	199.92
1977	33.37	18.61	96.90	0.05	50.86	52.60	84.36
1978	49.01	25.53	146.78	0.00	49.20	60.25	80.87
1979	59.82	11.19	201.07	0.00	48.50	59.14	159.31
1980	41.76	31.12	152.51	0.00	49.49	58.15	127.64
1981	35.46	6.80	43.32	0.01	51.45	55.09	17.27
1982	60.98	32.21	216.95	0.00	49.23	63.78	156.09
1983	65.42	25.62	262.19	0.00	47.81	59.82	237.48
1984	39.46	9.14	133.87	0.00	49.40	55.22	96.40
1985	49.94	33.92	150.34	0.00	48.74	57.37	114.75
1986	52.31	21.82	156.15	0.00	50.07	58.77	119.12
1987	47.30	15.83	174.53	0.00	48.36	58.40	141.23
1988	61.35	20.09	236.38	0.00	47.88	60.44	201.45
1989	37.57	5.25	55.00	0.00	51.05	56.50	15.11
1990	38.97	11.18	55.90	0.00	52.32	60.86	3.86

	INFLOW				OUTFLOW		
Year	**Rainfall**	**Runoff**	**From Alligator Creek**	**From Groundwater**	**Evaporation**	**To Groundwater**	**To Alligator Creek**
1991	56.41	12.17	185.39	0.00	48.47	68.46	110.31
1992	42.99	13.04	78.16	0.00	47.97	65.76	20.48
1993	51.65	10.06	102.63	0.00	49.76	66.62	52.87
1994	60.01	13.50	264.05	0.00	48.27	70.19	203.91
1995	50.77	11.29	271.98	0.00	45.29	65.78	225.78
1996	51.85	15.10	159.91	0.00	46.33	63.57	113.71
1997	52.37	16.43	197.29	0.00	45.17	65.20	150.68
1998	48.39	20.42	367.68	0.00	50.22	62.55	335.95
1999	40.98	8.99	36.40	0.00	49.32	57.66	20.01
2000	40.10	11.90	5.70	0.00	51.34	56.56	0.00
2001	45.64	16.39	6.76	0.00	46.92	58.79	0.00
2002	58.09	29.90	7.58	0.00	45.46	56.54	0.00
2003	53.20	25.48	134.27	0.00	43.51	70.20	0.00
2004	57.29	26.79	146.65	0.00	46.60	73.97	66.84
2005	58.36	18.88	284.76	0.00	45.88	70.44	242.52
2006	39.20	12.01	109.24	0.00	51.81	61.54	96.63
2007	43.77	14.42	6.14	0.00	50.23	59.43	0.00
2008	51.68	24.22	57.69	0.00	46.01	65.41	0.00
2009	54.34	14.68	231.60	0.00	54.76	76.19	104.95
2010	43.55	12.01	188.58	0.00	49.36	69.81	147.27
2011	46.28	13.41	10.35	0.00	55.90	63.29	0.00
2012	59.37	37.45	152.42	0.00	49.40	74.47	47.43
2013	48.18	14.06	173.37	0.00	47.52	73.59	117.69
2014	52.37	14.97	175.67	0.00	51.45	66.98	124.48
2015	48.78	5.98	186.93	0.00	47.06	65.25	127.34
2016	40.68	10.33	70.38	0.00	51.94	62.79	40.95
2017	61.01	51.49	336.83	0.00	48.36	66.21	294.37
2018	50.40	7.78	244.57	0.00	46.88	67.51	187.24
AVG	**50.98**	**19.49**	**174.45**	**0.01**	**48.40**	**58.84**	**137.55**

Table C-3. Lake Brooklyn annual water budget. All rates are in units of inches per year and 1957 results reflect July - December only.

	INFLOW				OUTFLOW		
Year	**Rainfall**	**Runoff**	**From Alligator Creek**	**From Groundwater**	**Evaporation**	**To Groundwater**	**To Alligator Creek**
1957*	28.48	14.37	37.04	3.88	21.95	17.05	0.00
1958	59.22	19.44	94.51	0.00	47.38	57.29	0.00
1959	60.69	21.24	105.54	0.00	47.80	75.25	0.00
1960	62.84	21.67	91.67	0.00	48.51	81.95	10.64
1961	47.66	13.83	60.59	0.00	49.58	78.72	10.55
1962	47.71	7.15	36.77	0.00	50.51	72.31	0.00
1963	37.53	3.30	19.99	0.00	49.97	68.63	0.00
1964	75.91	49.04	137.86	0.00	47.33	82.95	12.36
1965	64.16	24.11	110.35	0.00	48.05	88.57	73.08
1966	54.67	16.83	89.70	0.00	46.38	82.85	36.81
1967	52.50	18.47	66.84	0.00	48.73	80.68	14.67
1968	49.44	16.65	65.87	0.00	48.36	82.18	1.07
1969	53.34	11.53	63.45	0.00	46.75	85.67	1.33
1970	60.73	24.00	106.92	0.00	48.72	89.58	51.65
1971	50.14	12.75	47.10	0.00	49.19	78.81	0.00
1972	67.73	29.14	155.29	0.00	49.09	90.63	68.64
1973	50.97	10.74	81.00	0.00	48.72	82.76	50.88
1974	50.27	10.37	52.77	0.00	49.48	75.11	0.00
1975	51.27	14.51	63.36	0.00	48.64	78.79	0.00
1976	47.98	17.06	75.64	0.00	48.68	85.51	0.00
1977	33.38	6.70	32.74	0.00	51.14	83.74	0.00
1978	49.16	23.09	38.65	0.00	49.21	78.60	0.00
1979	59.39	25.80	68.19	0.00	48.43	78.91	0.00
1980	42.04	9.25	52.85	0.00	49.77	78.17	0.00
1981	35.69	6.28	10.09	0.00	51.76	68.29	0.00
1982	60.17	32.44	75.05	0.00	48.94	76.19	0.00
1983	65.00	23.42	98.90	0.00	47.75	79.64	0.00
1984	39.83	8.17	39.60	0.00	49.82	76.28	0.00
1985	48.93	16.67	50.89	0.00	48.12	70.01	0.00
1986	52.08	18.04	52.18	0.00	50.44	75.92	0.00
1987	47.30	13.44	59.78	0.00	49.05	77.86	0.00
1988	60.22	31.86	84.34	0.00	47.39	80.85	0.00
1989	37.69	9.75	8.76	0.00	51.45	76.17	0.00

	INFLOW				OUTFLOW		
Year	**Rainfall**	**Runoff**	**From Alligator Creek**	**From Groundwater**	**Evaporation**	**To Groundwater**	**To Alligator Creek**
1990	39.64	7.44	4.98	0.00	52.95	73.28	0.00
1991	55.37	15.69	72.94	0.00	48.23	83.60	0.00
1992	43.09	15.63	18.40	0.00	48.43	81.03	0.00
1993	51.33	19.42	48.60	0.00	50.53	82.44	0.00
1994	57.05	30.41	142.50	0.00	45.66	88.69	0.00
1995	56.00	15.34	108.77	0.00	43.82	79.92	0.00
1996	46.87	10.34	51.59	0.00	46.37	76.26	0.00
1997	65.37	27.57	65.53	0.00	45.14	81.69	0.00
1998	49.49	11.29	119.27	0.00	50.92	93.29	0.00
1999	40.32	2.40	8.77	0.00	49.54	77.62	0.00
2000	35.20	9.04	0.83	0.00	51.91	73.79	0.00
2001	41.88	25.66	1.56	0.00	47.77	84.87	0.00
2002	37.60	17.91	4.13	0.00	45.47	66.14	0.00
2003	42.66	8.94	12.52	0.00	45.47	42.92	0.00
2004	44.58	49.72	128.59	0.00	39.92	68.09	0.00
2005	55.55	10.76	161.60	0.00	44.87	87.34	0.00
2006	36.55	7.24	48.17	0.00	52.41	75.38	0.00
2007	40.64	15.63	1.62	0.00	50.02	80.95	0.00
2008	53.76	41.74	4.62	0.00	46.83	83.33	0.00
2009	54.44	46.68	107.40	0.00	54.17	95.37	0.00
2010	40.35	6.28	93.90	0.00	51.11	84.04	0.00
2011	36.50	12.87	1.41	0.00	56.58	75.68	0.00
2012	61.54	83.56	58.71	0.00	49.20	95.56	0.00
2013	46.65	18.03	104.45	0.00	46.09	95.78	0.00
2014	59.62	21.20	76.75	0.00	52.18	78.86	0.00
2015	50.98	7.23	74.80	0.00	45.98	74.09	0.00
2016	42.55	10.49	23.81	0.00	52.71	72.44	0.00
2017	60.81	61.84	174.93	0.00	42.81	88.11	0.00
2018	52.70	8.18	70.94	0.00	47.12	83.97	0.00
AVG	**50.05**	**19.35**	**64.94**	**0.06**	**48.25**	**78.39**	**5.35**

Table C-4. Keystone Lake annual water budget. All rates are in units of inches per year and 1957 results reflect July - December only.

	INFLOW				OUTFLOW		
Year	**Rainfall**	**Runoff**	**From Alligator Creek**	**From Groundwater**	**Evaporation**	**To Groundwater**	**To Alligator Creek**
1957*	32.36	148.40	0.00	0.00	24.11	153.42	0.00
1958	59.03	252.95	0.00	0.00	47.45	246.70	0.00
1959	63.58	288.19	0.00	0.00	49.68	312.66	0.00
1960	61.93	245.71	358.44	0.00	46.82	465.89	36.26
1961	49.25	214.66	325.23	0.00	51.34	507.04	125.00
1962	53.95	290.70	0.00	0.00	53.56	300.49	0.00
1963	38.79	283.85	0.00	0.00	52.01	288.00	0.00
1964	73.00	287.25	446.71	0.00	42.50	463.69	120.29
1965	63.89	154.22	2104.90	0.00	47.89	851.65	1440.20
1966	54.80	197.35	1047.29	0.00	46.48	735.11	531.85
1967	52.54	192.05	429.01	0.00	49.36	607.87	79.54
1968	56.71	297.21	37.96	0.00	49.63	370.15	0.00
1969	55.12	209.12	58.33	0.00	47.43	291.84	0.00
1970	60.09	153.16	1542.13	0.00	49.94	766.07	902.30
1971	51.88	254.85	0.00	0.00	50.08	299.91	0.00
1972	67.99	493.13	2292.59	0.00	49.86	724.45	1943.85
1973	52.57	244.33	1554.90	0.00	50.59	700.52	1203.16
1974	52.55	180.59	0.00	0.00	50.73	235.42	0.00
1975	55.14	280.24	0.00	0.00	49.50	291.19	0.00
1976	53.19	388.05	0.00	0.00	53.31	386.85	0.00
1977	34.23	286.57	0.00	0.00	48.93	288.95	0.00
1978	51.20	428.43	0.00	0.00	49.81	420.67	0.00
1979	60.61	253.00	0.00	0.00	50.35	297.99	0.00
1980	45.98	556.12	0.00	0.00	54.80	505.62	32.32
1981	34.28	200.38	0.00	0.00	50.86	206.66	0.00
1982	63.30	321.05	0.00	0.00	52.38	337.75	0.00
1983	65.65	409.36	0.00	0.00	48.45	373.50	0.00
1984	40.03	226.23	0.00	0.00	50.15	253.44	0.00
1985	59.77	563.13	0.00	0.00	51.33	561.78	0.00
1986	57.54	457.62	0.00	0.00	51.79	453.87	0.00
1987	48.85	314.79	0.00	0.00	50.19	343.53	0.00
1988	65.03	322.12	0.00	0.00	48.41	343.92	0.00
1989	38.51	217.17	0.00	0.00	51.31	215.32	0.00
1990	38.41	350.97	0.00	0.00	51.81	358.62	0.00

	INFLOW				OUTFLOW		
Year	**Rainfall**	**Runoff**	**From Alligator Creek**	**From Groundwater**	**Evaporation**	**To Groundwater**	**To Alligator Creek**
1991	60.51	468.38	0.00	0.00	50.67	505.96	0.00
1992	43.16	486.53	0.00	0.00	48.23	461.57	0.00
1993	51.84	406.66	0.00	0.00	49.88	393.60	0.00
1994	59.36	477.52	0.00	0.00	47.12	473.81	0.00
1995	59.09	406.79	0.00	0.00	45.80	414.98	0.00
1996	47.20	402.37	0.00	0.00	45.61	374.59	0.00
1997	67.69	445.59	0.00	0.00	44.47	434.72	0.00
1998	54.02	351.37	0.00	0.00	47.65	408.05	0.00
1999	41.63	320.74	0.00	0.00	48.18	326.88	0.00
2000	38.03	366.45	0.00	0.00	50.83	387.29	0.00
2001	41.80	432.89	0.00	0.00	46.27	438.49	0.00
2002	38.90	583.18	0.00	0.00	44.95	498.19	0.00
2003	41.68	546.62	0.00	0.00	43.88	629.62	0.00
2004	54.09	565.65	0.00	0.00	47.08	527.92	0.00
2005	57.70	528.39	0.00	0.00	46.29	494.17	0.00
2006	38.40	378.95	0.00	0.00	50.60	423.45	0.00
2007	41.86	447.74	0.00	0.00	49.92	476.16	0.00
2008	54.86	511.63	0.00	0.00	47.54	522.97	0.00
2009	57.79	542.01	0.00	0.00	54.01	517.46	0.00
2010	39.94	423.94	0.00	0.00	49.15	441.60	0.00
2011	34.18	474.62	0.00	0.00	55.68	472.32	0.00
2012	67.98	622.22	0.00	0.00	53.67	601.73	0.00
2013	49.74	478.35	0.00	0.00	48.64	468.11	0.00
2014	59.57	535.06	0.00	0.00	50.64	525.00	0.00
2015	52.99	37.25	0.00	0.08	47.62	103.68	0.00
2016	41.86	54.91	0.00	0.38	51.46	49.92	0.00
2017	68.02	338.29	0.00	0.21	49.37	343.77	0.00
2018	52.99	71.04	0.38	2.30	46.85	49.92	0.00
AVG	**52.07**	**349.49**	**164.48**	**0.05**	**48.95**	**414.94**	**103.46**

Table C-5. Lake Geneva annual water budget. All rates are in units of inches per year and 1957 results reflect July - December only.

	INFLOW					OUTFLOW			
Year	**Rainfall**	**From Lake Hutchinson & Runoff**	**From Alligator Creek**	**From Lake Geneva West**	**From Groundwater**	**Evaporation**	**To Groundwater**	**To Lake Geneva West**	**To Surface Water**
1957*	30.33	4.58	0.00	3.47	0.00	23.10	6.54	0.00	0.00
1958	59.80	6.68	0.00	5.34	0.00	47.25	13.67	0.00	0.00
1959	61.09	10.07	0.00	6.15	0.00	47.65	15.17	0.00	0.00
1960	62.90	11.62	0.13	6.14	0.00	48.54	15.72	0.00	0.00
1961	47.73	6.77	1.30	4.04	0.00	49.59	14.99	0.09	0.00
1962	47.88	2.95	0.00	2.58	0.00	50.57	14.65	0.00	0.00
1963	37.34	1.15	0.00	1.79	0.00	49.61	15.30	0.00	0.00
1964	76.63	24.79	1.03	13.73	0.00	47.74	17.60	0.00	0.00
1965	63.96	14.37	20.81	5.95	0.00	47.95	19.77	1.44	13.39
1966	54.72	9.74	7.21	7.45	0.00	46.38	18.34	0.00	19.79
1967	52.52	8.74	0.77	6.52	0.00	48.76	17.53	0.00	5.87
1968	49.77	7.25	0.00	5.11	0.00	48.66	19.02	0.00	0.31
1969	53.48	4.78	0.00	3.89	0.00	46.75	20.18	0.00	0.01
1970	60.54	13.48	11.95	6.92	0.00	48.66	21.03	0.31	12.29
1971	50.30	6.02	0.00	4.24	0.00	49.25	18.98	0.00	0.77
1972	67.71	15.24	25.09	7.44	0.00	48.96	21.03	0.52	20.58
1973	50.84	6.89	16.76	6.97	0.00	48.70	19.48	0.00	32.28
1974	50.49	4.24	0.00	3.28	0.00	49.62	17.93	0.00	0.03
1975	51.54	6.15	0.00	4.70	0.00	48.84	19.13	0.00	0.00
1976	48.10	7.44	0.00	5.51	0.00	48.76	20.40	0.00	0.00
1977	33.47	2.54	0.00	2.80	0.00	50.82	20.53	0.00	0.00
1978	49.21	9.14	0.00	6.97	0.00	49.15	20.75	0.00	0.00
1979	59.73	10.74	0.00	7.81	0.00	48.47	19.46	0.00	0.00
1980	41.79	3.93	0.01	3.46	0.00	49.54	18.25	0.00	0.00
1981	35.41	2.22	0.00	2.66	0.00	51.29	16.67	0.00	0.00
1982	60.99	12.25	0.00	8.98	0.00	49.08	19.50	0.00	0.00
1983	65.32	9.27	0.00	7.09	0.00	47.77	18.56	0.00	0.00
1984	39.50	3.52	0.00	3.30	0.00	49.49	16.71	0.00	0.00
1985	49.65	6.17	0.00	5.22	0.00	48.73	16.00	0.00	0.00
1986	52.20	7.39	0.00	5.98	0.00	50.25	17.05	0.00	0.00
1987	47.29	5.44	0.00	4.86	0.00	48.50	17.00	0.00	0.00
1988	60.87	14.08	0.00	10.11	0.00	47.69	17.89	0.00	0.00
1989	37.67	3.91	0.00	4.02	0.00	51.06	18.12	0.00	0.00
1990	39.01	2.30	0.00	1.78	0.00	52.17	19.25	0.00	0.00
1991	56.53	4.48	0.00	3.96	0.00	48.34	20.89	0.00	0.00
1992	43.15	4.71	0.00	0.00	0.00	48.07	19.19	0.00	0.00
1993	51.76	4.78	0.00	1.55	0.00	49.75	17.93	0.00	0.00
1994	59.70	9.74	0.00	10.68	0.00	47.96	18.13	0.00	0.00
1995	50.11	3.27	0.00	1.91	0.00	45.12	15.83	0.00	0.00

	INFLOW					OUTFLOW			
Year	**Rainfall**	**From Lake Hutchinson & Runoff**	**From Alligator Creek**	**From Lake Geneva West**	**From Groundwater**	**Evaporation**	**To Groundwater**	**To Lake Geneva West**	**To Surface Water**
1996	43.13	3.89	0.00	1.51	0.00	46.60	12.59	0.00	0.00
1997	59.01	13.15	0.00	14.37	0.00	45.08	14.01	0.00	0.00
1998	43.16	3.75	0.00	5.28	0.01	50.45	14.17	0.00	0.00
1999	37.38	2.10	0.00	0.00	0.01	49.20	11.21	0.00	0.00
2000	38.00	3.58	0.00	0.00	0.00	50.99	12.22	0.00	0.00
2001	45.84	3.68	0.00	0.00	0.00	47.07	13.78	0.00	0.00
2002	38.89	3.52	0.00	0.00	0.00	45.50	13.73	0.00	0.00
2003	44.57	1.83	0.00	0.00	0.00	45.25	13.07	0.00	0.00
2004	52.19	10.30	0.00	0.00	0.01	46.74	10.53	0.00	0.00
2005	56.81	3.50	0.00	0.00	0.02	45.74	9.61	0.00	0.00
2006	40.46	4.61	0.00	1.74	0.05	51.64	7.05	0.00	0.00
2007	46.02	5.71	0.00	0.00	0.03	49.38	8.58	0.00	0.00
2008	49.97	10.83	0.00	3.24	0.00	46.73	12.35	0.00	0.00
2009	58.22	11.52	0.00	10.14	0.00	54.87	12.69	0.00	0.00
2010	42.07	2.97	0.00	0.38	0.01	49.72	10.16	0.00	0.00
2011	34.38	3.39	0.00	0.00	0.02	56.25	7.81	0.00	0.00
2012	58.84	21.90	0.00	0.00	0.01	50.67	10.51	0.00	0.00
2013	46.82	7.87	0.00	2.94	0.01	47.82	10.41	0.00	0.00
2014	57.21	11.26	0.00	7.40	0.02	50.70	8.09	0.00	0.00
2015	47.94	1.43	0.00	0.40	0.02	47.04	7.17	0.00	0.00
2016	42.50	5.43	0.00	0.00	0.01	51.48	6.28	0.00	0.00
2017	65.49	27.26	0.00	28.20	0.00	46.66	10.48	0.00	0.00
2018	53.92	5.09	0.00	4.18	0.00	46.84	12.30	0.00	0.00
AVG	**50.22**	**7.44**	**1.37**	**4.58**	**0.00**	**48.40**	**15.21**	**0.04**	**1.70**

Table C-6. Lake Geneva West annual water budget. All rates are in units of inches per year and 1957 results reflect July - December only.

	INFLOW				OUTFLOW		
Year	**Rainfall**	**Runoff**	**From Alligator Creek**	**From Groundwater**	**Evaporation**	**To Groundwater**	**To Alligator Creek**
1957*	30.33	15.31	0.00	0.46	23.10	3.15	11.21
1958	59.87	24.14	0.00	0.54	47.32	9.27	17.11
1959	61.16	31.25	0.00	0.31	47.76	11.46	19.25
1960	62.97	32.96	0.00	0.23	48.54	12.28	18.95
1961	47.81	20.52	0.27	0.26	49.60	11.68	12.40
1962	47.83	9.76	0.00	0.33	50.54	11.08	8.05
1963	37.43	4.25	0.00	0.39	49.69	11.16	5.67
1964	76.72	78.04	0.00	0.23	47.50	13.89	43.01
1965	64.03	36.06	4.26	0.09	47.91	16.53	17.61
1966	54.82	22.90	0.00	0.12	46.44	14.97	21.84
1967	52.62	25.75	0.00	0.15	48.79	14.03	19.27
1968	49.70	23.12	0.00	0.15	48.56	15.07	15.30
1969	53.45	15.90	0.00	0.15	46.69	15.86	11.73
1970	60.65	34.94	0.91	0.11	48.78	17.00	20.37
1971	50.30	18.39	0.00	0.12	49.23	15.38	12.68
1972	67.66	42.78	1.52	0.10	48.88	17.01	21.87
1973	50.99	14.75	0.00	0.13	48.77	15.63	20.41
1974	50.51	13.43	0.00	0.19	49.62	14.17	9.86
1975	51.52	20.65	0.00	0.19	48.78	14.95	14.30
1976	48.15	25.36	0.00	0.17	48.83	16.02	16.94
1977	33.47	9.16	0.00	0.22	50.86	15.56	8.81
1978	49.38	32.71	0.00	0.23	49.25	15.30	22.33
1979	59.89	38.12	0.00	0.23	48.50	14.44	25.05
1980	41.94	13.91	0.00	0.22	49.58	13.78	11.10
1981	35.54	8.26	0.00	0.26	51.36	11.73	8.79
1982	61.18	44.81	0.00	0.16	49.25	13.52	29.71
1983	65.45	34.33	0.00	0.18	47.81	13.47	23.29
1984	39.68	12.77	0.00	0.26	49.60	12.20	10.84
1985	49.74	23.39	0.00	0.23	48.80	10.89	17.43
1986	52.27	27.75	0.00	0.21	50.27	11.70	19.93
1987	47.44	20.46	0.00	0.29	48.60	11.42	16.22
1988	61.07	51.94	0.00	0.22	47.72	12.16	33.73
1989	37.84	14.82	0.00	0.21	51.17	11.93	13.47
1990	38.98	8.86	0.00	0.14	52.05	10.88	5.97

	INFLOW				OUTFLOW		
Year	**Rainfall**	**Runoff**	**From Alligator Creek**	**From Groundwater**	**Evaporation**	**To Groundwater**	**To Alligator Creek**
1991	56.74	16.74	0.00	0.09	48.55	11.25	12.72
1992	42.84	16.27	0.00	0.08	47.54	10.31	0.00
1993	51.72	15.73	0.00	0.06	49.41	10.72	4.53
1994	60.67	31.73	0.00	0.06	48.43	11.31	30.47
1995	50.22	11.05	0.00	0.07	45.08	10.84	5.53
1996	43.12	12.80	0.00	0.08	46.41	9.63	4.34
1997	59.52	41.95	0.00	0.08	45.36	10.39	40.93
1998	43.52	13.69	0.00	0.15	50.32	8.70	16.64
1999	37.27	7.49	0.00	0.13	48.99	7.10	0.00
2000	37.88	12.53	0.00	0.07	50.61	6.59	0.00
2001	45.70	11.86	0.00	0.06	46.92	7.58	0.00
2002	39.51	10.32	0.00	0.05	45.41	7.12	0.00
2003	44.42	5.31	0.00	0.07	45.04	7.82	0.00
2004	52.38	25.68	0.00	0.06	46.65	7.68	0.00
2005	56.54	8.73	0.00	0.07	45.72	10.08	0.00
2006	40.56	11.19	0.00	0.06	51.48	9.53	3.67
2007	45.94	13.14	0.00	0.05	49.39	8.97	0.00
2008	50.67	23.81	0.00	0.05	46.90	11.16	6.02
2009	58.29	27.12	0.00	0.05	54.59	11.49	20.52
2010	41.86	7.26	0.00	0.05	49.39	10.64	0.72
2011	33.86	7.29	0.00	0.04	56.03	8.19	0.00
2012	58.67	42.73	0.00	0.03	50.70	9.78	0.00
2013	47.03	15.21	0.00	0.03	47.74	11.67	5.19
2014	57.61	23.54	0.00	0.04	51.24	10.91	13.72
2015	48.21	3.45	0.00	0.03	47.15	10.61	0.80
2016	42.69	12.08	0.00	0.01	51.50	10.00	0.00
2017	67.84	64.81	0.00	0.00	49.57	10.91	59.11
2018	54.16	14.85	0.00	0.00	47.00	10.95	10.57
AVG	**50.35**	**21.93**	**0.11**	**0.15**	**48.44**	**11.64**	**13.23**